JAERI-Conf
96-012

MINUTES OF THE SECOND IFMIF-CDA DESIGN INTEGRATION WORKSHOP
MAY 20-25, 1996, JAERI, TOKAI, JAPAN

August 1996

IFMIF-CDA Team

日本原子力研究所
Japan Atomic Energy Research Institute

本レポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11 茨城県那珂郡東海村）あて，お申し越しください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

This report is issued irregularly.
Inquiries about availability of the reports should be addressed to Information Division, Department of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　刷　いばらき印刷㈱

JAERI-Conf 96-012

Minutes of the Second IFMIF-CDA Design Integration Workshop
May 20-25, 1996, JAERI, Tokai, Japan

IFMIF-CDA Team

Department of Reactor Engineering
Department of Materials Science
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received July 1, 1996)

The second Design Integration Workshop of IFMIF-CDA was held on May 20-27, 1996 at JAERI/Tokai. The primary objectives were, (1) to review and update the Baseline Design Concept, (2) to review the preliminary schedule and cost estimates, and (3) to establish the R&D needs for the next phase of the activity. This report presents a brief summary of the objective and results of the meeting. Detailed information on the agenda, attendees, and presentation material is included in the Appendix.

Keywords: IFMIF-CDA, IEA, Fusion Material, Fusion Reactor, Intense Neutron Source, Cost Estimate, R&D

(Eds.) Hiroshi MAEKAWA (Department of Reactor Engineering)
Satoshi KONISHI (Department of Fusion Engineering, Naka Fusion Research Establishment)

第２回国際核融合炉材料照射施設概念設計（ＩＦＭＩＦ－ＣＤＡ）設計統合ワークショップ報告書
1996年５月20日～５月25日、東海研究所、東海村

日本原子力研究所東海研究所原子炉工学部・材料研究部
ＩＦＭＩＦ－ＣＤＡチーム

（1996年７月１日受理）

核融合炉材料照射試験を目的とした強力中性子源、国際核融合材料照射施設（ＩＦＭＩＦ）の概念設計活動（ＣＤＡ）における第２回設計統合ワークショップが５月20日－27日原研東海研で開催された。本ワークショップの目的は、(1) 基準設計案の検討と更新、(2) 暫定スケジュールとコスト評価の検討、(3) 次段階活動で要請される開発研究項目の洗い出し、である。本レポートでは会合の目的や成果の概要が述べられている。また、付録にはアジェンダ、参加者リスト、会合で配付された資料が集められている。

東海研究所：〒319－11　茨城県那珂郡東海村白方白根２－４
（編）前川　洋（原子炉工学部）、小西哲之（那珂研究所核融合工学部）

Contents

目　　次

1. Introduction

This meeting was the second Design Integration Workshop as part of the IFMIF Conceptual Design Activity (CDA). A detailed description of the CDA is included in the Interim Report [ORNL/M-4908 (Dec. 1995); JAERI-memo (Feb. 1996)]. The purpose of this document, the meeting Minutes, is to provide a reference for the information presented and discussed at the meeting. Changes in the design concept and new information for the CDA will be issued in a separate report as an addendum to the Interim Report. The final CDA report is scheduled for completion in December, 1996.

This report presents a brief summary of the objective and results of the meeting. Detailed information on the agenda, attendees, and presentation material is included in the Appendices.

2. Meeting Objective and Overview

The purpose of this meeting was to integrate the results of the IFMIF CDA activities since the last meeting at ORNL on October 16-27, 1995. The specific objectives were to:

1. Review and update the Baseline Design Concept
2. Review the preliminary schedule and cost estimates
3. Establish the R&D needs for the next phase of the activity

The format for the meeting consisted of mostly small group meetings in which specialists from the participating parties discussed the results and conclusions of their work. The technical results will be documented in this report and in the Addendum report as previously described. The detailed information on the schedule and cost estimate will be included in a third report with a limited distribution to the members of the IEA Executive Committee. The plan for the next phase, the Engineering Validation Phase (EVP) will be included in a fourth report.

A summary of the small group discussions is included in the following sections. A brief statement of the results is included as the final section followed by the Appendix.

3. Summary of Small Group Discussions

3.1. Test Facilities/Users Group Meetings

Participants:	**US**	J.R. Haines, I.C.Gomes
	EU	A. Möslang (Deputy)
	Japan	K. Noda, S. Jitsukawa, Y. Oyama, K. Watanabe, S. Konishi, T. Hoshiya, Y. Katano, K. Ebisawa

Group Meetings: May 20 (Monday) Afternoon
May 21 (Tuesday) Morning and Afternoon
May 22 (Wednesday) Afternoon
May 23 (Thursday) Morning
May 24 (Friday) Morning,and early Afternoon

Agenda: See Attachment

Item 1: Significant design progress has been achieved in all major fields of the Test Facilities the last few months. Meanwhile designs concepts, some already performed by the industry, are available for all relevant devices and components. The feasibility and design studies include the baseline design for

1. Introduction

This meeting was the second Design Integration Workshop as part of the IFMIF Conceptual Design Activity (CDA). A detailed description of the CDA is included in the Interim Report [ORNL/M-4908 (Dec. 1995); JAERI-memo (Feb. 1996)]. The purpose of this document, the meeting Minutes, is to provide a reference for the information presented and discussed at the meeting. Changes in the design concept and new information for the CDA will be issued in a separate report as an addendum to the Interim Report. The final CDA report is scheduled for completion in December, 1996.

This report presents a brief summary of the objective and results of the meeting. Detailed information on the agenda, attendees, and presentation material is included in the Appendices.

2. Meeting Objective and Overview

The purpose of this meeting was to integrate the results of the IFMIF CDA activities since the last meeting at ORNL on October 16-27, 1995. The specific objectives were to:

1. Review and update the Baseline Design Concept
2. Review the preliminary schedule and cost estimates
3. Establish the R&D needs for the next phase of the activity

The format for the meeting consisted of mostly small group meetings in which specialists from the participating parties discussed the results and conclusions of their work. The technical results will be documented in this report and in the Addendum report as previously described. The detailed information on the schedule and cost estimate will be included in a third report with a limited distribution to the members of the IEA Executive Committee. The plan for the next phase, the Engineering Validation Phase (EVP) will be included in a fourth report.

A summary of the small group discussions is included in the following sections. A brief statement of the results is included as the final section followed by the Appendix.

3. Summary of Small Group Discussions

3.1. Test Facilities/Users Group Meetings

Participants:	**US**	J.R. Haines, I.C.Gomes
	EU	A. Möslang (Deputy)
	Japan	K. Noda, S. Jitsukawa, Y. Oyama, K. Watanabe, S. Konishi, T. Hoshiya, Y. Katano, K. Ebisawa

Group Meetings: May 20 (Monday) Afternoon
May 21 (Tuesday) Morning and Afternoon
May 22 (Wednesday) Afternoon
May 23 (Thursday) Morning
May 24 (Friday) Morning,and early Afternoon

Agenda: See Attachment

Item 1: Significant design progress has been achieved in all major fields of the Test Facilities the last few months. Meanwhile designs concepts, some already performed by the industry, are available for all relevant devices and components. The feasibility and design studies include the baseline design for

1. Introduction

This meeting was the second Design Integration Workshop as part of the IFMIF Conceptual Design Activity (CDA). A detailed description of the CDA is included in the Interim Report [ORNL/M-4908 (Dec. 1995); JAERI-memo (Feb. 1996)]. The purpose of this document, the meeting Minutes, is to provide a reference for the information presented and discussed at the meeting. Changes in the design concept and new information for the CDA will be issued in a separate report as an addendum to the Interim Report. The final CDA report is scheduled for completion in December, 1996.

This report presents a brief summary of the objective and results of the meeting. Detailed information on the agenda, attendees, and presentation material is included in the Appendices.

2. Meeting Objective and Overview

The purpose of this meeting was to integrate the results of the IFMIF CDA activities since the last meeting at ORNL on October 16-27, 1995. The specific objectives were to:

1. Review and update the Baseline Design Concept
2. Review the preliminary schedule and cost estimates
3. Establish the R&D needs for the next phase of the activity

The format for the meeting consisted of mostly small group meetings in which specialists from the participating parties discussed the results and conclusions of their work. The technical results will be documented in this report and in the Addendum report as previously described. The detailed information on the schedule and cost estimate will be included in a third report with a limited distribution to the members of the IEA Executive Committee. The plan for the next phase, the Engineering Validation Phase (EVP) will be included in a fourth report.

A summary of the small group discussions is included in the following sections. A brief statement of the results is included as the final section followed by the Appendix.

3. Summary of Small Group Discussions

3.1. Test Facilities/Users Group Meetings

Participants:	**US**	J.R. Haines, I.C.Gomes
	EU	A. Möslang (Deputy)
	Japan	K. Noda, S. Jitsukawa, Y. Oyama, K. Watanabe, S. Konishi, T. Hoshiya, Y. Katano, K. Ebisawa

Group Meetings: May 20 (Monday) Afternoon
May 21 (Tuesday) Morning and Afternoon
May 22 (Wednesday) Afternoon
May 23 (Thursday) Morning
May 24 (Friday) Morning,and early Afternoon

Agenda: See Attachment

Item 1: Significant design progress has been achieved in all major fields of the Test Facilities the last few months. Meanwhile designs concepts, some already performed by the industry, are available for all relevant devices and components. The feasibility and design studies include the baseline design for

- all Test Assemblies necessary for the high, medium, low and very low flux regions,
- Shielding Plugs,
  - Removable Test Cell Cover,
  - Test Cell Liner and Heat Shield.

All essential equipment both for the Test Cell Technology Room and the Test Cell Users Room has been identified and specified. In order to have a basis for more complex design decisions, alternative concepts were also developed for the high and medium flux VTAs as well as for the Test Cell and its Removable Cover. A detailed design harmonization needs a careful consideration of all requirements, concepts and layouts on the basis of CAD programs and is therefore postponed (remaining tasks for summer 96). A feasibility study is foreseen to assess whether it is possible to irradiate in the medium flux position with one single VTA simultaneously two test modules, one for tritium release tests , the other for creep-fatigue experiments.

It is important to note, that for the present baseline concept sufficiently detailed designs are available for all relevant irradiation experiments defined in the Users community.

Item 2: Designs are meanwhile available for all major structures and components of Access Cell, Service Cell and Test Module Handling Cell. While the bulk of the design activities could be done based on the experience of already existing Hot Cell Facilities, the power remote handling equipment in the access cell is a challenge because within one single universal robot system heavy loads (up to 65 tons) and high precision with respect to positioning (1 mm) have to be combined.

Item 3: The design of the PIE Hot Cells and the Shielded Glove Box Laboratory has been reviewed and completely changed between the 1st and 2nd DI meeting. In order to significantly simplify the related ventilation systems and to reduce the costs, both subsystems can be operated with one single ventilation system each. The present Cell and Glove Box Laboratory design as well as the specified equipment allows maximum flexibility and reflects the needs of the users community.

Item 4: A detailed design concept from JAERI for a Tritium Facility consisting of the three major subsystems (i) Tritium Handling Hot Cells, (ii) Tritium Glove Boxes, and (iii) Tritium Processing Systems was presented and discussed. However, it should be noted, that

- the related cost estimate completely governs the overall Test Facility costs, and that
- a more global cost estimate from FZK based on the existing Tritium Laboratory Karlsruhe is a factor of two below the JAERI estimate.

At least in this case a general decision on how to handle the impact of different potential IFMIF sites on cost estimates seems to be necessary.

Item 5: Based on the experience of existing Hot Cells and Accelerator Facilities a concept for a ventilation system for all test facility cells and rooms consisting of five different zones has been developed and discussed. Because the concept should be applicable to the overall IFMIF Facility it has been decided that in future the Common Facilities will take the responsibility at least for the conventional ventilation systems (including hot cells). Source terms for tritium production were identified and concepts for Tritium processing and retention systems were discussed. The location of that systems needs to be clarified.

Item 6: The RAM, Safety and Maintenance requirements have been updated, discussed and further developed during the 2nd DI meeting together with the involved industry.

Item 7: Cost estimates are available for practically all elements of the present WBS already down to level 4 (only one exception). The overall estimate should be credible because (i) all completely individual devices and modules are estimated in detail, and (ii) other expensive subsystems and components could be estimated from existing facilities. Besides the Tritium Facility (see item 4) no major uncertainties have been identified in the cost estimate of the Test Facilities.

Item 8: Four presentations have been given showing that in various neutronics fields significant progress has been achieved. Besides more general investigations of nuclear data evaluation and library preparation, results were shown substantial for the engineering (e.g. total nuclear heating in different flux zones, decay heat in Li-target and high flux test module) and safety (e.g. 3D-shielding calculations). For the first time advanced MCNP calculations have been done on the basis of processed Fe-56 calculations and on real material distributions in the high flux test module.

Item 9: A report on the IEA meeting on small specimen test technology (IEA/SSTT) held in Sendai, Japan from March 14th to 16th 1996 has been given following discussions on the impact on changing specimen dimensions during the engineering design of the high flux test module.

Item 10: The relevant future activities have been discussed and described in detail. See „Remaining Test Facility Tasks“ (16 pages).

3.2. Accelerator Group Meeting

Participants:	**Japan**	M. Sugimoto, A. Miyahara, M. Odera, M. Kinsho, Y. Tanabe, K. Sawada, A. Maekawa
	EU	H. Klein, J-M. Lagniel, R. Ferdinand
	US	R. Jameson (Deputy), D. Berwald, D. Bruhwiler, T. Myers, C. Piaszczyk, J. Rathke
	RF	M. Chernogubovsky (assigned to JAERI)

Group Meetings: Monday through Friday, except for general meeting attendance.

Presentations:

- ECR source and injector studies, Lagniel
- Injector work in Japan, Kinsho
- Injector work at IAP, Klein
- Modeling of ion source/LEBT/RFQ transmission, beam loss, and neutron generation vs. source emittance, Bruhwiler
- Perspective on deuterium performance scaling for various positive ion sources at Northrup Grumman, Berwald
- Halo formation, Lagniel
- RF amplifiers for IFMIF, Lagniel
- Japan study of superconducting linac option, Tanabe
- Review/Update of accelerator interfaces, Berwald
- Comments on RFQ beam dynamics, Sawada and Chernogubovsky
- Japan RF system work (solid state, etc.), Maekawa
- Neutron activation of ion source/LEBT/RFQ, Gomes
- Design and RAM considerations for rapid replacement of ion injector, Rathke and Piaszczyk
- Accelerator access and maintainability, Rathke
- Accelerator I&C System, Berwald
- Cost, WBS and manufacturing schedule, Myers
- Reference Linac, Matching and HEBT, Jameson

1.) Significant progress has been made on all aspects of the 2nd year CDA tasks on the Accelerator System, as indicated in the list of presentations above. The material from these presentations will be included in the Tokai Design Integration Meeting Report. The CDA activities are proceeding on schedule.

2.) A deuteron current of 80 mA has been extracted at 35 keV from the IAP source. This is an important step toward reaching the full IFMIF specification of 140 mA at 100 keV. Injector development continues to be of high priority; the EVP plan shows injector development as the second highest priority task (after the RF amplifier, discussed below).

3.) Many changes were made to the facility layout, in coordination with the facilities group. The configuration of the accelerator halls, RF halls, and beam-turning room were all changed to minimize space and improve efficiency. One area where these changes are still under evaluation is the high-energy-beam-transport (HEBT) turning room, where the combination of space discussions and more detailed target specifications results in a difficult beam transport design problem.

4.) A detailed cost estimate has been prepared by the US, and was presented at this meeting for discussion. Japan has agreed to provide formal comment on the Cost Estimate, and EU comment will also be gathered.

5.) Considerably more detail has been added to the RAM model, maintainability and operability procedures, and control system definition.

6.) New work (beyond earlier FMIT studies) was done on the modeling of beam losses in the ion source/LEBT/RFQ. The beam loss model was used to develop radiation source-term models and estimation of radioactivity levels during planned operation and maintenance periods. This work was instrumental in helping decide that radiation would make it very difficult to do maintenance on a second injector while one was operating, so the two-injector concept has been replaced with an in-line injector concept.

7.) Concern about develop of the main rf amplifiers to full cw performance for IFMIF led to a major decision to reduce the specification from 1.3 MW to 1 MW per amplifier. This decision also has advantages in that more than one vendor can be involved. The major task of the EVP has been determined to be the successful test of a full-scale rf system for 100 hours cw.

8.) Evaluation of the superconducting linac as the primary alternative for the accelerator was reported by the Japanese group, with the conclusion that this approach is feasible from the technical view. Issues are cost, including the need for full development, and the type of rf amplifier that could be used. Japan is working on the development of 100-kW solid-state rf amplifiers, and will provide some budgetary cost estimates for projected near- and long-term prices. A second rf approach is to use the 1 MW tetrode amplifiers, but further study of power-splitting to the SC tanks is required.

9.) Discussion and planning for the Engineering Development Phase occupied a major portion of the meeting. A budget is 25M ICF is target to rf amplifier development to a 100 hour test (15M ICF), injector development to a 100 hour test (5M ICF) and all other tasks (5M ICF). This latter item can be summarized as minimization of beam loss and activation such that remote handling will not be necessary. It includes beam dynamics, linac structure mechanical aspects (but no prototype hardware), continued development of cost and RAM, and so on, and is considered marginal in terms of full preparation for a construction phase.

3.3. Target Group Meeting

Participants:	**Japan**	H. Katsuta (Deputy), Y. Kato, H. Nakamura, M. Ida, H. Kakui, M. Ogoshi, S. Konishi
	EU	G. Benamati
	US	T. Q. Hua, L. Green

Group Meetings: Monday through Friday, except for general meeting attendance.

Discussion Items:

The discussions taken place in the target group meetings consist of five main topics:

(1) Review and update of technical issues
(2) Review and update of Target Facility cost estimate
(3) Planning for the Engineering Validation Phase activities
(4) Determine remaining work of CDA
(5) Preparation of reports

Brief summary of each topic is given below. The presentations are attached for information.

(1) Review and update of technical issues

The referenced bolted replaceable backwall design developed after the first DI workshop in Oct. 95 was presented and discussed. Two new attachment schemes were proposed. They are (1) a Bayonet connection design with no bolts, and (2) Laser welding and cutting. The group will assess these different attachment schemes in the remaining work of CDA, and possibly continue the assessment into the next phase.

Nuclear heating analysis for the backwall and beam HEBT was presented. It was determined that separate cooling of the HEBT was needed by diverting a small stream of lithium coolant (15 cc/s) from the main flow. Decay heat can be removed by a few percent of normal flow after beam shutdown. The main concern is in the case of loop failure, excessive temperature rise in the backwall may lead to melting if there was no cooling technique. One possible solution is to flood and circulate Ar gas in the test cell.

Revisions to the lithium main loop and chemistry loop were presented. Changes to the heat exchanger and EMP were documented. Cold trap economizers were added to the lithium return line to avoid thermal shock. Four additional turbopumps were added to the vacuum differential pumping system for redundancy purpose.

The options for the lithium cell environment were discussed. At present, the reference option employs dry air. Other options being considered include nitrogen, dry air/Ar combination.

New FMEA analysis at component level of the target system was presented. The new analysis included about 65 tables for the individual components, system, and loops. Electronic version of the data was distributed to members of the Target group for comments and inclusion in the Addendum report.

(2) Review and update of cost estimate

The U.S. Target group costed the main loop, primary and secondary heat removal loops, and the impurity monitoring system. Japanese Target group costed almost all items in the WBS including all lithium loops, target assembly, remote handling, ventillation systems, instrumentation and control, and project management. For components costed by both parties, differences were identified and resolved. The differences stemed from (1) the use of nuclear (Japan assumption) vs non-nuclear (U.S.) grade components, (2) higher material cost in Japan, and (3) different construction practices. The use of nuclear grade materials was considered necessary for components that contain radioactive elements based on Japanese regulatory requirements.

(3) Planning for Engineering Validation Phase activities

Three major areas have been identified for development in the EVP phase. They were (1) Target assembly development and hydraulic performance validation, (2) Lithium purification and on-line monitoring development, and (3) Lithium safety. A development task for each activity has been defined and included in the attachment. The estimated cost for these activities were as follow:

- Target Assembly:	5,900 kICF	over 4 years
- Impurity...	2,400 kICF	over 3 years
- Li safety	660 kICF	over 3 years

The Target group strongly agreed that collaboration was essential to the success of the EVP tasks. Resources and expertise will be optimized and duplication of work should be avoided as much as possible. Collaboration may be carried out in the following forms:

- Joint design of facility
- Joint planning and execution of experiments
- Exchange of personnel
- Contribution of hardware such as the fabrication of a test section

(4) Determine remaining work of CDA

The remaining work for CDA includes assessment for

- the three attachment schemes for the replaceable backwall
- Li cell environment
- FMEA analysis
- design and test plan of chemical loop

Homework tasks were defined for each party. Correspondence by email was suggested for progress report and feedback.

(5) Preparation of Reports

Sharing of the immediate write-up task of the Addendum report was decided. A draft will be made available May 31, reviews by all parties will be completed by June 4. A final draft of the Addendum report will be submitted by June 7.

3.4. Design Integration/Conventional Facility Group

In this Meeting the following activity has been carried out:

1) IFMIF Layout updating
2) Review of Service Designs
3) Review of Cost Estimate
4) Planning of the Work to complete CDA
5) Planning of the Engineering Validation Phase

1) IFMIF Layout updating

The conceptual design of the Main IFMIF Building included in the Interim Report (Figs. 2.1.2) has been modified on the basis of the drawings/information provided by the Deputies of Test, Target and Accelerator Facilities before this Meeting. The accelerators are now closer together and there is a central pipe chase between the vaults where RF coaxial cables and other services are housed. A large High Bay (see drawings annexed to the Conventional Facility Report) has been added, to simplify the maintenance operation of Hot Cells, PIE and Tritium Laboratories and adjacent rooms. Following the decision that only one Li-loop will be provided for feeding both the Targets one at time, the Complex housing the Li-loop has been drawn again and integrated in the Main Building Layout.

At this meeting the problem of replacing accelerator components in the accelerator hall and the beam turning room has been discussed and solved. The accelerator length has been increased of about 10 meters and the length of the accelerator halls will be increased accordingly. A viable solution for entering into the Test Cell Technology Rooms and Li-Cells will be submitted to the Deputies as soon as possible and if approved included in the Main Building Layout. A new version of this last will be released within the end of next June and put on the PRIFMIF Server.

2) Review of Service Designs

The major issue was the identification of the functions of the Ventilation System and Gas Effluent Processing Systems. The Deputies agrees on the functions of the Ventilation System. Its design review and more accurate cost estimate have been assigned to the Conventional Facility Group. The functions of the Gas Effluent Processing Systems will be specified by a Japanese Expert and then will be decided how share out design review and related cost estimate. The Design and Cost Estimate of two Power Station for 380 and 120 kV grid have been provided. The former has been considered more appropriate for IFMIF and included in the Conventional Facility Cost Estimate. The type and quantity of the inert gas needed have not yet decided. The function of the radioactive waste processing will be identified within thegeneral issue of Safety assigned to the japanese expert. All the Facilities will be requested of collaborating to the analysis of this issue. A maintenance procedure for the Services has been discussed with the US expert.

3) Review of Cost Estimate

The US Group costed the Accelerator Halls, the RF Power Bay, the Beam Turning Room, the Accelerator Assembly/Maintenance Bays, the Support Facilitiy Buildings and the Water System. The EU Group costed the Target Complex, the Test and Examination Complex, the Building High Bay, the Ventilation System, the Power System and Building Lighting and Plumbing. No appreciable differences have been identified between US and UE Cost Estimates of Buildings. On the other hand for both the US and EU Cost Estimates the cost of Engineering as well as the Allowance for Indeterminates have been considered too low and have been increased as a result of discussion within the Design Integration Group.

4) Planning of the Work to Complete CDA

The updating of Plant Services and Building Designs and related Cost Estimates will continue following the Test Cell, Target and Accelerator Facility modification. The maintenance procedure for the Plant Services will be provited to the US expert within July 15, 1996.More detailed cost estimates for some expensive components will be provided too.

5) Planning of the Engineering Validation Phase

No task are needed for the Engineering Validation Phase. A budget for the work to be done for assisting the Facilities during the EVP, has been taken into account in the Project Management Cost Estimate.

3.5. Design Integration/Common Instrumentation & Central Control

The work breakdown Structure (WBS) has been modified from the Interim Report, based on the results of Preparation Meeting held at ORNL March 4 - 8, 1996, and on the additional considerations. The interface to the other facilities was discussed during the meeting with D. Berwald for Accelerator, H. Katsuta and his group for Accelerator, A. Möslang for Test Cell, and M. Martone for Conventional Facility.

(1) Common Istrumentation

The selection principle of common/central instrumentation is “the item may not be considered in the other systems” The items are "On-line Neutron Yield Monitor", "Beam Position/Profile Monitor on the Target", "Health Physic Radiation Monitor", "TV System", "Safety and Emergency Equipments" and so on.

Radiation Monitering System is designed based on the experiences of ENEA and JAERI. The nterface to the conventional facility was discussed on - space of control room,- space for gas sampling devices, etc. The cable trays, pipe chases are shared to conventional facility, while the wiring and piping are to common instrumentation.

(2) Central Controll

The basic concepts of central control system is shown below:

a) IFMIF control system consists of Central Control System (Main Computer & 2 Support Computers) and 4 Subsystems (Accelerator, Target, Test Cell/Experiment, Conventional Facility). Namely, the central control system can isolate from the Sub-Systems and each sub-control sytem can control independently the sub-facility such as accelerator system.
b) In normal operation phase, Central Control distributes request for states (e.g., STANDBY, READY and RUN) to Sub-Systems and gather status and diagnostics of Sub-Systems.
c) Sub-Systems should have predefined functions and sequences corresponding to the requested state. In normal operation phase, Sub-Systems should execute these operations synchronously according to timing signal.
d) Control parameters in Sub-Systems should also be controllable by Central Control.
e) Communications via LAN
    * down-load instrumentation of Sub-Systems
    * set point control
    * gather and store status and diagnostics of Sub-Systems and beam (period : TBD)

f) Central Control provides hardwired logic fast protect function to shut down deuteron beam and Sub-Systems.
g) Central Control accepts only a few important interlock signals from Sub-Systems, such as "Stop Beam!" Namely, all Sub-System have own interlock logic.
h) Interlock logic in Central Control serves Interlock signals to Target Control and Test Cell/Expr. Control according to the condition of Facility Service
i) Central Control provide timing signals for controlling, synchronized operations and data acquisition sequence.

(3) EVP Tasks

The following two tasks are proposed for EVP. Their cost are estimated to be 1.14 M-ICF (120 M-Yen).

- Optical IR Viewing on Li-Target
- Neutron Imaging Monitor

3.6. Design Integration/RAM

A general RAM overview presentation was delivered to the entire IFMIF team in the morning of Wednesday, May 22nd. The presentation included review of the reliability, availability, and maintainability methodology and recommendations for all facilities on the general level with detailed discussions of each individual facility deferred to the group meetings to be scheduled later. Updates to the availability models made since October 1995 were summarized: most of these were in the area of the accelerator system modeling where the most significant one was the transition to a single injector which was previously considered and which lead to difficulties with the beam dynamics in the LEBT. Higher than expected radiation environment made the previously planned on-line ion source replacements impossible anyway.

3.7. Design Integration/Safety

Some safety related technical issues are were identified to be further studied toward the end of the CDA. It is a general understanding that the CDA does not include a detailed safety analysis as a major part of the design. However it is also agreed among the participants that the conceptual design will be expected to provide some safety related information such as, environmental impact, possible hazard to the public, and requirements and limitation for the site selection in the aspect of safety, if any. It was agreed to form a special working group to address these issues. In a discussion in the general meeting on 23rd, Thursday, several subjects were identified as the issues of particular interests and importance. Lithium fire hazard and a design approach to confirm the safety to prevent any possible accidents was understood to be very important toward the siting of IFMIF. It was pointed out that the design of processing systems for radioactive waste in gaseous, liquid and solid forms have been partially performed by several facility groups , and needs to be organized to be completed by the lead of the conventional facility group. Particularly processing and control of tritium generated by the operation of IFMIF is anticipated to have a major impact in cost estimation.

An approach to respond the above requirements was proposed. Review of the previously completed Failure Mode Effect Analysis (FMEA) followed by the further considerations will be performed in the next 2 -3 months. Some subtask work requests will be issued by the special working group to complete such safety analysis and design efforts. In the next design integration meeting, results of the subtasks will be reviewed and be included as a part of the final design report.

4. Summary of Cost Estimation

A standard format for the IFMIF Cost Estimate was developed at the March planning meeting held in Oak Ridge. The format was approved by the Deputies and issued in April to provide a foundation for the preliminary estimate requested by the Executive Committee. Each of the Facility groups completed estimates prior to the May meeting and an initial summary was

f) Central Control provides hardwired logic fast protect function to shut down deuteron beam and Sub-Systems.
g) Central Control accepts only a few important interlock signals from Sub-Systems, such as "Stop Beam!" Namely, all Sub-System have own interlock logic.
h) Interlock logic in Central Control serves Interlock signals to Target Control and Test Cell/Expr. Control according to the condition of Facility Service
i) Central Control provide timing signals for controlling, synchronized operations and data acquisition sequence.

(3) EVP Tasks

The following two tasks are proposed for EVP. Their cost are estimated to be 1.14 M-ICF (120 M-Yen).
- Optical IR Viewing on Li-Target
- Neutron Imaging Monitor

3.6. Design Integration/RAM

A general RAM overview presentation was delivered to the entire IFMIF team in the morning of Wednesday, May 22nd. The presentation included review of the reliability, availability, and maintainability methodology and recommendations for all facilities on the general level with detailed discussions of each individual facility deferred to the group meetings to be scheduled later. Updates to the availability models made since October 1995 were summarized: most of these were in the area of the accelerator system modeling where the most significant one was the transition to a single injector which was previously considered and which lead to difficulties with the beam dynamics in the LEBT. Higher than expected radiation environment made the previously planned on-line ion source replacements impossible anyway.

3.7. Design Integration/Safety

Some safety related technical issues are were identified to be further studied toward the end of the CDA. It is a general understanding that the CDA does not include a detailed safety analysis as a major part of the design. However it is also agreed among the participants that the conceptual design will be expected to provide some safety related information such as, environmental impact, possible hazard to the public, and requirements and limitation for the site selection in the aspect of safety, if any. It was agreed to form a special working group to address these issues. In a discussion in the general meeting on 23rd, Thursday, several subjects were identified as the issues of particular interests and importance. Lithium fire hazard and a design approach to confirm the safety to prevent any possible accidents was understood to be very important toward the siting of IFMIF. It was pointed out that the design of processing systems for radioactive waste in gaseous, liquid and solid forms have been partially performed by several facility groups , and needs to be organized to be completed by the lead of the conventional facility group. Particularly processing and control of tritium generated by the operation of IFMIF is anticipated to have a major impact in cost estimation.

An approach to respond the above requirements was proposed. Review of the previously completed Failure Mode Effect Analysis (FMEA) followed by the further considerations will be performed in the next 2 -3 months. Some subtask work requests will be issued by the special working group to complete such safety analysis and design efforts. In the next design integration meeting, results of the subtasks will be reviewed and be included as a part of the final design report.

4. Summary of Cost Estimation

A standard format for the IFMIF Cost Estimate was developed at the March planning meeting held in Oak Ridge. The format was approved by the Deputies and issued in April to provide a foundation for the preliminary estimate requested by the Executive Committee. Each of the Facility groups completed estimates prior to the May meeting and an initial summary was

prepared by M.J. Rennich. During the first week the initial estimates were discussed to insure that all elements of the project were included. To aid in this effort the Work Breakdown Structure was developed to a total of approximately 1100 lines. The cost estimate was also expanded to include the Engineering Validation Phase proposals and startup and commissioning costs submitted during the meeting to provide the Total Project Cost.

To supplement the construction and supporting costs an annual operating budget was also prepared.

A detailed discussion of the cost estimate is included in the Addendum 1 to the IFMIF Interim Report. Cost numbers will be included in a separate, limited distribution report issued to governmental officials for planning purposes. The final cost estimate will be issued following the final CDA Design Integration Meeting to be held in October.

5. Schedule

The overall project schedule was cooperatively revised prior to the meeting; primarily with an emphasis on accommodating the critical path accelerator system. Both the top level and a detailed project schedule were completed based on the resulting revisions. During the meeting the schedule was discussed and approved.

6. Planning for the Engineering Validation Phase (EVP)

The Engineering Validation Phase (EVP) which follows the CDA will include design, research, development and other validation activities. This work is defined as that necessary to "validate" the baseline design concept prior to the start of the Engineering Design and Construction Phase. In addition to research and development activities, the EVP will sustain development work on the baseline design concept. There is additional, more conventional engineering development work that will be carried out as a normal part of the Engineering and Construction Phase. This work will be included as part of the project cost estimate.

This workshop developed the first draft of the EVP tasks. The individual task write-ups, included in a separate document, have a statement of the justification or need for the task, a brief description of the task and an estimate of the cost. The cost estimate is the total for the three year period 1997-1999.

7. Results and Conclusions

The primary results and conclusions of the meeting are summarized as follows.

1. The user requirements (FZK, Sept. '94) can be met by the CDA concept.
2. The basic design requirements established at the design meetings in 1995 are confirmed.
3. Several design changes were agreed upon with modest impact on the baseline design.
4. The detailed construction and R&D schedule required only minor modifications to the original proposal by Professor Kondo (Feb. '96).
5. There is good agreement on the preliminary cost estimate. However, several areas require checking and possible site-specific adjustments for national differences.
6. A detailed plan and cost estimate for the EVP has been prepared.

prepared by M.J. Rennich. During the first week the initial estimates were discussed to insure that all elements of the project were included. To aid in this effort the Work Breakdown Structure was developed to a total of approximately 1100 lines. The cost estimate was also expanded to include the Engineering Validation Phase proposals and startup and commissioning costs submitted during the meeting to provide the Total Project Cost.

To supplement the construction and supporting costs an annual operating budget was also prepared.

A detailed discussion of the cost estimate is included in the Addendum 1 to the IFMIF Interim Report. Cost numbers will be included in a separate, limited distribution report issued to governmental officials for planning purposes. The final cost estimate will be issued following the final CDA Design Integration Meeting to be held in October.

5. Schedule

The overall project schedule was cooperatively revised prior to the meeting; primarily with an emphasis on accommodating the critical path accelerator system. Both the top level and a detailed project schedule were completed based on the resulting revisions. During the meeting the schedule was discussed and approved.

6. Planning for the Engineering Validation Phase (EVP)

The Engineering Validation Phase (EVP) which follows the CDA will include design, research, development and other validation activities. This work is defined as that necessary to "validate" the baseline design concept prior to the start of the Engineering Design and Construction Phase. In addition to research and development activities, the EVP will sustain development work on the baseline design concept. There is additional, more conventional engineering development work that will be carried out as a normal part of the Engineering and Construction Phase. This work will be included as part of the project cost estimate.

This workshop developed the first draft of the EVP tasks. The individual task write-ups, included in a separate document, have a statement of the justification or need for the task, a brief description of the task and an estimate of the cost. The cost estimate is the total for the three year period 1997-1999.

7. Results and Conclusions

The primary results and conclusions of the meeting are summarized as follows.

1. The user requirements (FZK, Sept. '94) can be met by the CDA concept.
2. The basic design requirements established at the design meetings in 1995 are confirmed.
3. Several design changes were agreed upon with modest impact on the baseline design.
4. The detailed construction and R&D schedule required only minor modifications to the original proposal by Professor Kondo (Feb. '96).
5. There is good agreement on the preliminary cost estimate. However, several areas require checking and possible site-specific adjustments for national differences.
6. A detailed plan and cost estimate for the EVP has been prepared.

prepared by M.J. Rennich. During the first week the initial estimates were discussed to insure that all elements of the project were included. To aid in this effort the Work Breakdown Structure was developed to a total of approximately 1100 lines. The cost estimate was also expanded to include the Engineering Validation Phase proposals and startup and commissioning costs submitted during the meeting to provide the Total Project Cost.

To supplement the construction and supporting costs an annual operating budget was also prepared.

A detailed discussion of the cost estimate is included in the Addendum 1 to the IFMIF Interim Report. Cost numbers will be included in a separate, limited distribution report issued to governmental officials for planning purposes. The final cost estimate will be issued following the final CDA Design Integration Meeting to be held in October.

5. Schedule

The overall project schedule was cooperatively revised prior to the meeting; primarily with an emphasis on accommodating the critical path accelerator system. Both the top level and a detailed project schedule were completed based on the resulting revisions. During the meeting the schedule was discussed and approved.

6. Planning for the Engineering Validation Phase (EVP)

The Engineering Validation Phase (EVP) which follows the CDA will include design, research, development and other validation activities. This work is defined as that necessary to "validate" the baseline design concept prior to the start of the Engineering Design and Construction Phase. In addition to research and development activities, the EVP will sustain development work on the baseline design concept. There is additional, more conventional engineering development work that will be carried out as a normal part of the Engineering and Construction Phase. This work will be included as part of the project cost estimate.

This workshop developed the first draft of the EVP tasks. The individual task write-ups, included in a separate document, have a statement of the justification or need for the task, a brief description of the task and an estimate of the cost. The cost estimate is the total for the three year period 1997-1999.

7. Results and Conclusions

The primary results and conclusions of the meeting are summarized as follows.

1. The user requirements (FZK, Sept. '94) can be met by the CDA concept.
2. The basic design requirements established at the design meetings in 1995 are confirmed.
3. Several design changes were agreed upon with modest impact on the baseline design.
4. The detailed construction and R&D schedule required only minor modifications to the original proposal by Professor Kondo (Feb. '96).
5. There is good agreement on the preliminary cost estimate. However, several areas require checking and possible site-specific adjustments for national differences.
6. A detailed plan and cost estimate for the EVP has been prepared.

prepared by M.J. Rennich. During the first week the initial estimates were discussed to insure that all elements of the project were included. To aid in this effort the Work Breakdown Structure was developed to a total of approximately 1100 lines. The cost estimate was also expanded to include the Engineering Validation Phase proposals and startup and commissioning costs submitted during the meeting to provide the Total Project Cost.

To supplement the construction and supporting costs an annual operating budget was also prepared.

A detailed discussion of the cost estimate is included in the Addendum 1 to the IFMIF Interim Report. Cost numbers will be included in a separate, limited distribution report issued to governmental officials for planning purposes. The final cost estimate will be issued following the final CDA Design Integration Meeting to be held in October.

5. Schedule

The overall project schedule was cooperatively revised prior to the meeting; primarily with an emphasis on accommodating the critical path accelerator system. Both the top level and a detailed project schedule were completed based on the resulting revisions. During the meeting the schedule was discussed and approved.

6. Planning for the Engineering Validation Phase (EVP)

The Engineering Validation Phase (EVP) which follows the CDA will include design, research, development and other validation activities. This work is defined as that necessary to "validate" the baseline design concept prior to the start of the Engineering Design and Construction Phase. In addition to research and development activities, the EVP will sustain development work on the baseline design concept. There is additional, more conventional engineering development work that will be carried out as a normal part of the Engineering and Construction Phase. This work will be included as part of the project cost estimate.

This workshop developed the first draft of the EVP tasks. The individual task write-ups, included in a separate document, have a statement of the justification or need for the task, a brief description of the task and an estimate of the cost. The cost estimate is the total for the three year period 1997-1999.

7. Results and Conclusions

The primary results and conclusions of the meeting are summarized as follows.

1. The user requirements (FZK, Sept. '94) can be met by the CDA concept.
2. The basic design requirements established at the design meetings in 1995 are confirmed.
3. Several design changes were agreed upon with modest impact on the baseline design.
4. The detailed construction and R&D schedule required only minor modifications to the original proposal by Professor Kondo (Feb. '96).
5. There is good agreement on the preliminary cost estimate. However, several areas require checking and possible site-specific adjustments for national differences.
6. A detailed plan and cost estimate for the EVP has been prepared.

Appendix-1 Meeting Agenda

2nd IFMIF-CDA Design Integration Workshop

May 20 - 27, 1996
Research Bld. No. 1 and No. 2
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, 319-11Japan

Room Assignment:

Conference Room No. 6 at Laboratory Bldg. No. 1 (2nd floor)	**(Tel: 5004)**	General Session Design Integration Group Lunch
Conference Room No. 5 at Laboratory Bldg. No. 1 (1st floor)	**(Tel: 6621)**	Plenary Session Test Cell & User Group Target Group
Meeting Room #221 at Laboratory Bldg. No. 2 (2nd floor)	**(Tel: 6437)**	Accelerator Group
2nd Meeting Room #224 at Laboratory Bldg. No. 1 (2nd floor)		Drink Service,Spare

*** Each Facility Group Leader is requested to arrange "Facility Group Discussions", which is scheduled in the afternoon on May 20 (Mon) and in the morning on May 21 (Tue).**

Social Schedule

May 20 (Monday)	18:00 - 20:00	**Welcome Party** (JAERI Akogi-gaura Club)
May 23 (Thursday)	18:00 - 20:00	**Dinner** at Akogi-gaura Club
May 25 (Saturday)		Sight Seeing with lunch (Optional) place (TBD)

AGENDA

May 20 (Monday) **(Conf. Room No. 5)**

9:00 - 9:20:	Preparation Time	
9:20 Opening Plenary Session		Chairman: H. Maekawa
20-1 Welcome address		S. Funahashi
20-2 Outline of 2nd DI meeting		T. Shannon
20-3 Announcement for this meeting		S. Konishi
20-4 Discussion for this meeting schedule		
	Coffee Break	
10:50 Review of Baseline Design Activity		Chairman: T. Shannon
20-4 Test Cell		A. Moeslang
20-5 Target		H. Katsuta
20-6 Accelerator		R. Jameson
20-7 Design Integration		M. Martone
		H. Maekawa
12:00 - 13:10	**Lunch**	
13:10 - 17:30	Facility Group Discussions	
around 15:00	**Coffee Break**	
18:00 - 20:00	**Welcome Party** (JAERI Akogi-gaura Club)	

May 21 (Tuesday)

9:00 - 12:00	Facility Group Discussions
12:00 - 13:10	**Lunch**
13:10 - 17:30	Facility Group Discussions
around 15:00	**Coffee Break**

May 22 (Wednesday)

9:00 - 10:30	General Discussion	
22-1 Technical Status of Major Systems		
- Test Facilities		A. Möslang
- Target		H. Katsuta
- Accelerator		R. Jameson
22-2 Status of Integraltion Issues		
- RAM		C. Piaszczyk
- Maintenance		T. Shannon
- Common Instrumentation & Central Control, Operation	H. Maekaea	
22-3 Workshop Schedule and Report		
12:00 - 13:10	**Lunch**	
13:10 - 17:30	Small Group Discussions of Cost Estimate, Schedule, Operation,etc.	
around 15:00	**Coffee Break**	

May 23 (Thursday)

9:00 - 12:00	Small Group Discussion of Cost, Safety, Maintenace, RAM, etc.
12:00 - 13:10	**Lunch**
13:10 - 15:15	Small Group Discussion of Cost, Safety, Maintenace, RAM, etc.
15:00 - 15:30	**Coffee Break**
15:30 - 17:45	General Meeting

23-1 Status of Integrated Cost and Shedule Estimate
- Review of Cost Estimate — M. Rennich

23-2 Design Integration Issues
- Safety — S. Konishi
- Conventional Facilities — M. Martone
- Operations — H. Maekawa

23-3 Future Planning — T. Shannon

18:00 - 20:00 **Dinner** at Akogi-gaura Club

May 24 (Friday)

9:00 - 12:00 Small Group Meetings
- Complete Plan for EVP
- Plan Tasks to Complete CDA
- Plan for Final Report
- Discuss/Agree on Presentation to Subcommittee

12:00 - 13:10 **Lunch**

13:10 - 18:00 Small Group Meeting (Continued)

18:00 - 20:00 General Discussion
- Reported by Group Leaders
  * Review EVP
  * Review CDA Completion Plans
  * Review of Cost Estimate
  * Review of Final Report Plans

around 15:00 **Coffee Break**

May 25 (Saturday)

Sight Seeing with lunch (Optional) — place (TBD)

May 27 (Monday) **(Meeting Room #221)**

9:00 - 12:00	Preparation of Report to Executive Committee (Group Leaders only)
12:00 - 13:10	**Lunch**
13:10 - 17:30	Preparation of Report to Executive Committee (Continued))
around 15:00	**Coffee Break**

Appendix-2.1

IFMIF TEST CELL & USERS GROUP AGENDA

1) **Test Cell**
   a) Critical evaluation of new and more complete design concepts:
   - Test Modules and Test Assemlies for
     High flux, medium flux, low and very low flux region
   - Shielding Plugs
   - Removable Test Cell Cover
   - Test Cell Liner and Heat Shield
   - Instrumentation and control devices

2) **Access Cell, Service Cell and Remote Handling Cell**
   - Discussion on remote handling devices
   - Final definition of remote handling equipment and Access Cell dimensions

3) **PIE Laboratories**
   Agreement on design changes, equipment and instrumentation

4) **Tritium Facility**
   Presentation of concepts, discussion of design and costs

5) **Test Facility Ventilation System**
   Discussion on draft concepts

6) **RAM, Safety and Maintenance**
   Discussion

7) **Cost estimate**
   - Discussion on experience
   - Tasks to complete a sufficiently detailed estimate

8) **Neutronics**
   - Report on progress according to the items defined in the work packages
   - Discussion on the consequences of the results on design features

9) **SSTT Activities**
   - Status report on IEA-SSTT workshop in Sendai, March 1996
   - Discussion of future activities

10) **Future Activitiess**

Appendix-2.2 Accelerator Group Meeting Agenda

May 20 (Monday)

Morning - Opening Session and Design Integration Review

Afternoon -

(Nominally, Jameson, Berwald,Bruhwiler (and Gomes, Rathke 15:00-15:30) at Accelerator Group meeting; Rathke, Myers, Piaszczyk at Design Integration Facility Group discussions.)

13:10- 13:30 Opening of Accelerator Group Preparation for Injector Discussions
13:30-14:00 ECR Source and Injector Studies, Lagniel
14:00-14:30 Injector Work in Japan, Kinsho
14:30-15:00 Injector Work at IAP, Klein
15:00-15:30 Modeling of ion source/LEBT/RFQ transmission, deuteron beam loss, and neutron generation vs source emittance, Bruhwiler

15:30-15:50 Break

15:50-16:10 Perspective on deuterium performance/scaling for various positive ion sources at Northrup Grumman, Berwald for Sredniawski
16:10-16:30 Injector Discussion, Planning for Injector Working Group activity for the week; on injector decisions, technical report, and engineering development plan.

16:30-17:00 Halo Formation, Lagniel
17:00-17:30 RF Amplifiers for IFMIF, Lagniel

<u>May 21 (Tuesday)</u>

9:00-09:45 Japan Study of S/C Option, Tanabe
9:45-10:15 Other Information from IAP, Klein
10:15-10:45 Review/Update of Accelerator Interfaces, Berwald

10:45-11:00 Break

11:00-11:30 Comments on RFQ beam dynamics, Tatsumi/Chernogubovsky
11:30-12:00 Japan RF System Work (Solid State, etc), Maekawa

Afternoon - Design Integration Meeting, General Discussion of Cost Estimate, Schedule, Operation, etc.

May 22 (Wednesday)

9:00-10:30 Design Integration meeting; general discussion cont'd

10:30-12:00 Injector Session
- 10:30-10:50 Neutron activiation of ion source/LEBT/RFQ, Gomes
- 10:50-11:10 Design and RMA considerations for rapid replacement of ion injector, Rathke/Piaszczyk
- 11:10-12:00 Discussion

13:10-15:00 Design Integration Meeting; small group Discussions of Cost Estimate, Schedule, Operations, etc.
- 13:10-13:40 Accelerator Access & Maintainability, Rathke
- 13:40-14:00 Accelerator I&C System, Berwald
- 14:00-14:30 Cost, WBS and Manufacturing Schedule, Myers/Burger
- 14:30-15:00 Accelerator RAMI and Operations Update, Piaszczyk

15:00-15:20 Break

15:20-15:40 Reference Linac, Matching, and HEBT, Jameson
15:40-17:30 Injector Group working session
Other Acceleratory Group members working session on remainder of the CDA, final report, cost, schedule, etc

May 23 (Thursday)

9:00-12:00 General Meeting for Safety, RAM, Maintenance

13:10-16:30 Injector Group working session. By 1700, have injector decisions made, engineering development plan made, and outline and writing assignments made for injector technical report.

16:30-17:30 Full meeting of Accelerator Group; presention by Injector Group of decisions, engineering development plan, and technical report outline. General wrap-up of Accelerator Group meeting.

May 24 (Friday)

9:00-12:00 General Discussion: Review of Cost Estimate

Afternoon - as required

Appendix-2.3 Target Group Meeting Agenda

May 20 (Monday)

Morning : Opening Session and Design Integration Reviev
Afternoon :

13:10-13:30	Opening of Target Group (Group Discussion Schedule)
13:30-14:00	Discussion points for the Cost Estimation, Kato
	Cost estimation (1)
14:00-14:30	Review the US cost figures, Green
14:30-15:00	Total cost of target system, Kato
15:00-15:30	Discussion
15:30-15:50	Break
	Target Assembly (1): Design
15:50-16:20	Proposal of EU, Benamati
16:20-16:50	Proposal of US, Hua
16:50-17:30	Summary of discussion point

May 21 (Tuesday)

	Target Assembly(2): Analysys & Experiment	
9:00- 9:30	Neutron damage and nuclear heating in the backwall,	Gomes
9:30- 9:50	Planning and some results of target assembly water experiment,	Nakamura
9:50-10:10	Some comments on the analysis of target jet flow,	Ida
10:10-10:30	Break	
10:30-12:00	Visit a water experiment facility and discussion, Nakamura	

Afternoon : Design Integration Meeting, General discussion of Cost Estimate, Schedule, operation, etc.

May 22 (Wednesday)

9:00-12:00	Design Integration Meeting; general discussion continued	
Afternoon :	Small Group Discusions of Cost Estimate Schedule, Operation, etc	
13:10-13:40	Preliminary Hazard analysis at component level of targetsystem,	Benemati
13:40-14:10	Proposal of the ventilation system and interface issue with conventional facility,	Konishi
14:10-15:00	Discussion for Cost Estimation	
15:00-15:20	Break	
15:20-15:50	Target system Ram and operations Update, Piaszczyk	
15:50-17:30	Proposal for the IFMIF Engineering Validation Phase	
	JP : Katsuta	
	US: Hua	
	EU: Benemati	

May 23 (Thursday)

9:00-12:00	General Meeting for Safety, RAM, Maintenaqnce
13:10-15:10	Discussion & revise the cost estimation sheet
15:10-15:30	Break
15:30-17:30	Review reporting

May 24 (Friday)

9:00-12:00	General Discussion : Review of Cost Estimate

Afternoon: Continued,

Appendix-3 Participant List

EU

A. Möslang (FZK)
G. Benamati (ENEA)
M. Martone (ENEA)
S. Monti (ENEA)
H. Klein (IAP)
J-M Lagniel (CEA)
R. Ferdinand (CEA)

USA

T. E. Shannon (The University of Tennessee)
I. C. Gomes (ANL)
T. Q. Hua (ANL)
R. A. Jameson (LANL)
J. R. Haines (ORNL)
M. J. Rennich (ORNL)
D. Berwald (Northrop Grumman)
D. L. Bruhwiler (Northrop Grumman)
T. Myers (Northrop Grumman)
C. Piaszczyk (Northrop Grumman)
J. W. Rathke (Northrop Grumman)
L. Green (Westinghouse)

Japan

S. Funahashi (JAERI)
H. Maekawa (JAERI)
Y. Kato (JAERI)
M. Ida (JAERI)
H. Nakamura (JAERI)
S. Jitsukawa (JAERI)
Y. Oyama (JAERI)
Y. Katano (JAERI)
T. Saito (JAERI)
S. Hamada (JAERI)
A. Miyahara (Teikyo University)
T. Kondo (Tohoku University)
M. Takahashi (Tokyo Instidute of Technology)
M. Odera (IPCR)
S. Ioka (Toshiba)
Y. Tanabe (Toshiba)
K. Sawada (Sumitomo Juki)
M. Ogoshi (IHI)
H. Katsuta (JAERI)
K. Noda (JAERI)
M. Sugimoto (JAERI)
Y. Houjyo (JAERI)
M. Kinsho (JAERI)
S. Konishi (JAERI)
M. Mizumoto (JAERI)
T. Saito (JAERI)
K. Watanabe (JAERI)
T. Aruga (JAERI)
S. Ishino (Tokai University)
K. Ebisawa (Toshiba)
K. Kabuki (Toshiba)
R. Kitano (Toshiba)
A. Maekawa (Hitachi)
H. Kakui (IHI)

Russia

M. Chernogubovsky (NIIEFA, on assignment to JAERI)

Appendix-4 Revised Work Breakdown Structure

IFMIF Work Breakdown Structure (Jun 27, 1996)

1. 2. 3. 4. 5. 6. 7. Level

1. 0. 0. 0. 0. 0. 0. Project Management

1. 0. 0. 0. 0. 0. Project Management and Administration
1. 0. 0. 0. 0. Administration
2. 0. 0. 0. 0. Cost Control
3. 0. 0. 0. 0. Schedule
4. 0. 0. 0. 0. Development Oversight
5. 0. 0. 0. 0. Construction Management
6. 0. 0. 0. 0. Documentation

2. 0. 0. 0. 0. 0. Systems Engineering
1. 0. 0. 0. 0. Design Integration
2. 0. 0. 0. 0. Systems Analysis
3. 0. 0. 0. 0. Requirements/Specs
4. 0. 0. 0. 0. RAM Analysis

3. 0. 0. 0. 0. 0. Environmental, Safety & Health Documentation

4. 0. 0. 0. 0. 0. Quality Assurance

2. 0. 0. 0. 0. 0. 0. Test Facilities

1. 0. 0. 0. 0. 0. Test Facility Management
1. 0. 0. 0. 0. Project Management and Administration
1. 0. 0. 0. Administration
2. 0. 0. 0. Cost Control
3. 0. 0. 0. Schedule
4. 0. 0. 0. Documentation
2. 0. 0. 0. 0. Systems Engineering
1. 0. 0. 0. Design Integration
2. 0. 0. 0. Systems Analysis
3. 0. 0. 0. Requirements/Specs
4. 0. 0. 0. RAM Analysis
3. 0. 0. 0. 0. Environmental, Safety & Health Documentation
4. 0. 0. 0. 0. Quality Assurance

2 2 0 0 0 0 0 Subsystems
2 2 1 0 0 0 0 Vertical Test Assemblies
1 0 0 0 VTA1-NaK
2 0 0 0 VTA1-He
3 0 0 0 VTA2-NaK
4 0 0 0 VTA2-He
1 0 0 VTA2-He Concept 1
2 0 0 VTA2-He Concept 2
5 0 0 0 VIT-System
6 0 0 0 Shield Plug
2 2 2 0 0 0 0 Test Cell
1 0 0 0 Test Cell Cover
2 0 0 0 Test Cell Liner
3 0 0 0 Heat shield

4 0 0 0 Seal Plate
5 0 0 0 Camera System
6 0 0 0 Neutron Source Diagnostics
7 0 0 0 Test Cell Diagnostics
8 0 0 0 Emergency Shutdown System
2 2 3 0 0 0 0 Test Cell Technology Room
1 0 0 0 Assembly and Testing
2 0 0 0 Cooling System
3 0 0 0 Vacuum Pumping System
4 0 0 0 Ar backfill System
5 0 0 0 Diagnostics and Controls
6 0 0 0 Subsystem Power
2 2 4 0 0 0 0 Test Facility Control Room
1 0 0 0 Assembly and Testing
2 0 0 0 Data Acquisition - VTA 1 - NaK
3 0 0 0 Data Acquisition - VTA-1 - He
4 0 0 0 Data Acquisition. - Creep Fatigue
5 0 0 0 Data Acquisition - Tritium Release
6 0 0 0 Data Acquisition - VIT
7 0 0 0 Supervisory Computer
8 0 0 0 Subsystem Power
2 2 5 0 0 0 0 Access Cell
1 0 0 0 Assembly and Testing
2 0 0 0 Cell Structure
3 0 0 0 Universal Robot
4 0 0 0 Manipulator System
5 0 0 0 Maintenance Support Equipment
6 0 0 0 Infrastructure
2 2 6 0 0 0 0 Service Cell
1 0 0 0 Assembly and Testing
2 0 0 0 Cell Structure
3 0 0 0 Transfer System
4 0 0 0 Manipulator Systems
5 0 0 0 Bridge Crane
6 0 0 0 Maintenance Support Equip
7 0 0 0 Infrastructure
2 2 7 0 0 0 0 Test Module Handling Cell
1 0 0 0 Assembly and Testing
2 0 0 0 Cell Structure
3 0 0 0 Manipulator Systems
4 0 0 0 Bridge Crane
5 0 0 0 Maintenance Support Equip
6 0 0 0 Infrastructure
2 2 8 0 0 0 0 PIE Hot Cell
1 0 0 0 Assembly and Testing
2 0 0 0 Cell Structure
3 0 0 0 Manipulator Systems
4 0 0 0 Bridge Crane
5 0 0 0 Infrastructure
6 0 0 0 Examination Equipment
2 2 9 0 0 0 0 Shielded Glove Box Laboratory
1 0 0 0 Assembly and Testing
2 0 0 0 Structural and Support Systems
3 0 0 0 Examination Equipment
2 2 1 0 0 0 0 0 Tritium Laboratory
1 0 0 0 Assembly and Testing
2 0 0 0 Components
2 2 1 1 0 0 0 0 Test Facility Ventilation Systems

1 0 0 0 Ventilation
2 0 0 0 Tritium Retention
2 2 1 2 0 0 0 0 Maintenance System

2.3. 0.0.0.0.0.System Installation and Checkout
1.0.0.0.0.Installation
2.0.0.0.0.Facilities Verification Testing

2.4. 0.0.0.0.0.Subsystem Development

3.0.0. 0.0.0.0.Target Facility

---

1 0 0 0 0 0 Target Facility Management
1 0 0 0 0 Project Management and Administration
1 0 0 0 Administration
2 0 0 0 Cost Control
3 0 0 0 Schedule
4 0 0 0 Documentation
2 0 0 0 0 Systems Engineering
1 0 0 0 Design Integration
2 0 0 0 Systems Analysis
3 0 0 0 Requirements/Specs
4 0 0 0 RAM Analysis
3 0 0 0 0 Environmental, Safety & Health Documentation.
1 0 0 0 Environmental, Safety & Health Documentation.
2 0 0 0 Licenses
4 0 0 0 0 Quality Assurance
5 0 0 0 0 Other Costs
2 0 0 0 0 0 Subsystem
1 0 0 0 0 Lithium Target System
1 0 0 0 Assembly and Testing
1 0 0 Assembly
2 0 0 Testing
2 0 0 0 Components
1 0 0 Target Assembly
1 0 Li Inlet Piping
2 0 Flow Straightener
3 0 Nozzle
4 0 Replaceable Backwall
5 0 Downstream Diffuser
6 0 Downstream Baffles
7 0 Mechanical Connectors
8 0 Li System Target Assembly Interface
9 0 Measuring System
2 0 0 Beam-Target Interface
1 0 Beam-Target Interface Structure
2 0 Evacuation System
3 0 Emergency Shutdown System
3 0 0 Target-Test Cell Interface
1 0 Target-Test Cell Interface Structure
2 0 0 0 0 Lithium Cooling System
1 0 0 0 Assembly and Testing
1 0 0 Assembly
2 0 0 Testing
2 0 0 0 Components
1 0 0 Main Lithium Loop
1 0 EM Pump
2 0 Valves

3 0 Flow Meters
4 0 Piping
5 0 Quench Tank
6 0 Dump Tank
7 0 Surge Tank
8 0 Trace Heating
9 0 Insulation
10 0 Argon/Vacuum System
11 0 Instrumentation and Control
12 0 Lithium Metal
13 0 Radiation Shielding
2 0 0 Primary Heat Removal System
1 0 Primary Heat Exchanger(Li to Organic)
2 0 Piping
3 0 Pump
4 0 Valves
5 0 Flow Meters
6 0 Organic Dump Tank
7 0 Instrumentation and Control
8 0 Radiation Shielding
9 0 Organic Oil
10 0 Organic Heater
3 0 0 Secondary Heat Removal System
1 0 Secondary Heat Exchanger (Organic to Water)
2 0 Piping
3 0 Pump
4 0 Valves
5 0 Flow Meters
6 0 Instrumentation and Control
4 0 0 Tertiary Heat Exchanger(Water Cooling)

3 0 0 0 0 Purification and Impurity Monitoring System

1 0 0 0 Assembly and Testing
1 0 0 Assembly
2 0 0 Testing
2 0 0 0 Components
1 0 0 Lithium Purification System
1 0 Cold Trap
2 0 Hot Trap #1
3 0 Hot Trap #2
4 0 EM Pump
5 0 Cold Trap Cooler
6 0 Piping
7 0 Valves
8 0 Trace Heating
9 0 Insulation
10 0 Instrumentation and Control
11 0 Radiation Shielding
12 0 Flow Meters
13 0 Economizer
2 0 0 Impurity Monitoring System
1 0 On-Line Meters
2 0 Off-Line Monitors
3 0 Flow Meters
4 0 Piping
5 0 Valves
6 0 Main Heater
7 0 Economizer

8 0 Trace Heating
9 0 Insulation
1 0 0 Instrumentation and Control
1 1 0 Radiation Shielding
1 2 0 EM Pump
4 0 0 0 0 Lithium Recovery System
1 0 0 0 Leaked Lithium Recovery System
2 0 0 0 Leaked Lithium Detection System
3 0 0 0 Lithium Fire Control System
5 0 0 0 0 Target Facility Control System
1 0 0 0 Normal Operation Control System
2 0 0 0 Emergency Control System
6 0 0 0 0 Target Facility Ventilation System
1 0 0 0 Radioactive Gas Evacuation System
1 0 0 Tritium Treatment Facility
2 0 0 Other Radioisotope Treatment Facility
2 0 0 0 General Ventilation System
7 0 0 0 0 Target Facility Power System
1 0 0 0 Commercial Power
2 0 0 0 Emergency Power
8 0 0 0 0 Other Support Facilities
9 0 0 0 0 Maintenance Systems
1 0 0 0 Maintenance Procedure Development
2 0 0 0 Special Purpose Tooling
3 0 0 0 Remote Handling Equipment
1 0 0 For Target Assembly
2 0 0 For Purification Components
4 0 0 0 Mockup Facilities and Testing
3 0 0 0 0 0 System Installation and Checkout
1 0 0 0 0 Installation
1 0 0 0 Lithium Target System
2 0 0 0 Lithium Cooling System
3 0 0 0 Lithium Recovery System
4 0 0 0 Target Facility Control System
5 0 0 0 Target Facility Ventilation System
6 0 0 0 Target Facility Power System
7 0 0 0 Other Support Facilities
8 0 0 0 Maintenance Systems
2 0 0 0 0 Verification Testing
3 0 0 0 0 Startup
4 0 0 0 0 0 Subsystem Development

4. 0. 0. 0. 0. 0. 0. Accelerator Facility

1. 0. 0. 0. 0. 0. 0. Accelerator Facility Management
1. 0. 0. 0. 0. Project Management and Administration
1. 0. 0. 0. Administration
2. 0. 0. 0. Cost Control
3. 0. 0. 0. Schedule
4. 0. 0. 0. Documentation
2. 0. 0. 0. 0. Systems Engineering
1. 0. 0. 0. Design Integration
2. 0. 0. 0. Systems Analysis
3. 0. 0. 0. Requirements/Specs
4. 0. 0. 0. RAM Analysis
3. 0. 0. 0. 0. Environmental, Safety & Health Documentation
4. 0. 0. 0. 0. Quality Assurance

2. 0. 0. 0. 0. 0. Subsystems

1. 0. 0. 0. 0. Accelerator Equipment Preliminary Design (injector through HEBT)
2. 0. 0. 0. 0. Accelerator Equipment Physics (injector through HEBT)
3. 0. 0. 0. 0. Accelerator #1 (Castor)
   1. 0. 0. 0. Injector System
      1. 0. 0. Final Design labor
      2. 0. 0. Procurement support/Seller Surveillance
      3. 0. 0. Purchased Material
         1. 0. Source and RF power supply
         2. 0. LEBT
         3. 0. Power supplies
         4. 0. Operational Controls & Software
         5. 0. Vacuum Equipment & Services
         6. 0. Thermal Control Equip & Services
         7. 0. Structure and Shielding
      4. 0. 0. Fabrication Labor
      5. 0. 0. Sustaining Engineering
   2. 0. 0. 0. Radiofrequency Quadrupole System
      1. 0. 0. Cold Model Design & Test
      2. 0. 0. Final Design labor
      3. 0. 0. Procurement support/Seller Surveillance
      4. 0. 0. Purchased Material
         1. 0. Copper
         2. 0. Vacuum System Equipment & Services
         3. 0. Drive Loops
         4. 0. Electroforming
         5. 0. Miscellaneous Hardware
      5. 0. 0. Fabrication Labor
      6. 0. 0. Sustaining Engineering
   3. 0. 0. 0. Drift Tube Linac System
      1. 0. 0. Cold Model Design & Test
      2. 0. 0. Final Design Tanks #1-6
      3. 0. 0. Tank #1
         1. 0. Procurement support/Seller Surveillance
         2. 0. Purchased Material
            1. Drift Tubes
            2. Drift tube magnets
            3. Vacuum system equipment & Services
            4. OFHC Copper for tank shell
            5. Endwalls with magnets
            6. Tank support system
            7. Tuners
            8. RF drive loops
            9. Post couplers
            10. Drift tube support girder
            11. Focusing quadrupole package
            12. Miscellaneous hardware
         3. 0. Fabrication Labor
      4. 0. 0. Tank #2
         1. 0. Procurement support/Seller Surveillance
         2. 0. Purchased Material
            1. Drift Tubes
            2. Drift tube magnets

3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. Miscellaneous hardware

3. 0. Fabrication Labor
5. 0. 0. Tank #3
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. Miscellaneous hardware

3. 0. Fabrication Labor
6. 0. 0. Tank #4
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. Miscellaneous hardware

3. 0. Fabrication Labor
7. 0. 0. Tank #5
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services

4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. Miscellaneous hardware

3. 0. Fabrication Labor
8. 0. 0. Tank #6
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. Miscellaneous hardware

3. 0. Fabrication Labor
4. 0. 0. 0. HEBT System
1. 0. 0. Final Design labor
2. 0. 0. Procurement support/Seller Surveillance
3. 0. 0. Purchased Material
1. 0. Beam Tube, Flanges, Bellows, etc.
2. 0. RF Cavities
3. 0. Support/Alignment Structure
4. 0. Quadrupole magnets: 6" long x 5" dia bore
5. 0. Quadrupole magnets: 16" long x 5" dia bore
6. 0. Quadrupole magnets: 24" long x 5" dia bore
7. 0. Octupole magnets: 16" long x 3.5" dia bore
8. 0. Dipole (45°) magnets: 5" gap
9. 0. Dipole (10°) magnets: 5" gap
10. 0. Energy Spread Monitors
11. 0. Phase Spread Monitors
12. 0. Video Profile Monitor
13. 0. Microstriplines

4. 0. 0. Fabrication Labor
5. 0. 0. 0. RF Drive Loop
1. 0. 0. Final Design labor
6. 0. 0. 0. Accelerator & HEBT Thermal Control Engineering

1. 0. 0. Final Design labor
2. 0. 0. Fabrication support
7. 0. 0. 0. RF Power System
1. 0. 0. RF control
2. 0. 0. RF Pre-driver (first high gain stage - solid state)
3. 0. 0. RF Final Amplifier (including driver : Approx. 1.3 MW)
4. 0. 0. RF Transport
1. 0. RF station to RFQ
2. 0. RF station to DTL and Momentum Compactor
3. 0. RF station to Energy Dispersion Cavities
4. 0. Circulators (19" Y-junction)
5. 0. Filters (19")
6. 0. Low Power Couplers
7. 0. RF Dummy Loads
8. 0. Air pressurization and distribution
5. 0. 0. Cavity Resonance Control
6. 0. 0. Switchgear
7. 0. 0. Cooling
8. 0. 0. RF station Monitoring and Control
9. 0. 0. Integration Equipment
4. 0. 0. 0. 0. Accelerator #2 (Pollux)
1. 0. 0. 0. Design Updates
1. 0. 0. Injector system
2. 0. 0. RFQ system
3. 0. 0. DTL System
2. 0. 0. 0. Injector System
1. 0. 0. Procurement support/Seller Surveillance
2. 0. 0. Purchased Material
1. 0. Source and RF power supply
2. 0. LEBT
3. 0. Power supplies
4. 0. Operational Controls & Software
5. 0. Vacuum Equipment & Services
6. 0. Thermal Control Equip & Services
7. 0. Structure and Shielding
3. 0. 0. Fabrication Labor
3. 0. 0. 0. Radiofrequency Quadrupole System
1. 0. 0. Procurement support/Seller Surveillance
2. 0. 0. Purchased Material
1. 0. Copper
2. 0. Vacuum System Equipment & Services
3. 0. Drive Loops
4. 0. Electroforming
5. 0. Miscellaneous Hardware
3. 0. 0. Fabrication Labor
4. 0. 0. 0. Drift Tube Linac System
1. 0. 0. Tank #1
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners

8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. MIscellaneous hardware

3. 0. Fabrication Labor

2. 0. 0. Tank #2

1. 0. Procurement support/Seller Surveillance

2. 0. Purchased Material

1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. MIscellaneous hardware

3. 0. Fabrication Labor

3. 0. 0. Tank #3

1. 0. Procurement support/Seller Surveillance

2. 0. Purchased Material

1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
10. Drift tube support girder
11. Focusing quadrupole package
12. MIscellaneous hardware

3. 0. Fabrication Labor

4. 0. 0. Tank #4

1. 0. Procurement support/Seller Surveillance

2. 0. Purchased Material

1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops

9. Post couplers
1 0. Drift tube support girder
1 1. Focusing quadrupole package
1 2. MIscellaneous hardware
3. 0. Fabrication Labor
5. 0. 0. Tank #5
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
1 0. Drift tube support girder
1 1. Focusing quadrupole package
1 2. MIscellaneous hardware
3. 0. Fabrication Labor
6. 0. 0. Tank #6
1. 0. Procurement support/Seller Surveillance
2. 0. Purchased Material
1. Drift Tubes
2. Drift tube magnets
3. Vacuum system equipment & Services
4. OFHC Copper for tank shell
5. Endwalls with magnets
6. Tank support system
7. Tuners
8. RF drive loops
9. Post couplers
1 0. Drift tube support girder
1 1. Focusing quadrupole package
1 2. MIscellaneous hardware
3. 0. Fabrication Labor
5. 0. 0. 0. HEBT System
1. 0. 0. Procurement support/Seller Surveillance
2. 0. 0. Purchased Material
1. 0. Beam Tube, Flanges, Bellows, etc.
2. 0. RF Cavities
3. 0. Support/Alignment Structure
4. 0. Quadrupole magnets: 6" long x 5" dia bore
5. 0. Quadrupole magnets: 16" long x 5" dia bore
6. 0. Quadrupole magnets: 24" long x 5" dia bore
7. 0. Octupole magnets: 16" long x 3.5" dia bore
8. 0. Dipole (45°) magnets: 5" gap
9. 0. Dipole (10°) magnets: 5" gap

10.0. Energy Spread Monitors
11.0. Phase Spread Monitors
12.0. Video Profile Monitor
13.0. Microstriplines
3. 0. 0. Fabrication Labor
6. 0. 0. 0. RF Power System
1. 0. 0. RF control
2. 0. 0. RF Pre-driver (first high gain stage - solid state)
3. 0. 0. RF Final Amplifier (including driver : Approx. 1.3 MW)
4. 0. 0. RF Transport
1. 0. RF station to RFQ
2. 0. RF station to DTL and Momentum Compactor
3. 0. RF station to Energy Dispersion Cavities
4. 0. Circulators (19" Y-junction)
5. 0. Filters (19")
6. 0. Low Power Couplers
7. 0. RF Dummy Loads
8. 0. Air pressurization and distribution
5. 0. 0. Cavity Resonance Control
6. 0. 0. Switchgear
7. 0. 0. Cooling
8. 0. 0. RF station Monitoring and Control
9. 0. 0. Integration Equipment
5. 0. 0. 0. 0. Beam Calibration Dumps
1. 0. 0. 0. Moveable Beam Dump
1. 0. 0. Final Design
2. 0. 0. Procurement support/Seller Surveillance
3. 0. 0. Purchased Material
4. 0. 0. Fabrication Labor
2. 0. 0. 0. Fixed Beam Dump
1. 0. 0. Final Design
2. 0. 0. Procurement support/Seller Surveillance
3. 0. 0. Purchased Material
4. 0. 0. Fabrication Labor
6. 0. 0. 0. 0. Accelerator System Control
1. 0. 0. 0. Final Design labor
2. 0. 0. 0. Procurement support/Seller Surveillance
3. 0. 0. 0. Purchased Material
1. 0. 0. Central Computers
2. 0. 0. Data Transmission Network
3. 0. 0. Local Control
4. 0. 0. Database Computers
5. 0. 0. Logging and Facility Fault Analysis Computers
7. 0. 0. 0. 0. Accelerator Support Systems
8. 0. 0. 0. 0. Maintenance Systems
1. 0. 0. 0. Final Design labor
2. 0. 0. 0. Procurement support/Seller Surveillance
3. 0. 0. 0. Purchased Material
1. 0. 0. Special purpose tooling
2. 0. 0. Remote handling equipment
3. 0. 0. Mockup Facilities and Testing

3 . 0 . 0 . 0 . 0 . 0 . Subsystem Installation and Checkout
1. 0. 0. 0. 0. Accelerator #1 (Castor) Installation and Checkout
1. 0. 0. 0. Injector system
2. 0. 0. 0. RFQ system
3. 0. 0. 0. DTL Tank#1 system
4. 0. 0. 0. DTL Tanks #2-#6 system
5. 0. 0. 0. HEBT systems ("Abel", "Baker", and "Charlie")
6. 0. 0. 0. RF power system
7. 0. 0. 0. Beam Dumps
1. 0. 0. Moveable Beam Dump
2. 0. 0. Fixed Beam Dump
8. 0. 0. 0. Full Power Acceptance Test (125 mA)
2. 0. 0. 0. 0. Accelerator #2 (Pollux) Installation and Checkout
1. 0. 0. 0. Injector system
2. 0. 0. 0. RFQ system
3. 0. 0. 0. DTL Tank#1 system
4. 0. 0. 0. DTL Tanks #2-#6 system
5. 0. 0. 0. HEBT systems ("Abel", "Baker", and "Charlie")
6. 0. 0. 0. RF power system
7. 0. 0. 0. Full Power Acceptance Testing (250 mA)

4 . 0 . 0 . 0 . 0 . 0 . Subsystem Development

5 . 0 . 0 . 0 . 0 . 0 . 0 . Conventional Facilities

1 . 0 . 0 . 0 . 0 . 0 . Conventional Facility Management
1. 0. 0. 0. 0. Project Management and Administration
1. 0. 0. 0. Administration
2. 0. 0. 0. Cost Control
3. 0. 0. 0. Schedule
4. 0. 0. 0. Documentation
2. 0. 0. 0. 0. Systems Engineering
1. 0. 0. 0. Design Integration
2. 0. 0. 0. Requirements/Specs
3. 0. 0. 0. RAM Analysis
3. 0. 0. 0. 0. Environmental, Safety & Health Documentation
4. 0. 0. 0. 0. Quality Assurance

2 . 0 . 0 . 0 . 0 . 0 . Buildings (Conventional Construction)
1. 0. 0. 0. 0. Accelerator Complex
1. 0. 0. 0. Accelerator Hall
2. 0. 0. 0. Beam Turning Room
3. 0. 0. 0. RF Power Bay
4. 0. 0. 0. Accelerator Assembly/Maintenance Bay
2. 0. 0. 0. 0. Target Complex
1. 0. 0. 0. Lithium Processing Cells
3. 0. 0. 0. 0. Test and Examination Complex
1. 0. 0. 0. Test Cells
2. 0. 0. 0. Beam Calibration Station Cell
3. 0. 0. 0. Test Cell Technology Rooms
4. 0. 0. 0. Access Cell
1. 0. 0. Shielding Doors
5. 0. 0. 0. VTA & Target Service Cell
1. 0. 0. Shielding Doors
6. 0. 0. 0. Module Handling Cell
1. 0. 0. Shielding Door

7. 0. 0. 0. Operating Area
8. 0. 0. 0. Control Room
9. 0. 0. 0. Data Acquisition Room
10. 0. 0. 0. PIE Laboratory Area
11. 0. 0. 0. Tritium PIE Laboratory Area
12. 0. 0. 0. Hot Cell Utility Area
13. 0. 0. 0. Corridors
4. 0. 0. 0. 0. Building High Bay
1. 0. 0. 0. High Bay
1. 0. 0. Bridge Crane
2. 0. 0. 0. Hot Shop
1. 0. 0. Protective Clothes
2. 0. 0. Containment Structures
3. 0. 0. 0. Uncontaminated Shop
1. 0. 0. Machine Tools
4. 0. 0. 0. Manipulator Repair
1. 0. 0. Maintenance & Testing Equipment
5. 0. 0. 0. Shipping Bay
6. 0. 0. 0. Rad Waste Processing
7. 0. 0. 0. Rad Waste Shipping
8. 0. 0. 0. Health Physics Station
9. 0. 0. 0. Corridors
5. 0. 0. 0. 0. Support Facilities
1. 0. 0. 0. Plant Services Halls
2. 0. 0. 0. Office Complex

3. 0. 0. 0. 0. 0. Site Improvements
1. 0. 0. 0. 0. Roads and Parking
2. 0. 0. 0. 0. Grading and Landscaping
3. 0. 0. 0. 0. Storm Drainage

4. 0. 0. 0. 0. 0. Plant Services
1. 0. 0. 0. 0. Water Systems
1. 0. 0. 0. Cooling Water
2. 0. 0. 0. Service Water
2. 0. 0. 0. 0. Power System
1. 0. 0. 0. Substation
1. 0. 0. Main Transformer
2. 0. 0. Circuit Breakers
3. 0. 0. Generating set and UPS
3. 0. 0. 0. 0. Heat Rejection System
4. 0. 0. 0. 0. Compressed Air
5. 0. 0. 0. 0. Natural Gas
6. 0. 0. 0. 0. Argon
7. 0. 0. 0. 0. Building Conventional Services
1. 0. 0. 0. Heating, Ventilation and Air Conditioning (HVAC)
2. 0. 0. 0. Nuclear HVAC
3. 0. 0. 0. Industrial HVAC
4. 0. 0. 0. Plumbing
5. 0. 0. 0. Lighting
8. 0. 0. 0. 0. Vacuum Exhaust Collection System
1. 0. 0. 0. Clean up System
2. 0. 0. 0. Distribution

5. 0. 0. 0. 0. 0. Radiological Safety Monitoring
1. 0. 0. 0. 0. Site and Building Monitors
2. 0. 0. 0. 0. Access Monitor

6. 0. 0. 0. 0. 0. Temporary Facilities

6. 0. 0. 0. 0. 0. 0. Common Instrumentation and Central Control Systems

1. 0. 0. 0. 0. 0. System Management
1. 0. 0. 0. 0. Project Management and Administration
1. 0. 0. 0. Administration
2. 0. 0. 0. Cost Control
3. 0. 0. 0. Schedule
4. 0. 0. 0. Documentation
2. 0. 0. 0. 0. Systems Engineering
1. 0. 0. 0. Design Integration
2. 0. 0. 0. Systems Analysis
3. 0. 0. 0. Requirements/Specs
4. 0. 0. 0. RAM Analysis
3. 0. 0. 0. 0. Environmental, Safety & Health Documentation
4. 0. 0. 0. 0. Quality Assurance

2. 0. 0. 0. 0. 0. Common Instrumentation Subsystems
1. 0. 0. 0. 0. Beam Instrumentation
1. 0. 0. 0. On-Target Profile Monitor
1. 0. 0. Optical/IR Viewing
2. 0. 0. Neutron Imaging
2. 0. 0. 0. Neutron Yield Monitor
2. 0. 0. 0. 0. Radiation Monitoring
1. 0. 0. 0. Radiation Monitor
1. 0. 0. Hand & Foot Monitor
2. 0. 0. GM Survey Meter
3. 0. 0. Dose Meter (gamma & beta ray)
4. 0. 0. Neutron REM Counter
5. 0. 0. Surface Tritium Survey Meter
6. 0. 0. Portable Tritium Survey Meter
7. 0. 0. Pocket Dosimeter
8. 0. 0. Liquid Scintillation Counter
9. 0. 0. Personnel Glass Dosimeter
10. 0. 0. Stack Gas Monitor
11. 0. 0. Stack Dust Monitor
12. 0. 0. Integral Tritium Monitor
13. 0. 0. Room Gas Monitor
14. 0. 0. Neutron Area Monitor
15. 0. 0. Gamma-ray Area Monitor
16. 0. 0. Outdoor Monitoring Post

17 0. 0. Leak Detector for Organic Loop

18 0. 0. Indication Panel

19 0. 0. Air Sampling System

20 0. 0. Documents

2. 0. 0. 0. Device Controller
1. 0. 0. CPU (DVE-AT486, 486, 32MB)
2. 0. 0. ADC (MVNE-512, 16ch)
3. 0. 0. Data Input (DVE-528, 49ch)
4. 0. 0. Data Output (DVE-529, 16ch)
5. 0. 0. Chassis
6. 0. 0. Software (Windows-NT)

3. 0. 0. 0. 0. Video Monitoring

1. 0. 0. 0. ITV Camera (Low Radiation Area)
1. 0. 0. CCD Camera
2. 0. 0. Zoom Lens
3. 0. 0. Camera Case, Pan Head
4. 0. 0. Pan Head Controller
5. 0. 0. Power Supply
6. 0. 0. Modulator
7. 0. 0. UPS
2. 0. 0. 0. ITV Camera (High Radiation Area) - nc -
3. 0. 0. 0. Display
1. 0. 0. Demodulator
2. 0. 0. Video-amp
3. 0. 0. Video Monitor
4. 0. 0. CPU Unit
5. 0. 0. Touch Sensor
6. 0. 0. LAN Box, LAN Translator
7. 0. 0. Power Supply
4. 0. 0. 0. Device Controller
1. 0. 0. Cubicle
2. 0. 0. Video Switcher
1. 0. 0. Character/Symbol Generator
2. 0. 0. Video Controller
2. 0. 0. Camera Control Terminal

4. 0. 0. 0. 0. Access Control

1. 0. 0. 0. Door Limit Switch
1. 0. 0. Limit Switch
2. 0. 0. Door Lock
2. 0. 0. 0. Keybank
1. 0. 0. Key Switch Panel
2. 0. 0. Interlock Unit
3. 0. 0. CPU & Memory
4. 0. 0. I/O Unit
5. 0. 0. Programming Tool
6. 0. 0. Power Source
7. 0. 0. UPS
8. 0. 0. Cable, Connector, Terminal Block, MCB
3. 0. 0. 0. Warning Light
1. 0. 0. Warning Light
5. 0. 0. 0. Emergency Stop Switch
1. 0. 0. Switch Box

5. 0. 0. 0. 0. Enunciator

1. 0. 0. 0. Speaker

1. 0. 0. Speaker
2. 0. 0. 0. Device Controller
1. 0. 0. Cubicle
2. 0. 0. Amplifier
3. 0. 0. Auto-paging System
3. 0. 0. Control Unit
4. 0. 0. UPS
6. 0. 0. 0. 0. Information Display Stations
1. 0. 0. 0. CATV Network
1. 0. 0. Distributor
2. 0. 0. TV Processor
3. 0. 0. BS Tuner
4. 0. 0. Modulator
5. 0. 0. Mixer
6. 0. 0. Network
2. 0. 0. 0. Controller
1. 0. 0. Amplifier
2. 0. 0. Control System
3. 0. 0. Modulator
3. 0. 0. 0. Display Terminals
1. 0. 0. Demodulator
2. 0. 0. Video Monitor
7. 0. 0. 0. 0. Safety and Emergency Equipments
1. 0. 0. 0. Oxygen Deficit
1. 0. 0. Oxygen Sensor
2. 0. 0. Indicator/Controller
3. 0. 0. Recorder
2. 0. 0. Escape Mask for Oxygen Deficit
3. 0. 0. Oxygen Rescue
2. 0. 0. 0. Fire-proof
1. 0. 0. Fire-proof Protective Clothing
3. 0. 0. 0. Radio Active Gas Leak
1. 0. 0. Self-contained Breathing Apparatus
1. 1. Mask with Cylinder
2. 2. Storage Case

3. 0. 0. 0. 0. 0. Central Control Subsystems
1. 0. 0. 0. 0. Central Control
1. 0. 0. 0. Computer System
1. 0. 0. Main Computer (Data Server)
1. 0. Computer (VR410 Basic Set, 128MB)
2. 0. CPU Enhancement (120MHz)
3. 0. 128MB Memory
4. 0. FDDI Adapter
5. 0. Peripheral Equipment
6. 0. Software Manuals
2. 0. 0. Support Computers
1. 0. Computer (VJ110 Basic Set)
2. 0. 128MB Memory
3. 0. CD-ROM Driver
4. 0. Peripheral Equipment
5. 0. Software Manuals
3. 0. 0. Computer Racks, Furniture
1. 0. Cabinet
3. 0. Rack Mount, Filler Panel
4. 0. VR Class Server Mount Kit
2. 0. 0. 0. Data Storage
1. 0. 0. Internal S. E. SCSI DAT 2-16GB

2. 0. 0. Disk Array 16.8GB
3. 0. 0. Magneto-optical Disc 1.3GB
3. 0. 0. 0. Uninterruptable Power Supply
1. 0. 0. 1.8kVA UPS 200V
2. 0. 0. UPS Console
4. 0. 0. 0. Operator Interface
1. 0. 0. X-Window Terminal (21"CRT, 32MB)
2. 0. 0. Console
3. 0. 0. Touch Sensor, Rotary Encoder, Slider

2. 0. 0. 0. 0. LAN

1. 0. 0. 0. Network (Ethernet)
1. 0. 0. HUB for Terminals
2. 0. 0. FDDI Switch
3. 0. 0. PC for Network Observation
4. 0. 0. UPS
2. 0. 0. 0. Substation Interface
1. 0. 0. HUB for Central Control
2. 0. 0. Substation HUB
3. 0. 0. 0. Network Printer
1. 0. 0. Color Printer
2. 0. 0. Monochrome Printer

3. 0. 0. 0. 0. Interlock Logic

1. 0. 0. 0. Hardwired Logic
1. 0. 0. Cubicle
2. 0. 0. Auxiliary Relay Unit
3. 0. 0. Power Source
4. 0. 0. UPS
5. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.
2. 0. 0. 0. Logic & Status Display
1. 0. 0. Logic Display Panel
2. 0. 0. Auxiliary Relay Unit
3. 0. 0. Power Source
4. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.
3. 0. 0. 0. Interface for Computer Control
1. 0. 0. CPU & Memory
2. 0. 0. I/O Unit
3. 0. 0. Programming Tool
4. 0. 0. UPS
5. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.

4. 0. 0. 0. 0. Central Display Panel

1. 0. 0. 0. Subsystem Status (150")
2. 0. 0. 0. Radiation/Access Status (150")

5. 0. 0. 0. 0. Sequence Synchronizer

1. 0. 0. 0. Timing Data Generator
1. 0. 0. CPU & Memory
2. 0. 0. Clock Pulse Generator
3. 0. 0. Timing Generator
4. 0. 0. EO/OE (Electro-Optical Converter)
5. 0. 0. Clock Pulse Distributor
6. 0. 0. VME Chassis
7. 0. 0. Cubicle
7. 0. 0. UPS
8. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.
9. 0. 0. Software Development Tool, License
2. 0. 0. 0. Interface for Computer Control
1. 0. 0. Communication Controller
2. 0. 0. Software Development Tool, License

6. 0. 0. 0. 0. Dummy Substation

1. 0. 0. 0. Computer System
1. 0. 0. Work Station
2. 0. 0. Console Desk
2. 0. 0. 0. Operator Interface
1. 0. 0. Display Panel & Switch Board
2. 0. 0. Auxiliary Relay Unit
3. 0. 0. Power Source
4. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.
3. 0. 0. 0. Interface for Computer Control
1. 0. 0. CPU & Memory
2. 0. 0. I/O Unit
3. 0. 0. Programming Tool
4. 0. 0. Dummy VME System
5. 0. 0. Cubicle
6. 0. 0. Cables, Connectors, Terminal Blocks, MCB, etc.
7. 0. 0. 0. 0. Operation and Configuration Control
1. 0. 0. 0. Operation and Configuration Control Software

4. 0. 0. 0. 0. 0. System Installation and Checkout
1. 0. 0. 0. 0. Installation and Test
1. 0. 0. 0. Common Instrumentation Subsystem
2. 0. 0. 0. Central Control Subsystem
3. 0. 0. 0. Data Operations
2. 0. 0. 0. 0. System Verification Testing
1. 0. 0. 0. Subsystem Testing
2. 0. 0. 0. Facility Services/Interlock Testing
3. 0. 0. 0. Integrated System Testing
4. 0. 0. 0. Operational Startup

Total

5. 0. 0. 0. 0. 0. Maintenance
1. 0. 0. 0. 0. Operational Maintenance
1. 0. 0. 0. Computer System
1. 0. 0. Main Computer
1. 1. Hardware
2. 2. Software
2. 0. 0. Support Computer
1. 1. Hardware
2. 2. Software
2. 0. 0. 0. Central Control Subsystem
3. 0. 0. 0. Data Operations
2. 0. 0. 0. 0. System Update
1. 0. 0. 0.
2. 0. 0. 0.
3. 0. 0. 0.
4. 0. 0. 0.

7. 0. 0. 0. 0. 0. 0. Operational Startup and Commissioning

1. 0. 0. 0. 0. 0. Personnel & Overhead
1. 0. 0. 0. 0. Regular Staff
2. 0. 0. 0. 0. Visiting Scientists
3. 0. 0. 0. 0. Startup Staff
2. 0. 0. 0. 0. 0. Electrical Power
1. 0. 0. 0. 0. Accelerator #1
2. 0. 0. 0. 0. Accelerator #2

3. 0. 0. 0. 0. Beam Turning
4. 0. 0. 0. 0. Balance of Plant
3. 0. 0. 0. 0. 0. Utilities
1. 0. 0. 0. 0. Inert Gas
2. 0. 0. 0. 0. Deionized Water
3. 0. 0. 0. 0. Sewer/Water
4. 0. 0. 0. 0. 0. Maintenance
1. 0. 0. 0. 0. Maintenance
2. 0. 0. 0. 0. Capital Improvements
3. 0. 0. 0. 0. Spares
5. 0. 0. 0. 0. 0. Waste Disposal
1. 0. 0. 0. 0. Contaminated
2. 0. 0. 0. 0. Uncontaminated

Appendix-5.1 Documents Presented at Test Cell/User Group Meeting

Table of Contents

IFMIF Design Integration Workshop

May, 1996

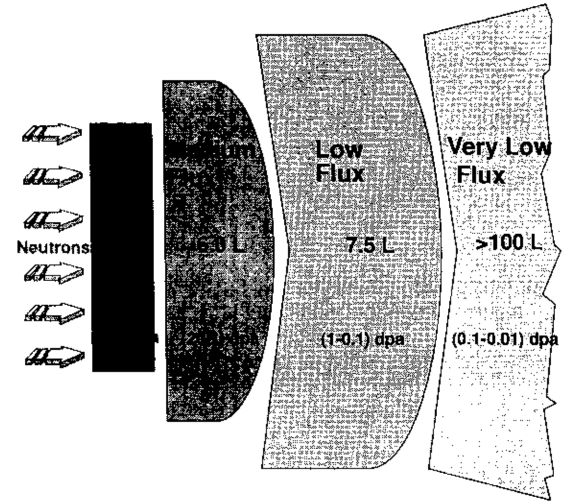
JAERI, Japan

- Test Cell Design - Progress
- Work Breakdown Structure
- Cost Estimate - Summary

Anton Möslang

International Fusion Materials Irradiation Facility IFMIF

Test Cell Zones



IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Removable Cover (ORNL)

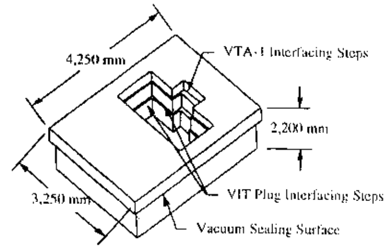


Figure of Test Cell Removable Cover

Test Cell Liner and Heat Shield (ORNL)

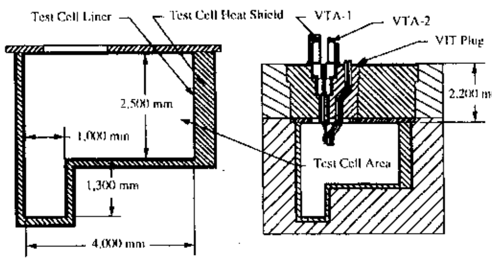


Figure Of Test Cell Liner And Heat Shield

IFMIF Design Integration Meeting May 1996, JAERI, Japan

NaK Controlled Vertical Test Assemblies VTA-1 and VTA-2 (ORNL)

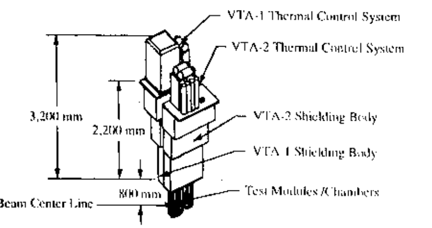


Figure Of NaK Thermally Controled Vertical Test Assemblies VTA-1 and VTA-2

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Vertical Irradiation Tube Plug VIT (ORNL)

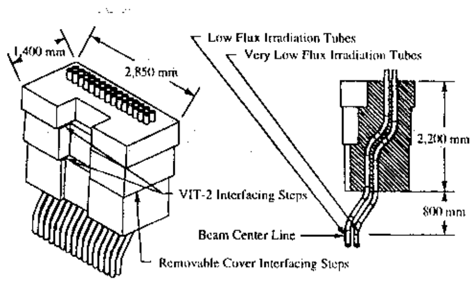


Figure Of The Vertical Irradiation Tube Plug

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Shielding Plug Arrangement (ORNL)

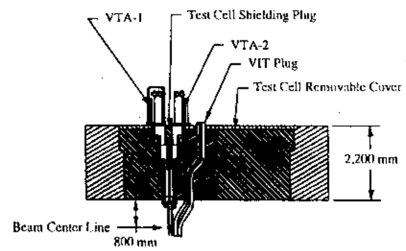
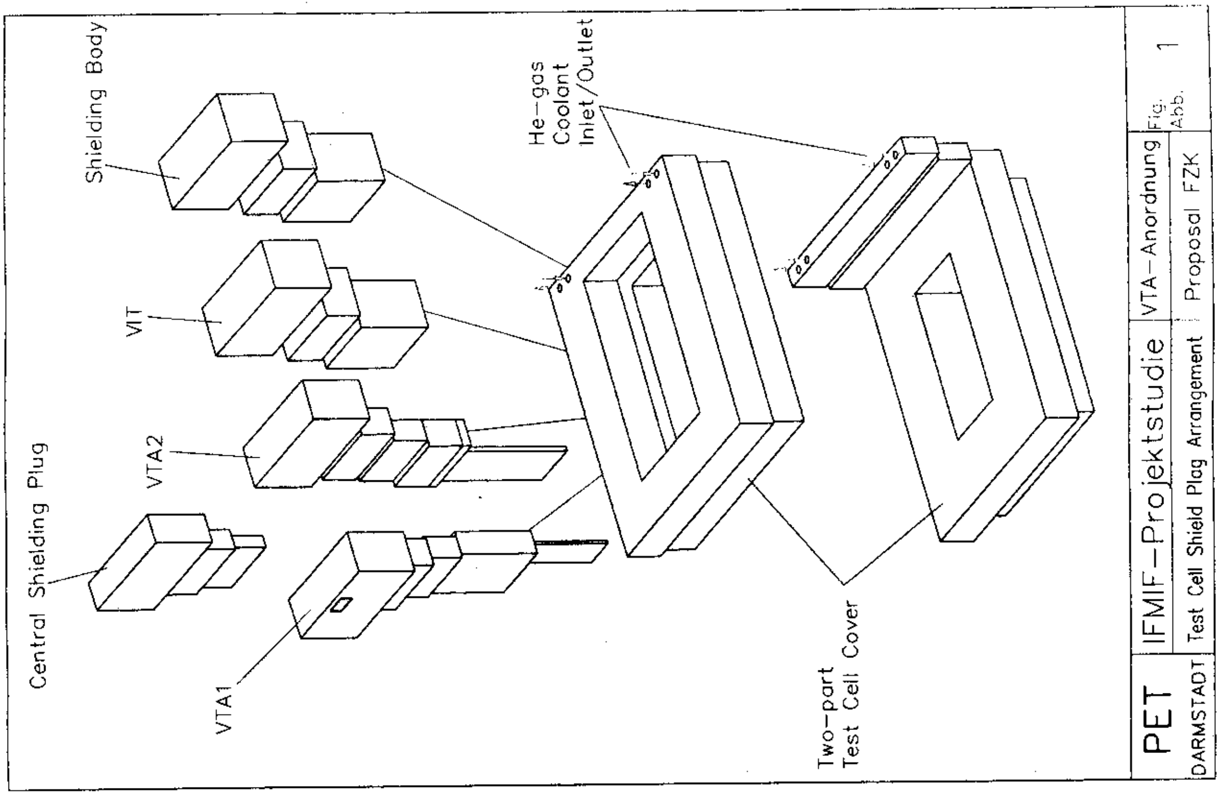
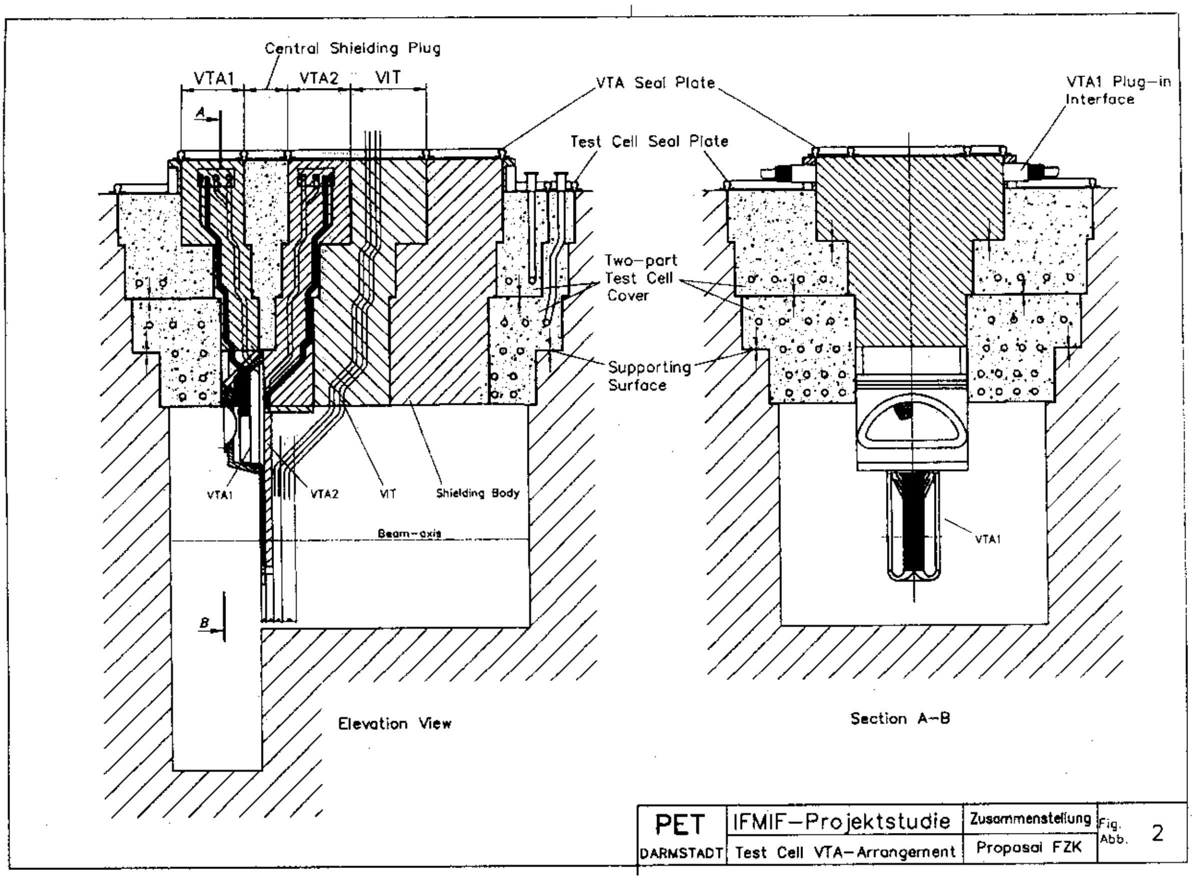
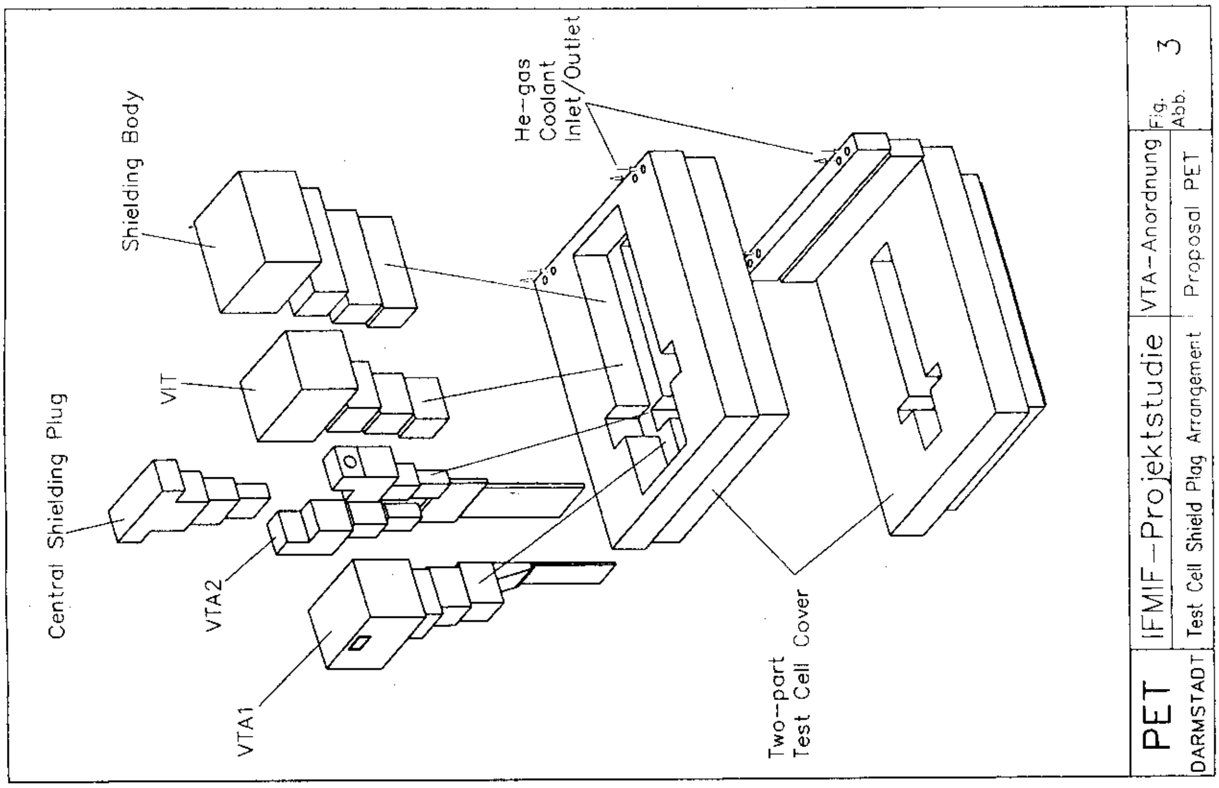
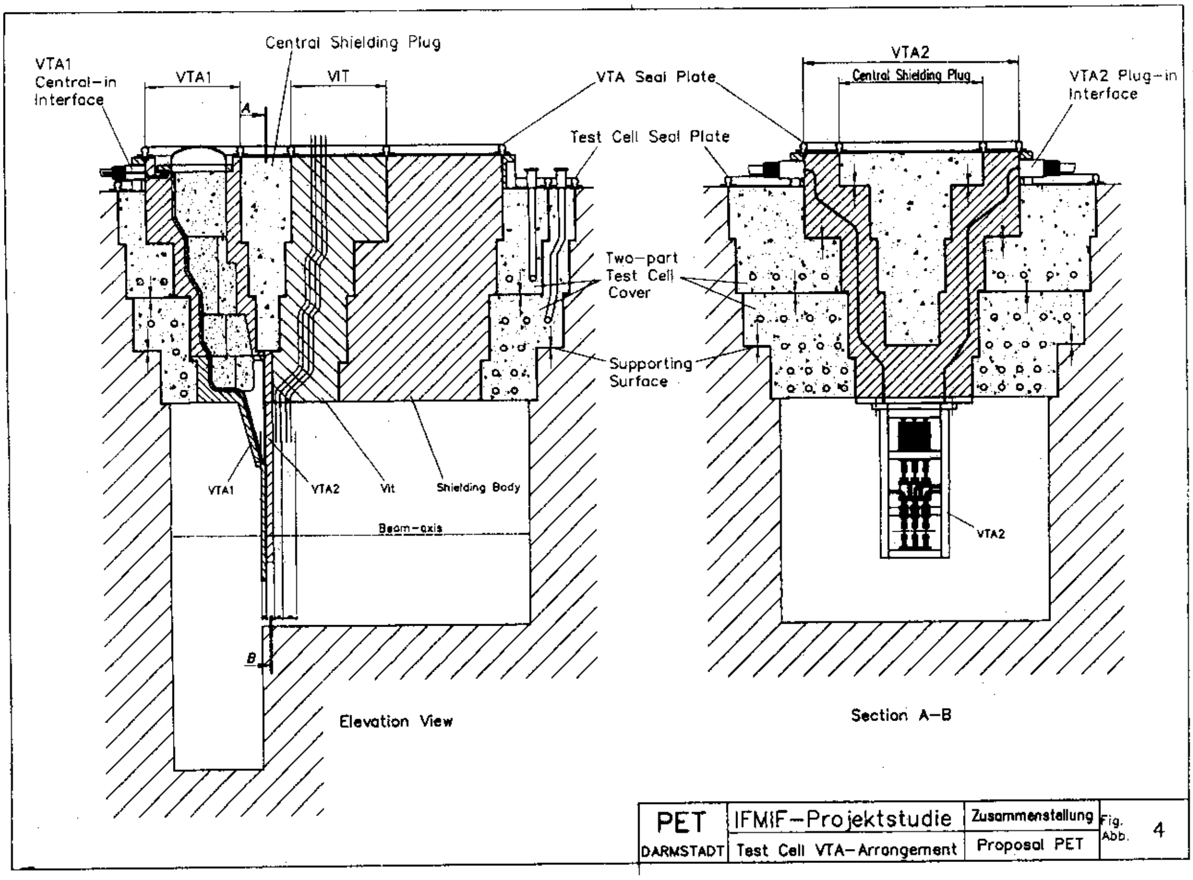


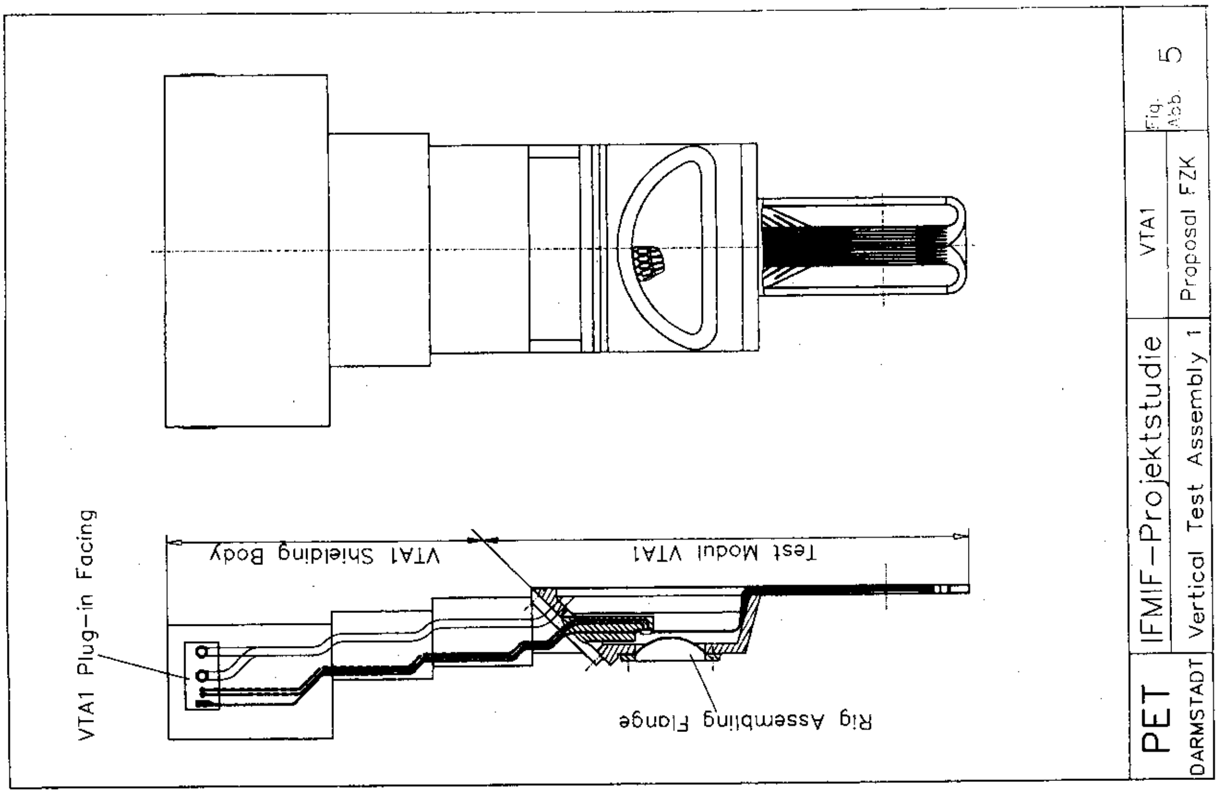
Figure OF Test Cell Shielding Plug Arrangement

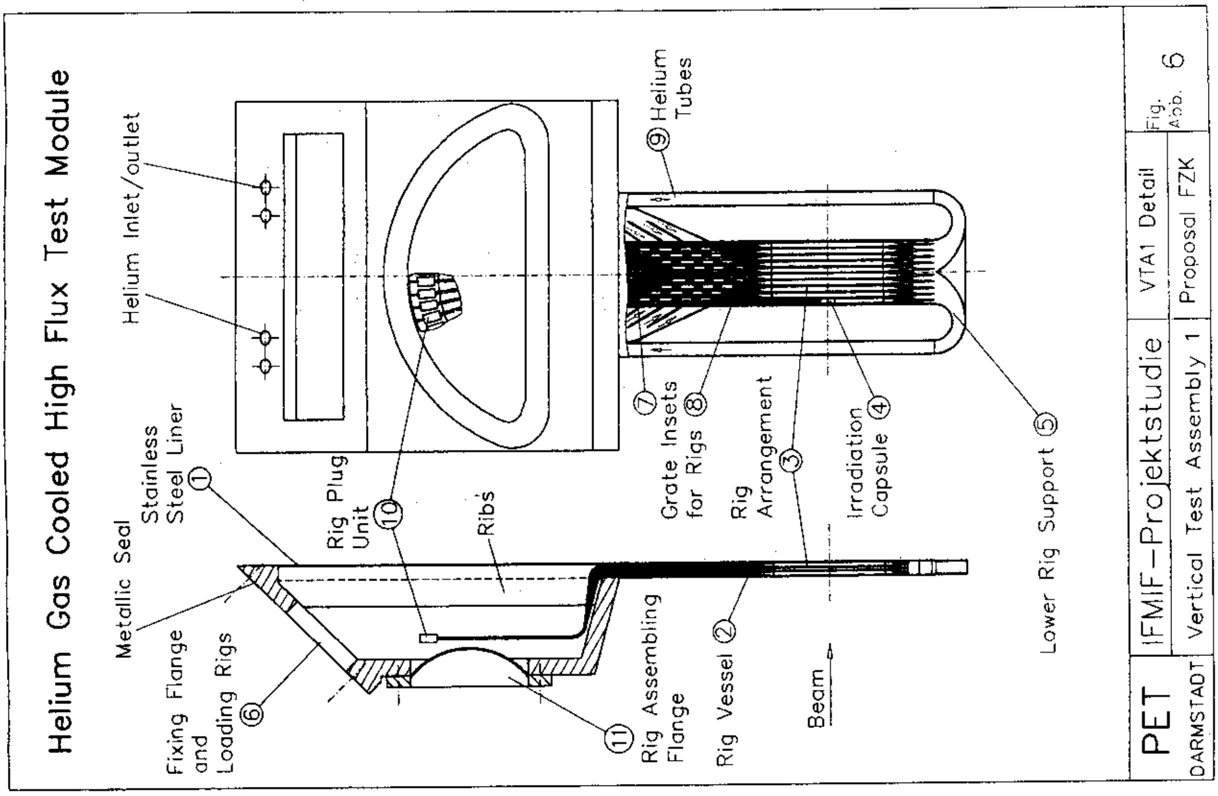

Shielding Body
VIT
VTA2
Central Shielding Plug
VTA1
He-gas
Coolant
Inlet/Outlet
Two-part
Test Cell Cover
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell Shield Plug Arrangement
VTA-Anordnung
Proposal FZK
Fig.
Abb.
1

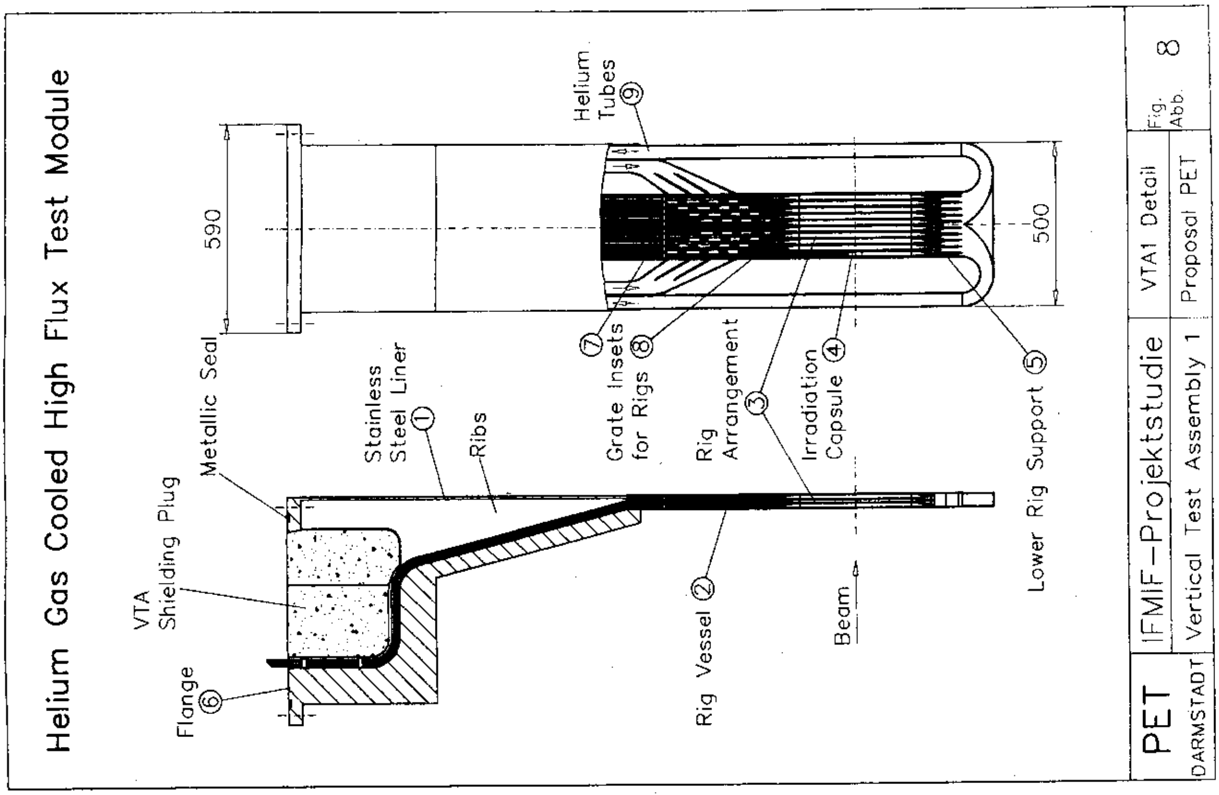

Central Shielding Plug
VTA1
VTA2
VIT
A
VTA Seal Plate
VTA1 Plug-in
Interface
Test Cell Seal Plate
Two-part
Test Cell
Cover
Supporting
Surface
VTA1
VTA2
VIT
Shielding Body
Beam-axis
B
VTA1
Elevation View
Section A-B
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell VTA-Arrangement
Zusammenstellung
Proposal FZK
Fig.
Abb.
2

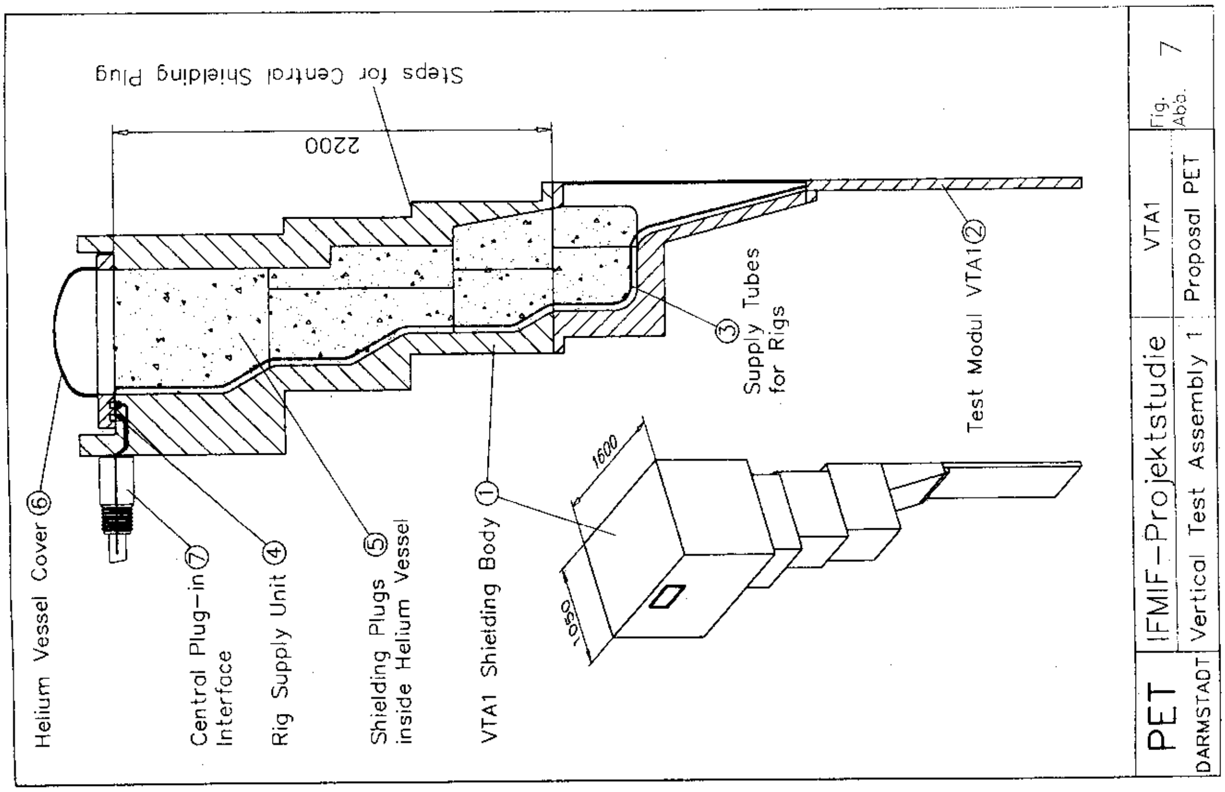

Shielding Body
He-gas
Coolant
Inlet/Outlet
VIT
Central Shielding Plug
VTA2
VTA1
Two-part
Test Cell Cover
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell Shield Plug Arrangement
VTA-Anordnung
Proposal PET
Fig.
Abb.
3


VTA1
Central-in
Interface
VTA1
Central Shielding Plug
VIT
A
VTA Seal Plate
Test Cell Seal Plate
Two-part
Test Cell
Cover
Supporting
Surface
VTA1
VTA2
Vit
Shielding Body
Beam-axis
B
Elevation View
VTA2
Central Shielding Plug
VTA2 Plug-in
Interface
VTA2
Section A-B
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell VTA-Arrangement
Zusammenstellung
Proposal PET
Fig.
Abb.
4


VTA1 Plug-in Facing
VTA1 Shielding Body
Test Modul VTA1
Rig Assembling Flange
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1
Proposal FZK
Fig.
Abb. 5


Helium Gas Cooled High Flux Test Module
Fixing Flange and Loading Rigs ⑥
Metallic Seal
Stainless Steel Liner ①
Helium Inlet/outlet
Rig Plug Unit ⑩
Ribs
Rig Assembling Flange ⑪
Rig Vessel ②
Beam
Grate Insets for Rigs ⑧
⑦
Rig Arrangement ③
Irradiation Capsule ④
⑨ Helium Tubes
Lower Rig Support ⑤
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1 Detail
Proposal FZK
Fig.
Abb. 6

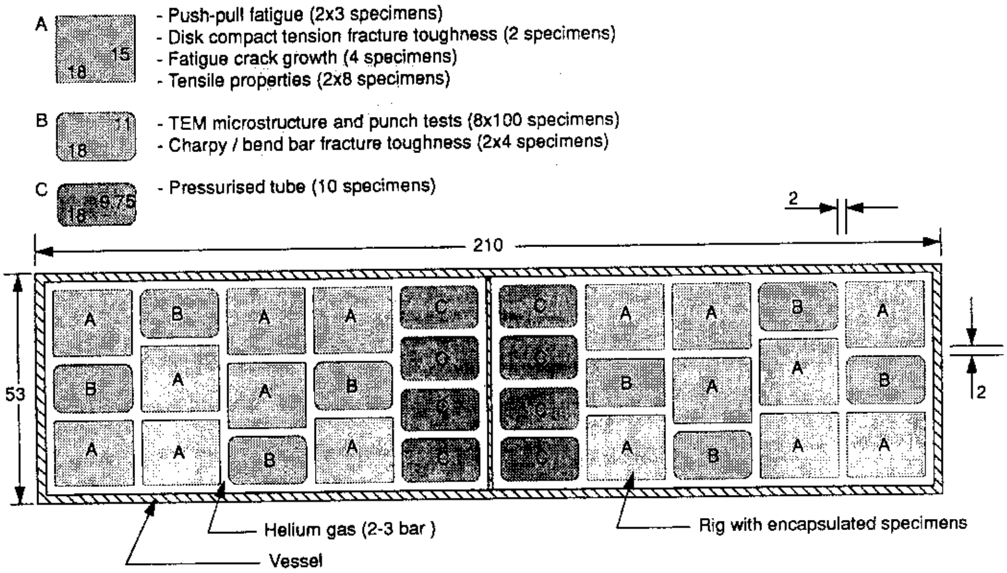

Helium Gas Cooled High Flux Test Module
590
500
Flange ⑥
VTA Shielding Plug
Metallic Seal
Stainless Steel Liner ①
Ribs
Rig Vessel ②
Grate Insets ⑦ for Rigs ⑧
Rig Arrangement ③
Irradiation Capsule ④
Beam
Lower Rig Support ⑤
Helium Tubes ⑨
PET DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1 Detail
Proposal PET
Fig. Abb. 8


Helium Vessel Cover ⑥
Central Plug-in ⑦ Interface
Rig Supply Unit ④
Shielding Plugs ⑤ inside Helium Vessel
VTA1 Shielding Body ①
2200
Steps for Central Shielding Plug
Supply ③ Tubes for Rigs
Test Modul VTA1 ②
1600
1050
PET DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1
Proposal PET
Fig. Abb. 7

Forschungszentrum Karlsruhe
Technik und Umwelt

A.M. 04. 1996

Cross section of helium gas cooled high flux test module - DRAFT -



Volume considerations

Typical volume fractions within the rigs:

	A	B	C
Helium for gas gaps	23%	26%	36%
rig and capsule	35%	37%	38%
specimens	42%	37%	26%

Because both the rigs and capsules will likely consist of materials very similar to the specimens itself, the following volume fractions for the neutron scattering can beused:

A: 77% structural material 23% void
B: 74% structural material 26% void
C: 64% structural material 36% void

Volume fractions within the high flux volume:

8 rigs for A : 39% of total vessel volume
8 rigs for B: 14% of total vessel volume
8 rigs for C: 12% of total vessel volume
Vessel structure: 10% of total vessel volume
He gas coolant: 25% of total vessel volume

Therefore, the following averaged volume fractions can be considered as typical for the high flux test module:

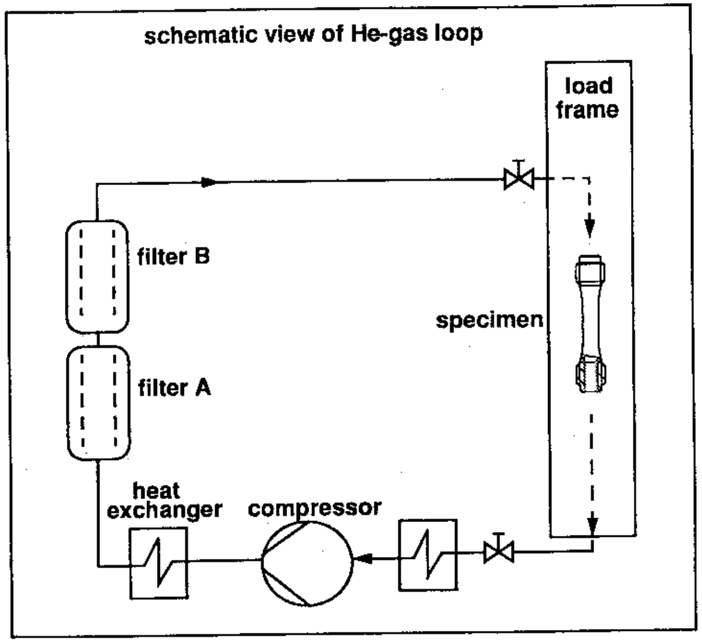
	Volume fraction
He-gas (coolant and gas gaps)	42 %
Material (specimens, rigs, capsules, vessel)	58 %

Helium gas coolant loop

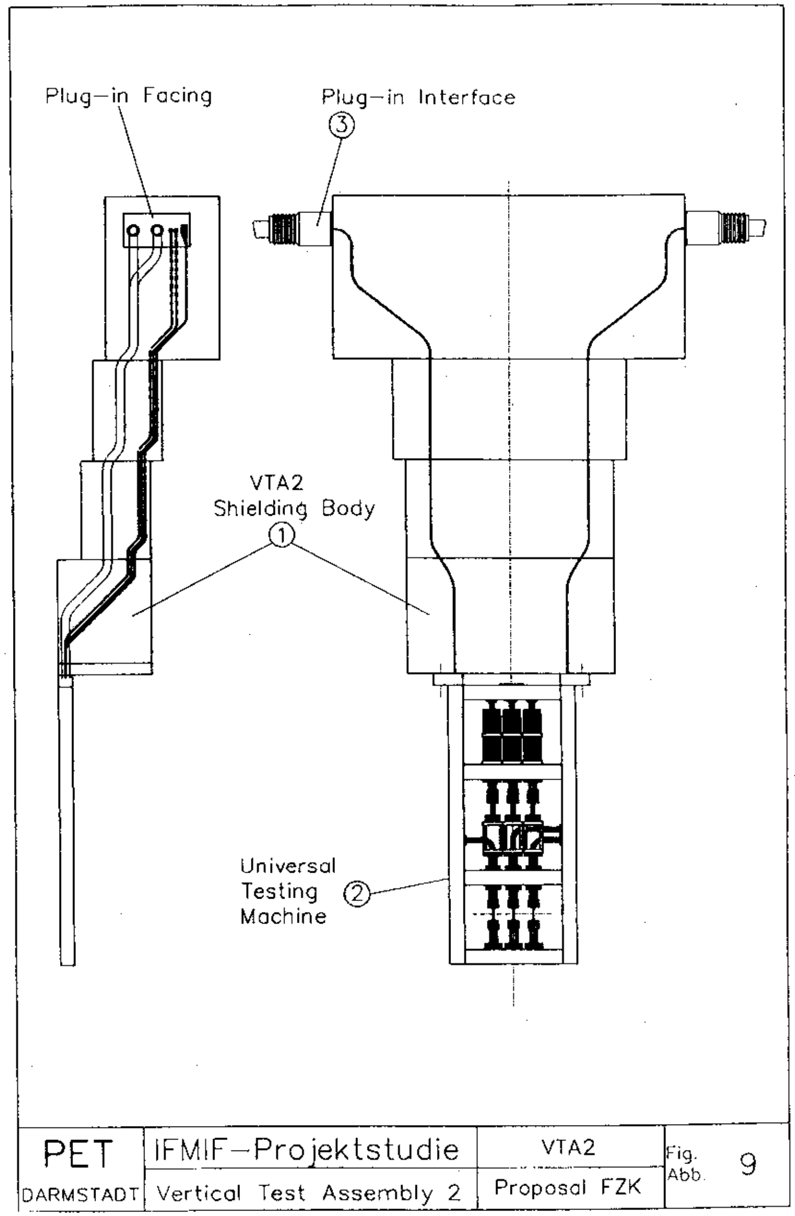
Long-term experience for He-loops operating in neutron and light ion irradiation facilities is available.

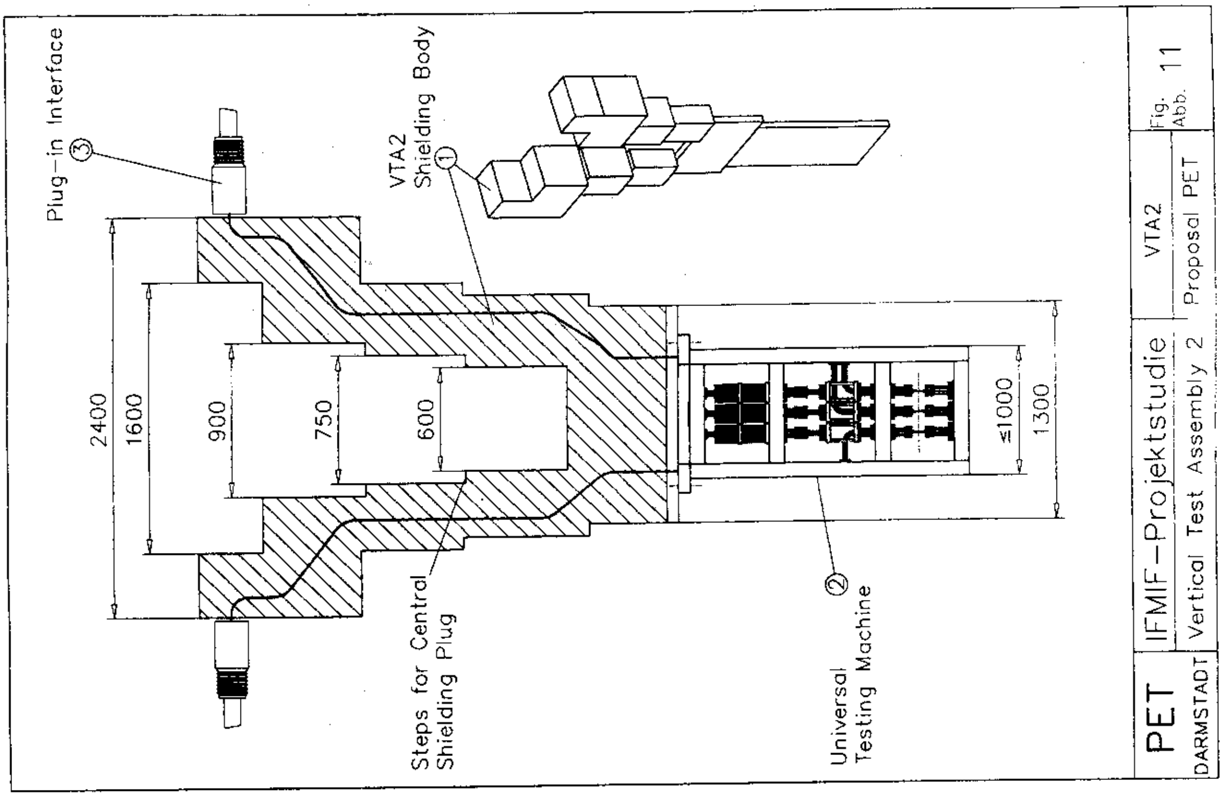
According to the proposed in-situ fatigue design, the following lay-out of a He-gas loop was found to be sufficient ($T_{specimen} \geq 250$ °C) for the med-flux region (≤8 dpa/year) of IFMIF downstream the P.I.E. module:

○ He inlet (pressure pipe)	≤ 2.5 bar_{abs}	25 °C
○ He outlet (suction pipe)	≥ 1.5 bar_{abs}	≤35 °C*
○ He pressure drop (specimen & rods)	≤0.9 bar	
○ He-gas throughput	12×10^{-3} kg/s	
○ Compressor size	240 m^3/h	25 kW
○ He-gas purity (C, N, O)	≤ 0.1 appm	



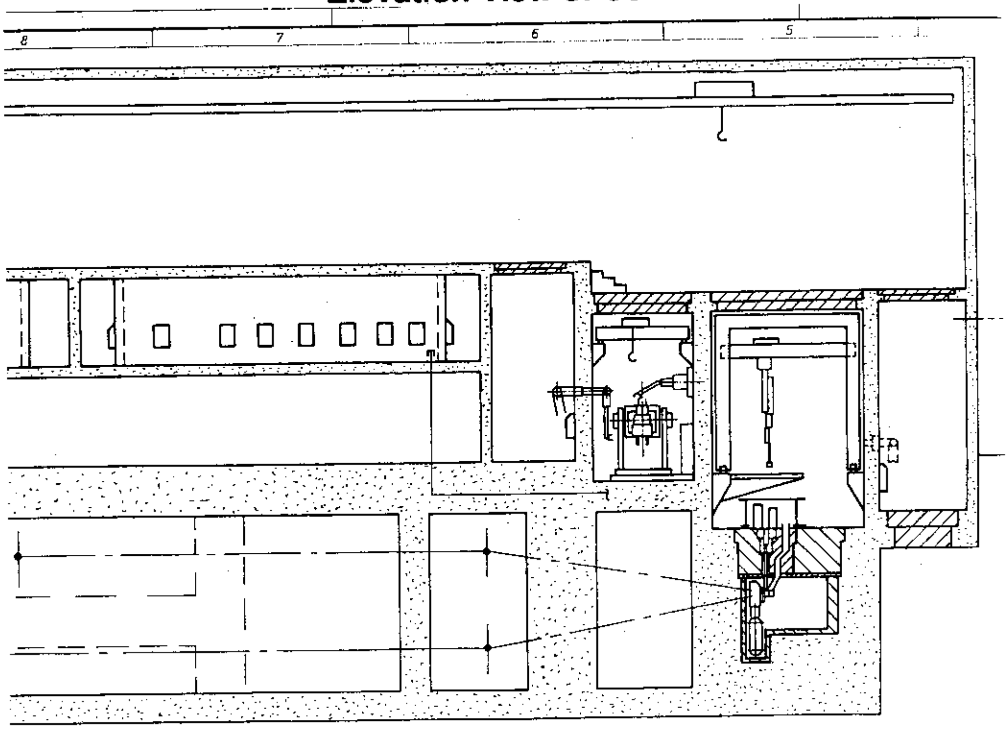
* at specimen outlet





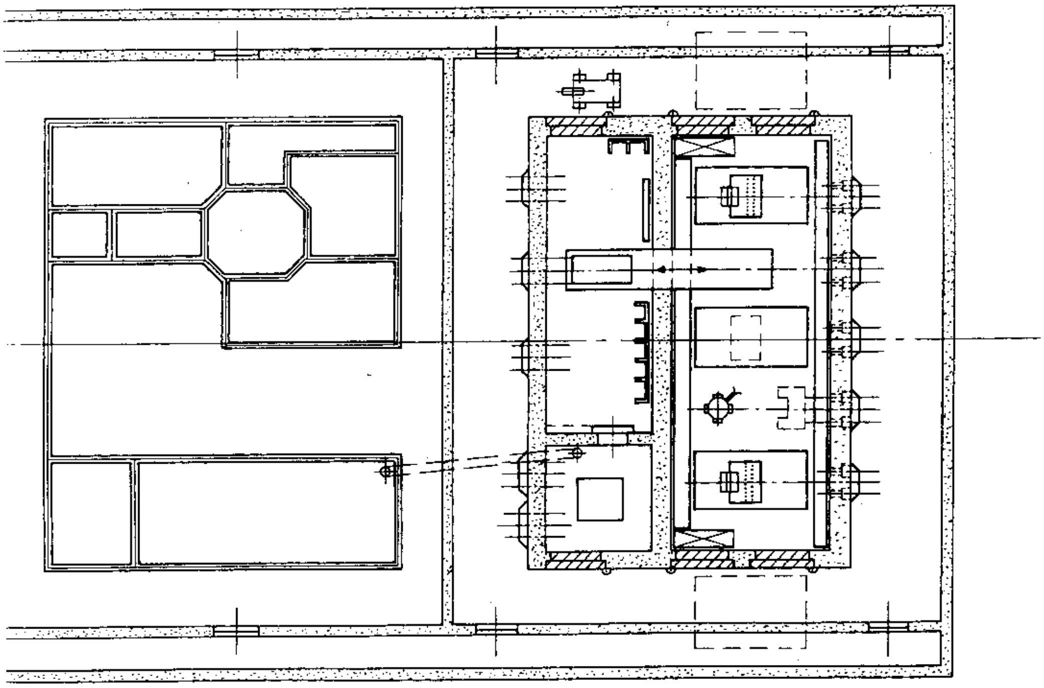
IFMIF Design Integration Meeting May 1996, JAERI, Japan

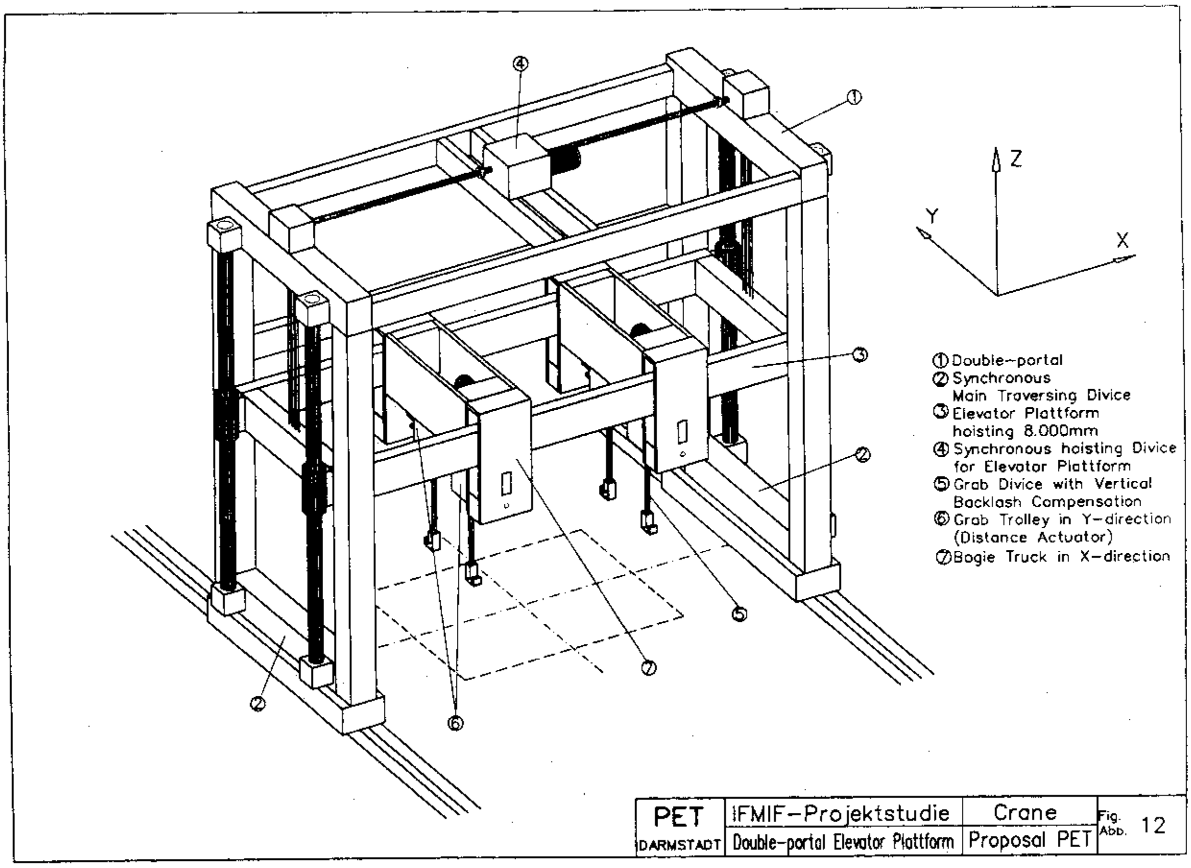
Elevation View of Cell Facilities



IFMIF Design Integration Meeting May 1996, JAERI, Japan

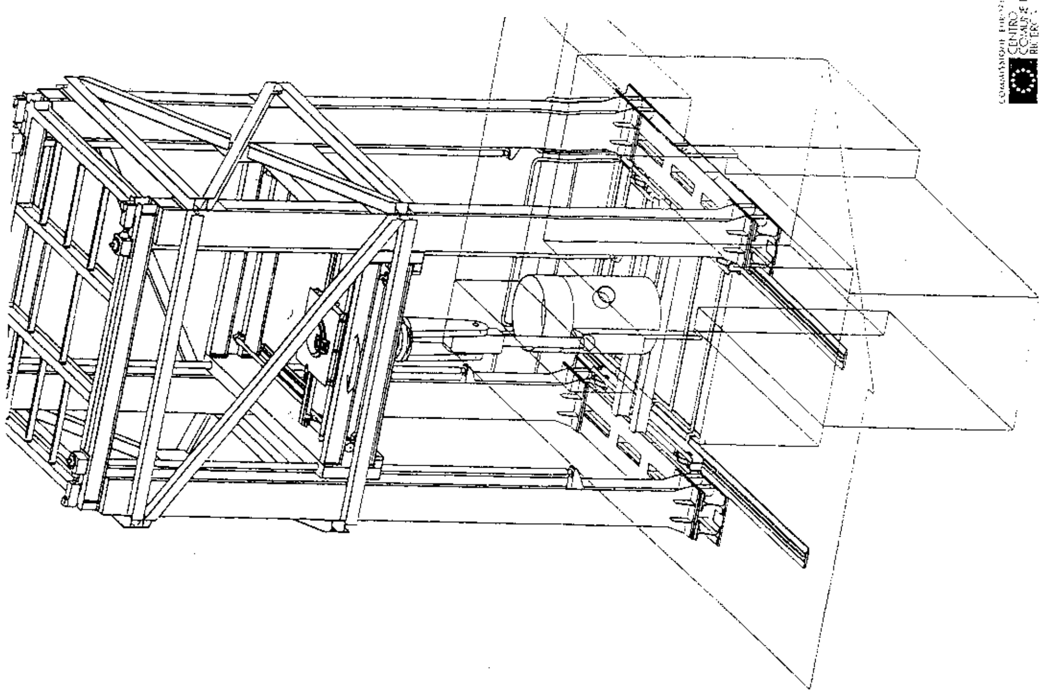
Plan View of Cell Facilities





IFMIF Design Integration Workshop May 1996 JAERI

Universal Robot System (ENEA)



Forschungszentrum Karlsruhe
Technik und Umwelt

Test Facilities Ventilation System - DRAFT-

L. Dörr, A. Möslang, W. Nägele

Design Integration Workshop, May 1996, JAERI, Japan

5 Zones Ventilation System:

A Ventilation System with five different zones is proposed. It supplies besides all Test Facility cells and rooms also various Li-Target rooms. The present proposal suggests the following zones:

□	White:	Office rooms, cold labs, workshops
▒	Yellow:	Manipulation rooms, shipping bay area, machine rooms
▓	Yellow-red:	High bay area
■	Red:	Cells (Access Cell, Service Cell, Test Module Handling Cell, PIE Hot Cell, Tritium Laboratory)
■	Green:	Protective gas for Lithium-zones (Test Cell, Lithium Processing Cells

Proposed IFMIF Ventilation System

Zone	Reduced Pressure	Risk	Air Exchange
White	~ 0 - 2 mbar	No handling with open radioactivity	4
Yellow	~ 3 - 6 mbar	Handling with radioactivity in exceptional cases	4
Yellow-red	~ 6 - 8 mbar	Frequent handling with radioactivity	4
Red	~ 20-50 mbar	Permanent handling with radioactivity	40 AE/h
Green	~ 3 - 5 mbar	Handling with Li-contaminated matter	Test Cell: Vacuum Li-Processing Cells: TBD *

- The reduced pressure increases from white to red
- The red zone is sucked in through a filter system from the yellow-red zone
- The exhaust air of the zones white, yellow and red is filtered separately before it goes to the Vent stack. Each group consists of various mechanical filters with 98.98% extraction (HEPA-filters).
- The ventilation system is pressure controlled by the exhaust air fan.
- Air Exchange: Red (40 AE/h) : ~ 100 000 m^3/h
  white/yellow: ~ 400 000 m^3/h

* Proposal: Inert gas (Argon), 3-4 AE/h : ~ 30 000 m^3/h Ar-gas closed loop

Preliminary Concept for Tritium Retention at IFMIF

1. Test Cell

To maintain a vacuum in the 30 m^3 large test cell the gas throughput rate of the pumps is low. The tritium concentration in the offgas is also low. Therefore for tritium retention a small molecular sieve / catalyst combination is suggested. Hydrogen that becomes eventually present in the offgas will be oxidised and trapped as tritiated water.

2. Medium Flux VTA

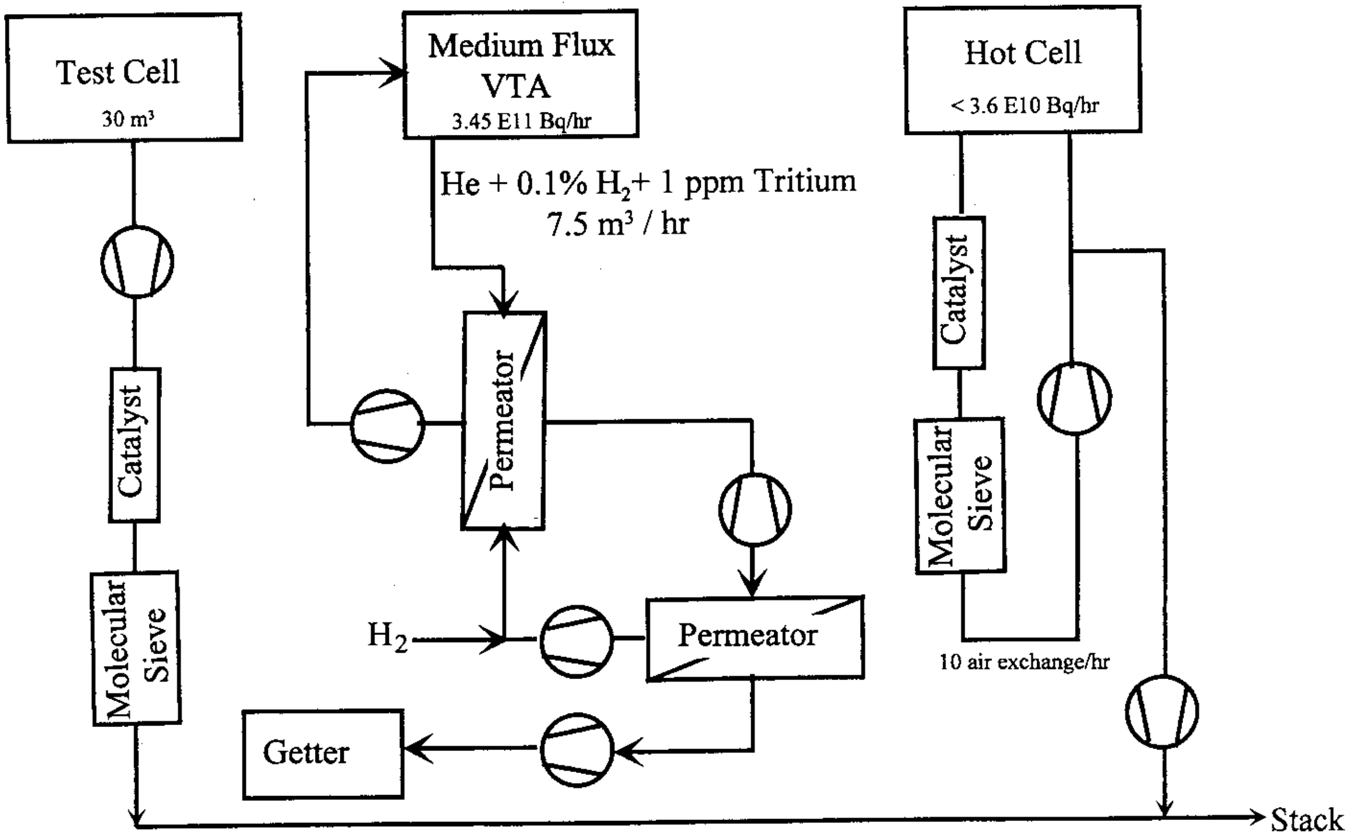
In the VTA the tritium production rate is high. To separate the tritium from the purge gas we propose to use two permeators. In these permeators the hydrogen is separated from helium. The helium can be led back to the process. The tritium will be stored in a matal-getter bed. The combination of two permeators as represented in the flow sheet is a process optimization for high decontamination factors at low tritium concentrations.

3. Hot Cell

The tritium release into the hot cell is less than 3.6E10 Bq/h. To remove hydrogen from the cell atmosphere a molecular sieve / catalyst combination is suggested. It will be operated in a loop with a gas stream of 10 air exchanges / hr.

4. Costs

The total amount of costs for the described tritium retention systems will be in the range of DM 7.5 M.



Proposed IFMIF Work Breakdown Structure DICM0801.XLS

1 2 3 4 5 6 *Level*	
1, 0, 0, 0, 0,	**Project Management**
1, 0, 0, 0, 0,	**Project Management and Administration**
1, 0, 0, 0,	Administration
2, 0, 0, 0,	Cost Control
3, 0, 0, 0,	Schedule
4, 0, 0, 0,	Development Oversight
5, 0, 0, 0,	Construction Management
6, 0, 0, 0,	Documentation
2, 0, 0, 0, 0,	**Systems Engineering**
1, 0, 0, 0,	Design Integration
2, 0, 0, 0,	Systems Analysis
3, 0, 0, 0,	Requirements/Specs
4, 0, 0, 0,	RAM Analysis
3, 0, 0, 0, 0,	**Environmental, Safety & Health Documentation**
4, 0, 0, 0, 0,	**Quality Assurance**
2, 0, 0, 0, 0, 0,	**Test Facilities**
1, 0, 0, 0, 0,	**Test Facility Management**
1, 0, 0, 0,	Project Management and Administration
1, 0, 0,	Administration
2, 0, 0,	Cost Control
3, 0, 0,	Schedule
4, 0, 0,	Documentation
2, 0, 0, 0,	Systems Engineering
1, 0, 0,	Design Integration
2, 0, 0,	Systems Analysis
3, 0, 0,	Requirements/Specs
4, 0, 0,	RAM Analysis
3, 0, 0, 0,	Environmental, Safety & Health Documentation
4, 0, 0, 0,	Quality Assurance
2, 0, 0, 0, 0,	**Test Facility Subsystems**
1, 0, 0, 0,	Vertical Test Assemblies
1, 0, 0,	Factory Assembly and Testing
1, 0,	Assembly
2, 0,	Testing
2, 0, 0,	High Flux VTA (VTA1- NaK)
3, 0, 0,	High Flux VTA (VTA1-Helium)
1, 0,	Test module with specimens
2, 0,	VTA shielding body
3, 0,	Helium coolant loop
4, 0, 0,	Medium Flux VTA (VTA2-NaK)-Breeders
5, 0, 0,	Medium Flux VTA (VTA2-He)-Fatigue
1, 0,	In-situ test module
2, 0,	VTA shielding body
3, 0,	Helium coolant loop
6, 0, 0,	Vertical Irradiation Tube (VIT) System
7, 0, 0,	Shielding plugs
2, 0, 0, 0,	Test Cell
1, 0, 0,	Test Cell Removable Cover
2, 0, 0,	Test Cell liner
3, 0, 0,	Test Cell heat shield
4, 0, 0,	Test Cell seal plate
5, 0, 0,	Test Cell camera system
6, 0, 0,	Test Arrey/Target interface assembly
7, 0, 0,	Beam and Test Cell diagnostic sensors
8, 0, 0,	Emergency shutdown system
3, 0, 0, 0,	Test Cell Technology Room
1, 0, 0,	Assembly and Testing
2, 0, 0,	Test Cell cooling system
3, 0, 0,	Test Cell pumping system

15.05.1996 Page 1

Proposed IFMIF Work Breakdown Structure DICM0801.XLS

1 2 3 4 5 6 Level
4, 0, 0, Argon backfill system
5, 0, 0, Test Cell diagnostic control system
6, 0, 0, Subsystem Power
4, 0, 0, 0, Test Facility Control Room
1, 0, 0, Assembly and Testing
2, 0, 0, Data Acquisition for VTA1-NaK
3, 0, 0, Data Acquisition for VTA1-Helium
4, 0, 0, Data Acquisition for VTA2-Fatigue
5, 0, 0, Data acquisition for VTA2-Tritium Release
6, 0, 0, Data Acquisition for VIT System
7, 0, 0, Supervising Computer
8, 0, 0, Subsystem power
5, 0, 0, 0, Access Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Access Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, 0, Universal Robot System
4, 0, 0, Manipulator Systems
5, 0, 0, Maintenance and Support Devices
1, 0, Telescopic Master/Slave Manipulators
2, 0, Service Robots
6, 0, 0, Infrastructure Installation
6, 0, 0, 0, Service Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Service Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, 0, Component Transfer Systems
1, 0, Transfer Rail System
2, 0, Transfer Chart
4, 0, 0, Manipulator Systems
1, 0, Telescopic Master7Slave Manipulators
2, 0, Service Robot
3, 0, Special Purpose Manipulator
5, 0, 0, Bridge Crane
6, 0, 0, Maintenance and Support Devices
7, 0, 0, Infrastructure Installation
7, 0, 0, 0, Test Module Handling Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, Tube Mailing System
3, 0, 0, Manipulator System
1, 0, Telescopic Master7Slave Manipulators
2, 0, Modular Robot Systems
4, 0, 0, Bridge Crane
5, 0, 0, Maintenance and Support Devices
6, 0, 0, Infrastructure Installatiton
8, 0, 0, 0, PIE Hot Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Cell Structure

15.05.1996 Page 2

Proposed IFMIF Work Breakdown Structure DICM0801.XLS

1 2 3 4 5 6 Level
1, 0, Cell Liner
2, 0, Lead shield
3, 0, Removable Cell Ceiling
3, 0, 0, Manipulator Systems
1, 0, Working Stations
2, 0, Power Manipulator Systems
4, 0, 0, Bridbe Crane
5, 0, 0, Infrastructure Installation
1, 0, Electric Power and Gases
2, 0, Mechanical Infrastructure
6, 0, 0, Examination Equipment
1, 0, Universial testing machines
2, 0, Vacuum furnaces
3, 0, Thermal fatigue test devices
4, 0, Corrosion test devices
5, 0, Fracture toughness test devices
6, 0, Fatigue crack growth
7, 0, Pressurized tube test devices
8, 0, Optical microscope
9, 0, Specimen preparation tools
9, 0, 0, 0, Shielded Glove Box Laboratory
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Structure and Support Systems
1, 0, Structure
2, 0, Support systems
3, 0, 0, Examination Equipment
1, 0, SEM
2, 0, TEM
3, 0, TEM preparation
4, 0, Specimen storage
5, 0, Optical Microscope
6, 0, Microhardness tester
7, 0, Activation analysis system
10, 0, 0, 0, Tritium Laboratory
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Laboratory installation
1, 0, Laboratory Structure
2, 0, Infrastructure
3, 0, Personal entry
3, 0, 0, Manipulator Systems
4, 0, 0, Examination Equipment
11, 0, 0, 0, Test Facility Ventilation Systems
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, 5 Zones Ventilation System
1, 0, Controls
2, 0, Component Systems
3, 0, 0, Tritium Retention System
1, 0, Controls
2, 0, Component Systems
12, 0, 0, 0, Maintenance Systems
1, 0, 0, Maintenance Procedure Development
2, 0, 0, Special Purpose Tooling
3, 0, 0, Remote Handling Equipment
4, 0, 0, Mockup Facilities and Testing

3, 0, 0, 0, 0, Subsystem Development

15.05.1996 Page 3

DICM0801.XLS

Proposed IFMIF Work Breakdown Structure

Level	
1 2 3 4 5 6	*Level*
4, 0, 0, 0, 0,	**System Installation and Startup**
1, 0, 0, 0,	Installation
2, 0, 0, 0,	Verification Testing
3, 0, 0, 0,	Startup
5, 0, 0, 0, 0,	**Maintenance Systems**
1, 0, 0, 0,	Maintenance Procedure Development
2, 0, 0, 0,	Special purpose tooling
3, 0, 0, 0,	Remote handling equipment
4, 0, 0, 0,	Mockup Facilities and Testing
3, 0, 0, 0, 0, 0,	**Target Facility**
1, 0, 0, 0, 0,	**Target Facility Management**
1, 0, 0, 0,	Project Management and Administration
1, 0, 0,	Administration
2, 0, 0,	Cost Control
3, 0, 0,	Schedule
4, 0, 0,	Documentation
2, 0, 0, 0,	Systems Engineering
1, 0, 0,	Design Integration
2, 0, 0,	Systems Analysis
3, 0, 0,	Requirements/Specs
4, 0, 0,	RAM Analysis
3, 0, 0, 0,	Environmental, Safety & Health Documentation
4, 0, 0, 0,	Quality Assurance
2, 0, 0, 0, 0,	**Subsystems**
1, 0, 0, 0,	Lithium Target System
1, 0, 0,	Assembly and Testing
1, 0,	Assembly
2, 0,	Testing
2, 0, 0,	Components
1, 0,	Target Assembly
1,	Li Flow Rectifier
2,	Nozzel
3,	Backwall
4,	Down Stream Guide
5,	Measuring System
6,	Li System/Target Interface
2, 0,	Beam-Target Interface
1,	Beam/Target Interface Structure
2,	Evacuation System
3,	Emergency Shutdown System
4,	Test Cell/Target Interface Structure
2, 0, 0, 0,	Lithium Cooling System
1, 0, 0,	Assembly and Testing
1, 0,	Assembly
2, 0,	Testing
2, 0, 0,	Components
1, 0,	Primary Cooling System
1,	EM pump
2,	Heat Exchanger
3,	Valve
4,	Piping
5,	Quench Tank
6,	Dump Tank
7,	Control System
8,	Measuring Devices
9,	Radiation Shielding
10,	Inert Gas System
2, 0,	Primary Purification System
1,	Cold Trap

15.05.1996

Page 4

IFMIF TEST FACILITIES

Cost Estimate

Anton Möslang
May 1996

- Practically all Elements of the present WBS are included
- Cost estimates are available down to level 4 of the WBS (only 2 exceptions)
- Input came from

O ORNL		~ 30 pages
O FZK	- Institute of Materials Research,	~ 80 pages
	- Hot Cell Facility	11 pages
	- Tritium Laboratory	2 pages
	- Financial System Department	14 pages
O German Industry		~ 35 pages

- Quality of the estimate: Because of the various sources the work sheets could not always be structured in the same way. However, the overall estimate should be credible because
  - practically all completely individual devices and modules (e.g. VTAs, Test Cell Structure and Removable Cover) are estimated in detail,
  - other expensive components (remote handling systems, cranes, hot cells, technical and scientific equipment) could be estimated from existing facilities.

1 11

IFMIF Cost Format Test Facility

WBS 2.1, 2.2.

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
		nc	3% (i)	TBE	TBE	TBE	TBE	c,d,e,f	TBE	TBE	TBE	TBE	h,i,j,k	b,g,l		
2.1.	Managem´t	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
2.2.1.2.	VTA1-NaK	nc	nc	134	143	59	nc	336	nc	nc	nc	nc	336	336	nc	nc
2.2.1.3	VTA1-He	nc	nc	1,230	218	60	nc	1,508	nc	nc	nc	nc	1,508	1,508		
2.2.1.4	VTA2-NaK	nc	nc	504	nc	258	nc	762	nc	nc	nc	nc	nc	762	nc	nc
2.2.1.5	VTA2-He	nc	nc	695	104	25	nc	824	nc	nc	nc	nc	nc	824	nc	nc
2.2.1.6	VIT-System	nc	nc	393	49	429	nc	871	nc	nc	nc	nc	nc	871	nc	nc
2.2.1.7	Shield Plug	nc	nc	9	nc	20	nc	29	nc		nc	nc	nc	29	nc	nc
2.2.2.1	TC Cover	nc	nc	1,049	nc	184	nc	1,233	nc	nc	nc	nc	nc	1,233	nc	nc
2.2.2.2.	TC Liner	nc	nc	681	nc	79	nc	760	nc	nc	nc	nc	nc	760	nc	nc
2.2.2.3	Heat shield	nc	nc	211	nc	138	nc	349	nc	nc	nc	nc	nc	349	nc	nc
2.2.2.4	Seal Plate	nc	nc	309	nc	94	nc	403	nc	nc	nc	nc	nc	403	nc	nc
2.2.2.5	Camera Sys.	nc	nc	162	nc	236	nc	398	nc	nc	nc	nc	nc	398	nc	nc
2.2.2.6	Test Array	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
2.2.2.7	Diagnostics	nc	nc	53	nc	nc	nc	53	nc	nc	nc	nc	nc	53	nc	nc
2.2.2.8	Emergency	nc	nc	40	nc	72	nc	112	nc	nc	nc	nc	nc	112	nc	nc
														7,638		

Abreviations:
- nc Nocost in this element
- TBE To be estimated
- AFI Allowance for Indeterminates

2 22

IFMIF Cost Format Test Facility

WBS 2.2.3, 2.2.4

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.3.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	77,9	nc	77,9	78	nc	nc
2.2.3.2	Cooling	nc	nc	124	nc	99	nc	223	107	nc	79		186	409	nc	nc
2.2.3.3	Vac. Pumps	nc	nc	89,3	nc	8,2	nc	97,5	nc	18,2	6,2	nc	24,4	122	nc	nc
2.2.3.4	Ar backfill	nc	nc	36	nc	19	nc	55	13	nc	6	nc	19	74	nc	nc
2.2.3.5	Diagn,Contr	nc	nc	62,5	nc	nc	nc	62,5	31,1	nc	62,3	nc	93,4	156	nc	nc
2.2.3.6	Syst. Power	nc	nc	nc	nc	0.5	nc	0.5	3,5	nc	nc	nc	3,5	4	nc	nc
2.2.4.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	62,3	nc	62,3	62	nc	nc
2.2.4.2	Data Acq	nc	nc	43,4	nc	nc	nc	43,4	nc	nc	36,3	nc	36,3	80	nc	nc
2.2.4.3	Data Acq	nc	nc	105,3	nc	nc	nc	105,3	nc	nc	36,3	nc	36,3	142	nc	nc
2.2.4.4	Data Acq.	nc	nc	262,9	nc	31,2	nc	294,1	nc	nc	62,3	nc	62,3	356	nc	nc
2.2.4.5	Data Acq	nc	nc											300	nc	nc
2.2.4.6	Data Acq	nc	nc	144,7	nc	41,2	nc	175,9	nc	nc	31,2	nc	31,2	207	nc	nc
2.2.4.7	Sperv Comp	nc	nc	46	nc	nc	nc	46	nc	nc	62,3	nc	62,3	108	nc	nc
2.2.4.8	Syst. Power	nc	nc	nc	nc	0,5	nc	0,5	3,5	nc	nc	nc	3,5	4	nc	nc
														2,102		

Abreviations:
- nc Nocost in this element
- TBE To be estimated
- AFI Allowance for Indeterminates

3 33

IFMIF Cost Format Test Facility

WBS 2.2.5, 2.2.6

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.5.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	125	nc	125	125	nc	nc
2.2.5.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	164	nc	13	nc	177	177	nc	nc
2.2.5.3	Univ. Robot	nc	nc	3,434	nc	nc	nc	3,434	nc	nc	395	nc	395	3,829	nc	nc
2.2.5.4	Manip. Syst	nc	nc	1,546	nc	nc	nc	1,546	nc	nc	165	nc	165	1,711	nc	nc
2.2.5.5	Maint, Supt	nc	nc	660	nc	nc	nc	660	nc	nc	132	nc	132	792	nc	nc
2.2.5.6	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	526	nc	79	nc	605	605	nc	nc
2.2.6.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	125	nc	125	125	nc	nc
2.2.6.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	573	nc	13	nc	586	586	nc	nc
2.2.6.3	Transf. Syst	nc	nc	nc	nc	nc	nc	nc	198	nc	26	nc	224	224	nc	nc
2.2.6.4	Manip. Syst	nc	nc	1,546	nc	nc	nc	1,546	nc	nc	224	nc	224	1,770	nc	nc
2.2.6.5	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	460	nc	6,2	nc	466	466	nc	nc
2.2.6.6	Maint, Supt	nc	nc	nc	nc	nc	nc	nc	660	nc	132	nc	792	792	nc	nc
2.2.6.7	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	658	nc	98,7	nc	757	757	nc	nc
														11,959		

Abreviations:

nc	Nocost in this element
TBE	To be estimated
AFI	Allowance for Indeterminates

4 44

IFMIF Cost Format Test Facility

WBS 2.2.7, 2.2.8

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.7.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	78	nc	78	78	nc	nc
2.2.7.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	280	nc	13	nc	293	293	nc	nc
2.2.7.3	Manip. Syst	nc	nc	1,414	nc	nc	nc	1,414	nc	nc	145	nc	145	1,559	nc	nc
2.2.7.4	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	197	nc	6,2	nc	203	203	nc	nc
2.2.7.5	Maint, Supt	nc	nc	nc	nc	nc	nc	nc	197	nc	79	nc	276	276	nc	nc
2.2.7.6	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	164,5	nc	24,7	nc	189	189	nc	nc
2.2.8.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	103	nc	103	103	nc	nc
2.2.8.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	1,868	nc	164	nc	2,032	2,032	nc	nc
2.2.8.3	Manip. Syst	nc	nc	2,214	nc	nc	nc	2,214	nc	nc	112	nc	112	2,326	nc	nc
2.2.8.4	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	197	nc	6,2	nc	203	203	nc	nc
2.2.8.5	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	1,317	nc	132	nc	1,449	1,449	nc	nc
2.2.8.6	Exam.Equip	nc	nc	1,074	nc	nc	nc	1,074	nc	nc	nc	nc	nc	1,074	nc	nc
														9,785		

Abreviations:

nc	Nocost in this element
TBE	To be estimated
AFI	Allowance for Indeterminates

5 55

IFMIF Cost Format Test Facility

WBS 2.2.9, 2.2.10, 2.2.11, 2.2.12

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.9.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	103	nc	103	103	nc	nc
2.2.9.2	Strct, Suppt	nc	nc	7,896	nc	nc	nc	7,896	nc	nc	nc	nc	nc	7,896	nc	nc
2.2.9.3	Exam.Equpt	nc	nc	1,945	nc	nc	nc	1,945	nc	nc	nc	nc	bc	1,945	nc	nc
2.2.10	Tritium Lab	nc	nc	nc	nc	nc	nc	nc	26,000	nc	nc	nc	26,000	<26,000	nc	nc
2.2.11.1	Ventilation	nc	nc	nc	nc	nc	nc	nc	6,578	nc	nc	nc	6,578	6,578	nc	nc
2.2.11.2	Trit. Retent	nc	nc	nc	nc	nc	nc	nc	4,934	nc	nc	nc	4,934	4,934	nc	nc
2.2.12	Maint. Syst	nc	nc	nc	nc	nc	nc	nc	1,970	nc	nc	nc	1,970	1,970	nc	nc
														~~9,785~~ <49,426		

Abreviations:

nc Nocost in this element
TBE To be estimated
AFI Allowance for Indeterminates
2.2.10 Tritium Laboratory: Global estimate (<26,000KCF)
2.2.11 Maintenance Systems:Global estimate (1,970KCF)

IFMIF Test Cell Design Studies

- Test Cell Liner and Heat Shield
- Test Cell Shield Plug
- NaK-Cooled Vertical Test Assemblies
- Vertical Irradiation Tubes (VIT)
- Test Cell Vacuum Pumping System

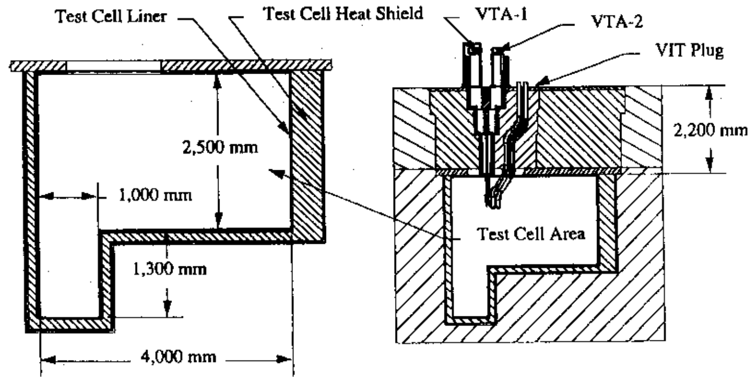
Danny Williams and John Haines (ORNL)

Presented by
John Haines
at the
2nd IFMIF-CDA Design Integration Meeting
May 20-25, 1996
JAERI - Tokai Research Establishment

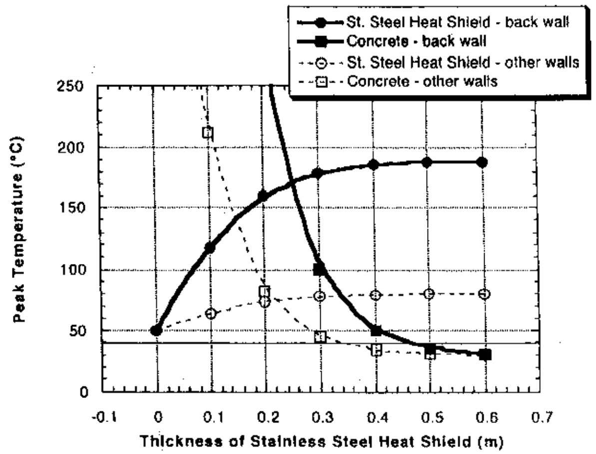
Test Cell Liner and Heat Shield Design Concept

- Test Cell Liner forms the vacuum boundary for the Test Cell
  - Stainless steel
  - 20 mm thick
  - Gas-cooled (He or Ar) on external surface
- Test Cell Heat Shield
  - Stainless steel "slabs" placed between the Test Cell Liner and concrete shielding
  - Function: Reduce neutronic heating in the concrete to a level which allows edge cooling (no internal cooling of concrete)
  - Thickness required = 0.5 m for beam facing surface, 0.3 m for other walls
  - Gas cooled on interior (Test Cell facing) surface

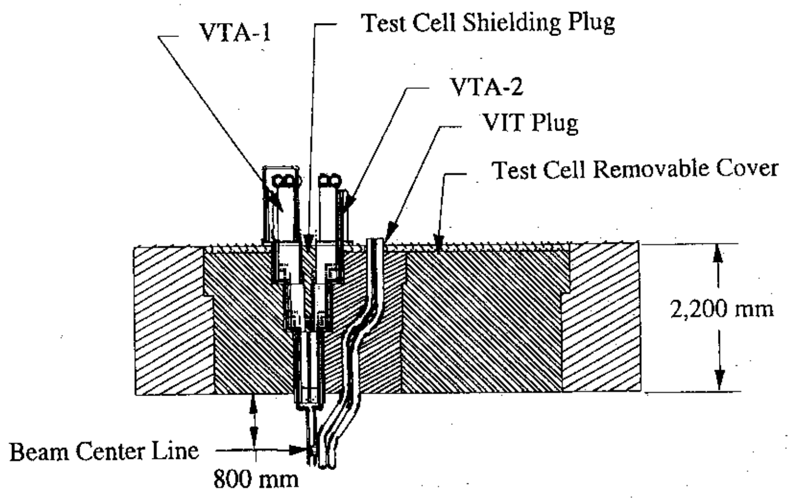
Test Cell Liner And Heat Shield



A Stainless Steel Heat Shield Protects the Concrete Neutron Shielding

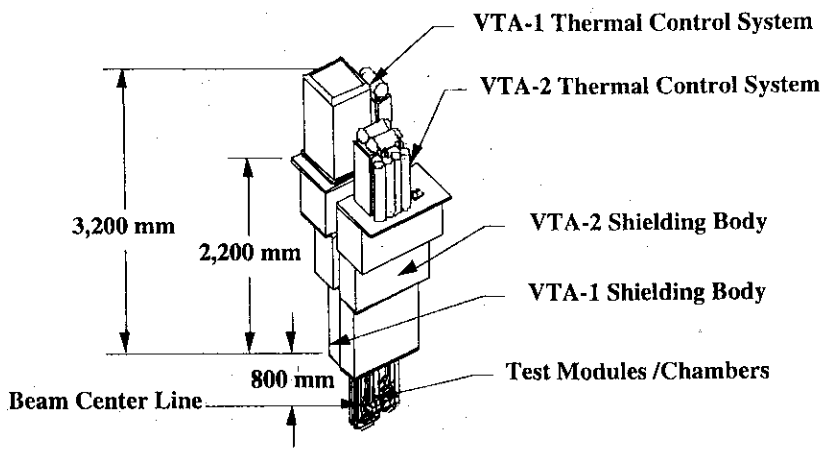


Test Cell Shield Plug



NaK Thermally Controlled Vertical Test Assemblies

VTA-1 and VTA-2



The Vertical Irradiation Tube (VIT) System Has Replaced the VTA's in the Low and Very Low Flux Regions

- Based on results of March planning meeting a new design approach for testing in the low and very low flux regions has been developed
  - Vertical Irradiation Tube (VIT) System - array of tubes with pneumatically fed and retracted capsules
  - 30 tubes with 75 mm diameter

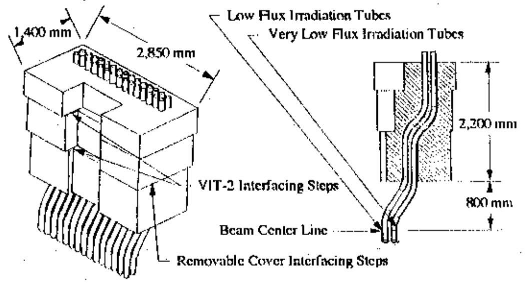
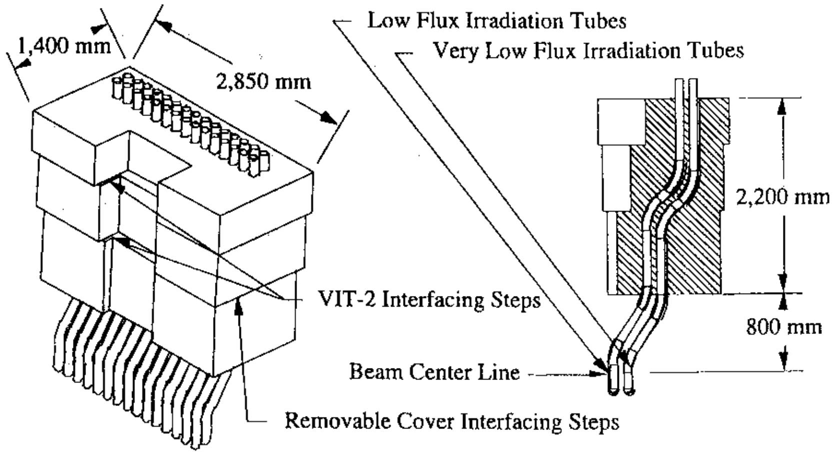


Figure Of The Vertical Irradiation Tube Plug

Vertical Irradiation Tube (VIT) Plug



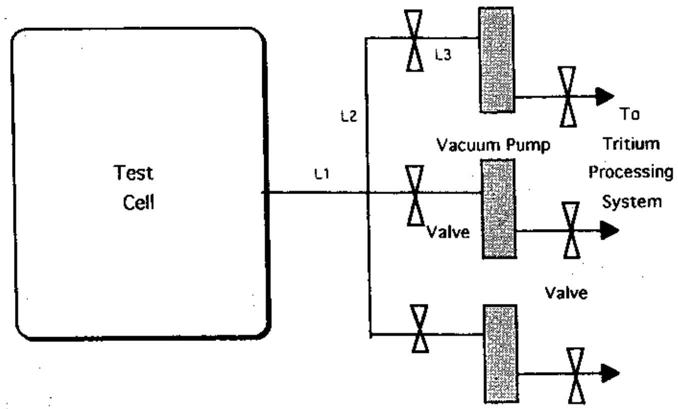
Test Cell Vacuum Pumping System

- Test Cell Vacuum Pumping System Performance "Requirements"

(1) Maintain test cell pressure ≤ 10 Pa
Outgassing rate = 0.13 Pa-L/s-m2 (10-7 torr-L/s-cm2) --- "dirty" for stainless steel
Total outgassing area ~ 150 m2
Total gas load ~ 20 Pa-L/s
Net pumping speed required at 10 Pa ~ 2 L/s

(2) Initial pumpdown time to 10 Pa ≤ 2 hours
Test Cell Volume ~30,000 L
Net Speed Required for pumpdown in two hours ~ 35 L/s

- The second requirement, i.e. initial pumpdown, sizes the vacuum pumping system



2nd IFMIF-CDA Design Integration Meeting

May 1996, JAERI, Japan

T. Hoshiya, S. Jitsukawa and K. Noda

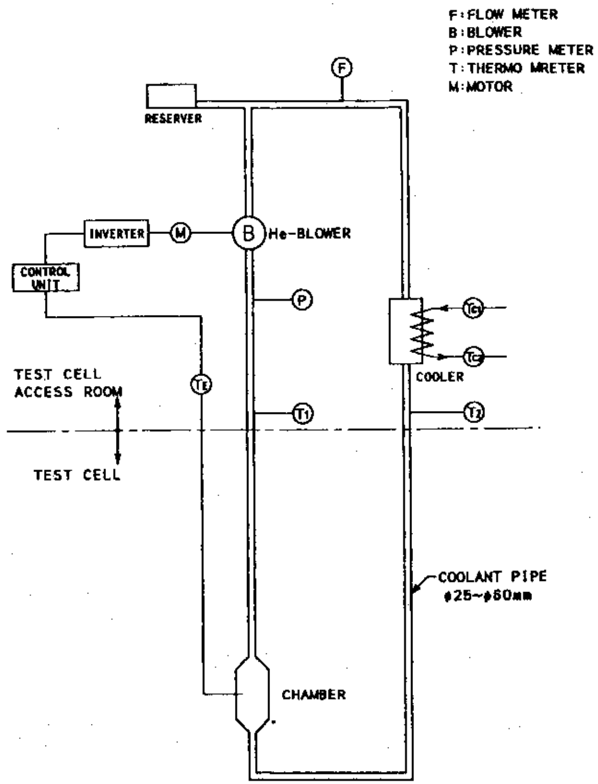
- Outline of Test Assembly Design
- Function of Medium Flux Region
  - Tritium Release Measurement
  - Creep Fatigue Measurement
- Coupling System for Pipe or T/C

JAERI

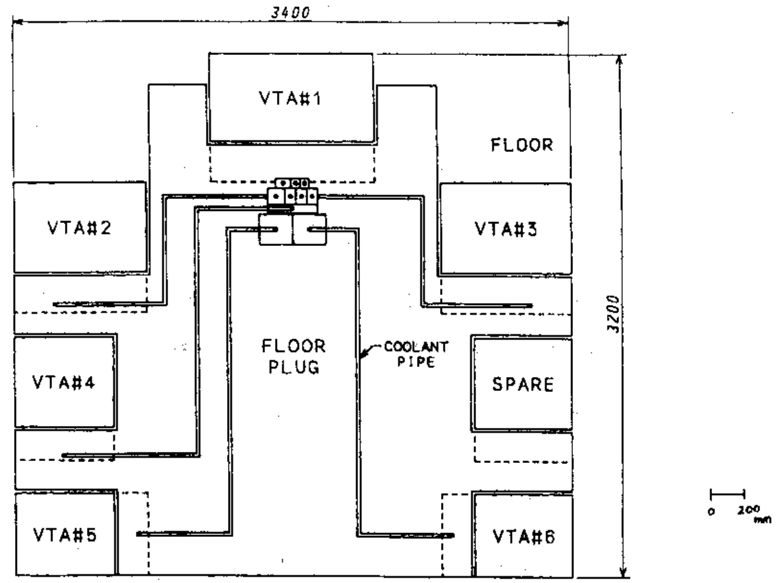
Test Cell Vacuum System Features and Performance Parameters

Vacuum pump type	Standard mechanical
Speed of vacuum pumps at 10 Pa	20 L/s
Number of Pumps Required	2 (3 included for redundancy)
Vacuum duct diameter (mm)	50
Number of 90° elbows in vacuum duct	2
Duct lengths (m)	
L_1	3
L_2	0.5
L_3	0.5
Net pumping speed	35 L/s
Test Cell Base Pressure	≥ 0.5 Pa

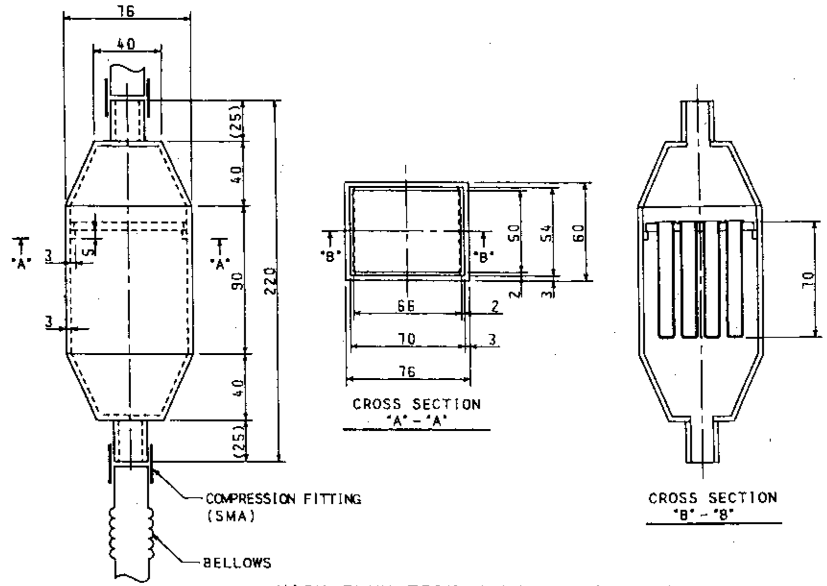
Outline of Test Assembly Design



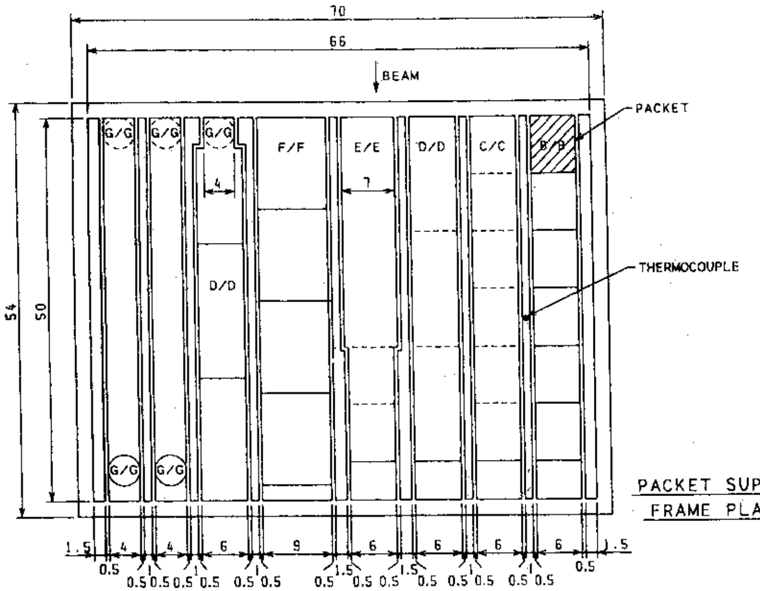
HeGAS-COOLANT CIRCUIT



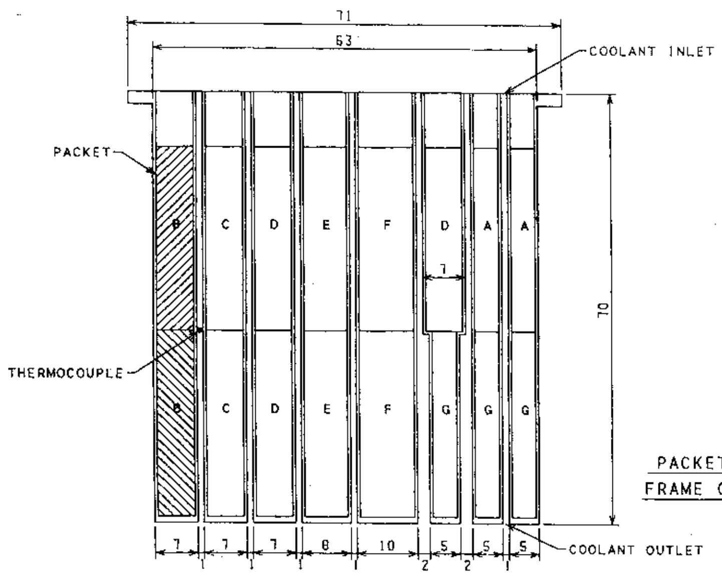
VTA'S PLAN VIEW (UNITS: mm)



HIGH FLUX TEST MODULE #1 (600°C)



PACKET SUPPORTING
FRAME PLAN VIEW
(UNIT: mm)

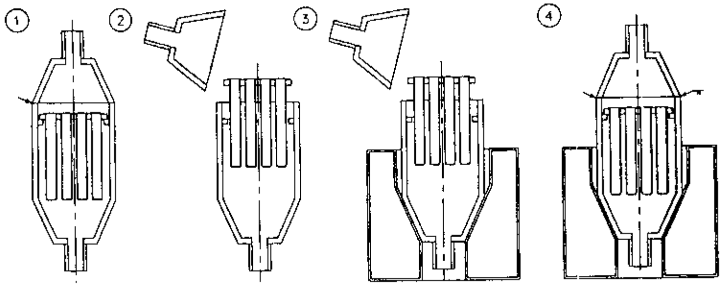


PACKET SUPPORTING
FRAME CROSS SECTION
(UNIT: mm)

2nd IFMIF-CDA Design Integration Meeting   May 1996, JAERI, Japan

Design of Medium Flux Chamber

1. Cutting of chamber
2. Removing of irradiated samples
3. Exchanging of damaged chamber
4. Welding of chamber



Exchange method of damaged chamber

Tritium Release Performance

Chamber 1 for Disk and Compatibility

Chamber 2 for Pellet and Pebble

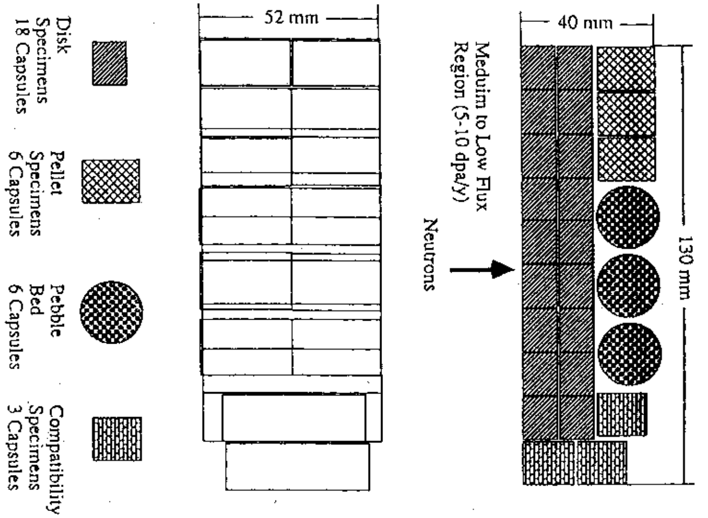
2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan

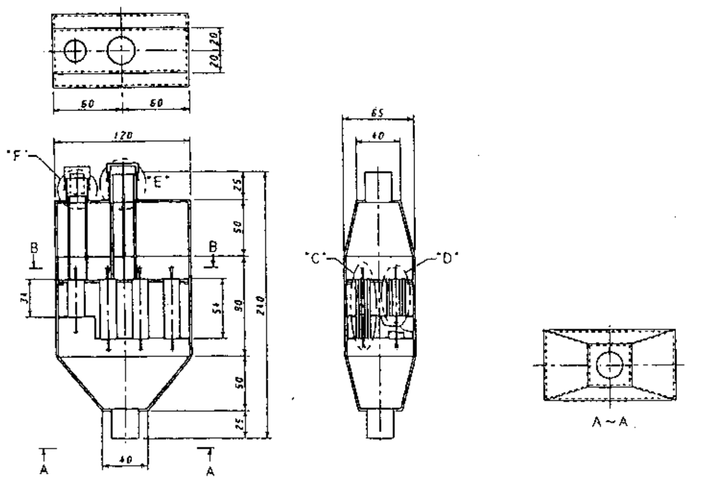
Specimen and Capsule Volume (Ceramic Breeder)

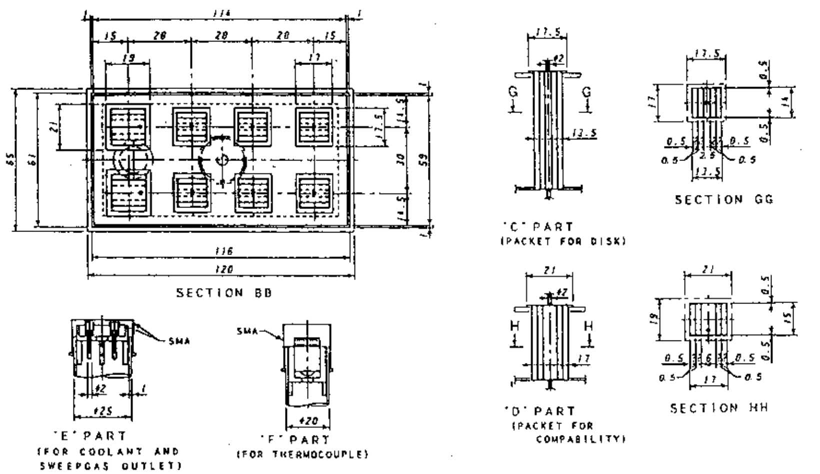
Specimen Type	Specimen Volume	Capsule Configuration and Volume	No of Specimens in Capsule	No. of Capsules	Materials	Temperature	Total Volume
Disl (10mm diam.) (2mm Thick.)	157mm³ 0.16cm³	10 x 12 x 52mm = 6240mm³ =6.3cm³	6	1 capsule for each materials and temp. =1 x 6 x 3 =18	L1,L2, L3, L4,. L5, I	400 C 600 C 800 C	114cm³
Pellet (10mm diam.) (10mm height)	785mm³ 0.79cm³	14 x 20 x 25mm =7000mm³ =7cm³	2	1 capsule for each materials =1 x 6 = 6	L1, L2, L3, L4, L5, I	Temp. gradient	42cm³
Pebble (1mm diam.)	0.26mm³ 0.00026mm³	9.5x9.5x3.14x25mm =7085mm³ =7.1cm³	Pebble bed	1 capsule for each material =1 x 6 = 6	L1, L2, L3, L4, L5, I	Temp. gradient	43cm³
Compatibility Breeder (5mm diam.) (1.5mm thick.) Structural (5mm diam.) (0.5mm thick.)	2 Breeder 29mm³x2 = 58mm³ 2 Structural 10mm³x2 =20mm³	13 x 15 x 38mm =7410mm³ =7.4cm³	12 specimen sets	1 capsule for each temp.	L1, L2, L3, L4, L5, I	400 C 600 C 800 C	22cm³
						Total	221cm³

L1:Li_2O, L2:Li_2ZrO_3, L3: Li_4SiO_4
L4 : $LiAlO_2$, L5: Li_2TiO_3, I: Innovative

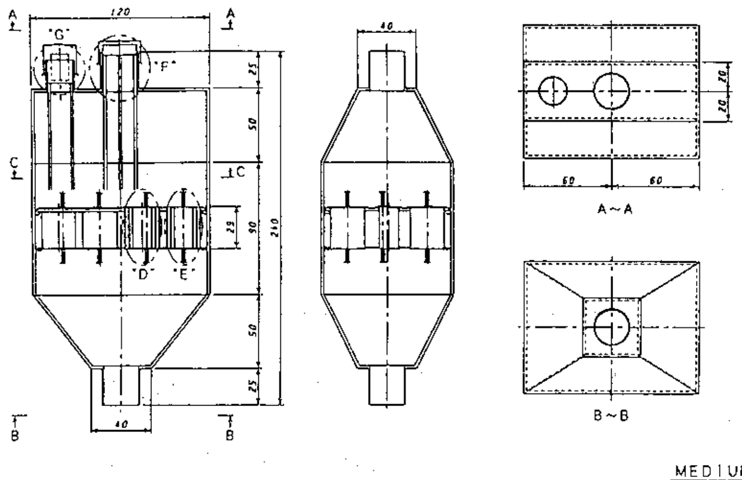
Irradiation Test Volume for In-situ experiments of Ceramic Breeder



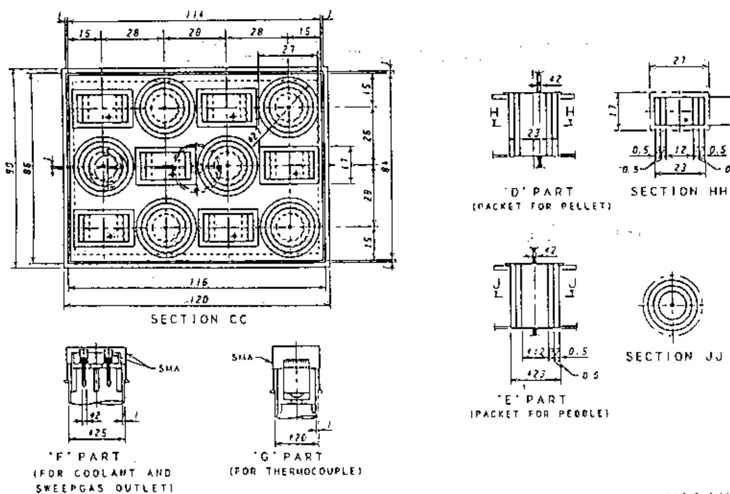




2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan



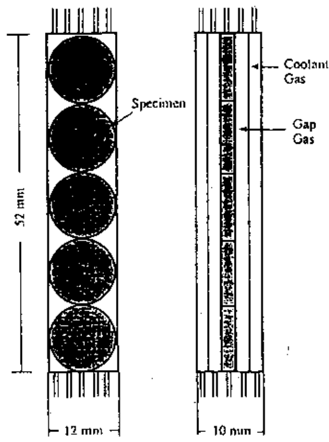
MEDIUM FLUX
CHAMBER-2
(UNITS: mm)



MIDIUM FLUX
CHAMBER-2
(UNITS: mm)

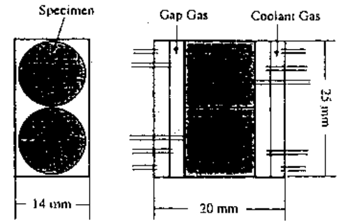
2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan

Irradiation Capsule for Disk Specimens

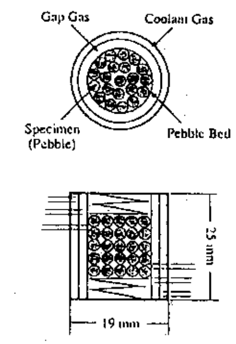


Disk Specimens:10 mm in diam. x2 mm in thick.

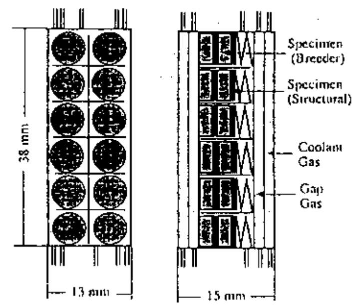
Irradiation Capsule for Pellet Specimens



Pellet Specimens:10 mm in diam. x 10 mm in thick.



Pebble: 1 mm in diam.
Pebble Bed: 10 mm in diam. x 10 mm in height



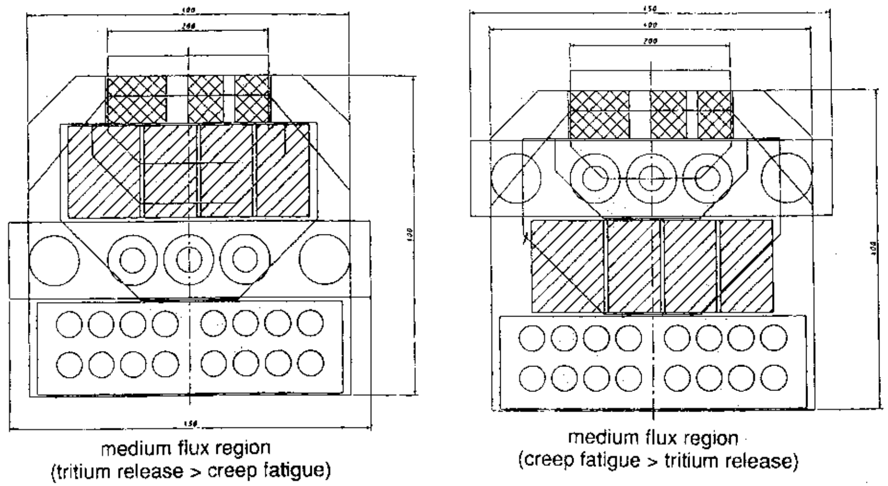
Compatibility Specimens:
Breeder (disks, 5 mm in diam. X 1.5 mm in thick.)
Structural (disks, 5 mm in diam. X 0.5 mm in thick.)

Design of Medium Flux Chamber

Creep Fatigue Performance

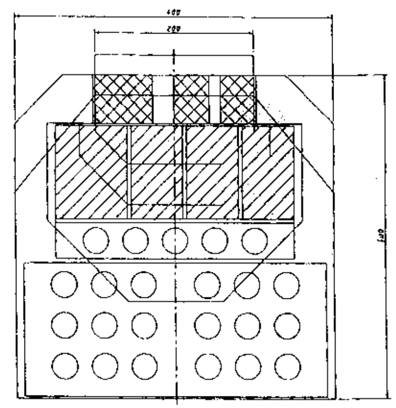
- Push-Pull rod machine
- JMTR capsule (bellows system)

2nd IFMIF-CDA Design Integration Meeting May 1996, JAERI, Japan



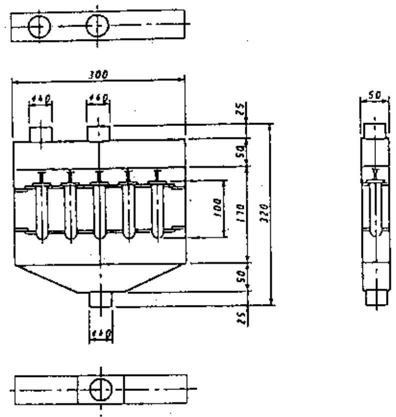
creep fatigue testing system (push-pull rod machine)

2nd IFMIF-CDA Design Integration Meeting May 1996, JAERI, Japan

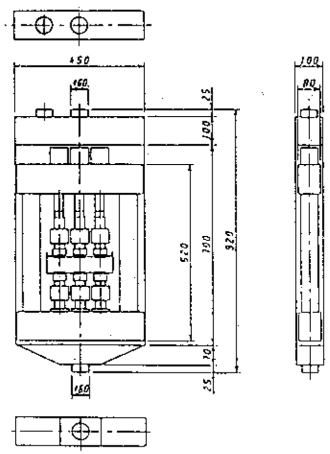


creep fatigue testing system (JMTR capsule)

2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan

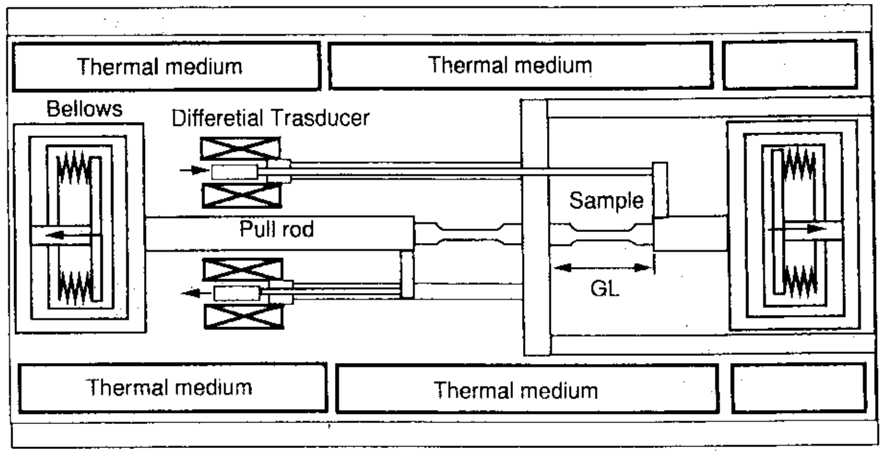


MEDIUM FLUX
CHAMBER-3
(FOR FATIGUE)
(JAPAN DESIGN)
(UNITS:mm)



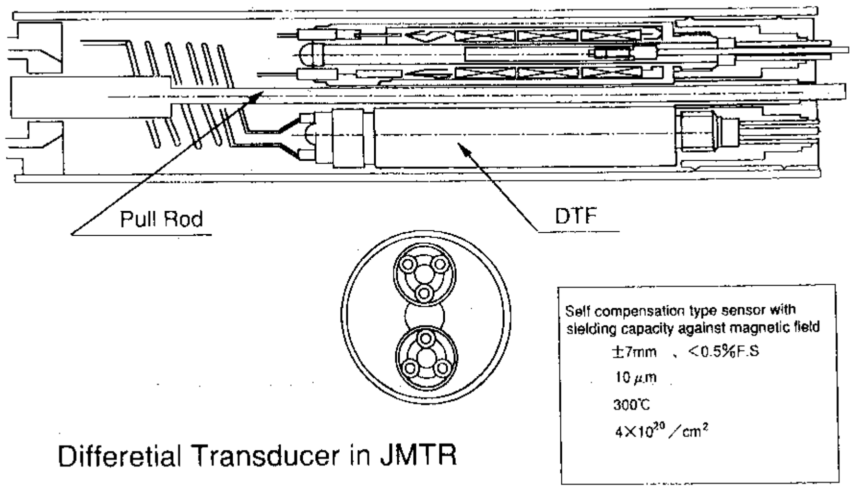
MIDIUM FLUX
CHAMBER-3
(FOR FATIGUE)
(EU DESIGN)
(UNITS:mm)

2nd IFMIF-CDA Design Integration Meeting May 1996, JAERI, Japan



In-situ creep fatigue system in JMTR

2nd IFMIF-CDA Design Integration Meeting May 1996, JAERI, Japan

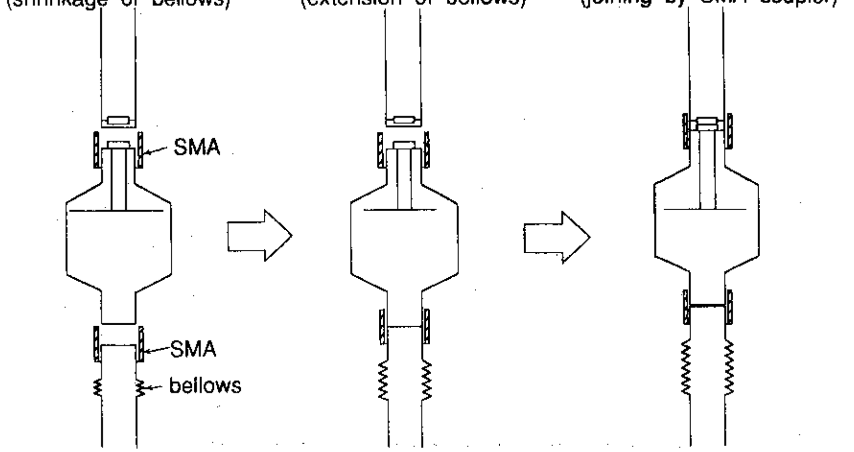


Differetial Transducer in JMTR

Coupling System for Pipe or T/C

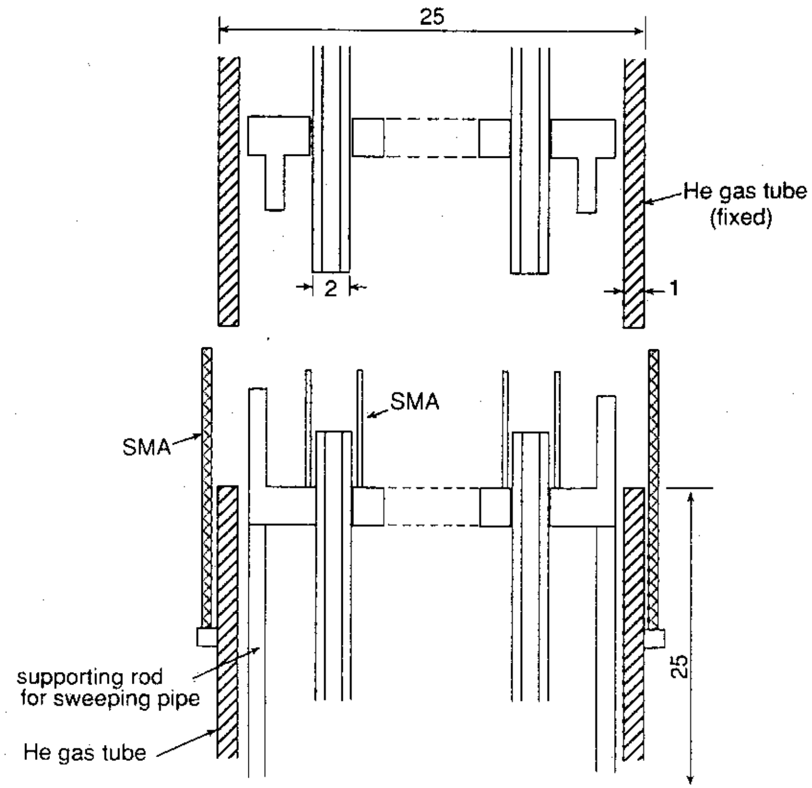
SMA Coupling System for pipe and/or T/C

2nd IFMIF-CDA Design Integration Meeting May 1996, JAERI, Japan



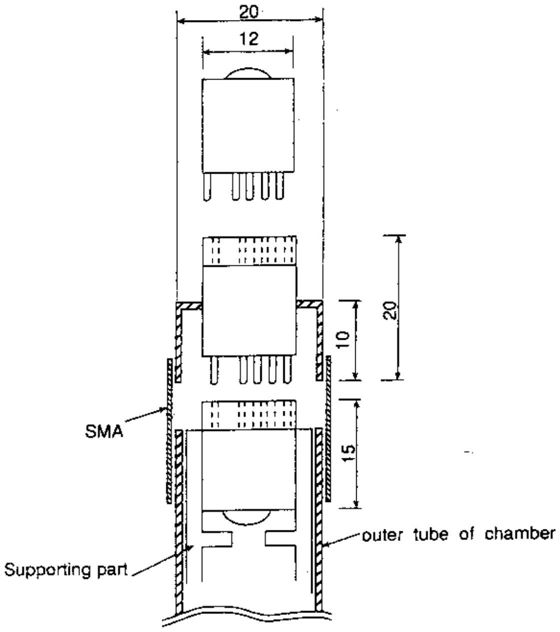
Coupling procedures of chamber

2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan



Connecting mechanism of He cooling tube and sweeping gas tube

2nd IFMIF-CDA Design Integration Meeting
May 1996, JAERI, Japan



Connecting device of thermocouples
(multi-connection coupler)

IFMIF-CDA

Design Integration Meeting

IFMIF Tritium System Proposal
-as a part of Post Irradiation Experiment Facility-

presented at the 2nd IFMIF-CDA
Design Integration Meeting
May 20-25, JAERI, Tokai, Japan

S. Konishi, K. Watanabe, K. Noda
JAERI IFMIF Test Cell Group

TRITIUM LABORATORY AND PIE FACILITY

Major function
- Handling tritium contaminated materials
- PIE of tritiated materials
- Tritium processing capability as a part of IFMIF

Purpose: Handling irradiated breeder materials
- Lithium compounds
- Volatile contamination
- Possible environmental hazard
- Accompanied with γ activity

Subsystems: Tritium Handling Hot Cells
- Tritium Gloveboxes
- Pritium Processing Systems

Special feature:Verious measurements needs
- Mixed contamination with T and γ activity
- More complicated operatiaon requirements (than regulra tritium facility)
- Required full tritium facility features
- Continuous maneuvering active samples

There are several other sources of contaminated exhausts. Optimized design for waste treatment is highly recommended.
- Lithium system exhaust
- Facility vacuum exhaust
- Solid, liquid waste

1. Tritium Handling Hot Cells

Function:
- Disassemble of sample capsules
- Sample identification
- Surface observation
- Sample preparation for closer observation in gloveboxes
- Sample maneuvaring
- Reassembly of capsules
- Containment of tritium and γ activity
- High level air tightness
- Continuous atmosphere control

Components:
- Two hot cells
  - Disassembly cell : $10m^3$
  - Measurement cell : $50m^3$
- Loading/unloding equipments
- Microscopes(SEM, optical)
- Mechanical test equipments
- Density measurement
- Ceramography equipments
- Specimen storage, identification
- Manipurators
- Universal mechanical test machine
- Enclosure and shielding
- Dedicated atmosphere control
- Crane and equipments

2. Gloveboxes

Function:

Various analyses of ceramic samples
Delicate operation with hands
Low γ activity sample handling
Continuous atmosphere control
Hands-on operation of sophisticated instruments
Possible tritium service for in-pile and/or in situ breeder tests
Other services for tritiated materials handling (from targets, solid wastes)

Components:

Ceramic test equipments
Optical analyses equipments
Li burnup measurement
Chemical test equipments
Glovebox enclosure and shielding
Glovebox equipments, instruments

Technical features

6 gloveboxes, total 70m^3
leak rate : 0.1 %/h
operating pressure : -50 ~ 0 mmAq
Ar atmosphere, oxygen, water <10ppm
tritium level 10^{-3} Ci/m^3, max 1 Ci/m^3

3. Detritiation systems for Hot cell and gloveboxes

Function:

Circulate air-tight tritium enclosures
Control oxygen, moisture and tritium
Once-through detritiation 10^2
Total volume ~70m^3, 2~5 /h circulation
Processin by water decomposition and tritium gettering
No regeneration needed
Tritium level normal 10^{-3} Ci/m^3

Components:

Hot cell atmosphere control 60 m^3/h
HEPA filter, oil-free blowers, preheater, electrolysis cell, getter bed, heat exchanger

Glovebox atmosphere control 20 m^3/h x 3
Filter, oil-free blowers, preheater, electrolysis cell, getter bed, heat exchanger

4. Other Tritium Safety Systems

Function:

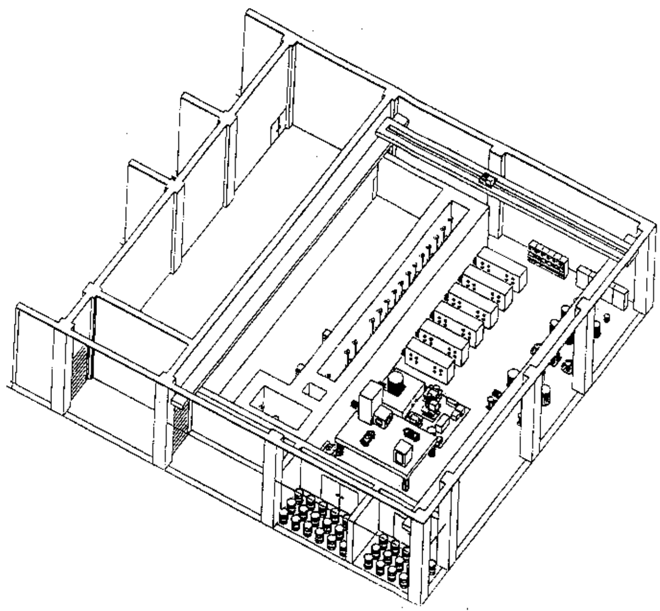
Once-through effluent detritiation for primary effluent, vacuum exhaust
Tritium monitoring systems throughout facility
Solid waste treatment
Liquid waste treatment
Tritium systems instrumentation and control
Tritium processing and storage (from target)

(These systems are not closely designed yet. However, It is understood that such functions are needed in the entire IFMIF facility. And the tritium laboratory in the test cell subsystem is one of the best part to equip with such systems to cover the requirements of the entire facility.)

Major components and anticipated specification:

Effluent tritium removal 20 m^3/h throughput
upto 1000 Ci/day processing
Over 10^6 DF for once-through processing
Accepts other tritiated evacuation discharge

Lithium cover gas control:
Control inert (He or Ar) atmosphere of lithium containment for positive pressure, oxygen/humidity control and tritium removal.

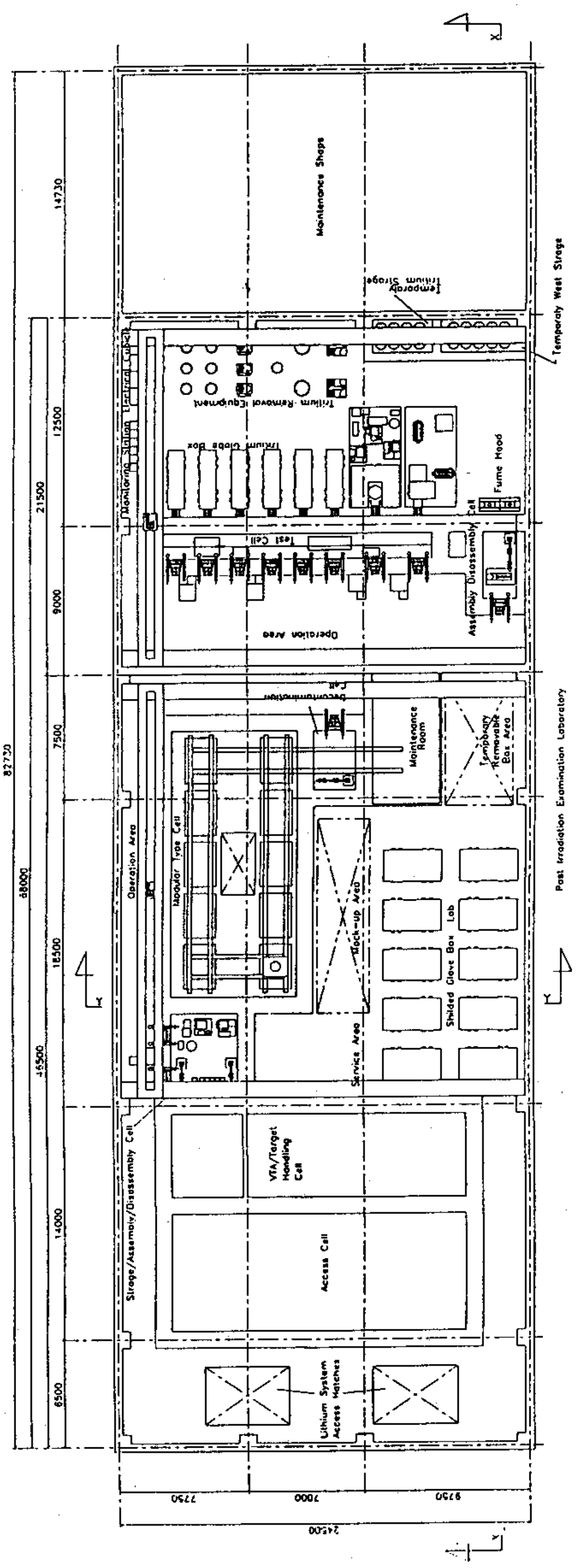


Solid waste treatment :
  Detritiation and packaging of solid waste
    for safe burial

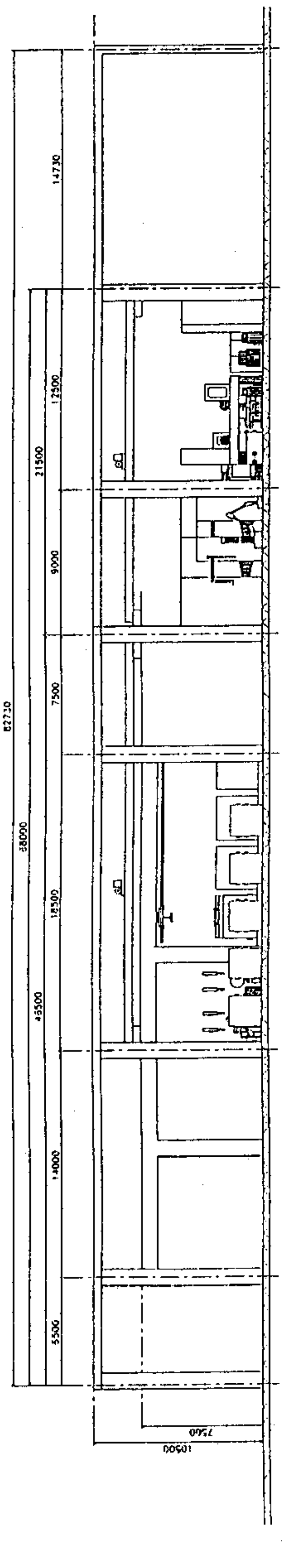
Liquid waste treatment :
  Detritiation, volume reduction and solidification,
    or dilution for environmentally acceptable form

Tritium systems instrumentation and control:
  Tritium monitors for subsystems, rooms, process,
    stack and environment for control.
  Instrumentation and interlock logic and action.
  Control console, automatic / manned operation
    system.

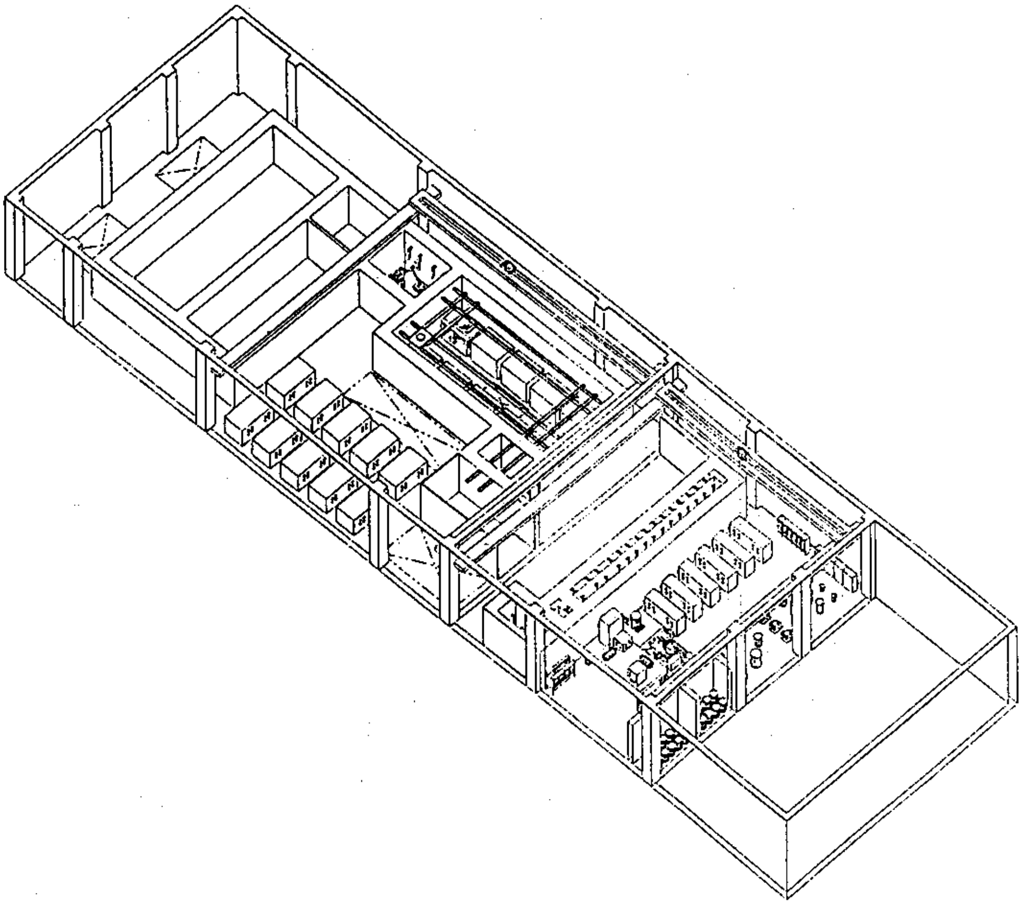
Tritium processing and storage:
  Tritium removal / recovery from in pile experiment.
  Tritium processing from lithium target.
  Safe packaging and shipping aid for tritium product.



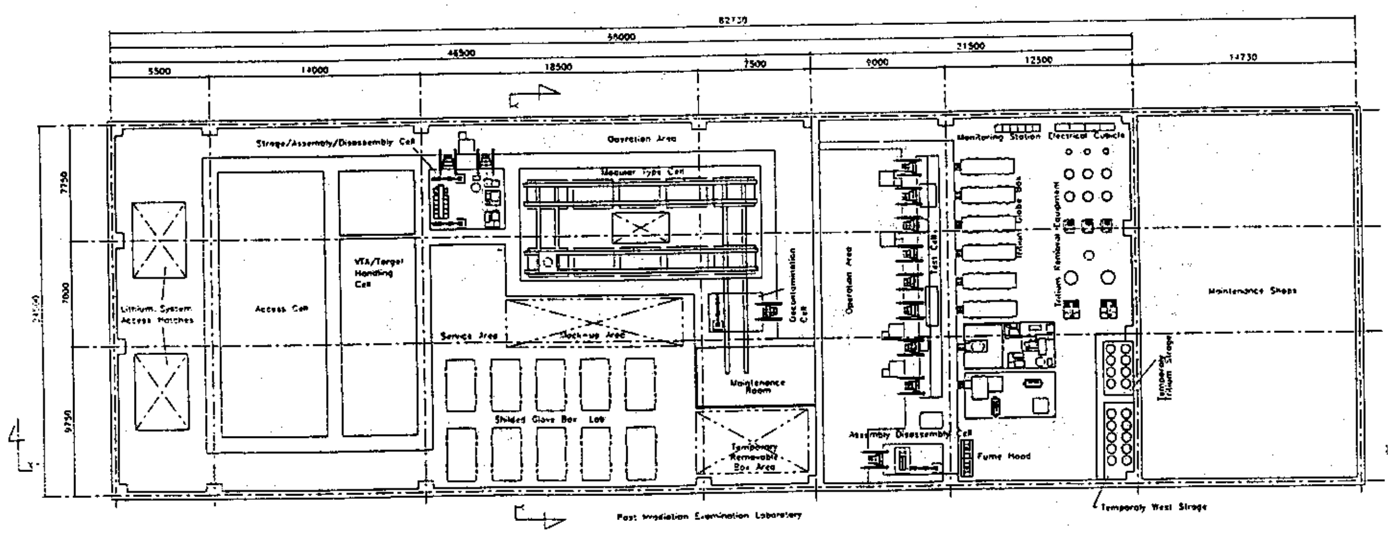
Plan of IFMIF PIE Building



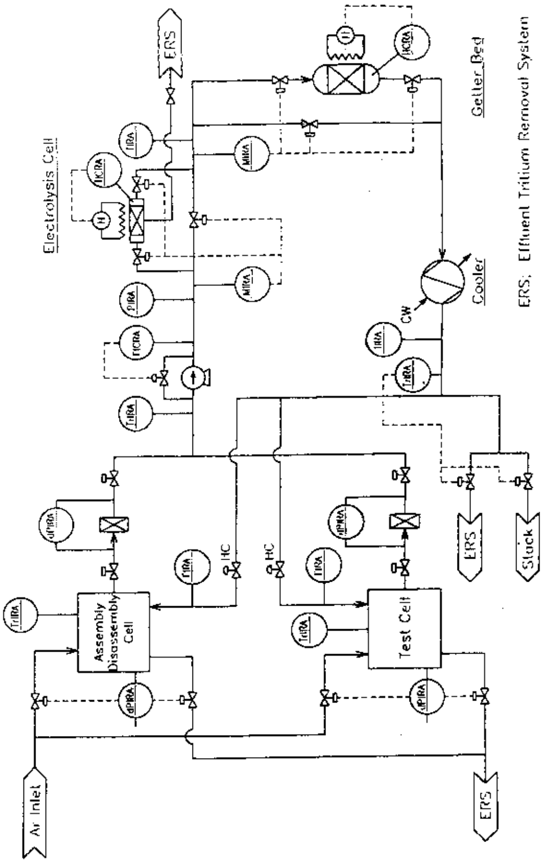
Section X-X



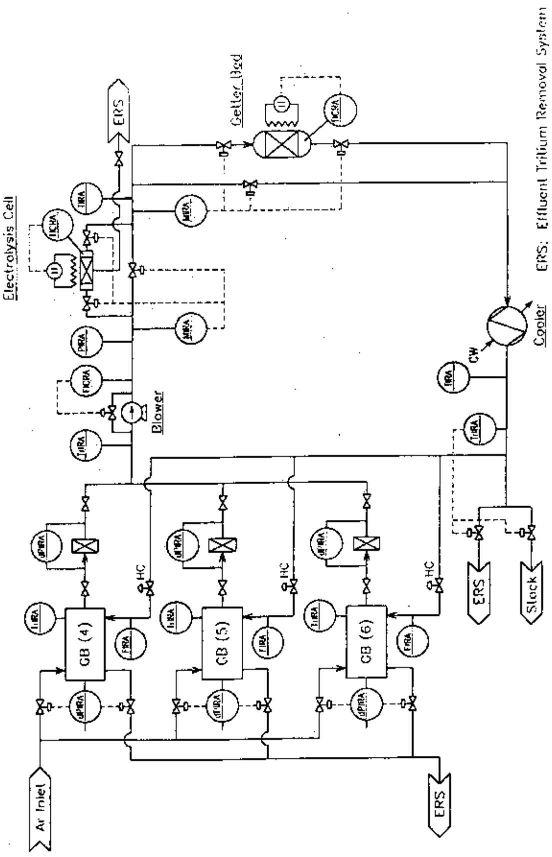
Bird's-eye View of IFMIF PIE Building



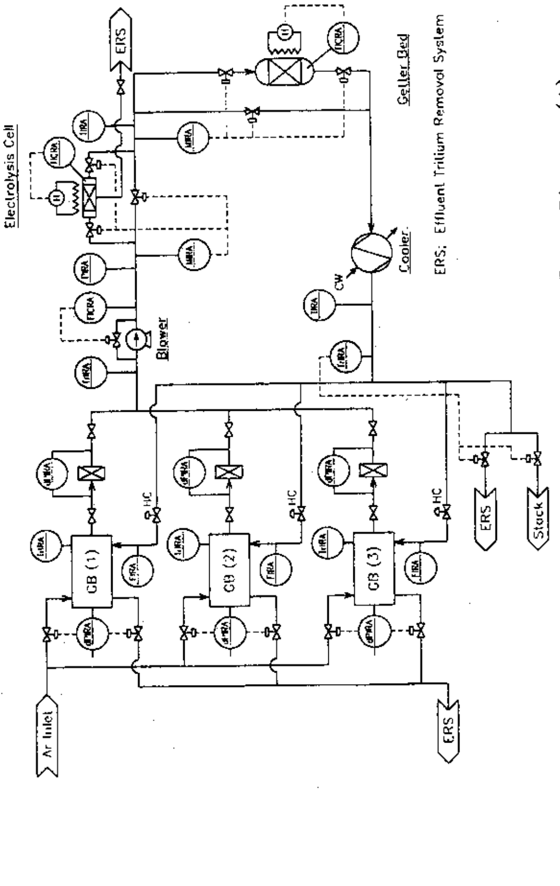
Plan of IFMIF PIE Building



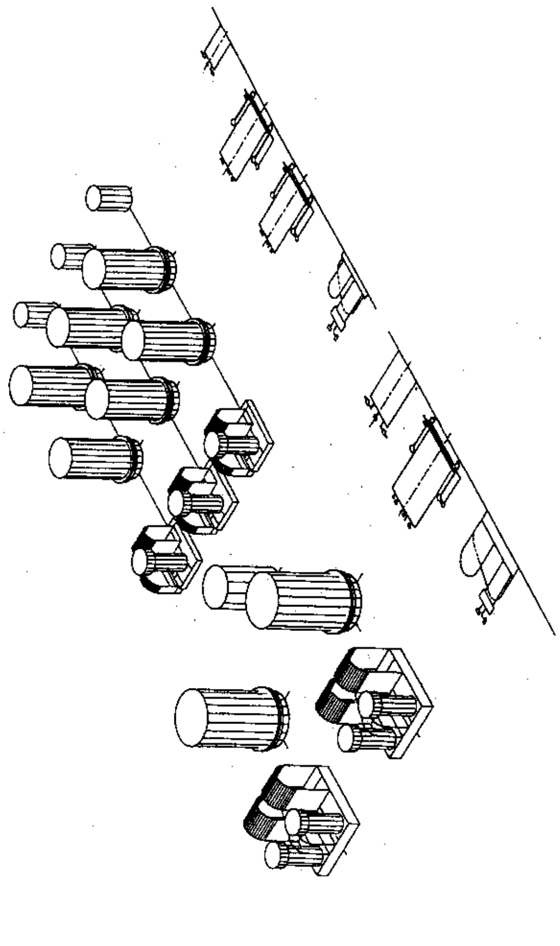
IFMIF Detritiation System Flow–Diagram

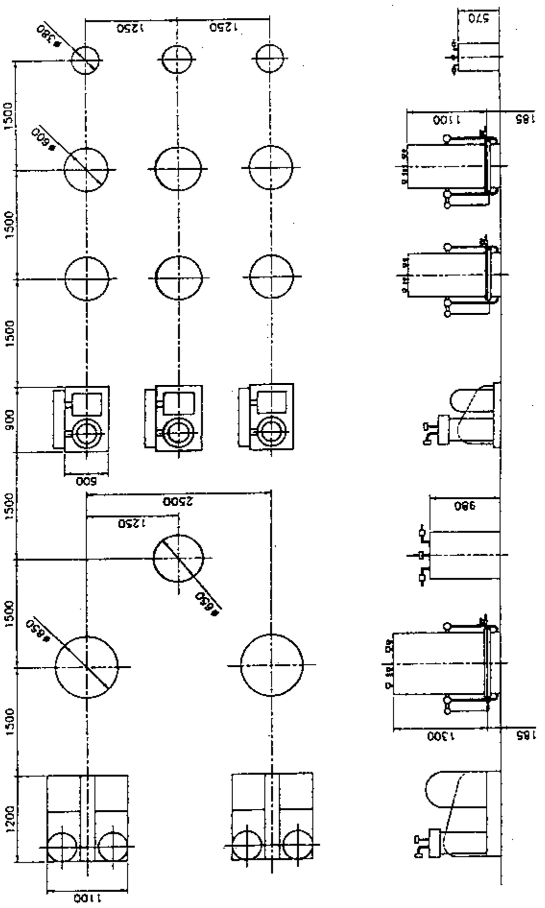


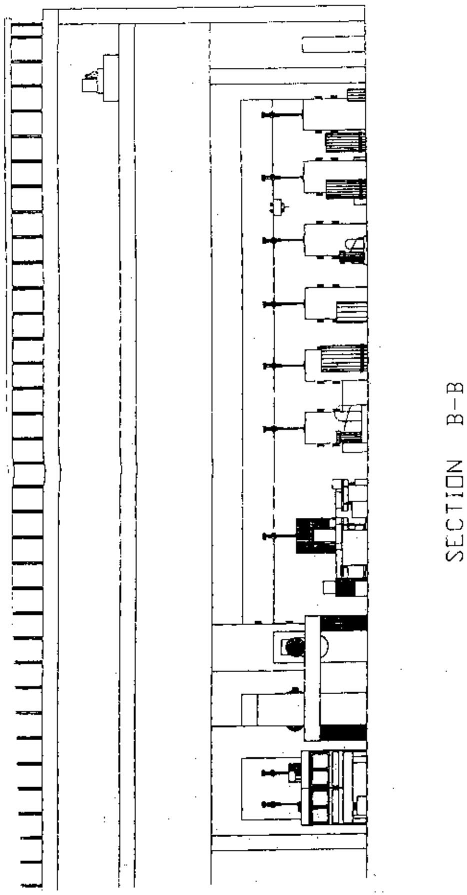
IFMIF Glovebox Detritiation System Flow–Diagram(2)

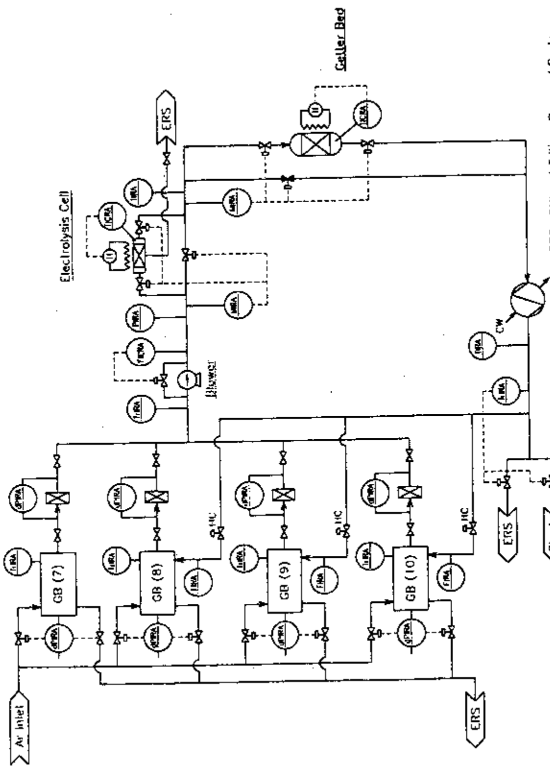


IFMIF Glovebox Detritiation System Flow–Diagram(1)



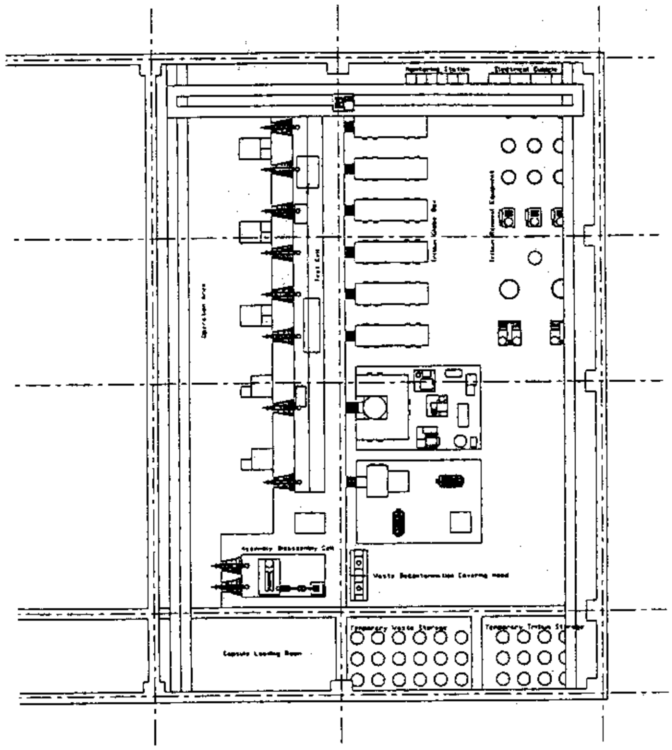




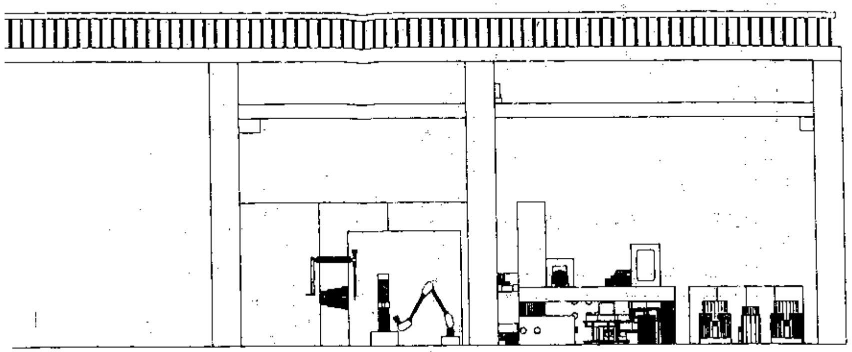


ERS: Effluent Tritium Removal System

IFMIF Glovebox Detritiation System Flow-Diagram(3)



Tritium Area Layout



SECTION A-A

WBS	WBS Description	c (Offsite, INDUSTRY) Hot/lab	d c-subtotal	e Engineering	f Inst./Engin. AFI	g	h sub-total	Total(c+e+f+g)	total 2.2.9.2	k (Onsite, INDUSTRY) Hot/lab	l	m Engin. dept. engs.	n AFI	o Total Onsite	Grand Total	Comments
2.2.9.0	Tritium laboratory															
2.2.9.1	Assembly and Testing							0								
2.2.9.1.1	Unit Assembly							0								
2.2.9.1.2	Unit Testing/QA/Doc./Insp.			95	30	25		150	150						150	
2.2.9.1.3	Installation									0	95	30	125	250	250	
2.2.9.1.4	Inspection/QA/doc./insp.															
2.2.9.2	Components															
2.2.9.2.1	Tritium Hot Cell		1,153	320	30		473		2,226	30	190	150	185	555	2,781	
	unit development and AFI					250										
2.2.9.2.1.1	Cap/cell disassembly equipments	10		0	0	5		15								
2.2.9.2.1.2	observation/microscopy	77		0	0	0		77								
2.2.9.2.1.3	identification	8		0	0	4		12								
2.2.9.2.1.4	sample handling	180		0	0	54		234								
2.2.9.2.1.5	cleaning/decontamination equipment	28		0	0	3		31								
2.2.9.2.1.6	[illegible]	30		0	0	15		45								
2.2.9.2.1.7	cell enclosure/shielding	600		0	0	120		720								
2.2.9.2.1.8	manipulators	180		0	0	18		198								
2.2.9.2.1.9	cell equipments	40		0	0	4		44								
2.2.9.2.2	Glovebox		367	380	15		122		904	10	190	120	160	480	1,384	
	unit development and AFI					65										
2.2.9.2.2.1	Ceramic test equipments	80		0	0	0		80								
2.2.9.2.2.2	Optic/glow/sensors	32		0	0	16		48								
2.2.9.2.2.3	mechanical test equipments	15		0	0	5		20								
2.2.9.2.2.4	chemical test equipments	20		0	0	10		30								
2.2.9.2.2.5	glovebox enclosure shielding	180		0	0	0		190								
2.2.9.2.2.6	glovebox equipments	60		0	0	6		66								
2.2.9.2.3	Tritium safety systems		4,880	780	45		1,818		7,503	30	380	180	305	915	8,418	
	unit development and AFI					250										
2.2.9.2.3.1	Test cell atmosphere	500		0	0	150		650								
2.2.9.2.3.2	Glovebox atmosphere	500		0	0	270		770								
2.2.9.2.3.3	Effluent tritium removal	1,500		0	0	450		1,950								
2.2.9.2.3.4	Tritium monitoring system	800		0	0	60		860								
2.2.9.2.3.5	Solid waste treatment	300		0	0	120		420								
2.2.9.2.3.6	Liquid waste treatment	600		0	0	300		900								
2.2.9.2.3.7	Auxiliary fume hood	80		0	0	6		86								
2.2.9.2.3.8	Instrumentation and Control	200		0	0	150		350								
2.2.9.2.3.9	Tritium storage	800		0	0	60		860								
								8,779								
	Totals	6,420		1,805	120	2,430			10,783	90	855	480	775	2,200	12,983	

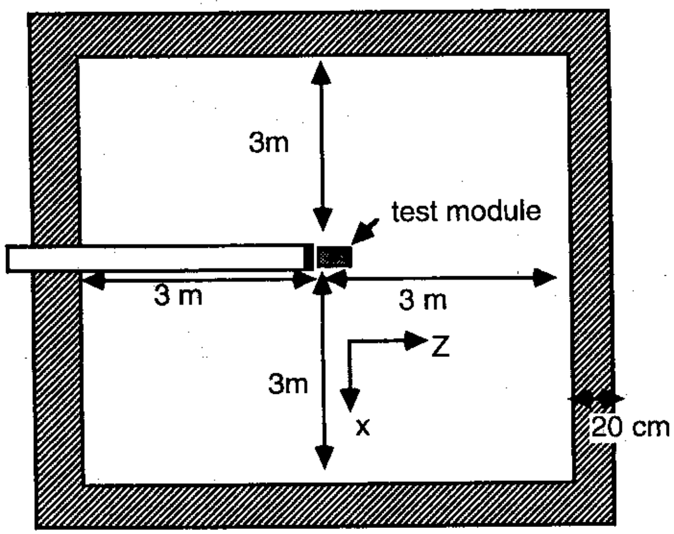
in Myen x9.5 = [illegible]

Status of Neutronics Task

Yukio Oyama

IFMIF DI Meeting
20-25, May 1996
Japan Atomic Energy Research Institute

Test cell model (horizontal)

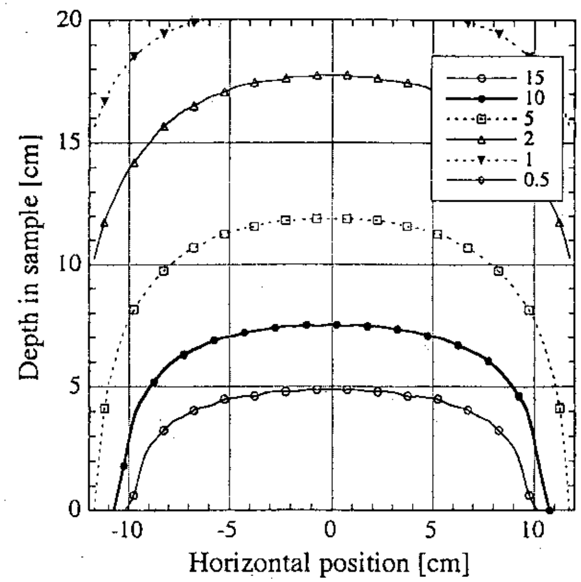


Nuclear Heating and DPA Distribution in Target Cell

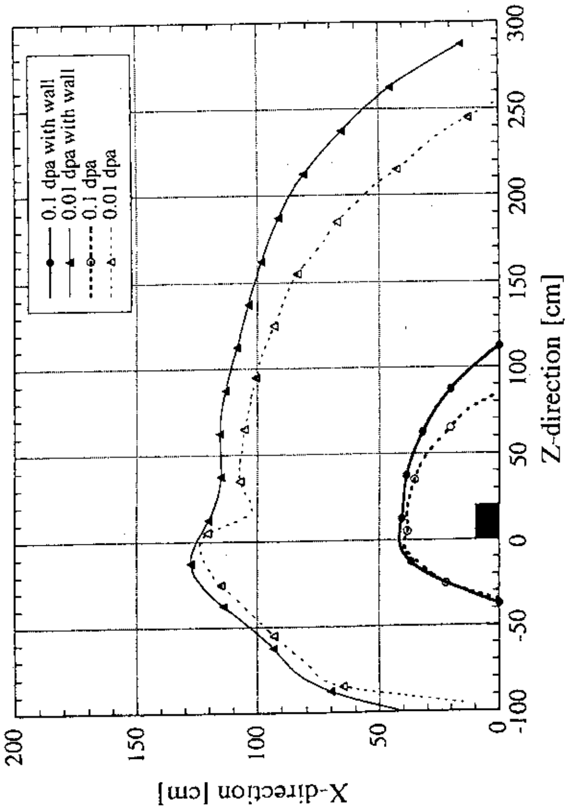
Assumptions

- $50^W x 200^H x 200^L$ module
- 3m distance from target to wall
- Fe atom placed in free space

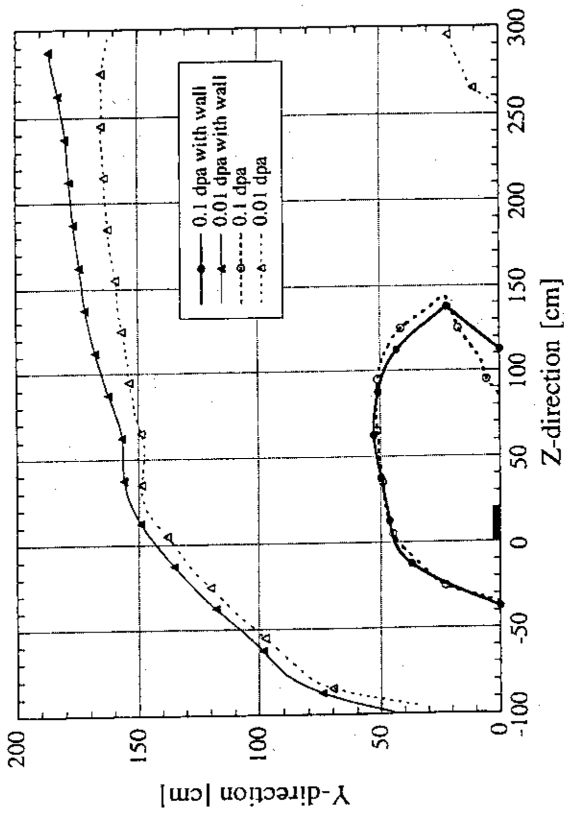
IFMIF : contour map of Fe total heating [W/cm³] on x-z plane (Fe-50%, NaK-30% ; 35MeV ; detailed)



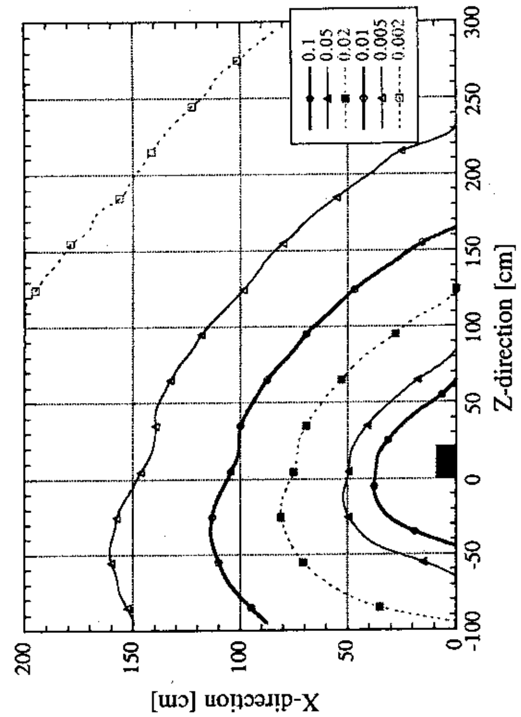
IFMIF : contour map of Fe dpa [/yr] on x-z plane between with and without concrete wall (Fe-50%, NaK-30% ; 35MeV)



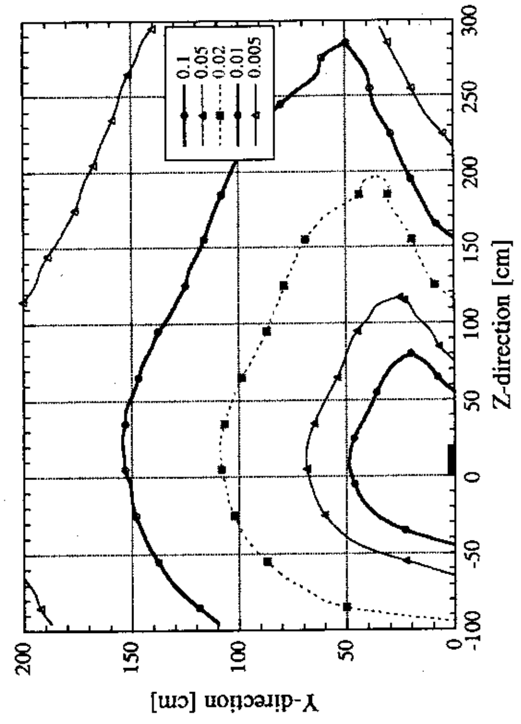
IFMIF : contour map of Fe dpa [/yr] on y-z plane between with and without concrete wall (Fe-50%, NaK-30% ; 35MeV)

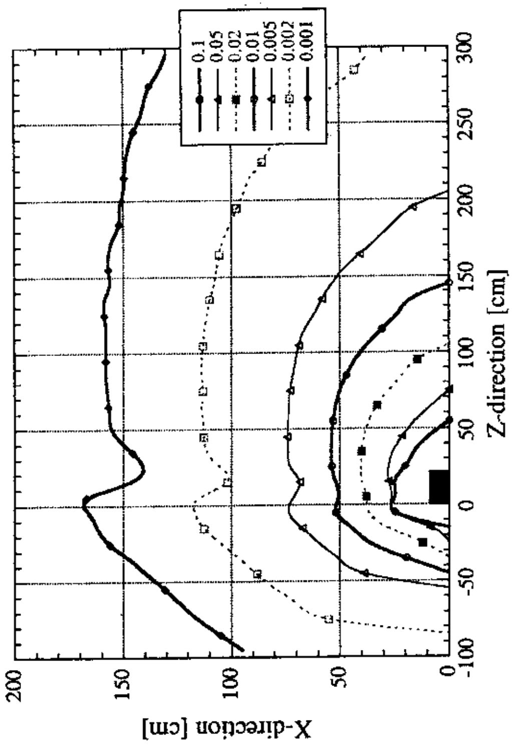


IFMIF : contour map of Fe total nuclear heating [W/cm³] on x-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)

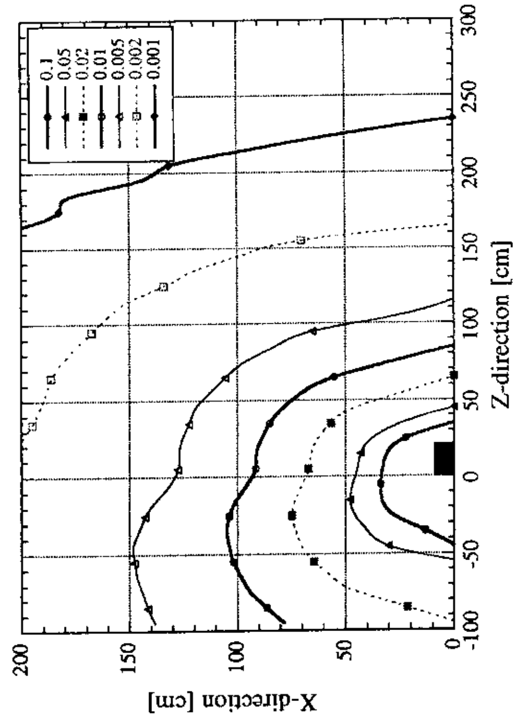


IFMIF : contour map of Fe total nuclear heating [W/cm³] on y-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)

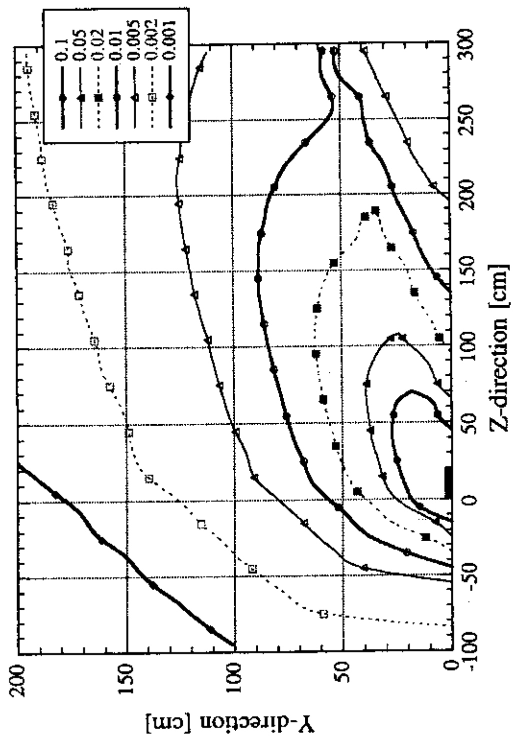




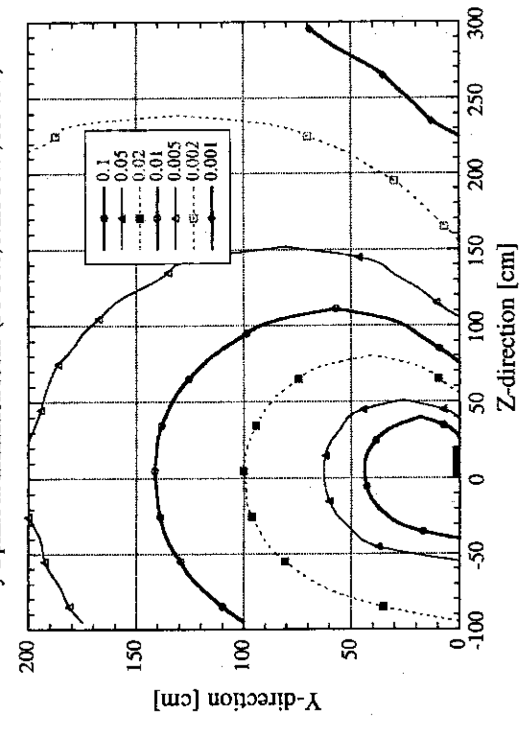
IFMIF : contour map of Fe neutron nuclear heating [W/cm^3] on x-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)



IFMIF : contour map of Fe gamma-ray nuclear heating [W/cm^3] on x-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)



IFMIF : contour map of Fe neutron nuclear heating [W/cm^3] on y-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)



IFMIF : contour map of Fe gamma-ray nuclear heating [W/cm^3] on y-z plane in irradiation room (Fe-50%, NaK-30% ; 35MeV)

Status of JENDL High Energy File for IFMIF

- Primary file has benn completed

- Presently under reviewing for check

- All works will be completed at end of July

-After internal procedure, it will be released in Oct.

- MCNP library will be available by end of Feb.

Status of JENDL High Energy File for IFMIF

T. Fukahori
Nuclear Data Center, Dept. of Reactor Engineering,
Japan Atomic Energy Research Institute,
Tokai-mura, Naka-gun, Ibaraki-ken, 319-11 Japan
fukahori@cracker.tokai.jaeri.go.jp

The JENDL High Energy File for IFMIF is a neutron nuclear data file of the phase-I of JENDL High Energy Files. The 27 elements from H to W are included in the JENDL High Energy File for IFMIF. The evaluated quantities are the total, elastic scattering, reaction, fission and isotope production cross sections, and double differential particle and γ-ray emission cross sections. The considered outgoing particles are neutron, proton, deuteron, triton, ^{3}He and α-particles. The present status of the JENDL High Energy File for IFMIF, and preliminary results for several nuclides are reported as well as their format.

1. Introduction

The JAERI Nuclear Data Center has started to generate evaluated high energy nuclear data files in cooperation with Japanese Nuclear Data Committee (JNDC) in order to give basic information to a lot of applications such as accelerator engineering, space physics and engineering and medical usage. The files considered here are JENDL High Energy File, JENDL PKA/KERMA File and JENDL Photonuclear Data File. The outlines of these files are summarized in **Table 1**.

The JENDL High Energy File will include nuclear data for proton- and neutron-induced reactions. The evaluation work is separated into two phases. The energy range of the phase-I is up to 50 MeV. The nuclear data in this energy range are needed mainly for the International Fusion Material Irradiation Facility (IFMIF)[1] which is an FMIT-type accelerator facility using Li(d,n) neutron source for an irradiation test of fusion reactor materials. The neutron spectrum of IFMIF has a high energy tail up to 50 MeV. The energy range for the phase-II is up to a few GeV mainly for an accelerator-driven radioactive waste transmutation system (OMEGA project).

The JENDL PKA/KERMA File is generated to give the primary knock-on atom (PKA) spectra, damage energy spectra, DPA (displacement per atom) cross section and kerma factor by neutron-induced nuclear reactions as basic information for estimation of material radiation damage. Incident neutron energy below 50 MeV is considered. The JENDL photonuclear data file consists evaluated gamma-ray induced nuclear reaction data below 140 MeV.

In this paper, the present status of the JENDL High Energy File for IFMIF, and preliminary results for several nuclides are reported as well as their format.

2. JENDL High Energy File for IFMIF

The JENDL High Energy File for IFMIF is a neutron nuclear data file of the phase-I of JENDL High Energy Files. The elements included in the JENDL High Energy File for IFMIF are summarized in **Table 2**. The evaluated quantities are total, elastic scattering, reaction and isotope production cross sections, and double differential particle and γ-ray emission cross sections. The outgoing particles considered are neutrons, protons, deuterons, tritons, ^{3}He and α-particles. For the evaluation, SINCROS-II is mainly used, except for light mass nuclei because of not enough experimental data. SCINFUL/DDX code is used for the evaluation of the light mass nuclei by considering break-up reactions. Below 20 MeV, the data of JENDL Fusion File and/or JENDL-3.2 are adopted basically for all the nuclei.

A review step after calculation step finished is newly adopted. Materials for data review (Review Kit) are numerical file of evaluated result, results of format and physical checking by using FISCON, PSYCHE, CHECKR and DOUBLEP codes, plots comparing with experimental data, index list of experimental data and list of produced isotopes. After re-evaluating according to the suggestion of reviewer, data is finally compiled and is sent to some benchmark tests.

3. FORMAT

For the JENDL High Energy File for IFMIF, ENDF-6 format must be selected fundamentally. MF and MT numbers in ENDF-6 format are assigned in **Table 3**. The major applications of intermediate energy nuclear data need isotope production cross section and double differential light particle, gamma-ray, meson and PKA spectra for neutron-, proton- and photo-induced reactions, fundamentally. Though it is necessary to include individual product nuclides for isotope production cross sections, it seems that composite particle spectra, which are not identified the emitted reaction and summing up the same particle from all the reaction channels, might be enough to use for each application. It is no meaning to separate the energy region in consideration of format.

For conservation of consistency, some rules should be promised inside the format, for instance, sum rule. The evaluation information and comments are included in MF=1. If fission reaction channel is included, the fission-related quantities, for example, fission neutron spectra (MF=5, MT=18), average prompt neutron number (MF=1, MT=452,455,456), fission product distribution (MF=6, MT=18), etc., should be compiled. For sum rule, 1) (MF=3, MT=1) = (MF=3, MT=2) + (MF=3, MT=3), 2) (MF=3, MT=3) = (MF=3, MT=5) + (MF=3, MT=18), 3) For MF=3, MT=201, 203, 204, 205, 206 and 207, the contributions of elastic scattering, discrete inelastic scattering and fission channels are not included. For the angular distributions of elastic and discrete inelastic scattering channels, it can be compiled both in MF=4 and in MF=6, LAW=2. For fission neutron spectrum, both MF=5 and MF=6 can be used. Other detail of rules for MF=6 are listed below:

MF=6, LAW=0:	in the case of only the isotope production ratio (MT=5) to MF=3, MT=5 is included (unknown distribution).
MF=6, LAW=1:	for MT=201-207, using Legendre coefficients or Kalbach systematics.
MF=6, LAW=2:	for MT=2, 51-90 (discrete two-body scattering), using Legendre coefficients or tabular expression.
MF=6, LAW=5:	for MT=2 of charged particle (charged particle elastic scattering).
MF=6, LAW=7:	for MT=201-207, using table type format, and MT=5 in the case including the isotope production ratio to MF=3, MT=5, and the PKA spectra.

4. STATUS OF EVALUATION

Preliminary evaluations have been almost finished for neutron-induced reactions of elements listed in **Table 2** up to 50 MeV. Reviews of the results are now in progress.

For neutron-induced ^{1}H total and elastic scattering cross sections up to 1 GeV, the evaluation was performed by fitting experimental data below 500 MeV with the least squares method and by calculating from phase-shift data above 500 MeV. The evaluated result of ^{1}H total cross section is shown in **Fig. 1** with experimental data. The phase-shift data was also converted to elastic scattering angular distribution. Nucleon inelastic scattering cross sections, which are pion production cross section and so on, are also evaluated. For ^{6}Li, ^{7}Li and ^{12}C, evaluations were performed by SCINFUL/DDX[2] with considering break-up reactions. The primary knock-on atom (PKA) spectra were also calculated simultaneously. The results of light particle spectra are in good agreement with the experimental data. In **Fig. 2**, evaluated spectra for proton, deuteron and α-particle from n+^{12}C reaction is compared with the experimental data. EXIFON[3], which is a multistep statistical model code with preequilibrium process corrections of FKK theory and Iwamoto-Harada cluster particle emission, is used to evaluation for ^{14}N and ^{16}O.

For evaluation of the other elements, SINCROS-II[4] is basically adopted and modified. As the example of evaluated result with SINCROS-II the isotope production cross sections for ^{nat}Cr(n,x)^{49}Cr, ^{nat}Cr(n,x)^{52}V, ^{nat}Cu(n,x)^{61}Cu and ^{nat}Cu(n,x)^{62}Cu reactions are shown in **Figs. 3-6** with experimental data measured by Uwamino et al.[5]. The calculated results are almost in good agreement with the experimental data. Hence, other results are expected to reproduce the isotope production cross sections.

5. SUMMARY

Neutron File, Phase-I of JENDL High Energy File, is now compiling in the energy region below 50 MeV for IFMIF. The compilation will be finished in 1996. The present status of evaluation of JENDL High Energy File for IFMIF was reviewed as well as the preliminary results and format description. These files are compiled in the ENDF-6 format. In addition, the review process is newly introduced for compilation of JENDL High Energy File. The first version of IFMIF File will be released in 1997 for 21 elements, 57 isotopes, after tested.

Acknowledgements

The evaluation and review work for the JENDL High Energy File is being performed by members of Japanese Nuclear Data Committee and Nuclear Data Center of JAERI, especially done by Dr. T. Asami. The author would like to thank them.

References

[1] Noda K.; "International Fusion Material Irradiation Facility (IFMIF) Program", *Proc. 1994 Symposium on Nuclear Data, Tokai, Ibaraki, Nov. 17-18, 1994, JAERI-Conf 95-008*, p.112 (1995).

[2] Kashimoto H., et al.: "Study of the ^{12}C Breakup Process and Carbon Kerma Factor", *Proc. 1992 Symposium on Nuclear Data, Tokai, Ibaraki, Nov. 26-27, 1992, JAERI-M 93-046*, p.287 (1993).

[3] Kalka H.: "Statistical Multistep Reaction Model for Nuclear Data", *Proc. Int. Conf. on Nuclear Data for Science and Technology, Julich, May 13-17, 1991*, p.897, Springer-Verlag, Berlin, Heidelberg (1992).

[4] Yamamuro N.: "A Nuclear Cross Section Calculation System with Simplified Input-Format Version II (SINCROS-II)", *JAERI-M 90-006* (1990).

[5] Uwamino Y., Sugita H., Kondo Y. and Nakamura T.; *Nucl. Sci. Eng.*, 111, 391 (1992).

Table 1 The Outline of Evaluated High Energy Nuclear Data Files

File Name / Incident Particle / Energy Range	priority	release
JENDL High Energy File		
Phase-I (< 50 MeV)		
neutron (for IFMIF)	1	1997
proton	2	1998
Phase-II (< a few GeV, for the OMEGA Project)		
neutron	3	1999
proton	3	1999
JENDL PKA/KERMA File(< 50 MeV)		
neutron	2	1998
JENDL Photonuclear Data File(< 140 MeV)		
gamma	1	1996

Table 2 The elements to be included in the JENDL High Energy File for IFMIF.

21 elements, 57 isotopes
H, Li, C, N, O, Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Y, Mo, W

Underline: high priority

Table 3 The MF and MT Numbers Defined in ENDF-6 Format

MT	MF	quantities
1	3	total (only for neutron-induced reaction)
2	3,6	elastic scattering
3	3	total reaction
5	3,6	isotope production by spallation and evaporation processes
18	3,6	fission
51-91	3,6	discrete inelastic scattering (not always)
102	3,6	capture
103-107	3,6	(n,z) reactions
151	2	resonance information
201	3,6	neutron production
202	3,6	gamma production
203	3,6	proton production
204	3,6	deuteron production
205	3,6	triton production
206	3,6	^{3}He production
207	3,6	α production

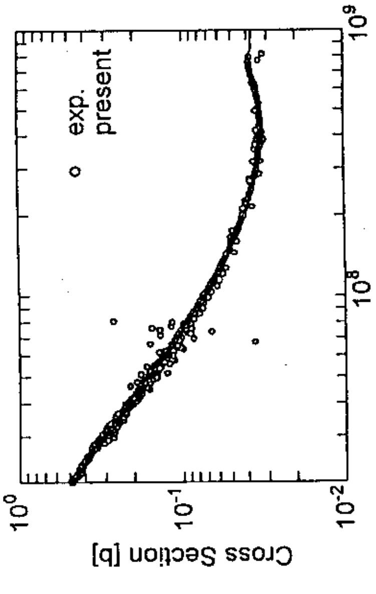


Fig.1 Neutron Total Cross Section of ^{1}H

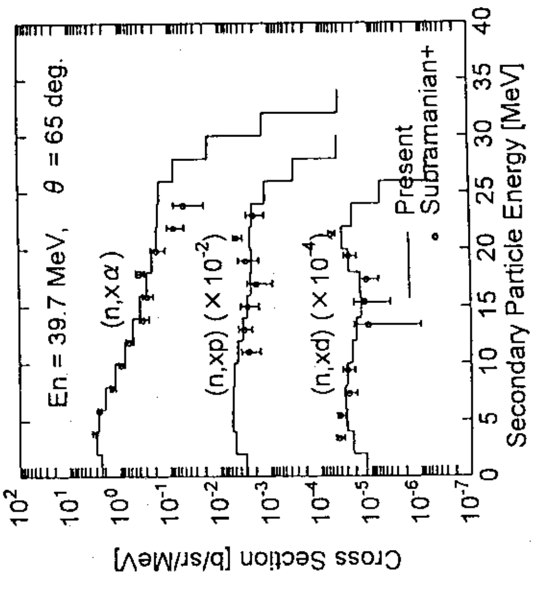


Fig.2 Double Differential Cross Section of n+^{12}C Reaction

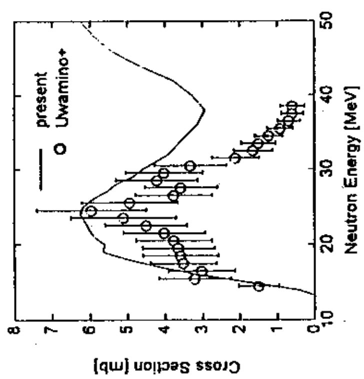


Fig.3 Cross Section of Cr-nat(n,x)Cr-49 Reaction

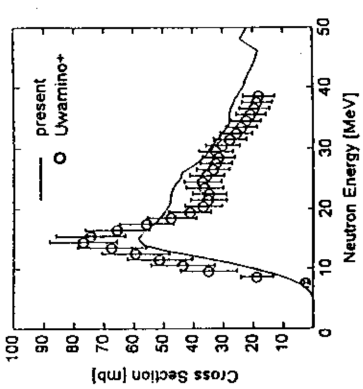


Fig.4 Cross Section of Cr-nat(n,x)V-52 Reaction

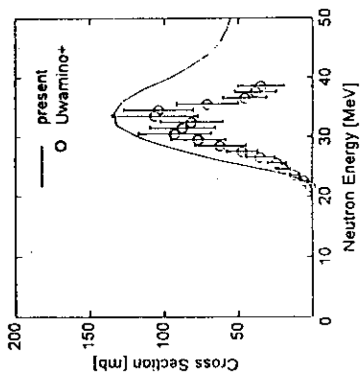


Fig.5 Cross Section of Cu-nat(n,x)Cu-61 Reaction

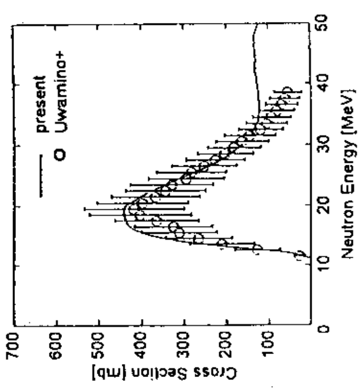
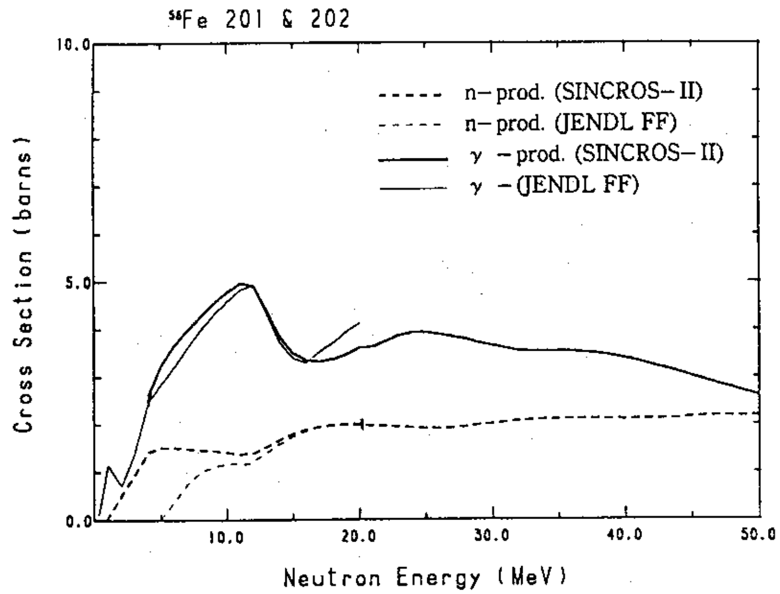
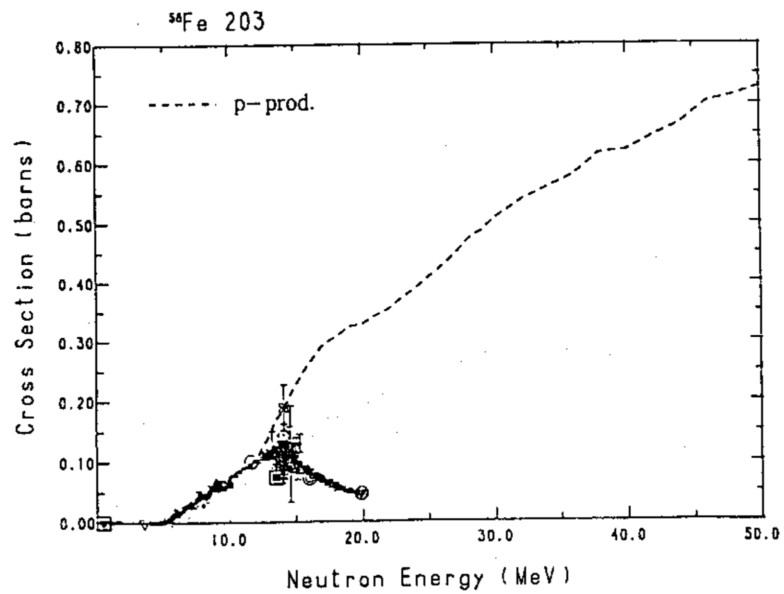


Fig.6 Cross Section of Cu-nat(n,x)Cu-62 Reaction





3 – 8

IFMIF NEUTRONICS SHIELDING CALCULATIONS

S. MONTI

Design Integration Meeting - Tokai - May 1996

Calculational Tools

Hybrid MCNP4A-MORSE code:

- MORSE code converted from Fortran 4 to Fortran77
- All Assembler parts removed
- Extensive "pruning" of MORSE
- Compatibility with MCNP

IFMIF Design Integration Workshop - Tokai - May 1996

Calculational Tools

- MORSE code combined with MCNP4A as patch file
- MCNP4A_MORSE coupled with HILO library

IFMIF Design Integration Workshop - Tokai - May 1996

Table of Appendix 1: Test on MCNP4A_MORSE; comparison with MORSE results

Tally type	MORSE	MCNP4A_MORSE group-wise	MCNP4A_MORSE point-wise (where possible)
Total n-flux	0.2314 (±0.0398)	0.2240 (±0.0338)	0.2275 (±0.0326)
n-response increasing with energy	50.55 (±0.0347)	47.87 (±0.0318)	49.15 (0.0312)
n-response decreasing with energy	17.37 (±0.0706)	19.89 (±0.0773)	18.67 (±0.0690)
Total gamma flux	0.02257 (±0.0927)	0.02369 (±0.0514)	0.03660 (±0.0600)
Gamma response increasing with energy	0.05350 (±0.1480)	0.05971 (±0.0704)	0.08622 (±0.0715)
Gamma response decreasing with energy	0.5015 (±0.1037)	0.5207 (±0.0550)	0.8049 (±0.0662)

Calculational Tools

Two versions of the code are available:

- Multigroup (66 neutrons, 22 photon groups) HILO library in the whole energy range
- HILO library above 20 MeV and point-wise MCNP treatment below 20 MeV

Is the IFMIF data file for MCNP calculations already available?

IFMIF Design Integration Workshop - Tokai - May 1996

Calculational Tools

Neutron induced activation calculations performed with FISPACT code and EAF4.1 cross section library

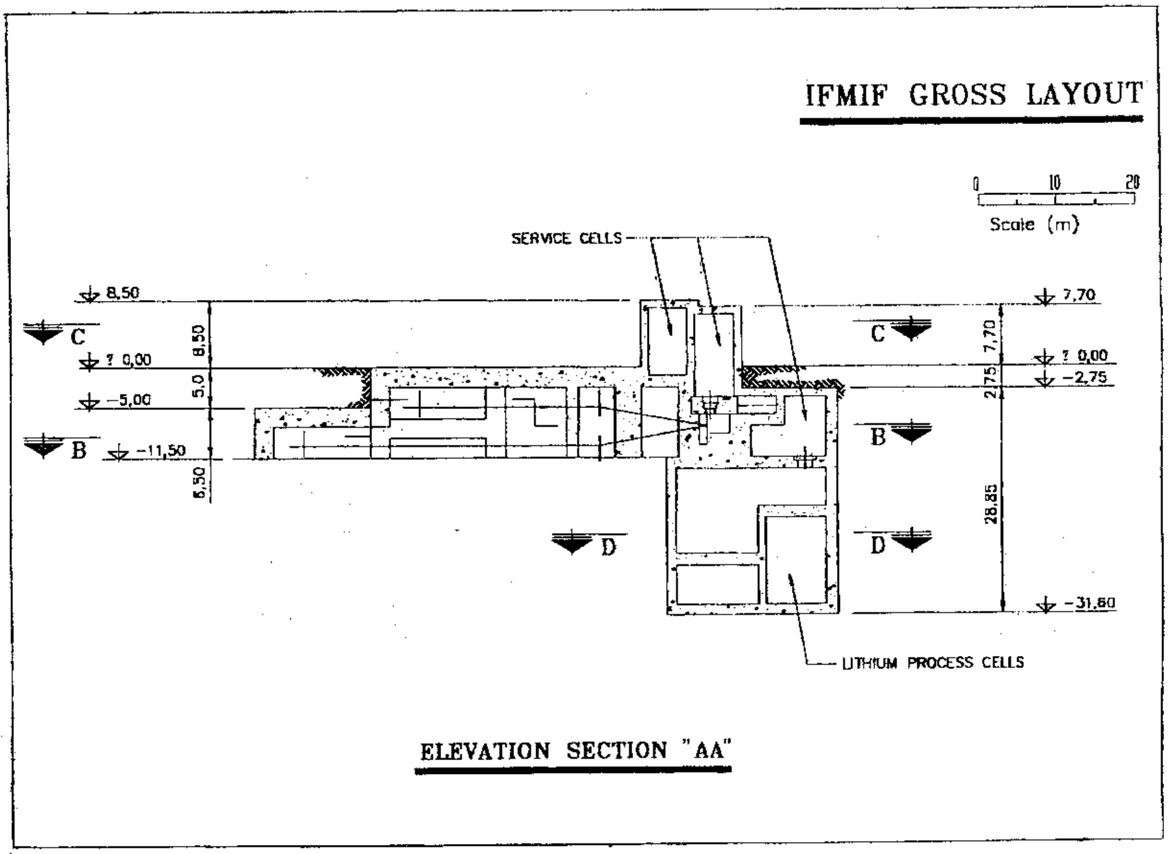
Only data from thermal to 20 MeV are available

IFMIF Design Integration Workshop - Tokai - May 1996

Test Cell Geometry Model

- Test Cell geometry, materials and dimensions as reported in IFMIF Interim Report
- Personnel accessibility during operation only at second floor
- MCNP4A Geometry Model with SABRINA code

IFMIF Design Integration Workshop - Tokai - May 1996



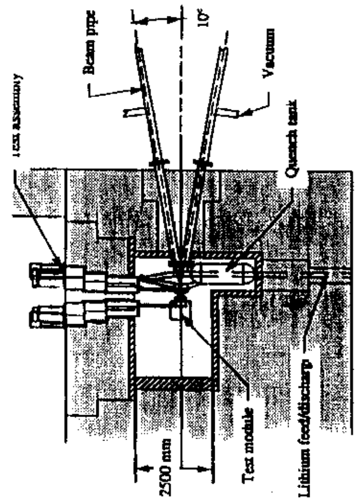


Fig. 12 - Elevation section view of Test Cell.

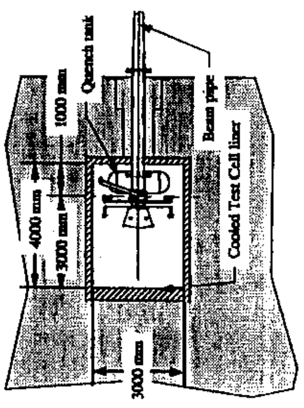
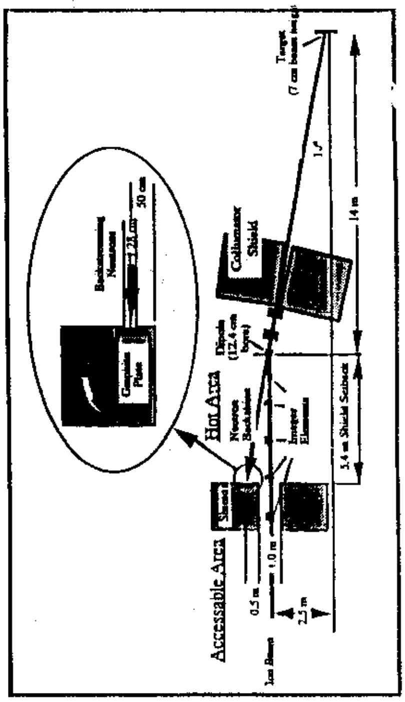
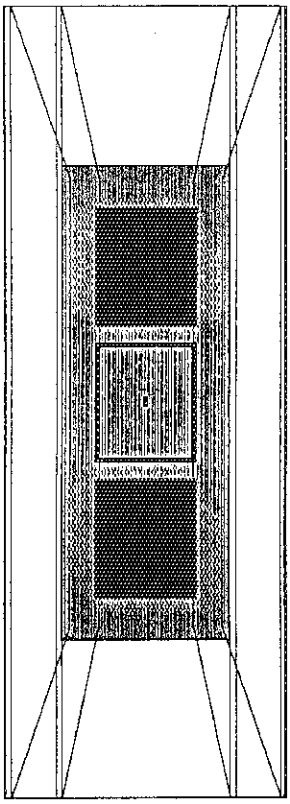
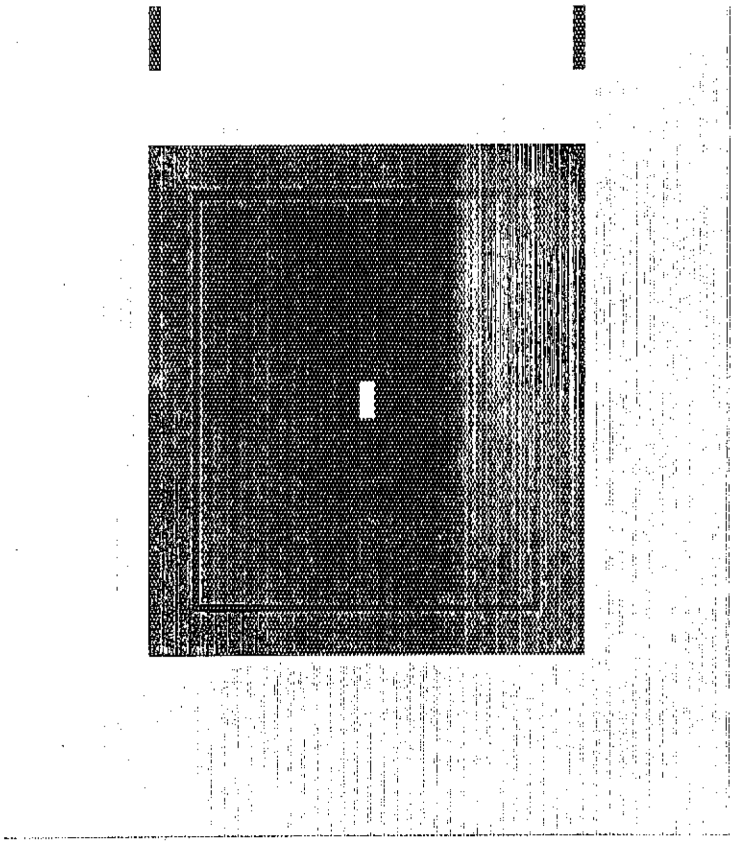
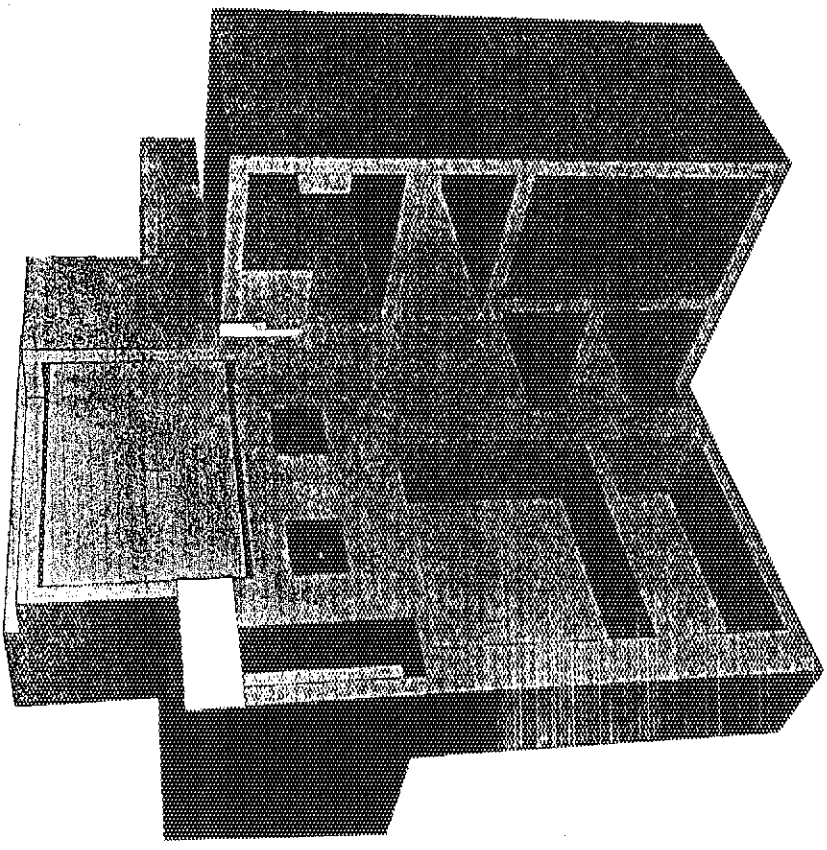


Fig. 13 - Plan section view of Test Cell.









Test Cell Source Term

- ◆ Two primary 40 MeV deuteron beams of 125 mA at 10 degrees on Li-target
- ◆ Neutron distribution in 22 Energy bins, 30 azimuthal bins, 26 polar bins (Oyama)
- ◆ Suitable source routine to randomly sample the neutron distribution in energy, polar and azimuthal angle
- ◆ Source volume of 20x5x2.2 cc

IFMIF Design Integration Workshop - Tokai - May 1996

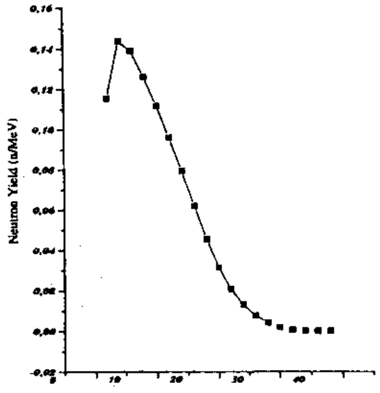


Fig. 8: Neutron energy spectrum for 35 MeV deuteron beam

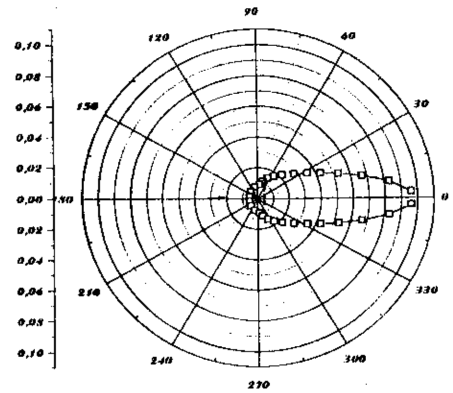
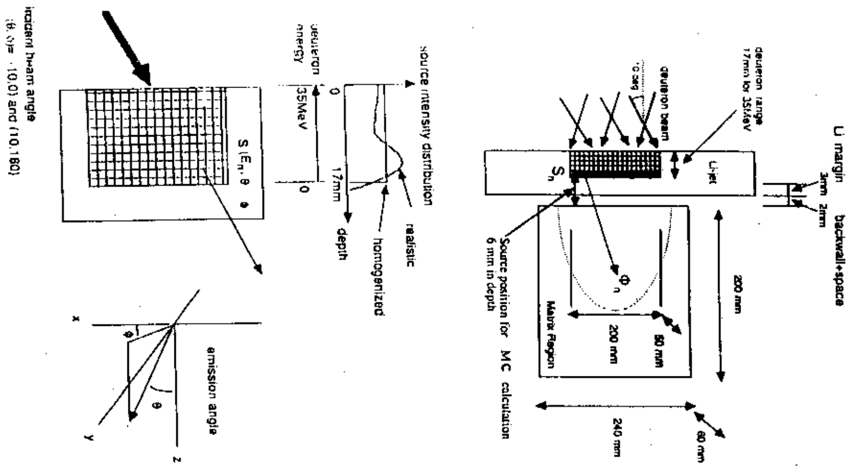


Fig. 9 - Neutron polar distribution vs. azimuthal angle phi

Other Input Data

- ◆ According to ICRP60: 20mSv per year (10 μSv/hr for 2000 hr/yr)
- ◆ Fluence-to-personal dose equivalent conversion factors by Siebert (new ICRU stopping power) with log-log Lagrange interpolation

IFMIF Design Integration Workshop - Tokai - May 1996



Because of deep penetration of neutrons in the concrete structures and, consequently, the high attenuation factor of neutron flux, importance sampling biasing (Russian Roulette/splitting) at boundary crossing of different regions was applied. The neutron fluence was scored on boundary crossing detectors placed on the cold side of shielding structures. The position of the detectors is shown in figs. 1, 5 and 6 correspondingly to the notation in table 4.

Table 4 summarizes the results of the calculations. Particularly, all the equivalent dose rates are provided in the zone of maximum dose on the external (cold) surface of the test cell structures (walls, ceiling and floor), which also represent the shields of the test cell. Also the equivalent dose rate in the accessible area closed to the Hot Cells is given at position 5 of fig. 1.

All the equivalent dose rates were obtained multipling the fluxes for each energy group as calculated by FLUKA, by the fluence-to-dose equivalent conversion factors for each energy group, given in table 3.

Table 4. Equivalent dose rates (µSv/h) on the cold side of Test Cell and concrete shield thicknesses assumed. Test assembly of half density iron.

Position	Shielding structure	Thickness (cm)	Equivalent Dose Rate (µSv/h)
1	Test Cell 1 Frontal Wall	150	3.4E+6 (±0.022)
2	Test Cell 1 Lateral Wall	250	1.2
3	Test Cell 1 Ceiling	200	5.6E+3 (±0.089)
4	Test Cell 1 Floor	200	5.5E+3 (±0.091)
5	Hot Cell Frontal Wall	150 +50 +50	11.4 (±0.21)

It must be pointed out that position 1 is not accessible during operation. The dose rate at this location may be of some interest with respect to the expected dose on the equipment in the cells adiacent to the lithium target & test cells. Particularly, this dose should be small enough to allow the use of organic seal, lubricating and insulating materials.

The same simulations were repeated for position 1 without test assembly (i.e. putting air instead of half density iron in the matrix region): in such a case the equivalent dose rate on the cold side of test cell frontal wall increases of more than a

15

DTL & HEBT Activation:
extrapolation from FMIT shielding design

FMIT deuteron losses in CW operation:

- ◆ 3 µA/m along the DTL and the straight sections of the HEBT
- ◆ 10 µA (point loss) at each bending magnets and the final three focusing magnets

Direct activation from deuterons and activation from neutrons generated when deuterons strike the beam tube

IFMIF Design Integration Workshop - Tokai - May 1996

DTL & HEBT Activation: Extrapolation from FMIT Shielding Design

Table 2

Dose Rate (mSv/hr) from Deuteron and Neutron Activation of Beam Tube as a Function of Decay Time

- 40 MeV Deuterons
- 20 yr irradiation
- 3 µamp/m
- 30 cm from beam tube
- no shielding

DECAY TIME / MATERIALS	1 hr		8 hr		16 hr		1 Wk	
	d	n	d	n	d	n	d	n
Fe	230	2.4	120	1.4	98	1.2	63	1.1
Al	150	7.1	75	4.9	52	3.4	0.1	0.003
Au	8		7.5		7		3	

Note: $\Phi_n^{Fe} = 3.1\times10^7$ n/cm^2 - sec
$\Phi_n^{Al} = 6.2\times10^7$ n/cm^2 - sec
Because of lack of data, the same neutron spectrum on lithium was assumed

DTL & HEBT Activation:
extrapolation from FMIT shielding design

- ◆ For the next generation of RF Linacs the beam loss goal is: **3 nA/m** and order of few nA point loss in bending magnets
- ◆ If this goal will be achieved, maximum dose due to activation is 0.1-0.5 mSv/hr depending on materials and decay time
- ◆ An occupancy factor of about 100 hr/yr allows the respect of 20 mSv/yr

IFMIF Design Integration Workshop - Tokai - May 1996

DTL & HEBT Activation: Extrapolation from FMIT Shielding Design

Table 1
Dose Rate (mSv/hr) from Deuteron and Neutron Activation in a Bending Magnet as a Function of Decay Time

- 40 MeV Deuterons
- 20 yr irradiation
- 10 µamp
- 30 cm from loss point
- no shielding

DECAY TIME / MATERIALS	1 hr		8 hr		16 hr		1 Wk	
	d	n	d	n	d	n	d	n
Fe	870	1.4	450	0.5	370	0.4	240	0.35
Al	580		290		200		4.5	
Au	30		28		27		11	
Cu		0.9		0.8		0.76		0.63

Note: Because of lack of data, the same neutron spectrum on lithium was assumed

Proposed activities for the IFMIF Engineering Validation Phase

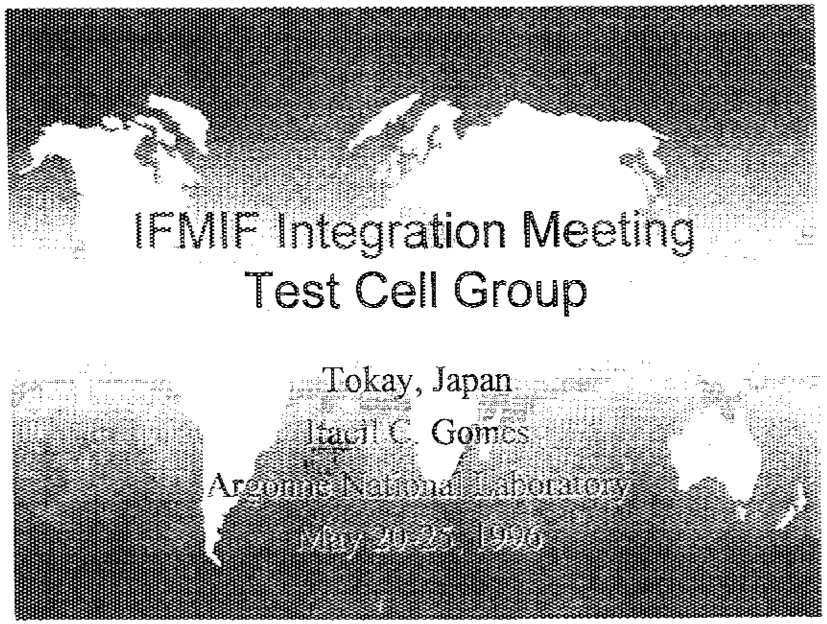
- Windows, penetrations, ducts and mazes
- NaK coolant activation
- Lithium System Shielding (corrosion products plateout)
- LINAC cooling water activation
- Service and Hot Cells Shielding (Activation of Test modules, etc.)

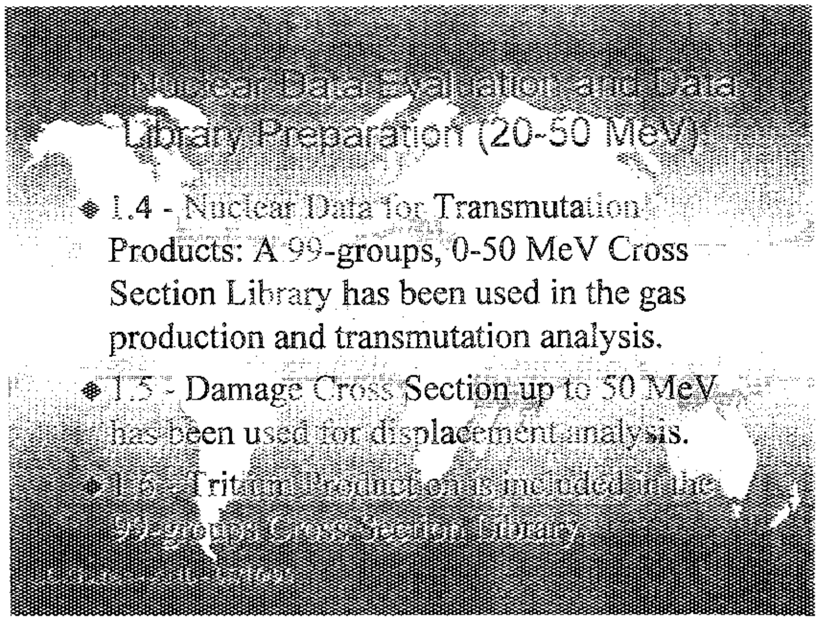
IFMIF Design Integration Workshop - Tokai - May 1996

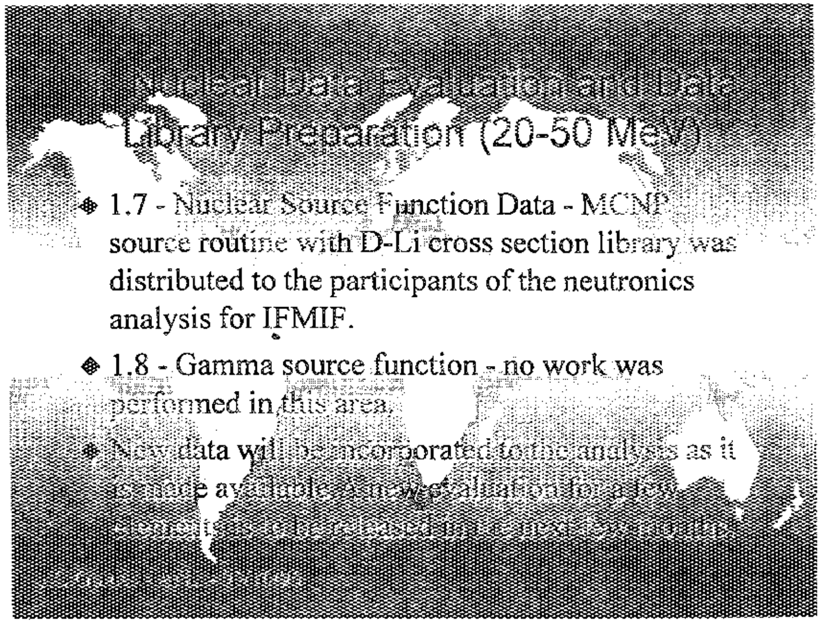
RFQ & LEBT Activation:
extrapolation from FMIT shielding design

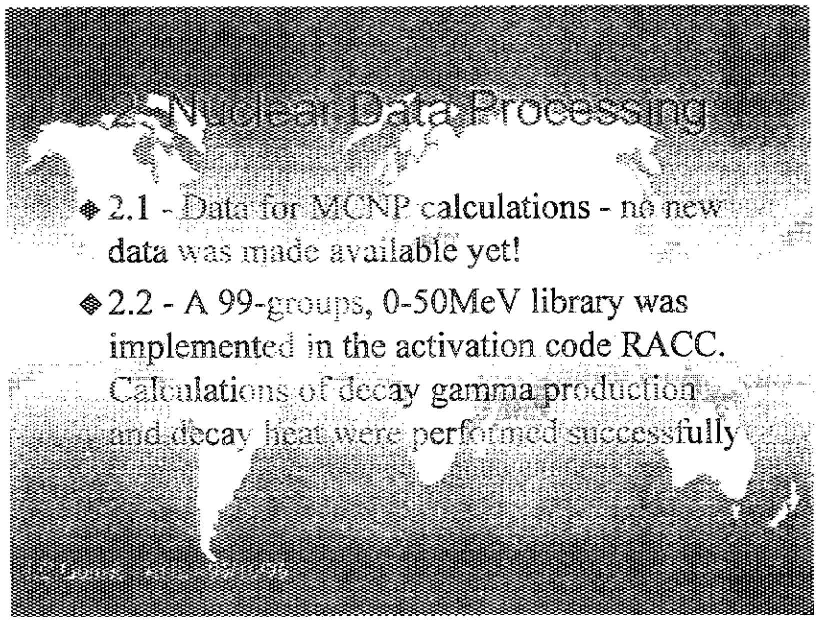
- Losses much greater in magnitude (neutron source of the order of 10^{10} n/s) but deuteron energy much lower (0.1-2 MeV)
- Neutrons streaming back from the high energy end of the LINAC will be probably the dominant source

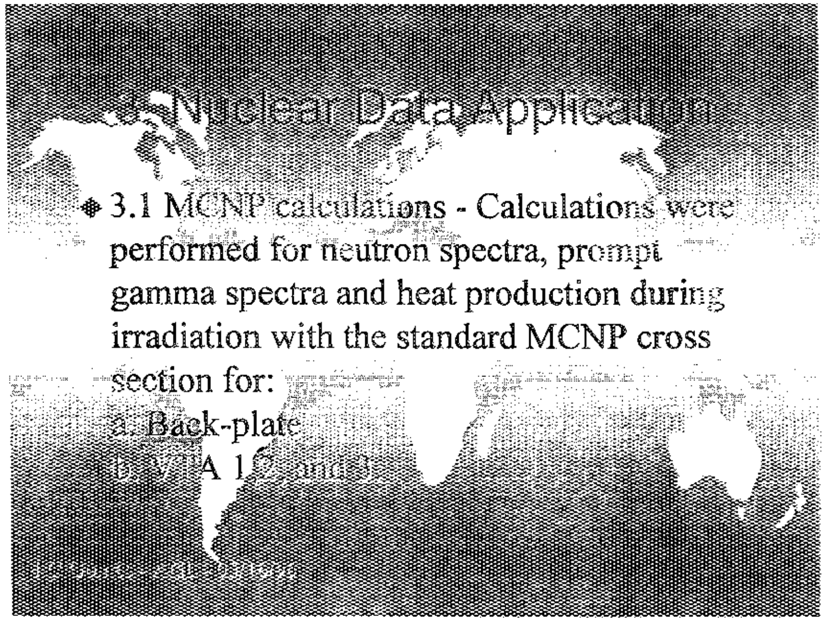
IFMIF Design Integration Workshop - Tokai - May 1996

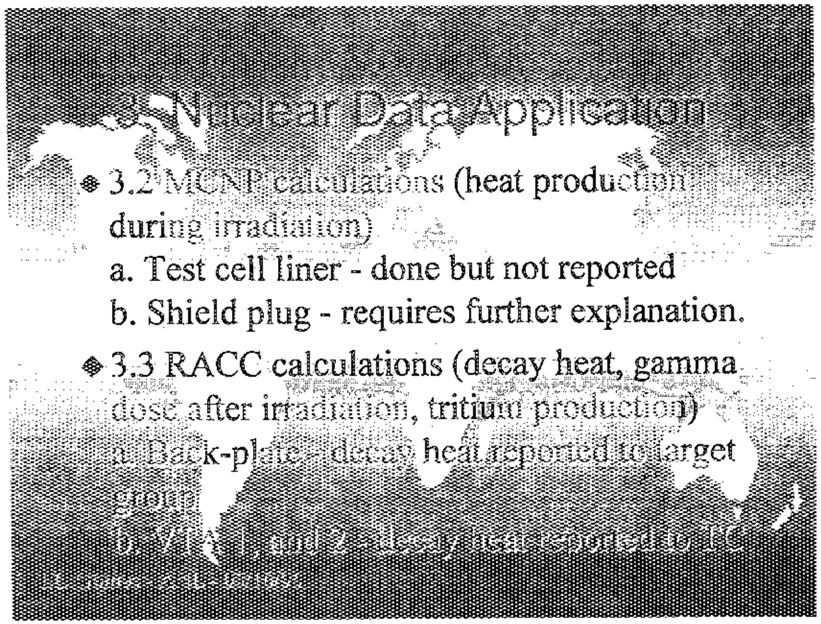


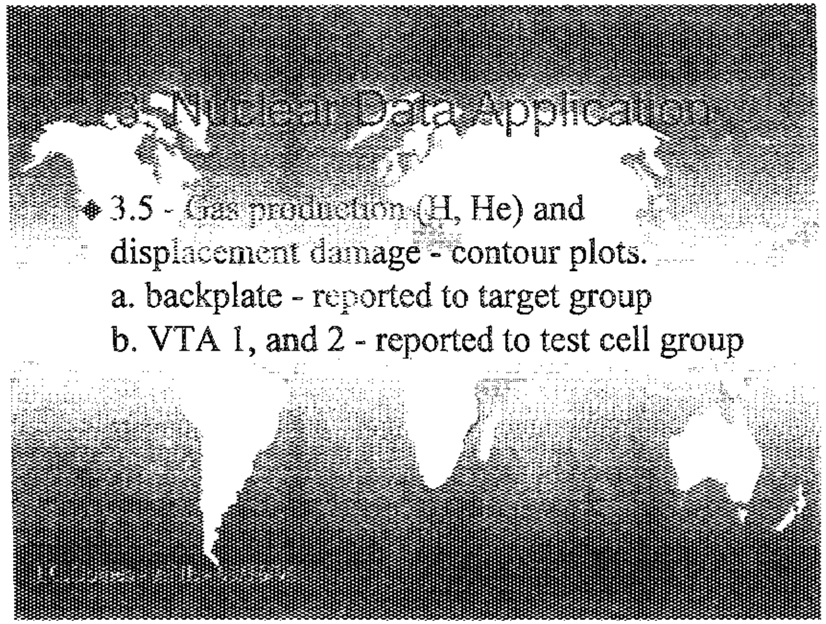

1. Nuclear Data Evaluation and Data Library Preparation (20-50 MeV)
1.4 - Nuclear Data for Transmutation Products: A 99-groups, 0-50 MeV Cross Section Library has been used in the gas production and transmutation analysis.
1.5 - Damage Cross Section up to 50 MeV has been used for displacement analysis.
1.6 - Tritium Production is included in the 99-groups Cross Section Library.


Nuclear Data Evaluation and Data Library Preparation (20-50 MeV)
1.7 - Nuclear Source Function Data - MCNP source routine with D-Li cross section library was distributed to the participants of the neutronics analysis for IFMIF.
1.8 - Gamma source function - no work was performed in this area.
New data will be incorporated to the analysis as it


2. Nuclear Data Processing
2.1 - Data for MCNP calculations - no new data was made available yet!
2.2 - A 99-groups, 0-50MeV library was implemented in the activation code RACC. Calculations of decay gamma production and decay heat were performed successfully


3. Nuclear Data Application
3.1 MCNP calculations - Calculations were performed for neutron spectra, prompt gamma spectra and heat production during irradiation with the standard MCNP cross section for:
a. Back-plate





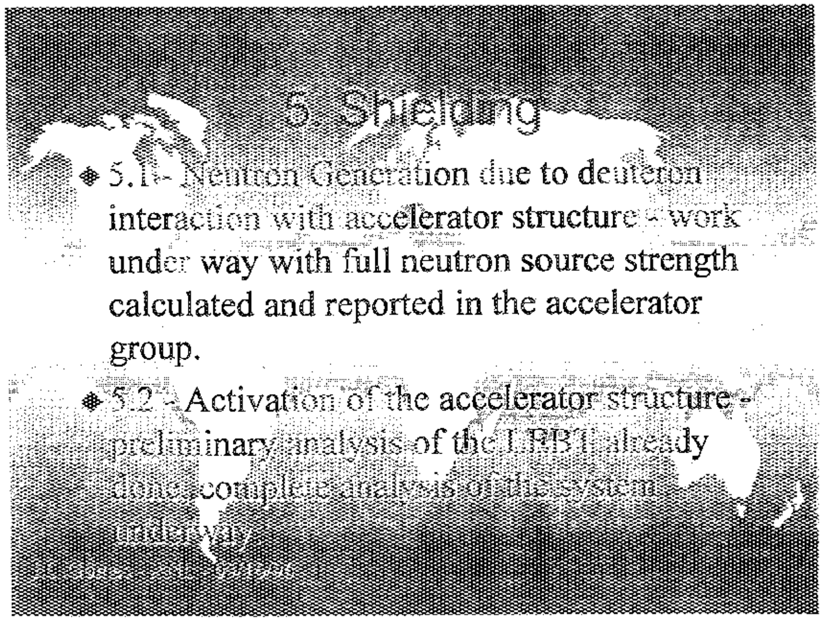


Fig.1 - Decay Heat in the High Flux Region for SS-304 - 0<x<0.5cm.

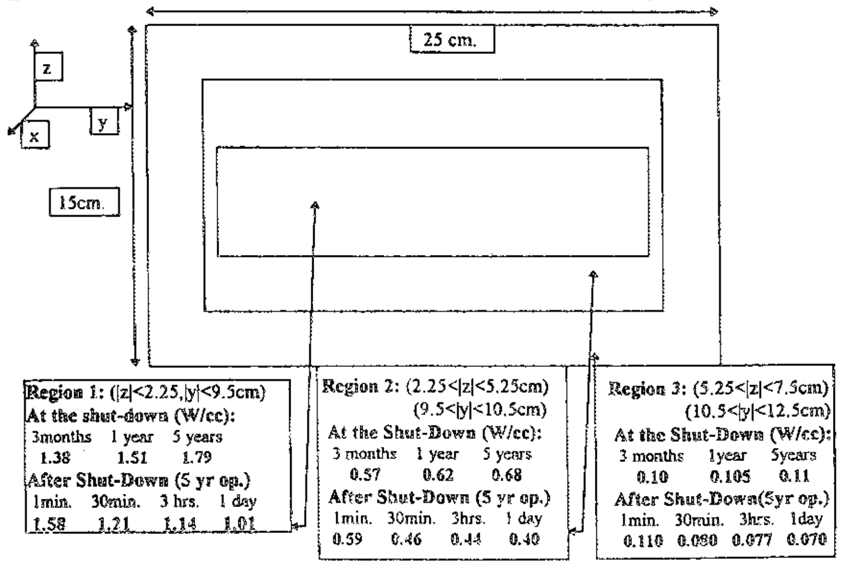
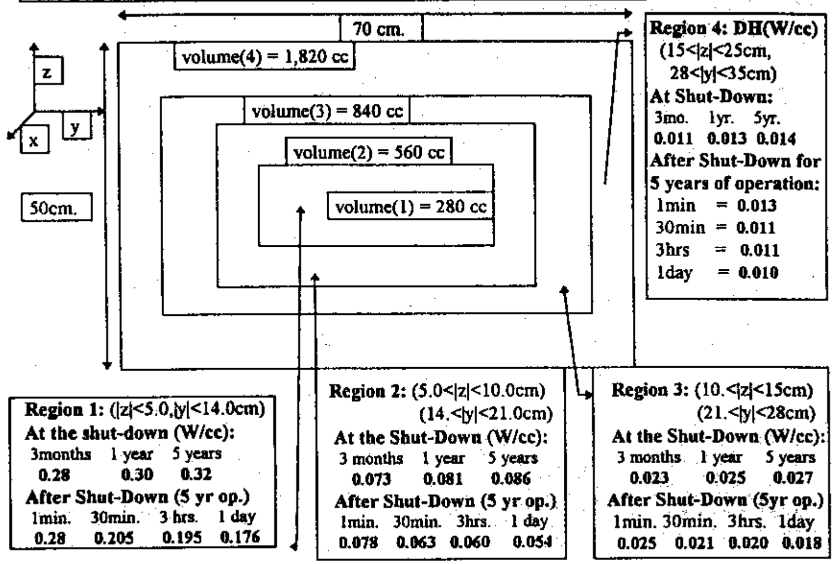
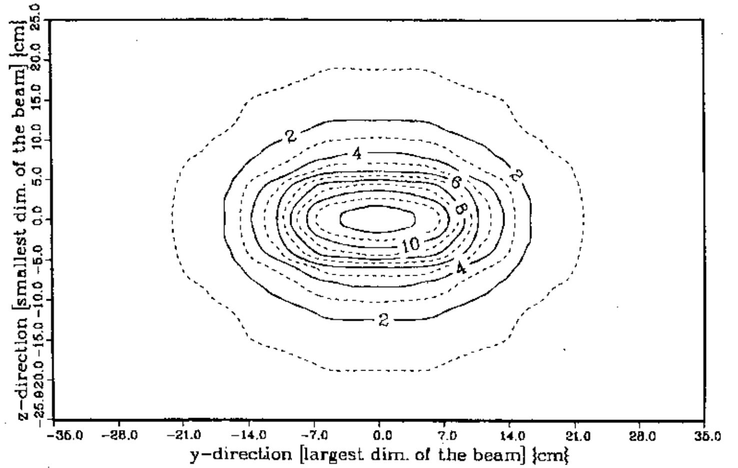


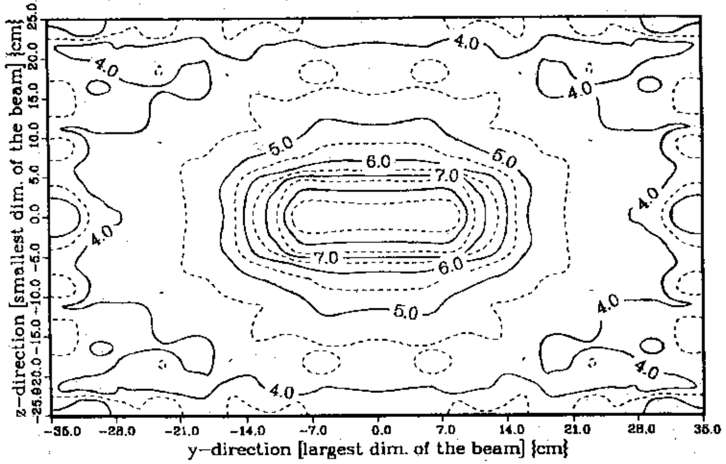
Fig.1 - Decay Heat in the Medium Flux Region - 5<x<6.0 cm.



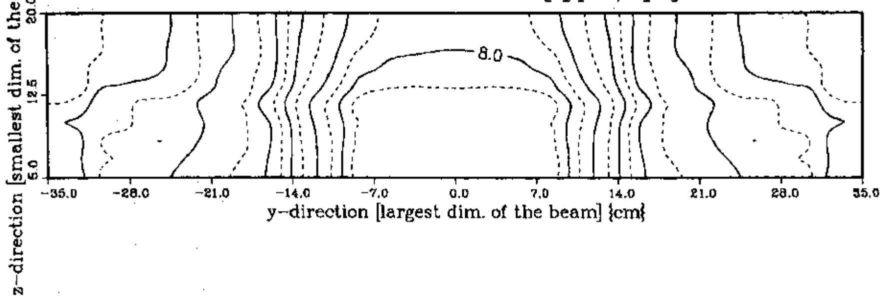
Contour Plot for Total Nuclear Heating [W/cc] X = 5.5000c

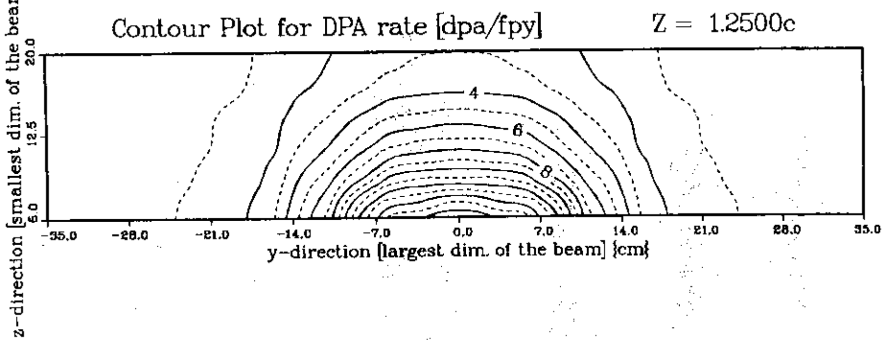


Contour Plot for Helium to DPA Ratio [appm/dpa] X = 5.5000c



Contour Plot for Helium to DPA Ratio [appm/dpa] Z = 1.2500c





A report about the presentations and the discussion relevant to IFMIF at the meeting on SSTT

DI meeting, May 1996, JAERI

S. Jitsukawa

IEA meeting on small specimen test technology (IEA/SSTT) held in Sendai Japan from 14 th to 16 th March '96.

Participants
EU: M. Victoria, P. Jung, ---, U. S. A: G.E. Lucas, M.L. Hamilton, ---
Japan: T. Kondo, S. Ishino, K. Abe (Chairman), ---

Presentations about IFMIF and IFMIF small size specimens

Following presentations relevant to IFMIF were made at the meeting.

1. T. Kondo, "Overview of IFMIF program"
- About the progress of IFMIF CDA and introductions of IFMIF.

2. S. Jitsukawa, A. Moeslang and S. J. Zinkle,
"Capability of the Irradiation Experiment with IFMIF"
- Test assemblies, test modules, small specimens and test matrix

3. P. Jung, A. Hishinuma, G. E. Lucas and H. Ullmaier,
"Review of Recommendation of Miniaturized Techniques for Mechanical Testing of Fusion Materials in an Intense Neutron Source"
- Small specimens for IFMIF (tensile, fatigue fracture toughness, m-CVN, punch, hardeness, and other test methods)

Comments from S. Zinkle, G.E. Lucas and S. Jitsukawa

"Questions from the members of IFMIF user's group" (Questions/Key issues)

1. Is the geometry of miniaturized specimen established?

2. How do you think the difference (not large) between SSTTs proposed by IEA/SSTT and IFMIF.

3. Key issues

- What data do we need to generate?

- Should the materials scientists continue to use Charpy type tests?

- Is it possible to use bend bar specimens to evaluate static and dynamic fracture toughness?

- Is it necessary to include both DCT and bend bar specimens in the IFMIF?

- Is it preferable to prepare another set of SSTT for composites?"

Comparison of SSTTs from IFMIF test cell/users group and IEA/SSTT

- There existed significant differences for DCT and fatigue specimens.

Tensile IEA/SSTT proposed smaller specimen
Not very effective for space saving

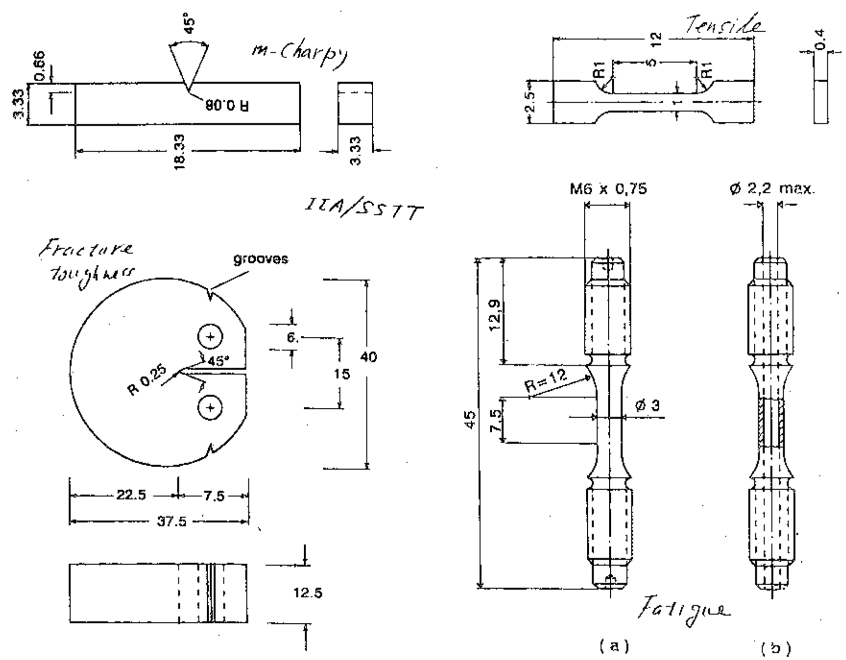
Creep (pressurized tube) IEA/SSTT proposed larger but conventional one
5 times as large as (in vol.), but not very effective for irradiation volume

Fatigue IEA/SSTT proposed larger specimen (Identical to in situ C-F)
Need to establish tests with smaller specimen with straight cross section

Fracture toughness IEA/SSTT 30 times as large as that of IFMIF

Crack propagation IEA/SSTT 30 times as large as that of IFMIF

m-Charpy (impact test) No difference



Discussion 1 (Key notes)

Prof. T. Kondo encouraged to make recommendations to IFMIF not only on specimen but also from the materials scientist's point of view.

Prof. G.E. Lucas indicated IFMIF should be used for the verification of the model for irradiation damage (e.g., Model relates fracture of specimen/component; Model of cascade damage; Model relates microstructure and mechanical properties).

S. Jitsukawa: (i) IFMIF: materials irradiation database,
(ii) further needs for specimen miniaturization (fracture toughness, m-Charpy and pressurized tube),
(iii) in situ test development (no proposal from IEA/SSTT),
(iv) SSTT for composites,
(v) Reconsideration of test matrix

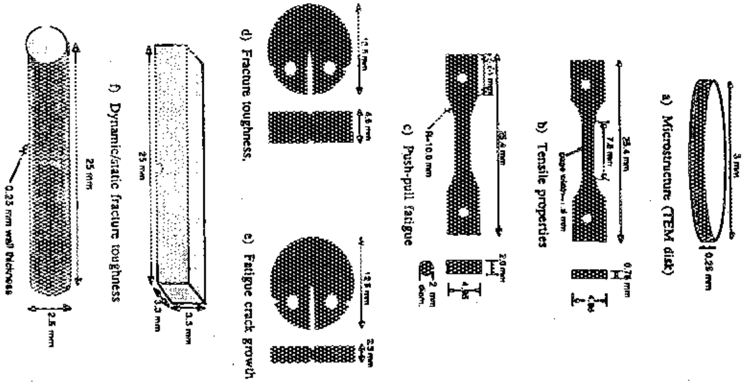


Fig. 2.2.4-1. Summary of proposed specimen geometries for mechanical and physical property tests on specimens irradiated in the high flux region of IFMIF.

2.2 Page 8

Discussion 2 (cont.)

1. Importance of DBTT evaluation (A. Kimura, M. Victoria, M. Eto, ---)

2. Use of IFMIF (model verification?)

3. Pressurized tubes (test method, verification of specimen fabrication)

4. It was proposed to prepare Working Groups for several important subjects (replacement of m-Charpy with fracture toughness specimen, miniaturization and verification of fracture toughness specimen, What data do we need to generate?; what data are useful for evaluate structural integrity?

Working Groups (How do we work together with IEA/SSTT?)

1. Tensile test (Round robin test); IEA/SSTT

2. Creep test (Reexamination of test method; IEA/SSTT, Verification of specimen fabrication; IFMIF?)

3. Push-pull fatigue (Verification + round robin test); IEA/SSTT?

4. Fracture toughness (Verification relation between SSTT and component, including the need of DBTT measurement); IEA/SSTT + IFMIF

5. Database/structural integrity; IFMIF (cooperation with SSTT and design)

- Some (2, 4 and 5) may be treated in EVP

Forschungszentrum Karlsruhe
Technik und Umwelt

Neutronics Calculations for IFMIF High Flux Test Module VTA-1

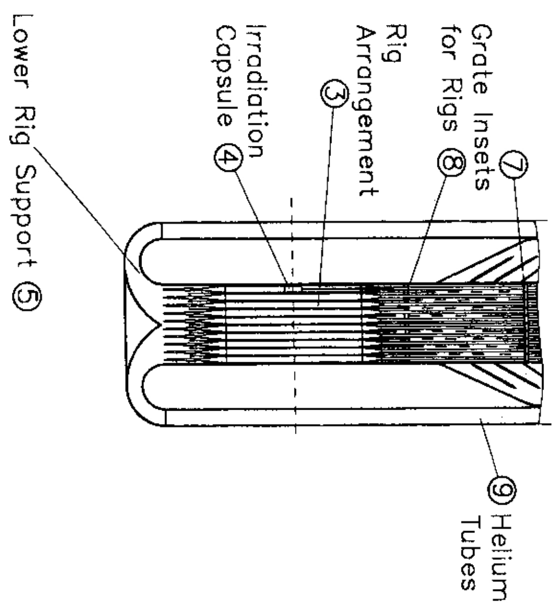
P. Wilson, U. Fischer, A. Möslang

Design Integration Workshop, May 1996, JAERI, Japan

- First results will be given on detailed neutron transport calculations.
- Comprehensively evaluated neutron data ($E_n < 50$ MeV) using state-of-the-art theoretical modelling have been processed.
- MCNP calculations were done for the helium cooled VTA-1 using realistic irradiation rig and coolant distributions.

IFMIF - Testfacilities

Design Integration Workshop, May 20-24, 1996, JAERI, Japan



Volume considerations

Typical volume fractions within the rigs:

	A	B	C
Helium for gas gaps	23%	26%	36%
rig and capsule	35%	37%	38%
specimens	42%	37%	26%

Because both the rigs and capsules will likely consist of materials very similar to the specimens itself, the following volume fractions for the neutron scattering can beused:

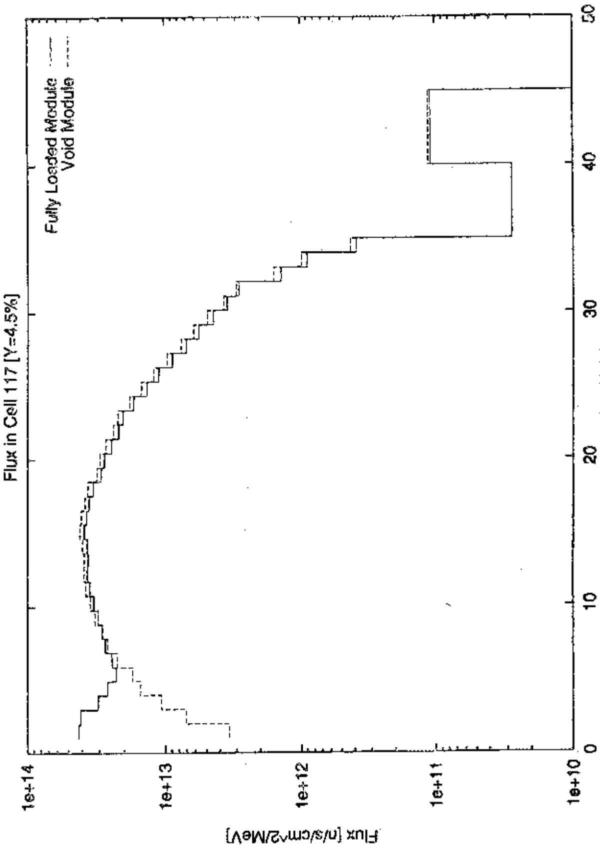
A: 77% structural material 23% void
B: 74% structural material 26% void
C: 64% structural material 36% void

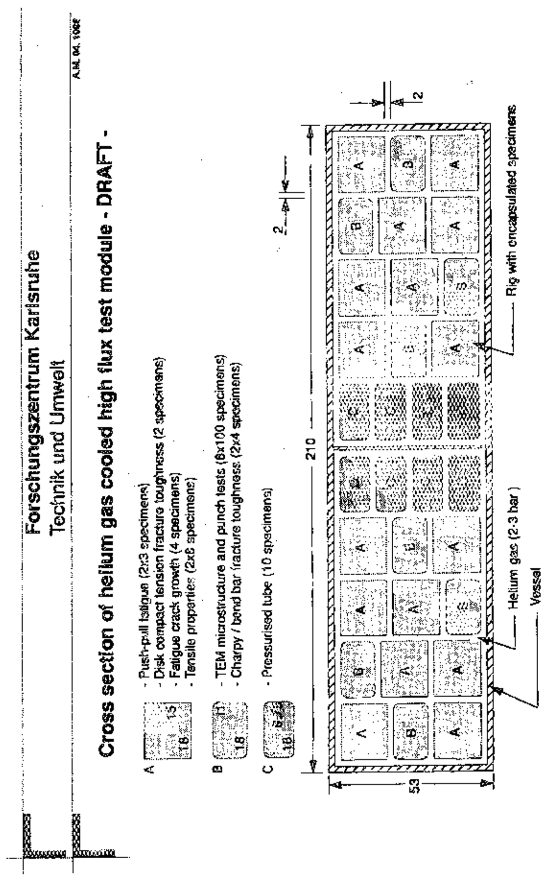
Volume fractions within the high flux volume:

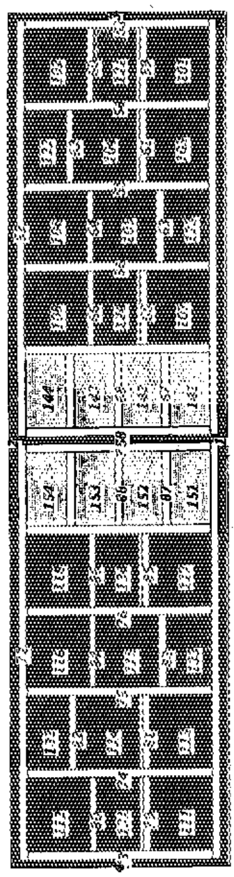
8 rigs for A : 39% of total vessel volume
8 rigs for B: 14% of total vessel volume
8 rigs for C: 12% of total vessel volume
Vessel structure: 10% of total vessel volume
He gas coolant: 25% of total vessel volume

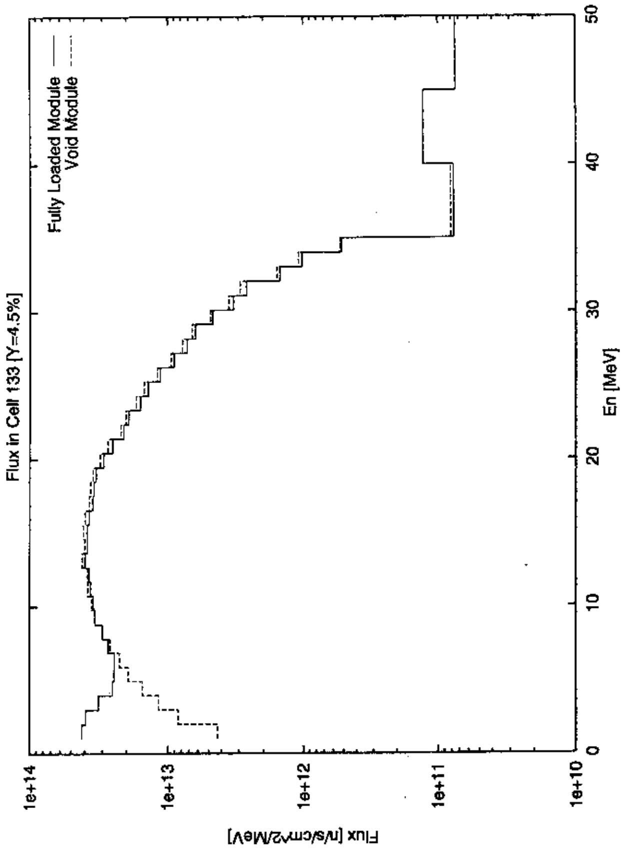
Therefore, the following averaged volume fractions can be considered as typical for the high flux test module:

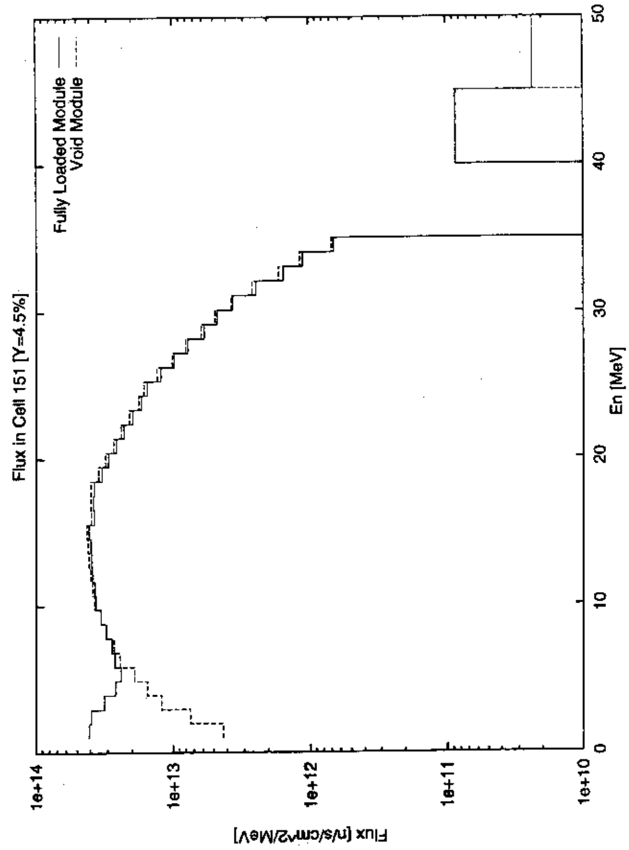
	Volume fraction
He-gas (coolant and gas gaps)	42 %
Material (specimens, rigs, capsules, vessel)	58 %

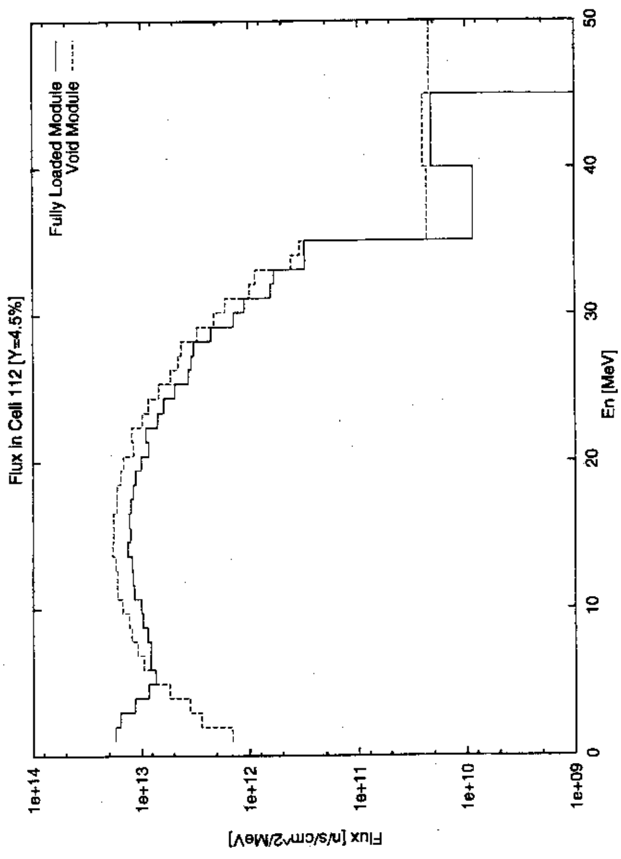


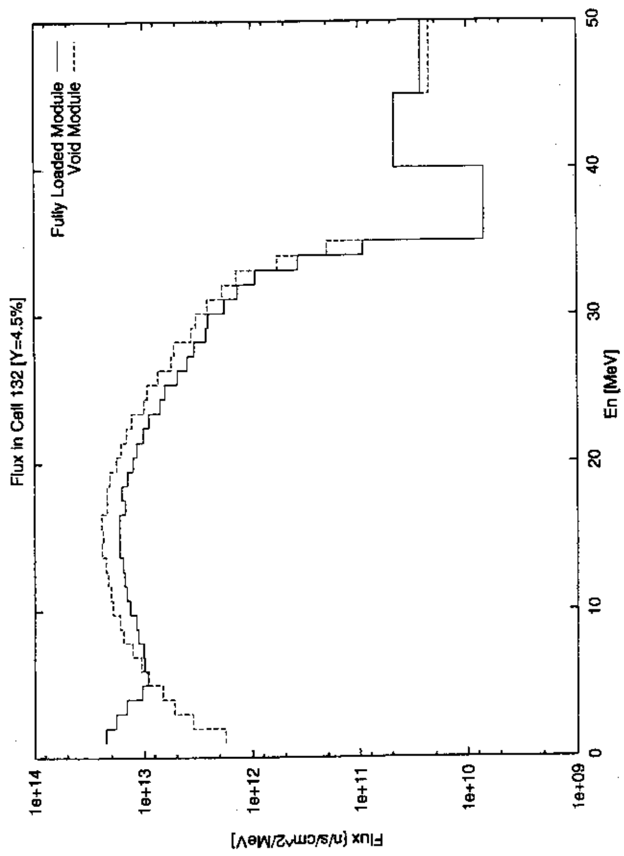


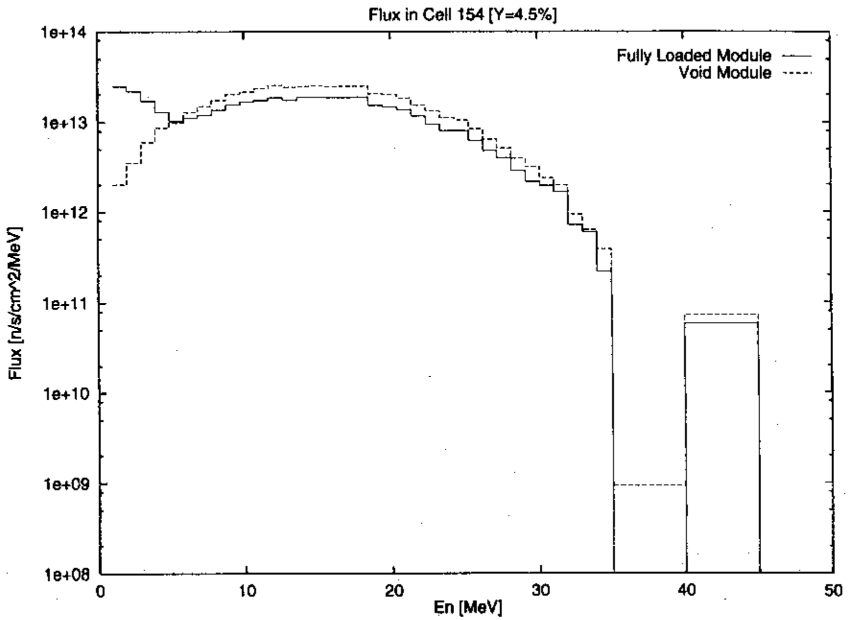


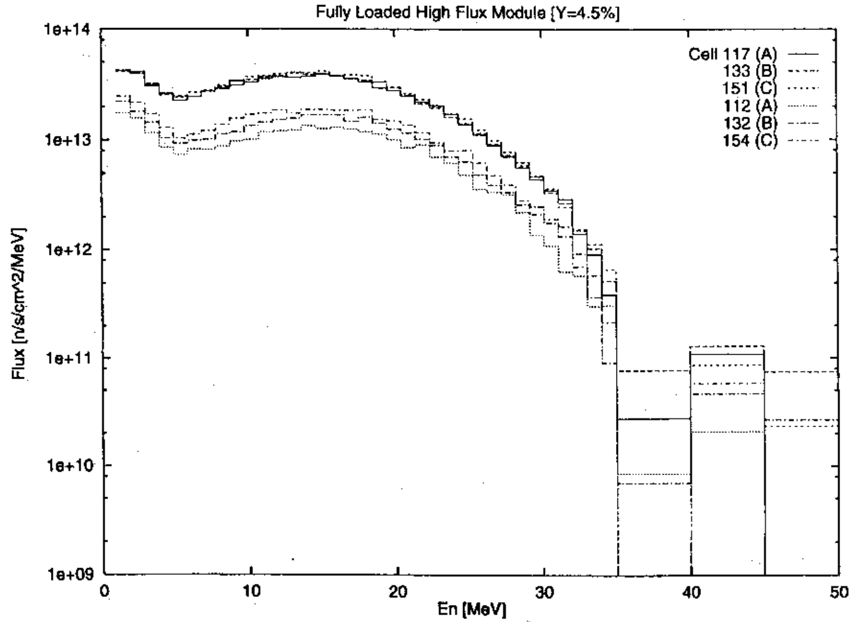

Flux in Cell 133 [Y=4.5%]
Fully Loaded Module
Void Module
En [MeV]
Flux [n/s/cm^2/MeV]


Flux in Cell 151 [Y=4.5%]
Fully Loaded Module
Void Module
En [MeV]
Flux [n/s/cm^2/MeV]


Flux in Cell 112 [Y=4.5%]
Fully Loaded Module
Void Module
En [MeV]
Flux [n/s/cm^2/MeV]


Flux in Cell 132 [Y=4.5%]
Fully Loaded Module
Void Module
En [MeV]
Flux [n/s/cm^2/MeV]





Summary to date: May 15, 1996

Cell/Type	Loading	$\phi_{tot}[\times 10^{14} n/s/cm^2]$	$\phi_{(E>20MeV)}/\phi_{tot}$
112/A	void	3.21	0.21
	full	2.78	0.17
117/A	void	7.24	0.20
	full	7.95	0.17
132/B	void	4.13	0.21
	full	3.49	0.17
133/B	void	7.38	0.19
	full	8.15	0.16
151/C	void	7.59	0.19
	full	8.40	0.16
154/C	void	4.55	0.21
	full	4.08	0.17

Appendix-5.2 Documents Presented at Accelerator Group Meeting

Table of Contents

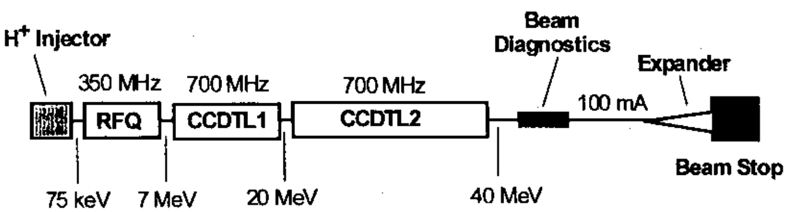
IFMIF
may 1996

FERDINAND Robin

CEA-DSM-GECA

- Los Alamos dc Proton Injector Program (J. SHERMAN)
- The SACLAY source : SILHI

CW Linear Accelerator Proposal



- 75-keV, 110-mA Proton Injector (dc)
- 7-MeV Radio-Frequency Quadrupole, RFQ (350 MHz)
- Coupled-Cavity Drift-Tube Linac, CCDTL (700 MHz)

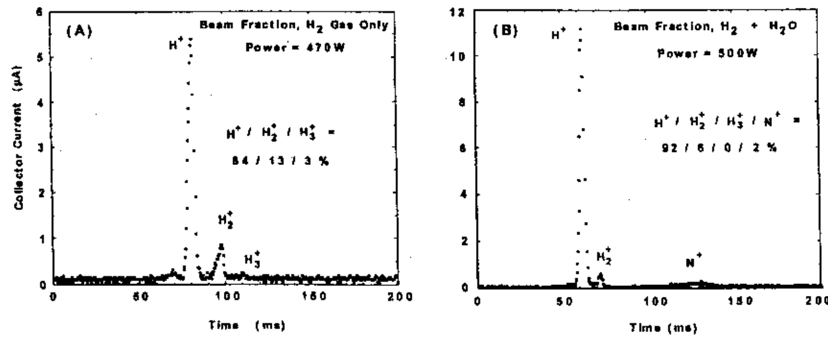
Los Alamos

Los Alamos dc Proton Injector Program

- Initiated at LANL in May, 1993 when Chalk River Laboratories dc microwave proton source and 50 keV dc injector were moved to Los Alamos. (CRITS.)
- 75 keV injector is now being tested at Los Alamos for a 100 mA, 8 meter long, 6.8 MeV radio frequency quadrupole (RFQ).
- The injector has recently demonstrated RFQ input beam requirements: >110 mA dc proton beam with 0.20 π.mm.mrad rms normalized emittance.
- The project is now focused on increasing the injector reliability, and development of the low-energy beam transport system.

Los Alamos

Proton Beam Fraction Enhancement from the Microwave Source*

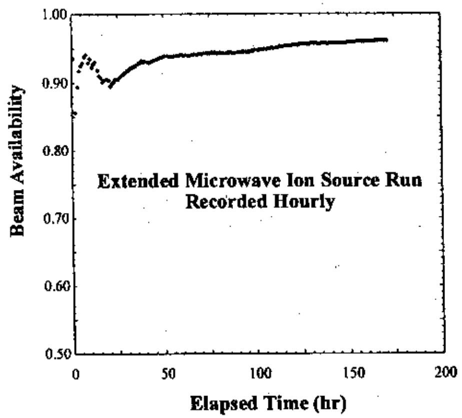


(A) Pure H_2 gas discharge, (B) H_2 plus 1% H_2O in discharge (CRITS test stand)

*Presented at ICIS95, Whistler, B.C., Dave Spence, et. al.,

Los Alamos

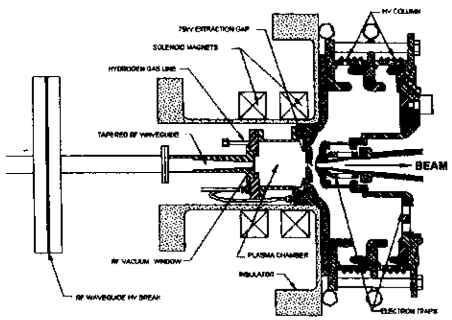
Lifetime/Reliability Test



- dc Test at 47 keV, 65 mA for 170 hours. (330 mA/cm^2) (CRITS test stand)
- Beam Availability: 96.2% = 47 keV beam on/elapsed time
- No ion source hardware failures for 170 hour operating time.
- Most of the downtime spent resetting the HVPS variac

Los Alamos

75-keV Microwave Ion Source



Design Considerations

- **No HV deck for ion source operations**
- **75-kV single-gap extractor based on FMIT design**
- **Extraction gap: 13.7 mm**
- **Emitter radius: 4.2 mm**
- **245 mA/cm^2 total current density at 90% proton fraction (130 mA total current gives 117 mA proton current)**
- **RFQ matchpoint emittance: 0.20 (π.mm.mrad)**

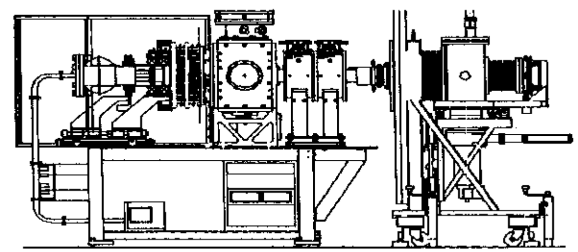
Los Alamos

75-keV Injector Specifications

Parameter	Specification	Observed
Beam current, protons (mA)	110	117
Beam energy (keV)	75	75
Beam Noise (%)	±1	±1
Discharge power (W)	450	600
Frequency (GHz)	2.45	2.45
Axial magnetic field (G)	875	875 - 920
Duty factor (%)	100,dc	100
Gas flow (sccm)	2.8 - 8.5	4.0 - 7.5
Emission radius (mm)	4.2	4.2
Extraction gap (mm)	14.5	13.7
Proton fraction	0.85	0.88
Reliability (%)	98	To do
Ion source emittance (π.mm.mrad)	0.13 (rms, normalized)	
LEBT exit emittance (π.mm.mrad)	0.20	0.20

Los Alamos

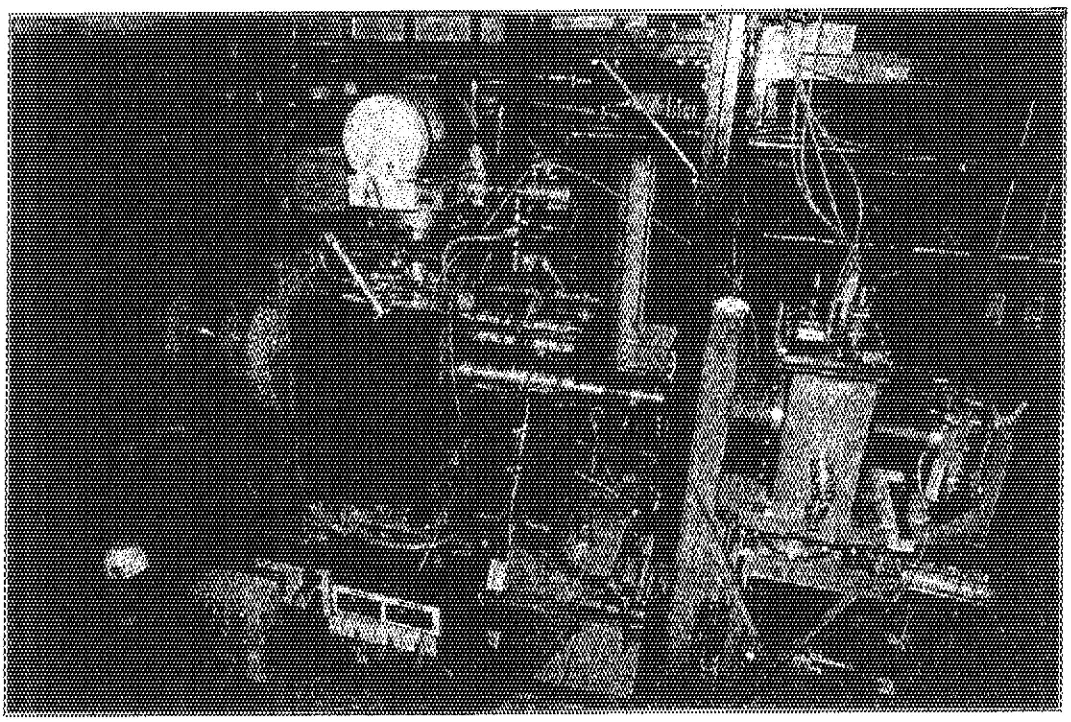
75-keV Injector with EMU



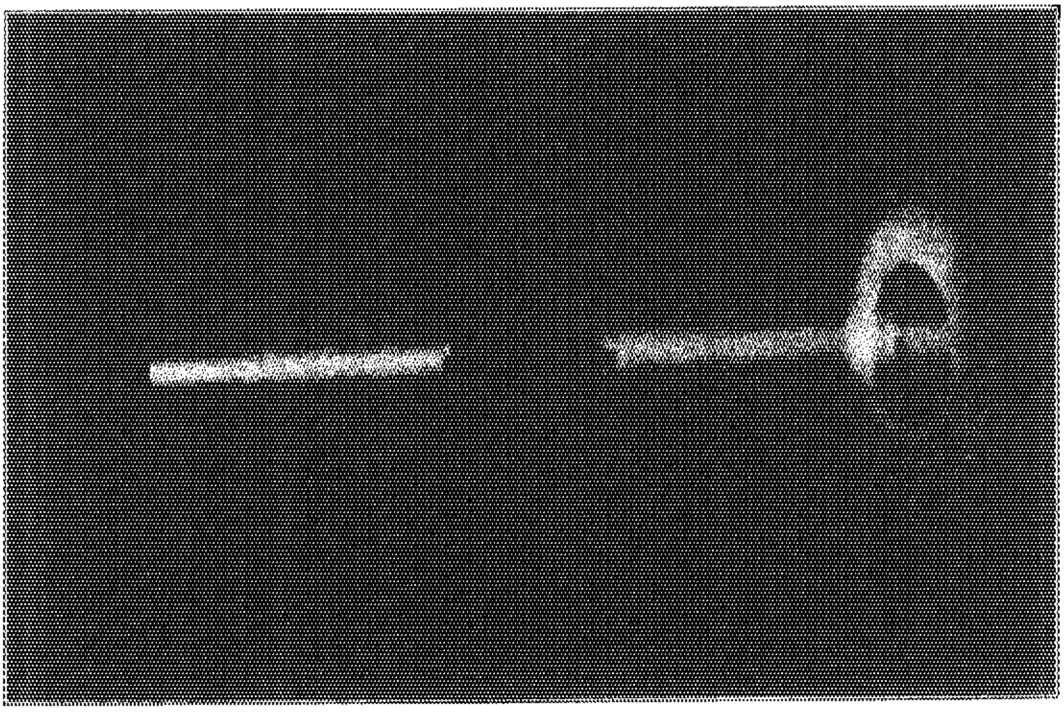
- Two-solenoid transport, 2000 l/s pump
- dc, ac current toroids, CCD camera, and emittance measurement (EMU) operational
- Beam currents up to 130 mA at 75 keV

Los Alamos

LOS ALAMOS
NATIONAL LABORATORY

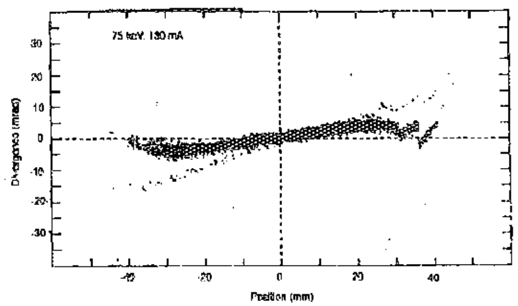


75-keV dc Proton Injector



75 keV, 110 mA hydrogen-ion beam propagating in $2\ 10^{-5}$ Torr H_2 gas

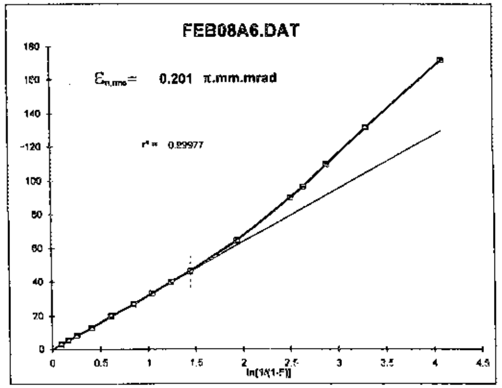
75-keV Beam Phase-Space Measurement



- 75 keV, 117 mA dc proton beam
- 125 A LEBT focus solenoid currents
- rms normalized emittance is 0.20 (π.mm.mrad) after 2.1 m transport.

Los Alamos

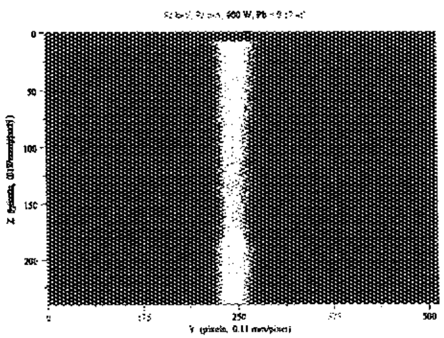
Proton-Beam Emittance Analysis



- Gaussian beam emittance model gives a linear relation between $\varepsilon(F)$ and $\ln(1-F)^{-1}$. $\varepsilon(F)$ is lab emittance at beam fraction F
- Slope gives the RMS emittance
- $F > 90\%$ includes H_2^+, H_3^+

Los Alamos

CCD Camera Image



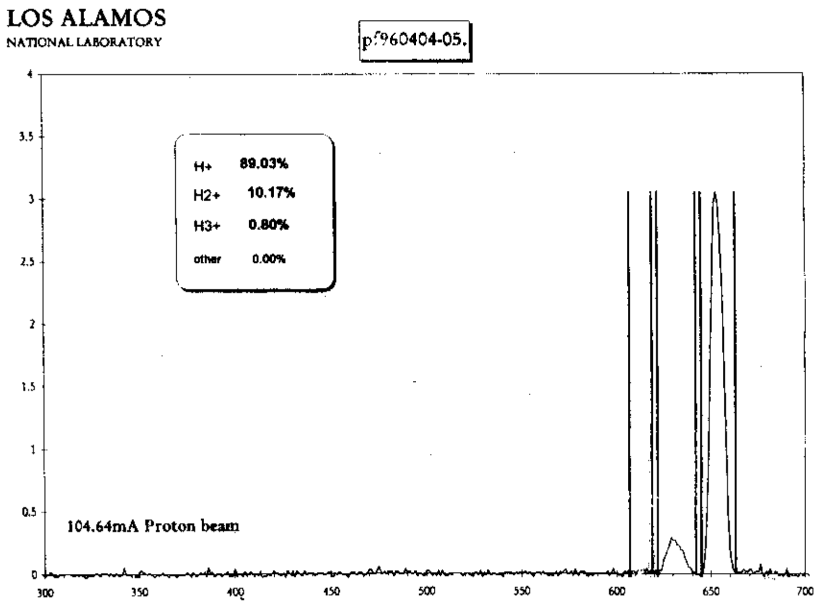
COHU Two-Dimensional Beam Profile Measurement - Computer Graphics

Los Alamos

LANL Injector Summary

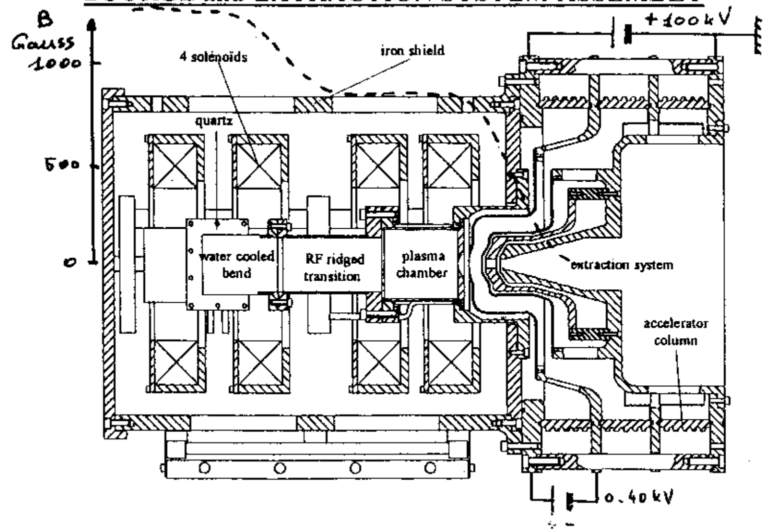
- 75 keV injector has been tested to 117 mA proton current. Emittance measurements consistent with the injector design.
- LEBT must be carefully designed to preserve ion source emittance.
- Microwave source appears to be sufficiently robust for CW linac.
- Plans are to test microwave source and LEBT concepts on the CRITS CW RFQ at 50 keV injection energy.

Los Alamos



SACLAY SOURCE

SOURCE and EXTRACTION SYSTEM ASSEMBLY



SILHI

SILHI is a PROTON and DEUTERON ECR SOURCE

studied by DSM / **GECA** (CEA SACLAY)

in collaboration with DSM / DRFMC / **PSI** (CEA GRENOBLE)

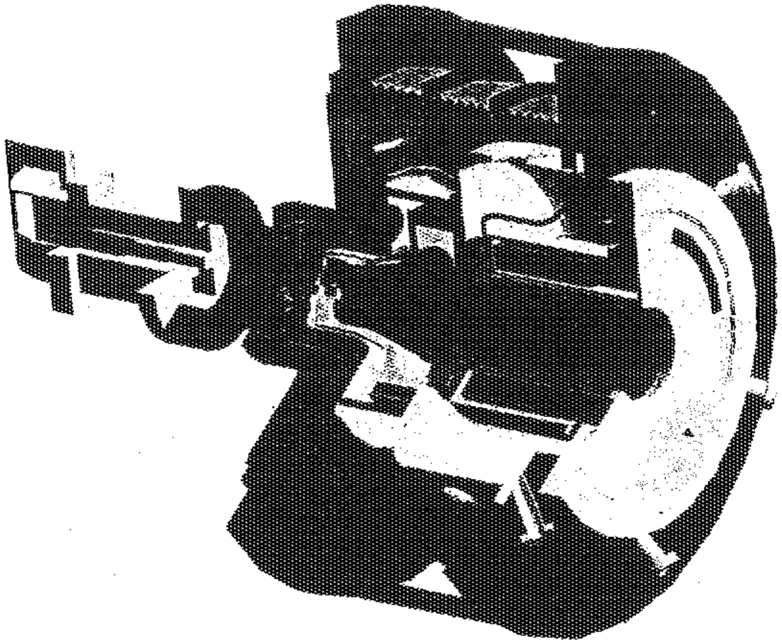
For **HIGH INTENSITY ACCELERATORS**

like: IFMIF, TRISPAL, ESS and ISAAC program

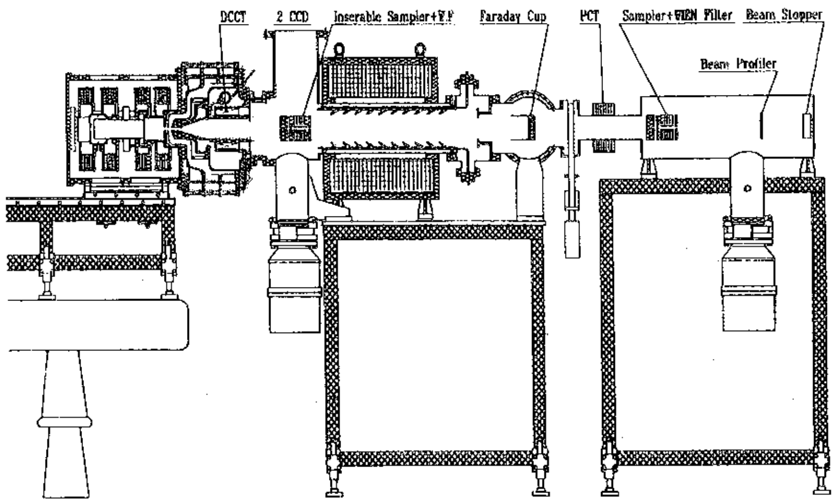
SOURCE CARACTERISTICS REQUIRED:

- **CONTINUOUS BEAM**
- **INTENSITY:** **100 mA PROTON**
  140 mA DEUTERON
- **ENERGY:** **100 keV**
- **EMITTANCE:** **0.1 π mm mrad rms norm**
- **H^+ or D^+ FRACTION ≥ 90 %**

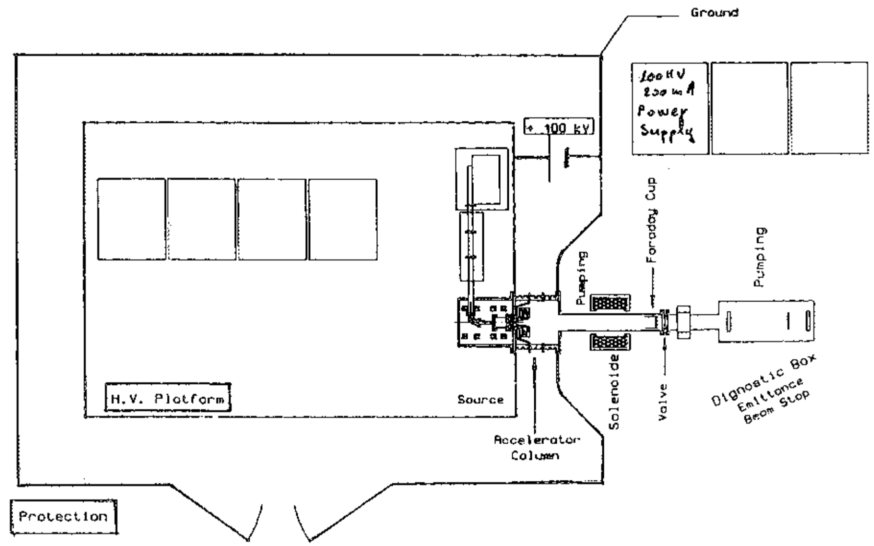
Collaborators:
P. Antoine, P. Ausset, P.Y. Beauvais, D. Bogard, T. Cacérès, L. Cadelis, G. Charruau, A. Courtois, O. Dalifart, M. Delaunay, O. Delferrière, A. Farchi, J. Faure, R. Ferdinand, A. France, B. Gastineau, P. Gros, F. Harrault, J.L. Jannin, J.M. Lagniel, F. Launay, P. Léaux, P.A. Leroy, G. Melin, J.P. Pénicaud, J. Royer, V. Voisin, M. Woivré.



SOURCE and L.E.B.T. ASSEMBLY

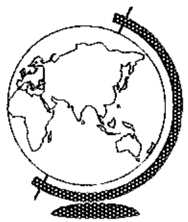


SILHI HV PLATFORM OVERVIEW

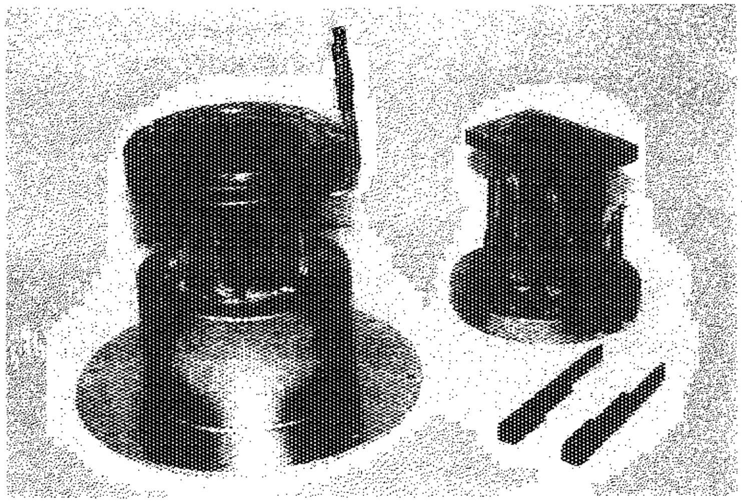


Diagnostics

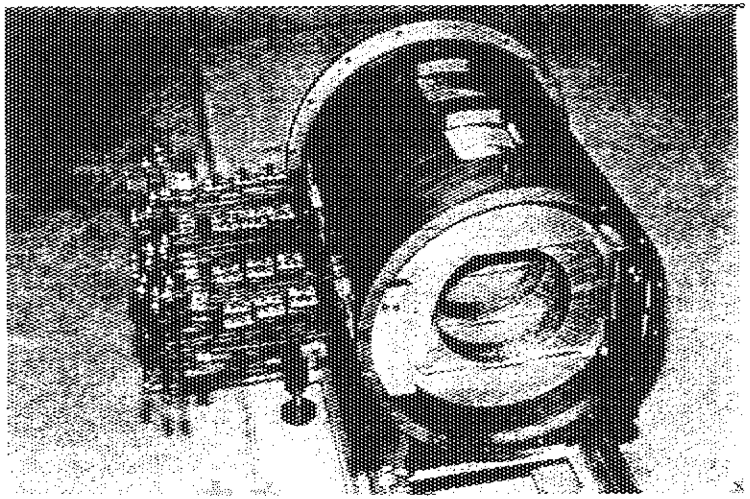
- Two CCD cameras
- Direct Current Continuous Transformer
- Beam stopper (Faraday cup)
- Pulsed Curent Transformer
- Emittance measurement
  - Thermal calculations
  - Beam profile monitor
  - Wien filter (+analyze)
- RGA
- Four Parts Faraday Cup
- Temperatures and currents measurements



SILHI Source 1996

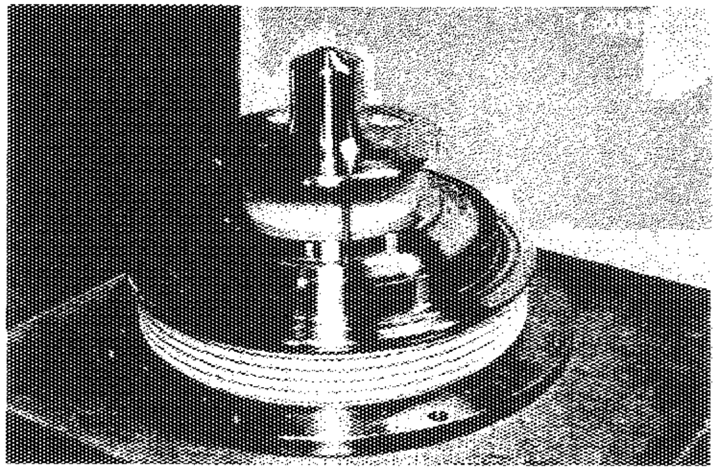


Plasma Chamber and Ridges



Coils and magnetic shield

SILHI Source 1996

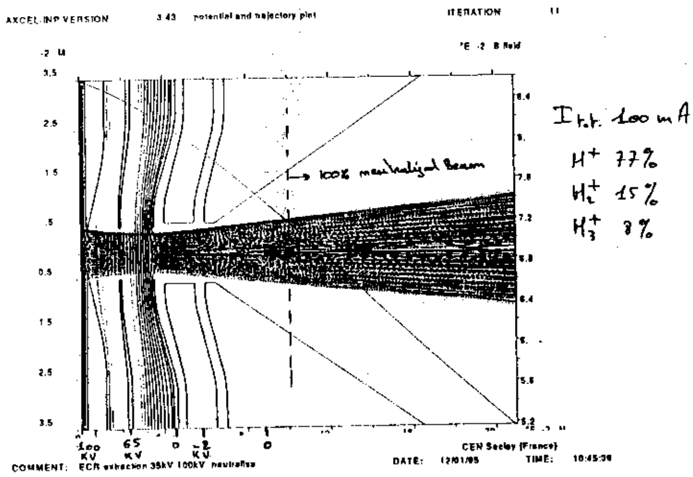


Acceleration tube

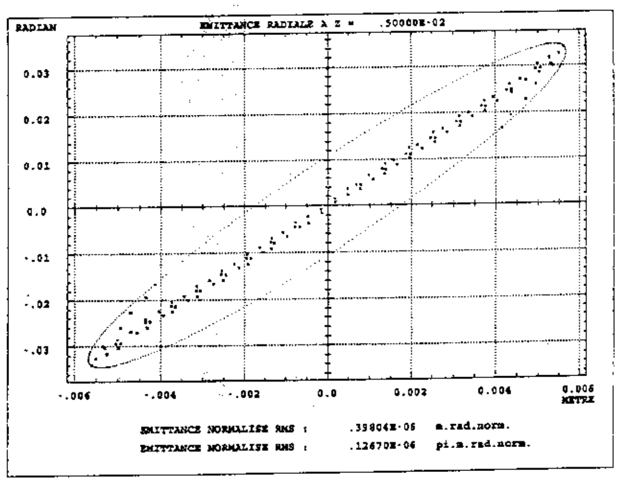
ION SOURCE EMITTANCE

at Z = 100 mm (AXCEL and BACCHUS junction)

ε = 0.13 π mm. mrad. rms. norm.



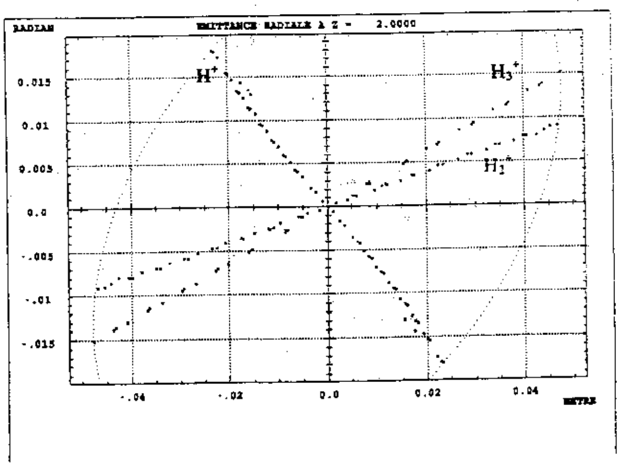
100 % H^+



EMITTANCE

of H^+ (77 %), H_2^+ (15 %) and H_3^+ (8 %) IONS

at Z = 2.1 m



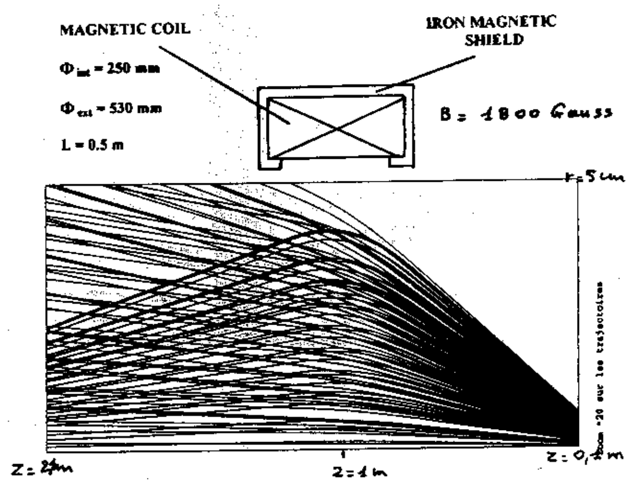
ION TRAJECTORIES

with B = 0.18 T

H^+ GREEN, H_2^+ ORANGE, H_3^+ BLUE

77 % 15 % 8 %

100% Neutralised Beam



INTERMEDIATE
ELECTRODE
PLOTTING
I 100mA H^+

fig. 15 : Système d'extraction en charge d'espace et neutralisation du faisceau pour z > 0.1 m
V_I = -30 kV

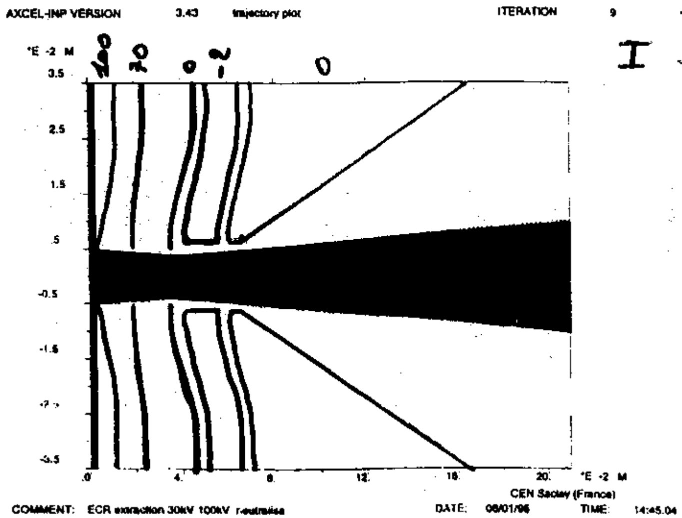


fig. 11 : Système d'extraction en charge d'espace et neutralisation du faisceau pour z > 0.1 m
V_I = -40 kV

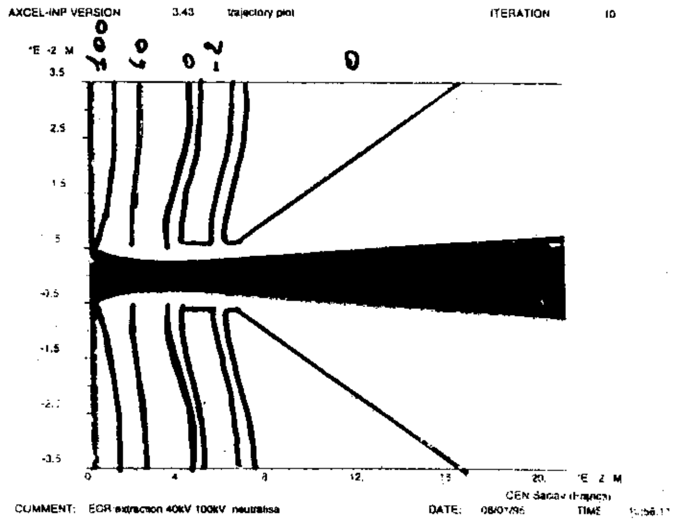


fig. 9 : Système d'extraction en charge d'espace et neutralisation du faisceau pour z > 0.1 m
V_I = -45 kV

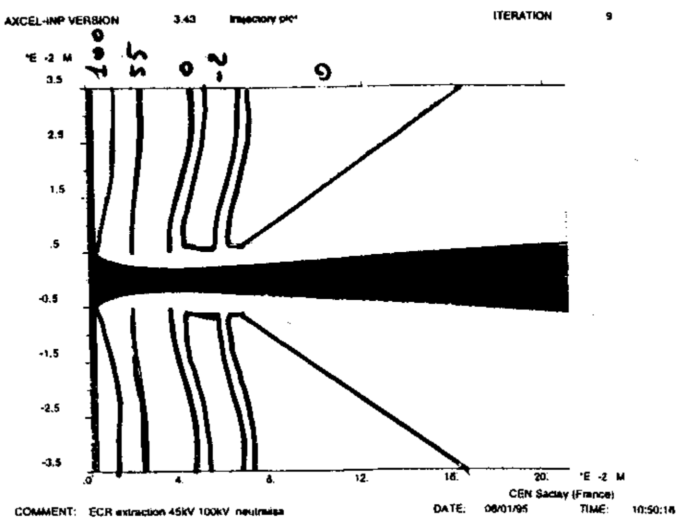
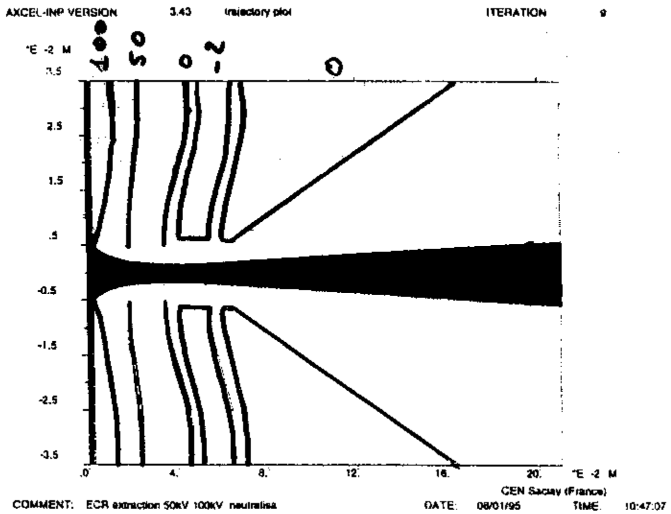
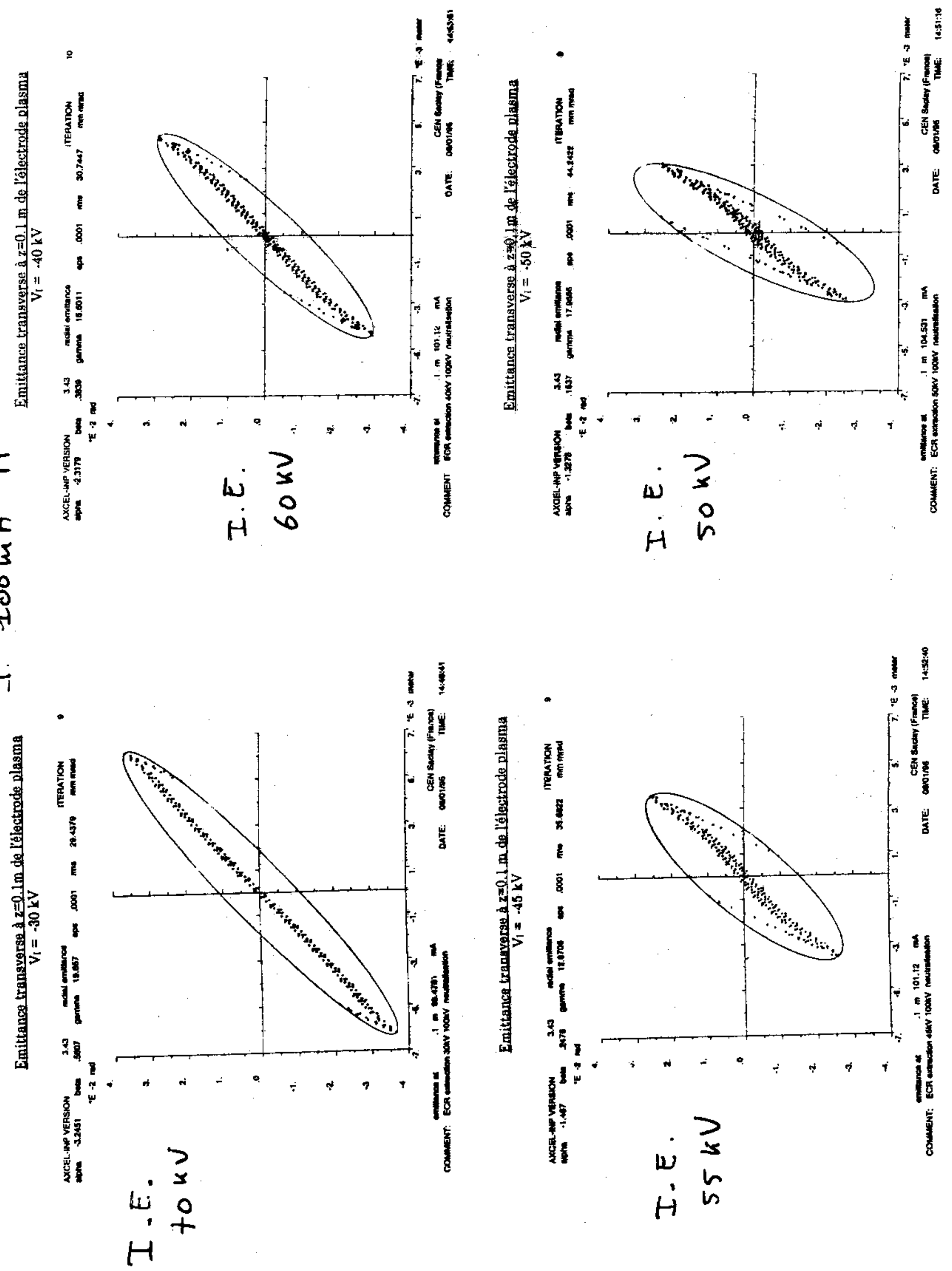


fig. 7: Système d'extraction en charge d'espace et neutralisation du faisceau pour z > 0.1 m
V_I = -50 kV




I 100mA H+
Emittance transverse à z=0.1 m de l'électrode plasma
V_I = -40 kV
I.E. 60kV
Emittance transverse à z=0.1 m de l'électrode plasma
V_I = -50 kV
I.E. 50kV
Emittance transverse à z=0.1m de l'électrode plasma
V_I = -30 kV
I.E. 70kV
Emittance transverse à z=0.1 m de l'électrode plasma
V_I = -45 kV
I.E. 55kV

SILHI PLANNING

1995

- First experimentations at Grenoble
- Computations and design
- H.V. platform realisation
- H.V. Power supply tests (100kV, 200mA)
- Control system definition

1996

- march-april : Source assembly
- may : First plasma measure
- june : Beam extraction
- september : Emittance measurements

Estimated Cost (based on SIHLI source)

- Source
  - Platform : 200kF ($40k)
  - Mechanical part : 250kF ($50k)
  - H.V. power supplies : 530kF + 70kF ($106k + $14k)
  - Coils : 90kF ($18k)
  - Alumina ceramics : 120kF ($24kF)
  - Microwave 2.45GHz : 100kF ($20k)
  - Automatic stub tunner : 60kF ($12k)
  - Coils power supplies : 300kF ($60kF)
- LEBT (first section)
  - Mechanical part : 350kF ($70k)
  - Solenoides : 120kF ($24k)
  - Power supplies : 100kF ($20k)
  - Diagnostics : 150kF ($30k)
  - Vaccuum pump : 250kF ($50k)
- Miscellaneous
  - Cables and Mouting : 100kF ($20k)
  - Drawing : 100kF ($20k)
  - Control system : 200kF ($40k)
  - Cooling : 50kF ($10k)

TOTAL : 3.14MF ($628k)

Manpower

- Studies : 0.5 man/year
- Drawing : 1 man/year
- Order : 1 man/year
- Reception/Assembly : 1.5 man/year
- Cables : 1 man/year
- Starting/tests : 1.5 man/year

Injector Work in Japan

Michikazu Kinsho

Japan Atomic Energy Research Institute

1. Ion Source for High Intensity Proton Linac in JAERI
   H.Oguri, Y.Okumura, and M.Mizumoto

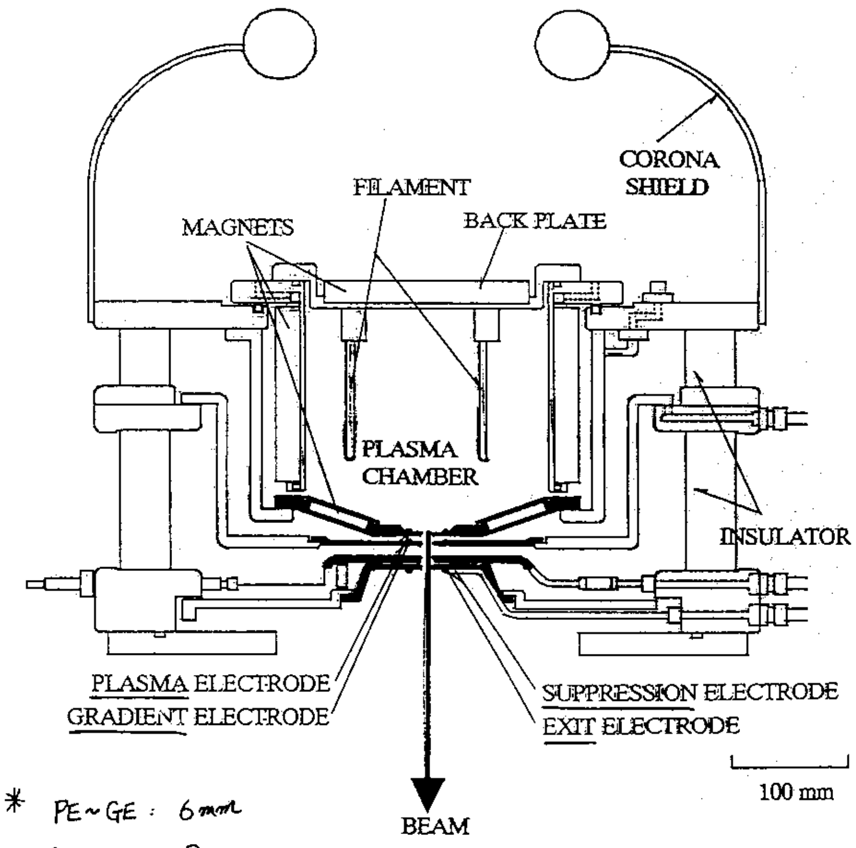
2. Ion Source for Fusion Neutronic Source(FNS) in JAERI
   N.Miyamoto, M.Seki, Y.Okumura, et al

3. Future Plan

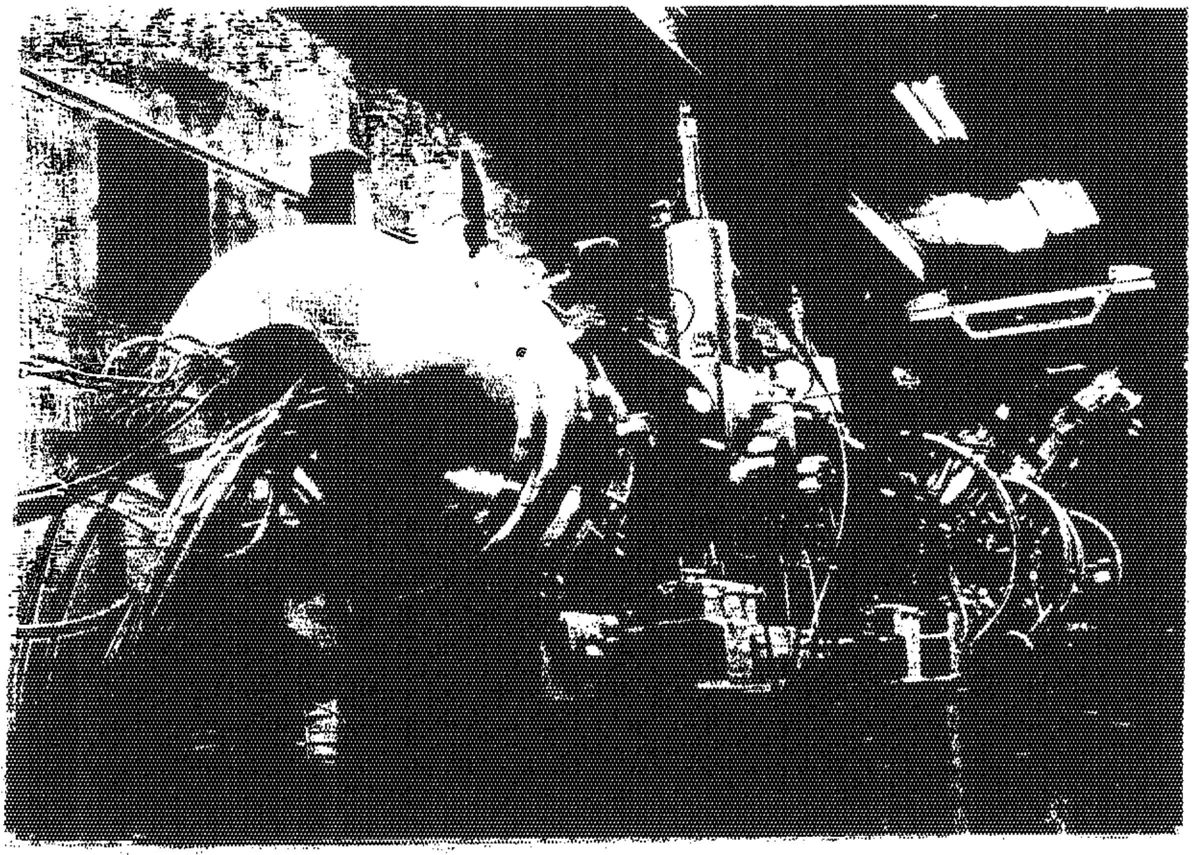
FEATURE

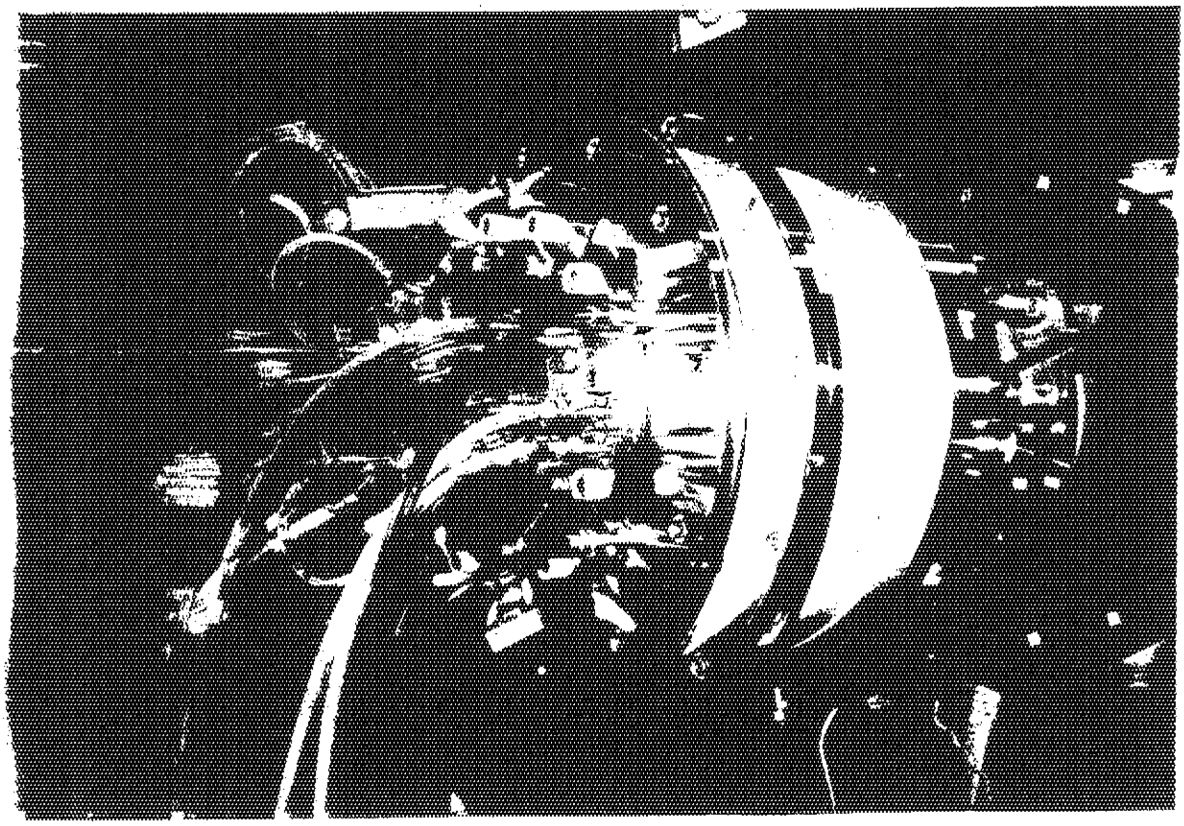
Type	:	Multi-cusp Type Ion Source
Plasma Chamber		
Production	:	Arc Discharge (Tungsten Filaments)
Confinement	:	Multicusp Magnetic Field (Permanent Magnets)
Beam Extractor		
Aperture	:	10 mmφ, Single
Electrode	:	Two Stage Extraction System

Cross sectional view

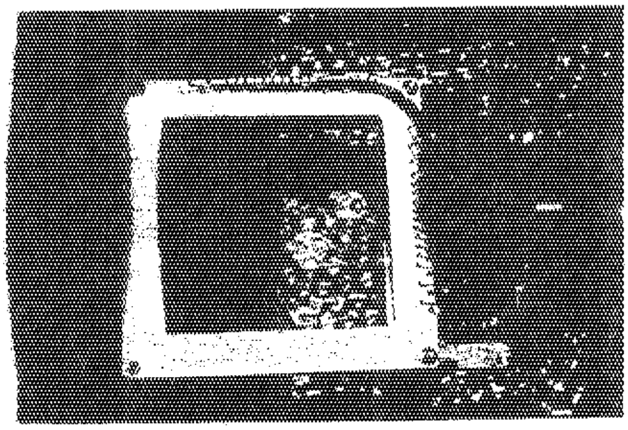


* PE~GE : 6mm
GE~SE : 8mm
SE~EE : 2mm



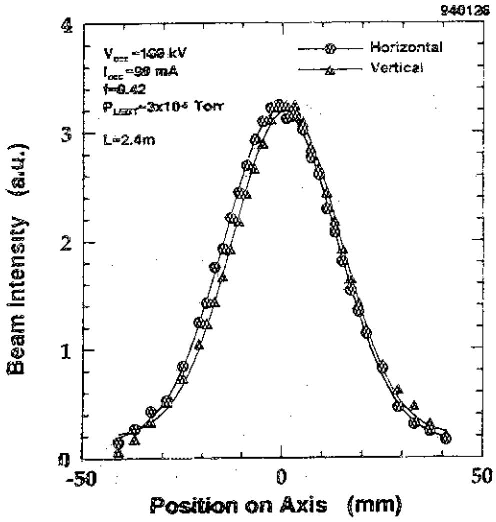


Multi-Channel Wire Monitor



32 channels X-Y each
0.1 mm in diam. Tungsten wire
Central region 2 mm mesh
Outer region 4 mm mesh

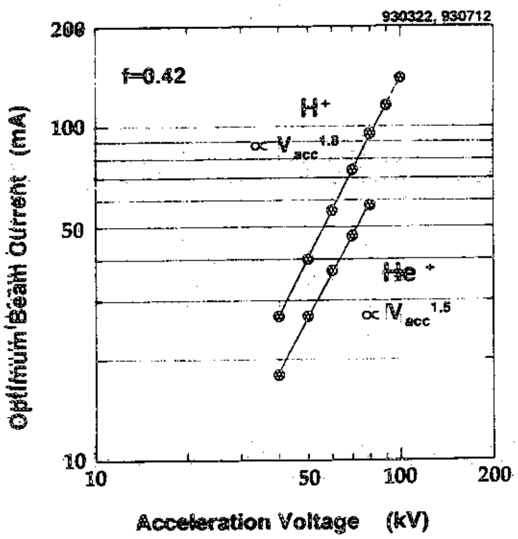
Typical beam profile



A beam profile was measured by a two dimensional 32 channels wire type monitor installed in the vacuum chamber at 2.4 m downstream from the ion source.

Two solid lines show the Gaussian fitting results. The fitting curves reproduce well the data with the beam divergence of 8.5 mrad.

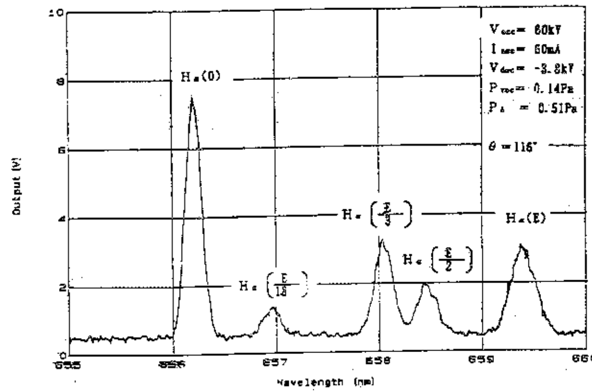
Optimum beam current



The red circles and green ones show the hydrogen and helium data, respectively.

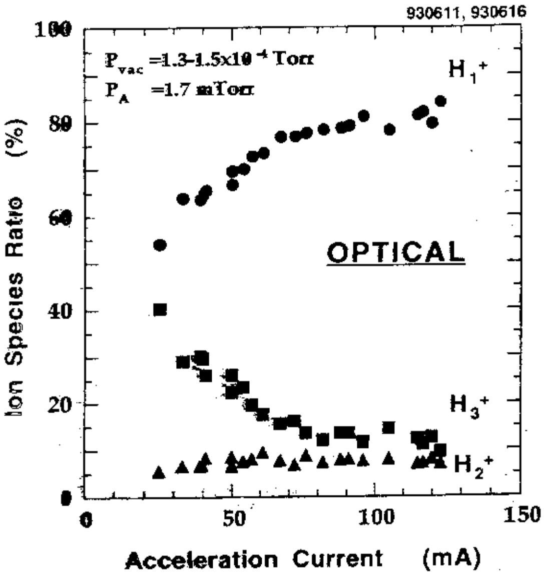
The hydrogen optimum beam current, which gives the minimum beam divergence, reached 140 mA at 160 kV.

Typical spectrum of Balmer-alpha light



The highest peak at 656.3 nm is the Balmer-alpha light emitted from hydrogen atom in the beam plasma. The four peaks above 656.3 nm are the Doppler-shifted lights emitted from the accelerated hydrogen atoms. These correspond to the peaks due to the H_1^+, H_2^+, H_3^+ and H_2O^+ ions from the right side of the spectrum .

Ion species ratio vs. acceleration current



The ion species ratio in the hydrogen beam was measured by observing the Doppler-shifted Balmer alpha radiation emitted from fast hydrogen atoms.

The proton yield increased with the acceleration current and reached more than 85 % at 120 mA.

CONCLUSION

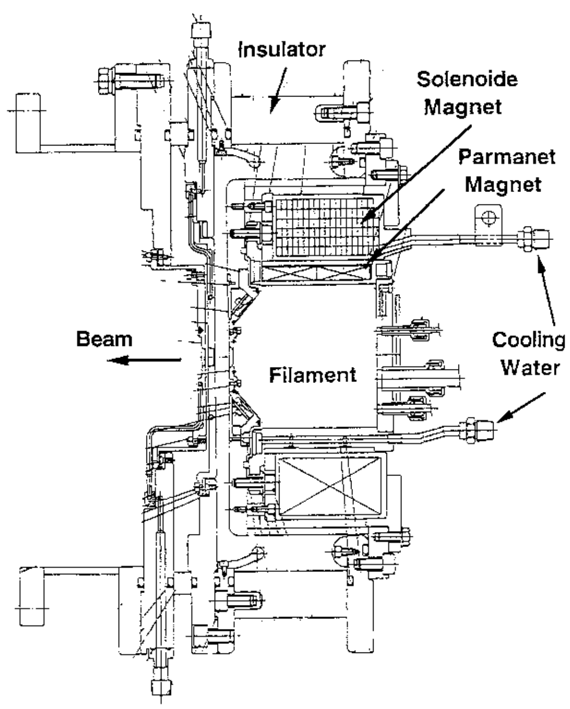
Results of the beam test

Opt. Beam Current	: 140 mA (100 kV)
Norm. Emittance	: 0.5 πmm.mrad (90 %) (100 kV, 133 mA)
Proton Yield	: >85 % (120 mA)
Impurity	: < 1 %
Arc Efficiency	: 18 mA/kW (5 SCCM)

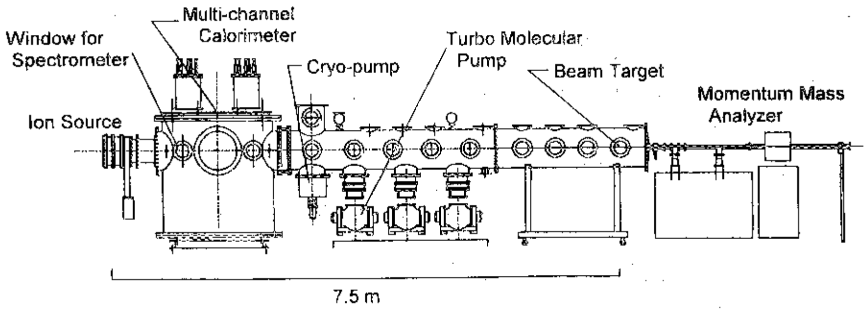
Feature

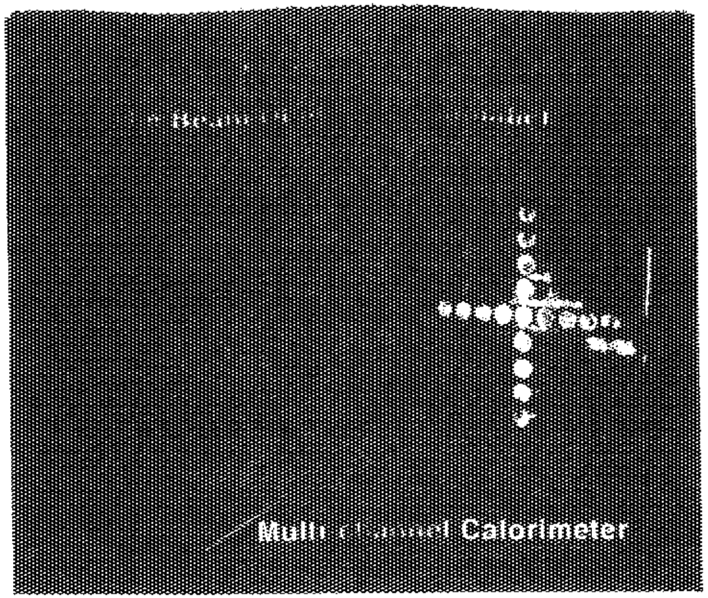
Type	: Multi-cusp Type Ion Source
Plasma Chamber	
Production	: Arc Discharge (Tungsten Filaments)
Confiement	: Multicusp Magnetic Field (Permanent Magnets)
Beam Extraction	: 12 mm φ , Single

Cross Section View of Ion Source for FNS



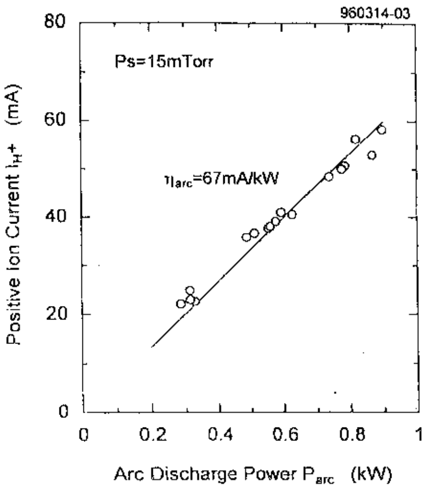
ITS-2 Test Stand



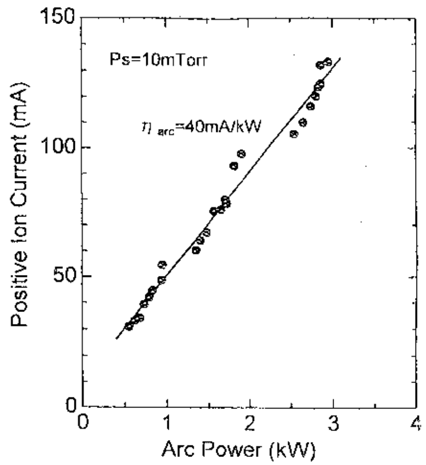


Arc Efficiency

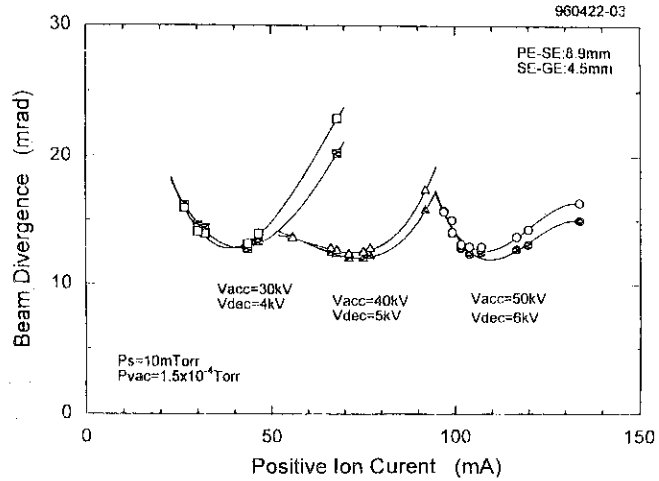
(a) without magnetic field



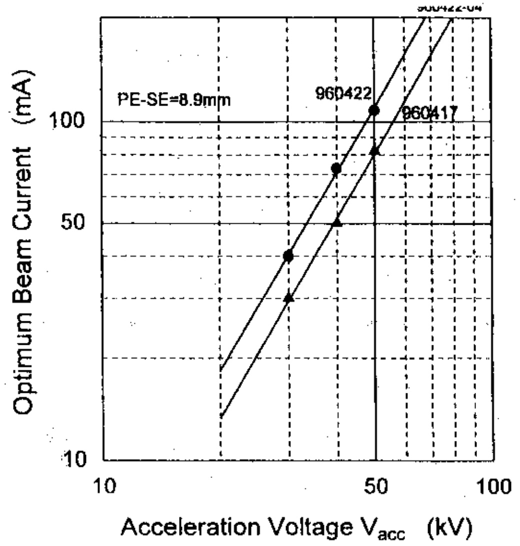
(b) with magnetic field



Beam Divergence



Optimum Beam Current



Lifetime Estimation

Tungsten Filament : 1.2 mm (diameter), 60 mm (length)

After 15 hours operation (CW, 50 keV, > 100 mA)
measurement of the filament mass

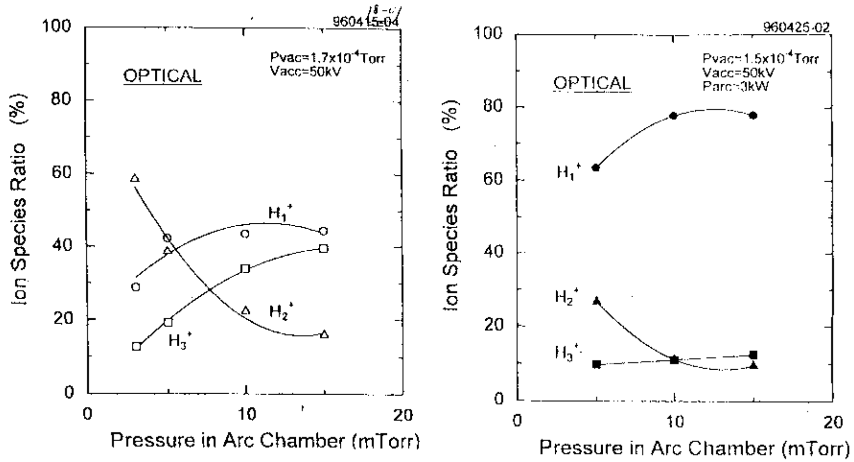
2.599 g ----> 2.573 g : 0.226 (about 1%) decrease

Assuming it is possible to use it
until the diameter becomes 90 % (81 % at mass)

19 x 15 (hours) = 285 hours

Ion Species Ratio

(a) without magnetic field **(b) with magnetic field**



Summary

	Design (D+)	Design (H+)	Achieved (H+)
Beam Energy	50 keV	←	60 keV
Beam Current (Total)	>67 mA	>95 mA	130 mA
Beam Current (Proton)	>42 mA	>60 mA	101 mA
Ion Species	D+	H+	H+
Beam Divergence	< 17 mrad	←	13 mrad
Proton Ratio	> 65 %	←	80%
Pulse Length	DC	←	DC
Arc Power	5 kW	←	3 kW (60V,50A)
Source Pressure	5 mTorr	←	6.5 mTorr
Gas Flow Rate	4 SCCM	←	13 SCCM
Breakdown Frequency			1 breakdown every 1 hours at 50keV

Future Plan

Lifetime of tungsten filament : 200 ~ 300 hours

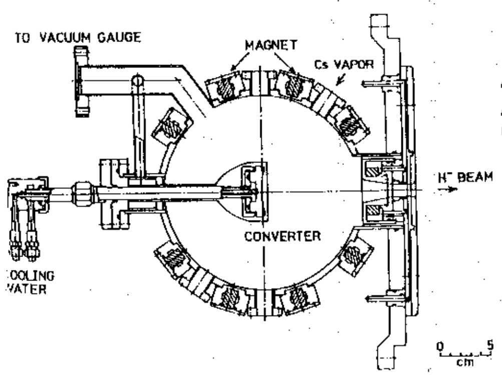
Plasma production without filament

Test of plasma production with microwave in the ion source for FNS
(5 kW, 2.45 GHz, CW Operation)

- Option -

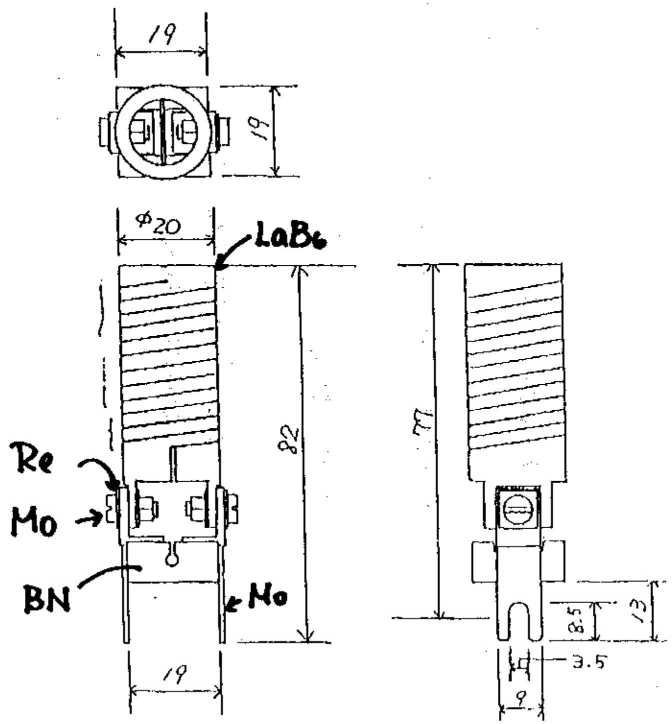
Lifetime measurement of LaB_6 filament

Multicusp H^- ion source in KEK



parameter	parameter
Arc current :	29 A
Arc voltage :	173 V
Pulse duration :	200μsec
repetition rate :	20 Hz
Converter voltage :	-500 V
Hydrogen gas flow :	7 atm.cc/min
Cesium reservior temperature :	150 C°
Filament current :	130 A
Filament temperature :	1400 C°
H^- beam current :	21 mA
Lifetime of filament :	6500 hours

LaB_6 filament developed at KEK



Baseline accelerator concepts for IFMIF

H. Klein
A. Lakatos, A. Maaser, K. Volk, M. Weber
R. Dölling, J. Pozimski
H. Deitinghoff, R. A. Jameson, D. Li

presented by:
H. Klein
Universität Frankfurt
Institut für Angewandte Physik

Tokai
Mai 1996

Table of Contents

- Ion Source
- Low Energy Beam Transport
- D^+ RFQ
- Low Energy Neutron Activation Considerations

Institut für Angewandte Physik *H. Klein*

The IFMIF project requires the development of a high brilliance deuterium source. The ion source parameters are listed in table 1.

deuteron current (D^+)	**140 mA**
extraction voltage	**65 kV**
mode of operation	c.w.
availability	>70%
$\varepsilon_{90\%, n, rms}$	> 0.01 π mm mrad

Table 1: Parameters of the IFMIF deuteron source

The current status at IAP Frankfurt is:
A current of **80 mA D⁺** has been extracted at **35 kV**. The outlet aperture in this case was 8 mm. This result was limited by the power supply, which has just been replaced by a new 65 kV - 300 mA supply.
Deuteron current and energy have great significance for neutron production in the low energy range.

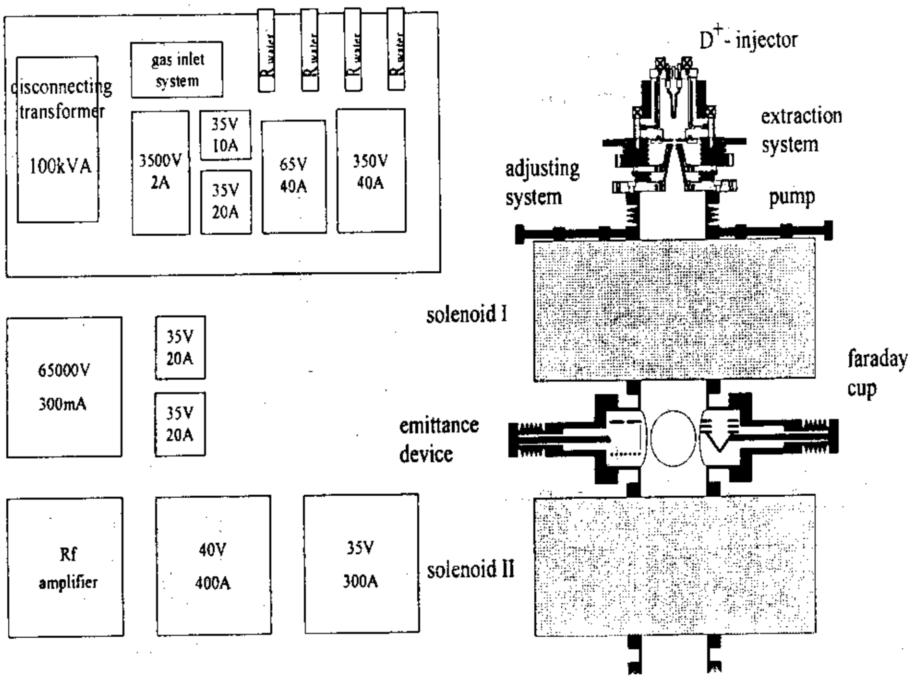
IFMIF Design integration meeting Tokai, Japan, May 20 - 24, 1996

140 mA D^+ Ion Source

- Experimental Set Up
- Plasma Generator
- Extraction System

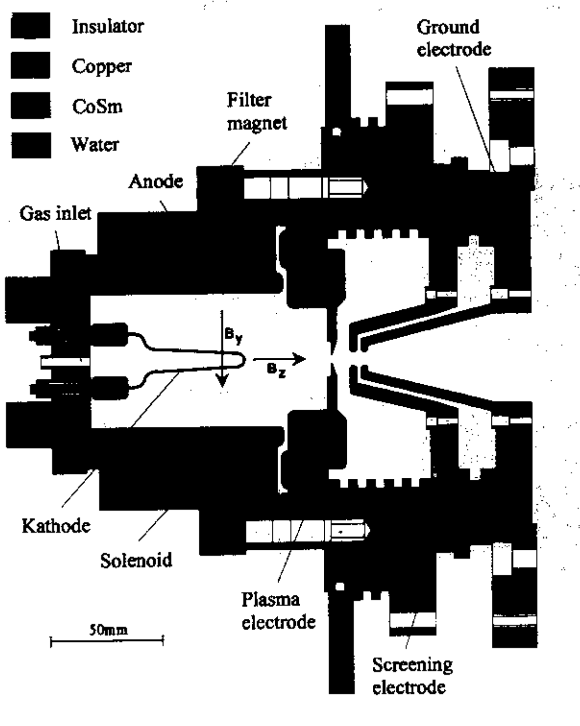
Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Schematic drawing of the experimental set up



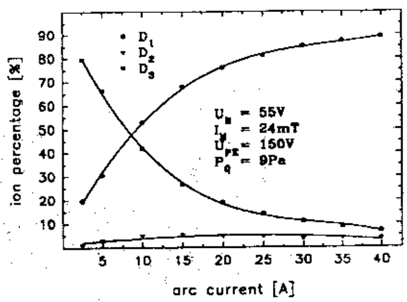
Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Schematic drawing of the deuterium source

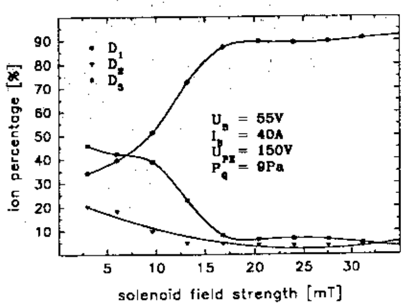


Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Influence of the Plasmaparameter to the D⁺ fraction

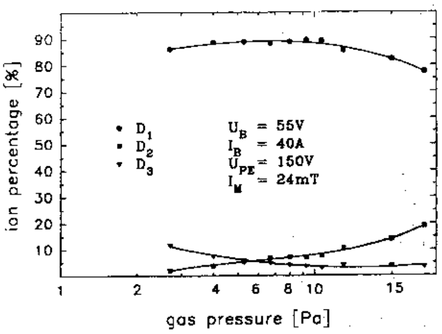


a) plasma density

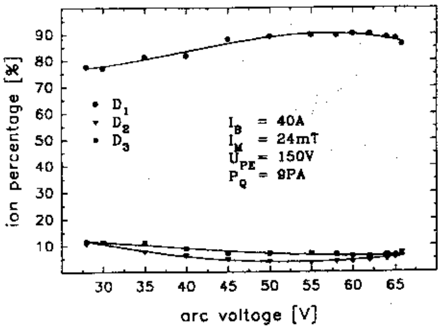


b) solenoid field strength

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*



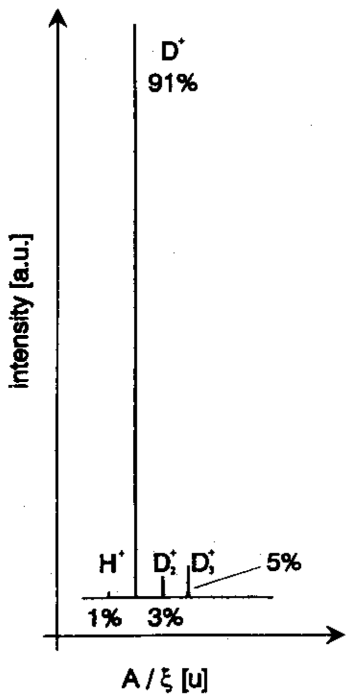
c) gas pressure



d) arc voltage

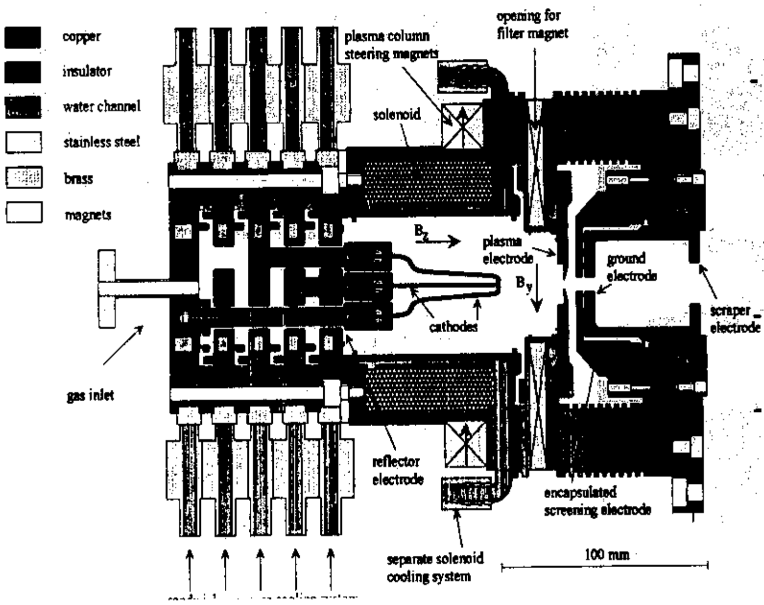
Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Deuterium Spectrum



Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

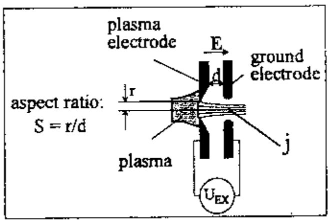
Schematic drawing of the advanced deuterium source



- 4 cathodes
- high efficient water cooling system
- 2 filter magnets
- upgradeable extraction system

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Maximum current density (triode system)



Child-Langmuir:

$$j_{CL} = 4/9\ \varepsilon_0 \sqrt{\frac{2e\zeta}{m}} \sqrt{\frac{S}{r}}\ E^{3/2}$$

R. Keller:

$$j_K = 4/9\ \varepsilon_0\ \frac{0{,}279}{(1+3S^2)} \sqrt{\frac{2e\zeta}{m}} \sqrt{\frac{S}{r}} E^{3/2}$$

with: $d = 4{,}4721 \cdot 10^{-10}\, U^{3/2}$ ***(Kilpatrik),*** and with: $S = 0{,}58$

(we use: $E \sim 5$ kV/mm)

$$j_K = 98\ \sqrt{\frac{\zeta}{A}}\frac{1}{r} \quad [\text{mA/cm}^2]$$

$$I_K = 310\ \sqrt{\frac{\zeta}{A}}\, r \quad [\text{mA}]$$

[r] = cm, [A] = mass number, [ζ] = charge state

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Rough area emittance estimation

measured with the HIEFS:

for r = 1.5 mm $\Rightarrow \varepsilon_{(90\%,\ norm.,\ rms)} = 0.0025\pi$ **[mm mrad]**

R. Keller:

assumption:

- **divergence half-angle ~ 20 mrad**
- **beam waist is half as wide as the outlet aperture**

ε ~ radius of the outlet aperture

for 140 mA D^+:

5.5 mm aperture radius are required

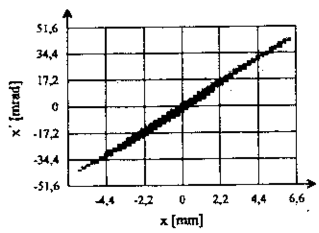
$\Rightarrow$

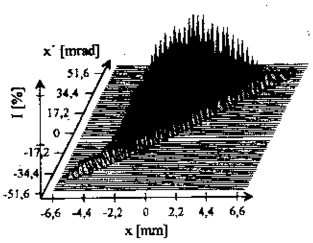
the minimum emittance

$$\varepsilon_{(90\%,\ norm.,\ rms)} \geq \mathbf{0.01\pi}\ \ \textbf{[mm mrad]}$$

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Emittance of the HIEFS in operation with nitrogen (molecular gas)





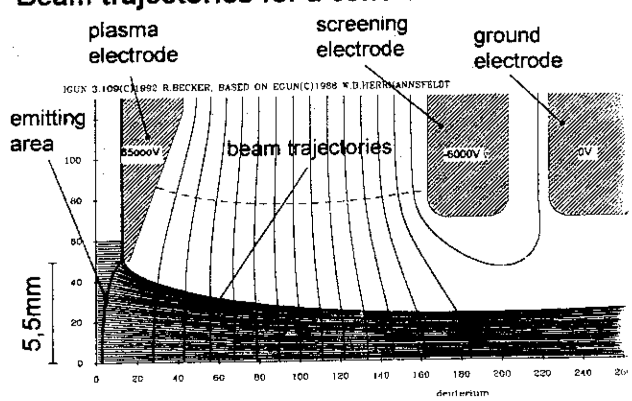
U_{EX}	= 17kV	I_{EX}	= 4,8mA
$\varepsilon_{(80\%,\ 4rms)}$	= 6,4π mm mrad	$\varepsilon_{(80\%,\ norm.,\ 4rms)}$	= 0,01π mm mrad
$x_{(80\%)}$	= 3,3mm	$x'_{(80\%)}$	= 23,6mrad
r	= 1,5mm	T_i	~ 1500K

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

Layout for the 140mA D^+ source

field strength in the gap	[kV/mm]	5
radius of the emitting hole	[mm]	5,5
emitting area	[cm²]	0.95
gap distance	[mm]	13
aspect ratio		0.42
extraction voltage	[kV]	65
extraction current	[mA]	140
current density	[mA/cm²]	147
rms emittance	[π mmmrad]	~0.01

Beam trajectories for a 65kV 140mA D^+ beam



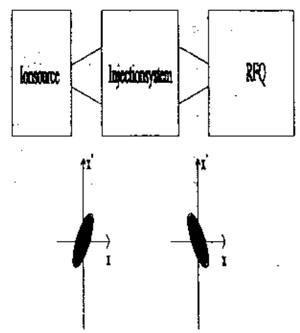
Conclusion

- 80 mA D^+ with a 4 mm aperture radius has been achieved
- The plasma density for a 140 mA D^+ source (147 mA/cm^2) has been reached
- 5.5 mm aperture $\Rightarrow$ 140 mA
- A beam composition of > 90% D^+ has been reached
- In operation with N^+ (measured):
  $\Rightarrow \varepsilon_{(90\%,\ \mathrm{norm,\ rms})} = 0.0025\pi$ mm mrad

  $\Rightarrow$ in operation with D^+ (scaled):
  $\varepsilon_{(90\%,\ \mathrm{norm,\ rms})} = 0.01\pi$ mm mrad (minimal)
- The volume source is a promising candidate for the IFMIF 140 mA D^+ ion source

2. Low Energy Beam Transport

Matching a maximized fraction of beam current from the ion source into e.g. an RFQ requires :



- **sufficient focusing strength**
- **control of emittance growth due to**
  - * aberrations of the focusing elements
  - * nonlinear space charge forces
  - * plasma instabilities
- **high transmission**
  - * minimisation of losses due to charge exchange and stripping
  - * minimal beam losses on LEBT walls / D^+ neutron production
- **mass separation**

Beam Enveloppe, Perveance and Emittance

the enveloppe equation $\frac{d^2}{dz^2}R = \frac{\varepsilon^2}{R^3} + \frac{K}{R} - \kappa(z)R$

is for high intensity accelerators like IFMIF dominated by the generalized perveance given by $K = \frac{Ie\zeta}{2\pi\varepsilon_0\beta^3c^3\gamma^3 mA}$

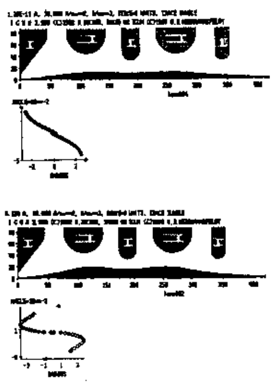
The rms emittance growth due to charge redistribution given by $\frac{\varepsilon_f}{\varepsilon_i} = \sqrt{1 + \frac{K\langle x^2\rangle f}{2\varepsilon_i^2}}$ is again a function of space charge.

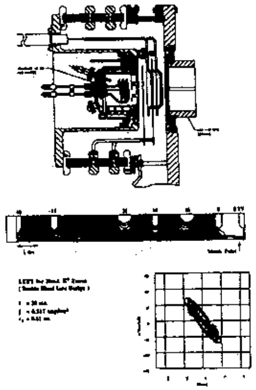
This has to be taken into consideration for the LEBT design. Two principal approaches for LEBT design

- electrostatic focussing with full space charge forces
- magnetic focussing with space charge compensation

will be discussed comparing their advantages and disadvantages.

Electrostatic LEBT - Decompensated Transport





Calculations of beam transport (100 keV D^+) using a electrostatic double lens system. In the upper example the current and therefore the space charge is zero (ε_n = 0.1 π*mm*mrad). The lower calculation with a current of 120 mA and adapted electrode potentials shows the influence of the space charge on transport and the typical emittance pattern (ε_n= 1.4 π*mm*mrad).

Compact electrostatic LEBT [Berkeley design, J. Staples] with splitted electrodes for steering integrated into the source vacuum tank (upper) and calculation of the transport property (lower) for an H^- beam equivalent to appr. 82 mA D^+ of 100 keV. Even for appr. 60 % of IFMIF space charge the emittance growth pattern is clearly visible.

Summarization of electrostatic LEBT

+ small size, short length

+ beam dynamics can be numerically simulated

+ minimized beam loss due to charge exchange (stripping) if LEBT is highly vacuum-transparent

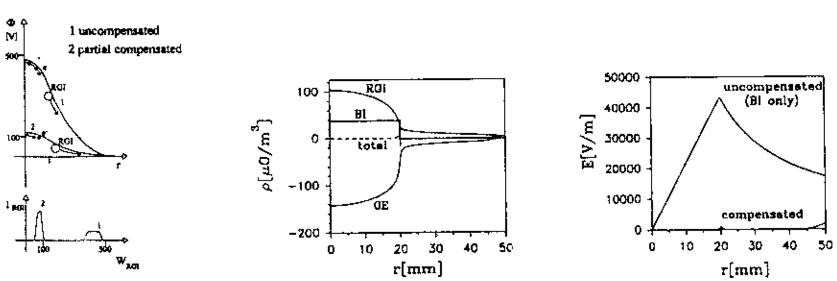
+ integrated steerers

- significant emittance growth for high intensity beams due to lens aberrations and charge redistribution

- no space for beam diagnostics

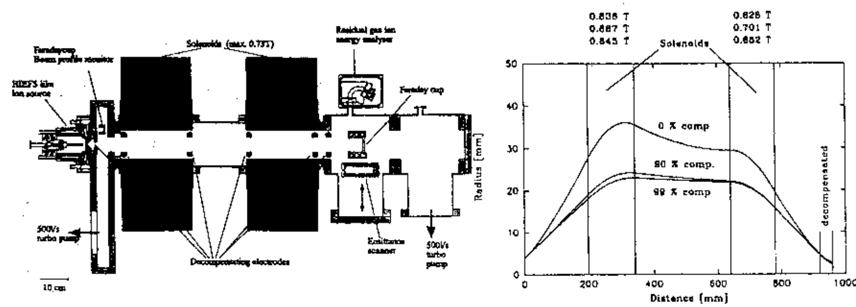
- difficult alignment

Magnetic LEBT - Space Charge Compensated Transport



Principle of space charge compensation. Electrons produced by collisions of the beam ions with residual gas are encased in the beam potential and reduce the effective space charge forces (left). Self consistent calculation of radial charge density distribution (D^+, 100 keV, 140 mA, kT_e = 0.65 eV, $\sigma_{RGI} * n_{RGA}$ = 0.12 m^{-1})(center). The reduction of space charge forces (right) induce a reduction of necessary focussing strength and therefore smaller beamradii, less aberrations and less emittance growth due to charge redistributions.

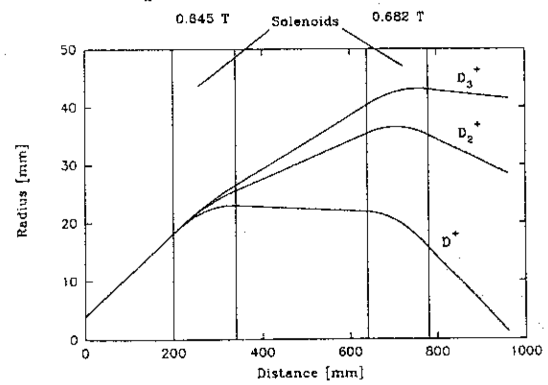
Frankfurt LEBT



	I [mA]	W [keV]	β	K	Δϕ KV [V]	$\varepsilon_{n,rms}$ [π*mm*mrad]
He	3	10	0.0023	0.004	39	0.008
D^+	140	100	0.0103	0.0041	406.3	0.01-0.1

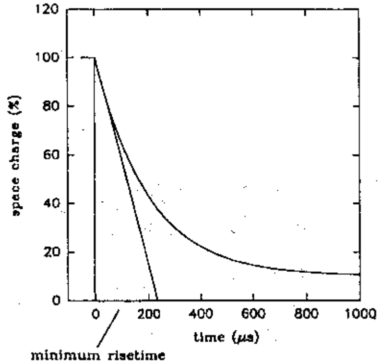
Typical layout of a magnetic LEBT used in Frankfurt consisting of two solenoids (left). Beam enveloppe calculation for Frankfurt LEBT for different global degrees of compensation (D^+, 140 mA, 100 keV) additional redistribution due to decompensation in front of RFQ (right). Table shows the relevant beam parameters used in Frankfurt in comparison to the IFMIF parameters.

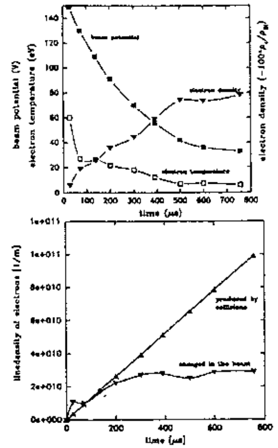
Mass separation by solenoid doublet



Effect of mass separation due to different focussing capabilities of solenoids for different masses.

Rise time of compensation





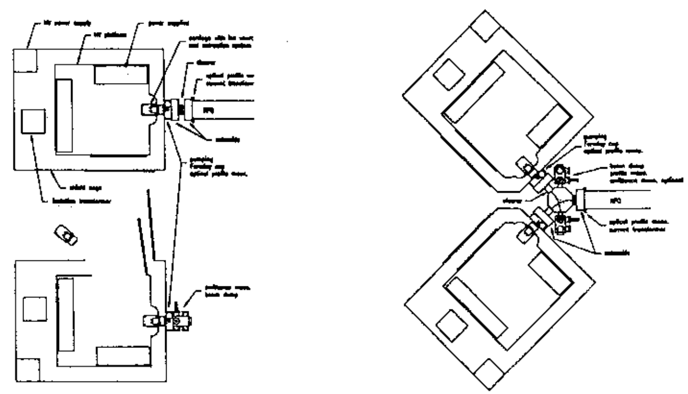
Rise time of compensation idealistic (left) and measured (upper right) and number of compensating electrons (lower right). For IFMIF the minimum rise time will be appr. 100 µs.

Summarization of magnetic LEBT

+ small beam radius in long LEBT
+ less emittance growth due to aberrations
+ space for diagnostics, steerers, ...
+ less emittance growth due to charge redistribution if the compensation is not disturbed

- higher technical effort
- beam loss due to stripping / charge exchange (pressure)
- no closed theory of space charge compensation available - optimization on the run

LEBT Conclusions



Linear LEBT with exchange capabilities for source maintenance possible with electrostatic and magnetic LEBT. Short LEBT with advantage of reduction of emittance growth but longer source change time and for electrostatic LEBT also no diagnostics available (left). Double LEBT with switching dipole. Only magnetic transport possible with a fast switching time between sources (for maintenance) but longer LEBT with possibly more redistributions and non linear behavior of compensation in dipole.

D$^+$ - RFQ

4.4. Comparisons of Deuteron RFQs with Different Frequencies

In the Karlsruhe IEA-Technical Workshop for the International Fusion Materials Irradiation Facility [33], two frequencies, 120MHz and 175MHz, were proposed for deuteron RFQs. It raised the question of the choice of frequency. In order to evaluate the differences of RFQs with different frequencies in respect of beam quality, the dynamics parameters were prepared with frequencies of 120MHz, 175MHz, 200MHz, and 240MHz, and dynamics simulations were also carried out with PARMTEQ.

4.4.1. Dynamics Parameters

The dynamics parameters are generated by GENRFQ. For comparisons, the same parameters of Δ_r = -0.11, and B = 5.6 are taken with all of the four frequencies. The voltages are ramped throughout the structure according to 1.8 times the Kilpatrick limits. The parameters are illustrated in Fig. 4-4–4-7 respectively. The main parameters are summarized in Table 4-1. It can be seen that all of the four RFQs have approximately the same phase advance profiles. Since the same focusing factor are chosen, the aperture has to be decreased with increase of the frequency, as indicated in Eq. (2.48). The intervane voltage, therefore, must be decreased in spite of the fact that the Kilpatrick limit is higher in case of larger frequencies. This results in the approximately same overall lengths.

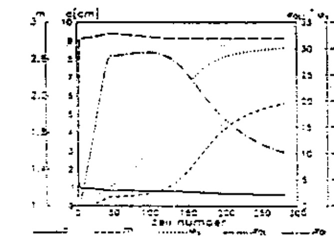


Fig. 4-4. Parameters of the deuteron RFQ with 120mhz.

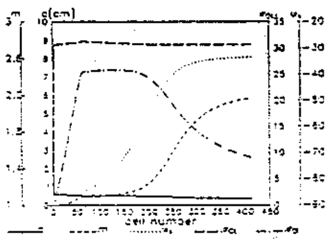


Fig. 4-5. Parameters of the deuteron RFQ with 175 MHz.

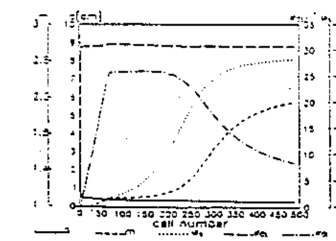


Fig. 4-6. Parameters of the deuteron RFQ with 200 Mhz.

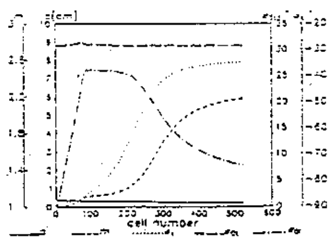


Fig. 4-7. Parameters of the deuteron RFQ with 240 MHz.

Table 1. 120 MHz RFQ

Energy	etrms in pi.mm.mrad	etrms, out	a rms, cm	eln rms, deg.keV/u	b rms, degrees	# lost xverse	# lost longit	trans-mission
0.7	0.1	0.42	0.194	98.75	16.7	52	244	92.6
	0.2	0.43	0.20	76.57	16.1	11	217	94.3
	0.4	0.53	0.22	81.27	14.1	16	213	94.2
3.0	0.1	0.33	0.19	104	11.6	73	247	90.2
	0.2	0.33	0.20	88.9	11.4	27	217	93.4
	0.4	0.47	0.21	89.4	10.7	29	213	93.9
8.0	0.1	.30	.156	114	10.3	77	247	90.2
	0.2	.32	.17	97.4	10.0	31	217	93.8
	0.4	.46	.172	95.5	9.4	32	213	93.9

	w = wg = 0.7 MeV	w = 3.0 MeV
a	0.784	0.74
m	1.323	1.520
phis	-48.8	-42.2
sig0t	31.97	31.95
sig0l	23.56	13.87

File DRFQ92.dat -0.145 6.0 2.1 1.1 0.9 50
A = 9.43 α_{in} = 0.22 β_{in} = 6.42 V = 140 kV = 21.4 MV/m
length = 7.54 m (3 MeV), 22.5 m (8 MeV)

Table 2. 175 MHz RFQ

Energy	etrms in pi.mm.mrad	etrms, out	a rms, cm	eln rms, deg.keV/u	b rms, degrees	# lost xverse	# lost longit	trans-mission
0.7	0.1	0.26	0.135	70.8	16.8	126	260	90.3
	0.2	0.32	0.14	68.9	16.0	65	207	93.2
	0.4	0.47	0.155	83.4	15.3	124	208	91.7
3.0	0.1	0.20	0.127	79.4	11.8	161	262	89.4
	0.2	0.23	0.137	76.3	11.8	98	208	92.3
	0.4	0.40	0.156	87.3	11.2	171	209	90.1
8.0	0.1	.18	.10	90.6	10.4	185	209	89.3
	0.2	.225	.11	83.4	10.3	101	208	92.3
	0.4	.38	.13	90.3	9.6	185	209	90.0

	w = wg = 0.7MeV	w = 3.0 MeV
a	0.476	0.441
m	1.311	1.538
phis	-50	-43.4
sig0t	30.78	30.73
sig0l	20.7	12.26

File DRFQ72.dat -0.11 5.6 1.55 1.4 0.9 50.
A = 4.78 α_{in} = 0.22 β_{in} = 4.42 V = 103 kV = 25.2 MV/m
length = 7.37 m (3 MeV), 21.2 m (8 MeV)

2

Table 3. 200 MHz RFQ

Energy	etrms in pi.mm.mrad	etrms, out	a rms, cm	eln rms, deg.keV/u	b rms, degrees	# lost xverse	# lost longit	trans-mission
0.7	0.1	0.21	0.119	59.8	15.8	247	251	87.5
	0.2	0.26	0.12	70.1	16.4	217	230	88.8
	0.4	0.39	0.132	87.4	14.4	714	238	76.2
3.0	0.1	0.14	0.10	84.6	11.65	322	258	89.3
	0.2	0.21	0.117	72.0	11.0	312	239	86.2
	0.4	0.35	0.132	86.7	9.75	913	245	70.0
8.0	0.1	.135	.092	123.7	9.2	338	265	84.9
	0.2	.20	.048	83.6	8.6	346	247	84.2
	0.4	.33	.112	102.1	8.15	1093	252	66.4

	w = wg = 0.7MeV	w = 3 MeV	w = 8 MeV
a	0.365	0.328	0.328
m	1.357	1.645	1.645
phis	-50	-44	-44
sig0t	31.25	31.25	31.9
sig0l	19.81	11.84	7.31

File DRFQ82.dat -0.1 5.6 4.35 1.5 0.9 50
A = 3.1 α_{in} = 0.22 β_{in} = 3.88 V = 83 kV = 26.6 MV/m
length = 7.25 m (3 MeV), 20.6 m (8 MeV)

Table 4. 240 MHz RFQ

Energy	etrms in pi.mm.mrad	etrms, out	a rms, cm	eln rms, deg.keV/u	b rms, degrees	# lost xverse	# lost longit	trans-mission
0.7	0.1	0.17	0.093	104.2	16.36	685	243	76.8
	0.2	0.22	0.097	100.9	16.9	845	200	73.9
	0.4	0.33	0.104	125.9	14.9	1641	194	54.1
3.0	0.1	0.13	0.09	97.7	12.2	487	335	79.4
	0.2	0.18	0.08	151.0	11.8	955	215	70.1
	0.4	0.30	0.106	157.9	10.0	1835	209	48.6
8.0	0.1	.11	.071	196.9	9.9	759	276	74.1
	0.2	.17	.078	104.5	10.0	960	233	70.2
	0.4	.28	.091	143.4	8.12	1880	227	47.3

	w = wg = 0.7 MeV	w = 3.0 MeV
a	0.278	0.256
m	1.350	1.58
phis	-53.1	-47.2
sig0t	31.04	31.02
sig0l	18.35	10.67

File DRFQ102.dat -0.09 5.5 1.15 1.9 0.9 50
A = 2.2 α_{in} = 0.22 β_{in} = 3.2 V = 68 kV = 28.7 MV/m
length = 7.98 m (3 MeV), 23.5 m (8 MeV)

3

Table 5.

etrms in = 0.2 pi.mm.mrad

Ener	Freq	b, deg	b, cm	eln rms keV deg/u	eln rms, mm mrad	a, cm	etn rms, mm mrad	eln/etn	b/a	# lost xvers	# lost long	transmission
0.7	120	16.1	.305	76.6	.283	.20	.43	.66	1.53	11	217	94.3
	175	16.0	.208	68.9	.175	.14	.32	.55	1.49	65	207	93.2
	200	16.4	.186	70.1	.155	.12	.26	.60	1.55	217	230	88.8
	240	16.9	.160	101.	.187	.097	.217	.86	1.65	845	200	73.9
3.0	120	11.4	.447	88.9	.329	.20	.33	1.0	2.24	27	217	93.4
	175	11.8	.317	76.3	.194	.137	.23	.84	2.31	98	208	92.3
	200	11.0	.259	72.0	.160	.117	.21	.76	2.21	312	239	86.2
	240	11.8	.231	151.	.279	.08	.18	1.55	2.89	955	215	70.1
8.0	120	10.0	.639	114.	.422	.17	.32	1.32	3.75	31	217	93.8
	175	10.3	.451	83.4	.211	.11	.225	.94	4.1	101	208	92.3
	200	8.6	.330	83.6	.185	.098	.20	.93	3.37	346	247	84.2
	240	9.86	.315	104.5	.193	.078	.17	1.14	4.04	960	233	70.2

Table 6.

etrms in = 0.2 pi.mm.mrad

Frequency	Energy	eln/etn	b/a	(eln.a)/(etn.b)	eln, mm.mrad	etn, mm.mrad
120	0.7	.66	1.53	.43	.283	.43
	3.0	1.0	2.24	.45	.329	.33
	8.0	1.32	3.75	.35	.422	.32
175	0.7	.55	1.49	.37	.175	.32
	3.0	.84	2.31	.36	.194	.23
	8.0	.94	4.1	.23	.211	.225
200	0.7	.60	1.55	.39	.155	.26
	3.0	.76	2.21	.34	.160	.21
	8.0	.93	3.37	.28	.185	.20
240	0.7	.86	1.65	.52	.187	.217
	3.0	1.55	2.89	.54	.279	.18
	8.0	1.14	4.04	.28	.193	.17

- The RFQ accelerating efficiency falls rapidly from 3-8 MeV and the length becomes very long. The best choice of transition energy is an important question.
- RFQ buncher design is such that the rf bucket is filled to a constant level; thus the bunch length b in degrees is approximately constant with frequency. The phase length scales with

4 P. STREHL

Li, Deshan, Horst Deitinghoff, R. A. Jameson

Main parameters of the 175 MHz D^+ RFQ, 140 mA

Input energy [MeV]	0.1
Output energy [MeV]	8.0
Voltage [KV] 1.8 Kilpatrick	100-157
Power [MW]	4.1
Peak surface field [MV/m]	25.8
Modulation Factor	1.0-1.873 !
Synchronous phase [deg.]	-90–-28.9
Length [m]	12.7 !
σ_t'[deg.]	33-23
σ_l'[deg.]	30-9.1
Input norm. trans. rms emitt. [π cm mrad]	0.02
Output norm. trans. rms emitt. [π cm mrad]	0.0236
Output norm. long. rms emitt. [π cm mrad]	0.0583
Transmission efficiency	92.2%

Multipoles included

Output energy [MeV]:	3	5
Length [m]:	6.22	8.71
Power [MW]:	1.4	2.3

New design!

Low Energy Neutron Activation Considerations

- Nuclear reactions
- Cross sections
- Neutron yield
- Differential cross sections
- Neutron attenuation in matter
- Estimations and preliminary measurements of neutron production

Nuclear reactions involving deuterium:

$D(d,n)He^3$: $D + D \rightarrow He^3 + n + 3.3$ MeV

$D(d,p)H^3$: $D + D \rightarrow H^3 + p + 4.0$ MeV

These reactions always occur simultaneously and have almost identical cross sections. The former is of particular interest as it has been used as neutron source in the "old days".

The binding energy of proton and neutron in the deuterium atom is low, only 2.23 MeV. Thus, most (d,n) reactions are exothermal as the binding energy of the proton in most nuclei is higher.

The characteristics of the $D(d,p)H^3$-reaction are:

- relatively high neutron yield even at low projectile energies
- strong angular dependence of neutron energy

The total cross section for the $D(d,n)He^3$-reaction rises monotonously in the low energy range. The data are taken from Nuclear Data Tables 11, 569 - 619 (1973).

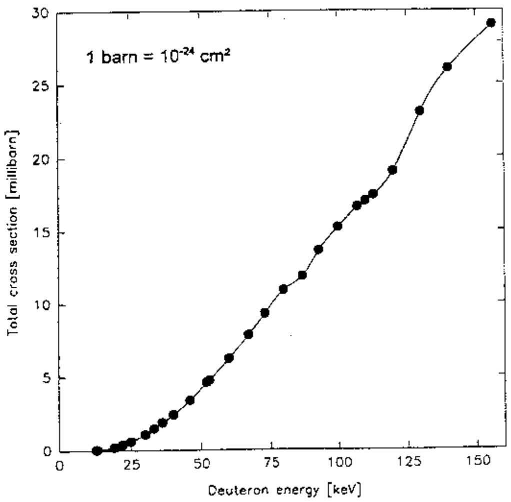


Fig. 1: Experimental total cross sections for the reaction $D(d,n)He^3$ in the low energy range

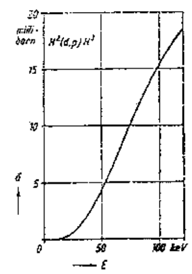


Fig. 2: Total cross sections for the reaction $D(d,n)He^3$ in the low energy range

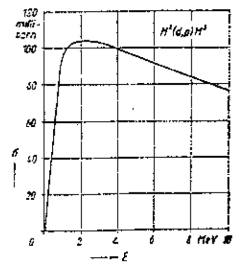


Fig. 3: Total cross sections for the reaction $D(d,n)He^3$ up to 10 MeV

The D(d,n)He[3]-reaction is a productive neutron source even for low deuteron energies. Fig. 4 shows the neutron yield on a thick heavy ice target as function of the deuteron energy. Data are taken from Wirtz-Beckurtz, "Neutron Physics" and have been extrapolated to lower energies.

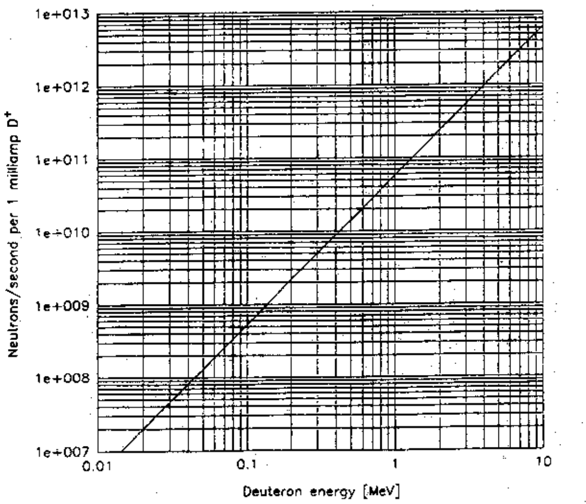


Fig. 4: Neutron yield from D(d,n)He[3] on D_2O-target

The angular distribution of the neutrons depends on the energy of the bombarding deuterons.

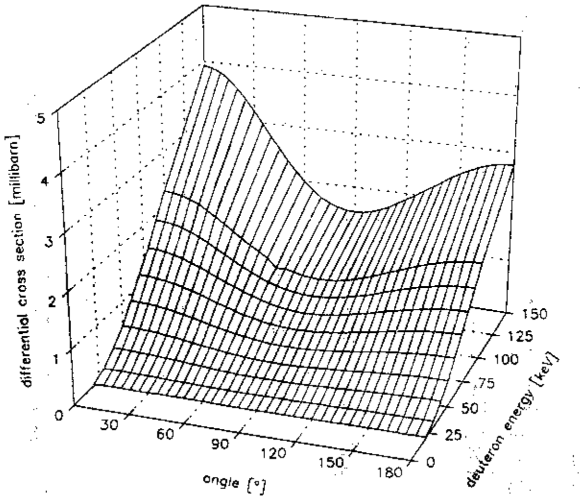


Fig. 5: Differential cross sections and their depence on deuteron energy and angle.

The neutron current is largest in the direction of the deuteron beam (0°). The data are taken from Nuclear Data Tables 11, 569 - 619 (1973).

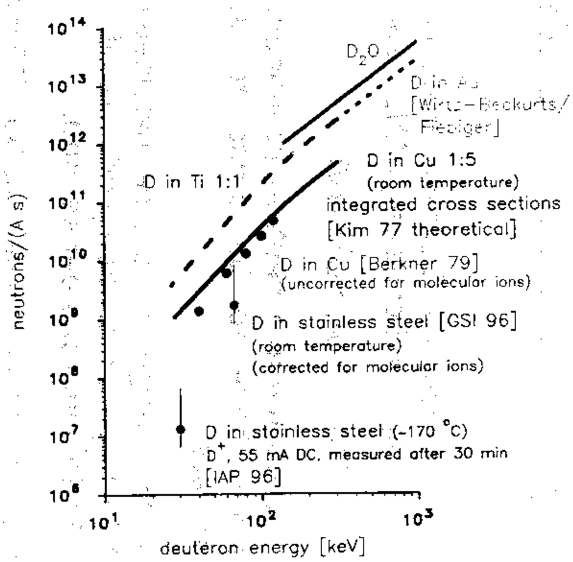
Below energies of 600 keV, elastic scattering is the ruling process to slow down neutrons. Consequently, light atoms are best suited as moderator materials.

E_0 [keV]	H_2 ρ=1g/cm³	H_2O ρ=1g/cm³	D_2O ρ=1.1g/cm³	C ρ=1.6g/cm³	O_2 ρ=1g/cm³
	required length of material [cm]				
100	0.3	2.4	9.0	13.25	37.0
250	0.34	2.7	9.3	14.0	38.0
500	0.4	3.1	9.7	14.9	38.9
1000	0.49	3.8	10.0	16.1	42.4
2000	0.65	5.3	10.5	18.0	49.4
3000	0.79	6.4	11.2	19.5	59.7

Table 2: Approximate length required to slow down neutrons from initial energy E_0 to E=1.44 eV (from Marshak, Rev. Mod. Phys. 19, 185 (1947)

The range of 1 MeV neutrons in organic tissue or water is about 20 cm.

neutron production from D(d,n)^{3}He reactions



(deuteron density in metal depends on implantation/ diffusion and thereby on material, time and temperature)

Est. neutron production from D-D reaction on a Cu substrate according to D. Schneider, LANL, 1994):

$$n = 640 * I\,[mA] * U^{2.32}\,[kV]$$

Note: For a considerable neutron production, the deuterons have to be close to the substrate surface!

Accordingly, the design ion source parameters (140 mA @ 65kV) yield a neutron production of
$1.44 * 10^9$ neutrons per second.

The actual ion source parameters at IAP (80 mA @ 35kV) yield a neutron production of
$1.96 * 10^8$ neutrons per second.

Preliminary measurement of the dose rate at a distance of 2 meters was 0.2 mrem/h (@ 30 kV, 55 mA).
With a human body sensitivity of about 8 n / cm^2s = 1 mrem/h, this corresponds to a neutron production rate of about:

$2*10^4$ n/sec per one milliamp. deuteron current.

Modeling of Injector and RFQ Beam Loss and the resulting Neutron Source

David L. Bruhwiler, Stephen R. Gottesman & David H. Berwald

Northrop Grumman Corp.
Princeton, NJ & Bethpage, NY

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

OUTLINE

- Modeling of Beam Loss in the Injector and RFQ
  - Ion Source
  - Low Energy Beam Transport (LEBT)
  - Radio Frequency Quadrupole (RFQ)
- Side Study: RFQ Transmission vs. Input Emittance
- Data required for calculating Neutron Production
  - Thin target cross-sections
  - Stopping power of deuterium in copper
  - Thick target cross-sections (neutrons per deuteron)
- Neutron Source arising from Deuterium Beam Loss
  - Neutron source in LEBT
  - Estimate of deuterium concentrations in RFQ vanes
  - Neutron source along RFQ
- Low Energy Beam Loss Conclusions
- Lessons from FMIT Program on Activation at High Energy
- Tentative Conclusions & Future Work for High Energy Beam Loss

Simulation of Ion Source Extraction Optics with IGUN

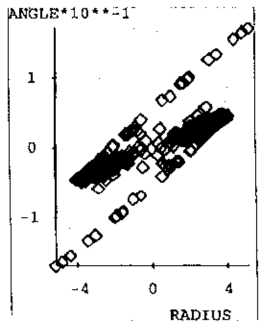
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Extraction optics is scaled from Northrop Grumman CW test stand
  - 9 mm radius extraction aperture
- Assumed 85% D+ (155 mA); 200 mA effective (for space charge)
- T_e = 5 eV in extraction region; T_i = 1 eV (somewhat high)
- Scanned voltage on 2nd electrode to obtain minimum divergence
- IGUN output beams show following characteristics:
  - 90% of beam is in a well-defined core with low emittance
  - 10% of beam is highly aberrated
    - » referred to as halo throughout this presentation
    - » RMS quantities of the entire beam are not useful
    - » RMS quantities for the core (i.e RMS of 90% of beam) are quoted below
  - core is artificially hollow, because IGUN has trouble near the axis
  - core emittance is lower than expected for actual experiments
- RMS emittance: **0.011 cm-mR** (normalized); **1.1 cm-mR** (un-norm'd)

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

IGUN Simulations: Beam Profile, Phase Space, Emittance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



```
UNIT=2.50E-2 cm
% OF CURRENT 62.26   100
EMITTANCE    0.942 3.154 cm*mrad
BRILLIANCE   2.84E-2 4.07E-3 A/cm**2/sterad
```

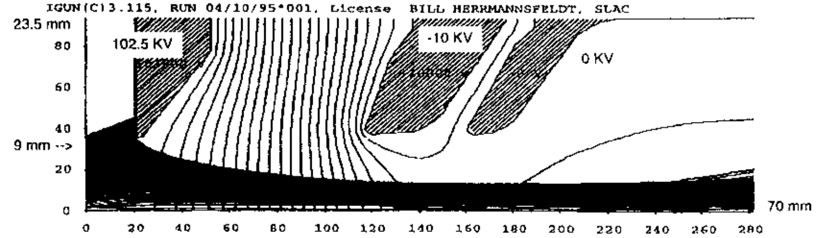
- (hollow) core and halo are seen
- RMS radius = 0.2 cm
- RMS divergence = 20 mR
- RMS emittance:
  - 0.011 cm-mR (normalized)
  - 1.1 cm-mR (un-normalized)

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

IGUN Simulations: Extraction Optics Geometry, Voltages

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Voltage on first electrode raised to obtain average energy of 100 KeV
- Peak field is 60 KV / cm, which is agressive (but not necessary)
- Ray plot shows that the beam center is underpopulated (unphysical)

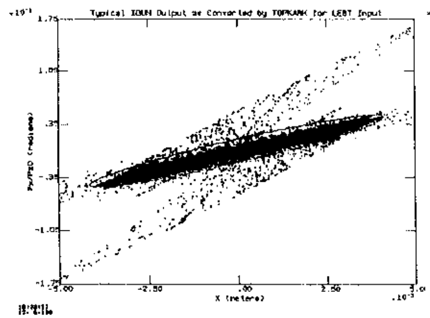


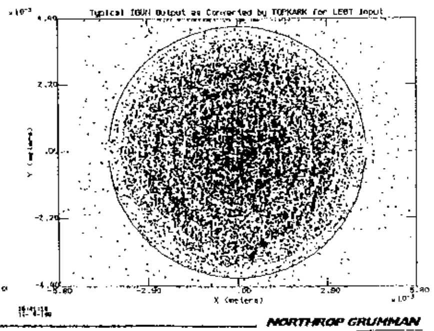
Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

IGUN Output Trajectories Converted to TOPKARK Particles

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Northrop Grumman code TOPKARK was used to model the LEBT
  - IGUN assumes cylindrical symmetry; uses radially-weighted "rays"
  - TOPKARK uses unweighted macroparticles & Cartesian coord.'s
- A small-radius Gaussian distribution was added to plug "hole" in beam
- Circles show envelope of beam with "total" emittance equal to 6 times the RMS emittance (such as a waterbag distribution)



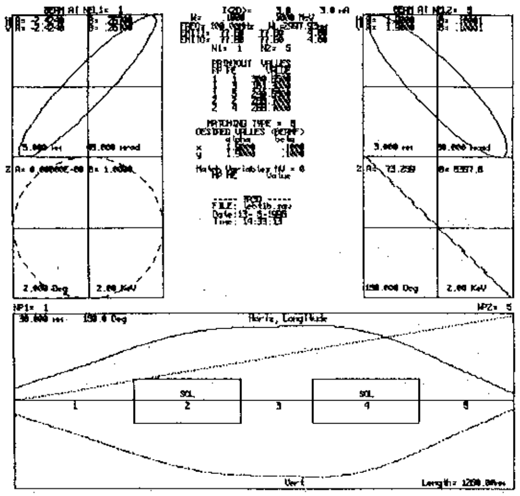


Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Two-Solenoid Low Energy Beam Transport (LEBT)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- TRACE design of simple two-solenoid LEBT
- Emittance was inflated to RFQ input specification of 0.02 cm-mR (RMS, normalized)
  - Trace uses 4 times RMS (un-normalized) = 77.6 mm-mR
- Initial Twiss parameters were chosen to be consistent with RMS radius and divergence of core, given the assumed higher emittance
- Match into RFQ is easily achieved
- Total length: 1.26 meters



Bechtel - Northrop Grumman - Westinghouse

Simulations of the LEBT with the NGC TOPKARK code

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

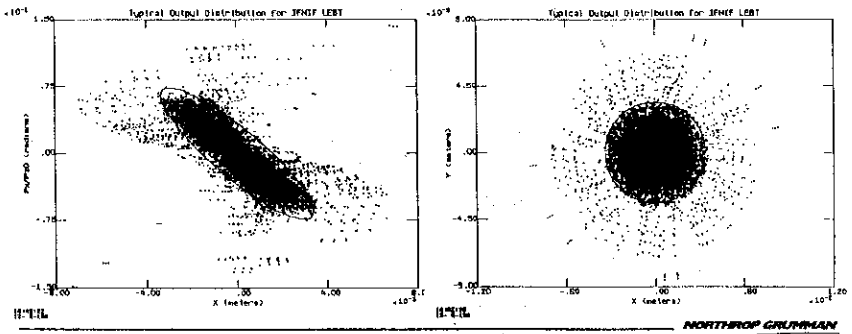
- An extended fringe-field solenoid model is used
  - analytical expression derived from thin-sheet solenoid model
  - agrees well with measurements of solenoids encased in iron shield
  - assumed 15 cm length, 6 cm radius, .55 Tesla peak on-axis field
- Uses Gauss' law for calculating space charge fields
  - accurate for 2-D, cylindrically-symmetric beam
  - works well for halo as well as core
- 98% space charge neutralization was assumed (3 mA effective current)
- Assumed 1% current fluctuations on time scale faster than the neutralization time (==> 4.5 mA maximum and 1.5 mA minimum)
- Change in space charge defocusing leads to mismatch at RFQ
- Overlapping the three beams yields an effective 33% emittance growth
- Negligible third-order aberrations from solenoid fields were seen.

Bechtel - Northrop Grumman - Westinghouse

Typical LEBT Output as Simulated with TOPKARK Code

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Typical beam as injected into PARMTEQ
- Shows three overlapping beams due to differing neutralization
- Circles show envelope of idealized waterbag distribution for the nominal RFQ input emittance of 0.02 cm-mR (RMS, normalized)
- Roughly 10% of beam lies outside of the circles (the halo)
- TOPKARK output was converted directly to PARMTEQ input



Bechtel - Northrop Grumman - Westinghouse

Simulations of the RFQ with PARMTEQ

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- LANL provided a PARMTEQ input file for the present IFMIF RFQ design
- The Northrop Grumman version of PARMTEQ was used to simulate the RFQ and determine the location and energy of lost particles
- The matched input beam:
  - 140 mA; Twiss alpha = 1.88; Twiss beta = .00976 cm / mR
  - RMS normalized emittance: 0.02 cm-mR
  - RMS Un-normalized emittance: 1.94 cm-mR
  - RMS size 0.14 cm; RMS divergence 30 mR (converging)
- PARMTEQ nominally uses an idealized input distribution:
  - waterbag; total emittance = 6 * RMS (0.011622 cm-Rad)
- 96% nominal transmission (4% of beam lost)
- Our simulations show a total loss of 11% of the beam in the RFQ:
  - 1% to 3% of beam lost in LEBT (all halo)
  - remainder of halo (7% of beam) lost in RFQ
  - 4% of core also lost, in agreement with nominal case

Bechtel - Northrop Grumman - Westinghouse

PARMTEQ simulations: the Input Distributions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

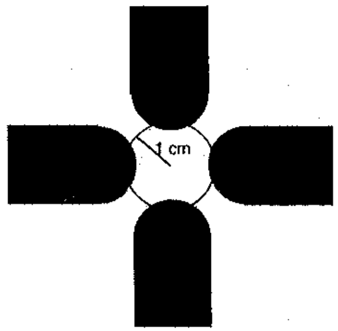
- Variety of input distributions were run through the RFQ
  - goal was to obtain reasonable statistics for lost particle data
  - all of the simulations derived from the output of one IGUN run
    - » but different seed for random # generator was used in each case to convert IGUN rays to TOPKARK macroparticles
  - in one case, we used overlapping beams as described above
  - we also used mismatched beams arising from incorrect effective space charge (i.e. 1.5 mA or 4.5 mA), scaled to nominal emittance
  - in addition, we considered well-matched beams, scaled to nominal emittance, with 0.5 mm displacement or 10 mR angle offset
- Each PARMTEQ run used approximately 12,000 macroparticles
- 11% of particles lost; 10 different runs ==> 14,000 lost macroparticles
  - good statistics near RFQ entrance, at low energy
  - poor statistics near end of RFQ, at high energy

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Treatment of Lost Particles in PARMTEQ

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Schematic of RFQ Vanes



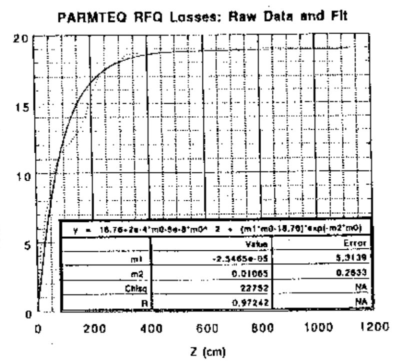
- 0.43 cm < min. vane radius < 0.69 cm
- 0.47 cm < max. vane radius < 1.3 cm
- Particles that exceed the vane radius are declared lost; energy & location noted
- Particles that exceed the vane radius at an angle of 45 deg are assumed to strike the side of a vane soon thereafter
- Some large-radius particles may actually strike the endwall of the RFQ, but it is assumed this will be a negligible effect
- Image charge effects were neglected
  - should be included, but will probably not change transmission much
- Higher-order multipoles were neglected
  - this effect could potentially reduce transmission significantly

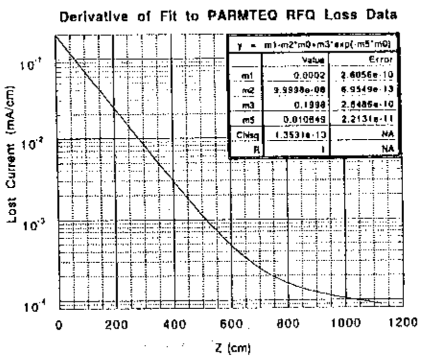
Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Beam Loss in the RFQ

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- The aggregate beam loss data was fit with a function
  - The fit was required to be very close at high-energy end of RFQ
- This function was differentiated to obtain lost current in mA/cm



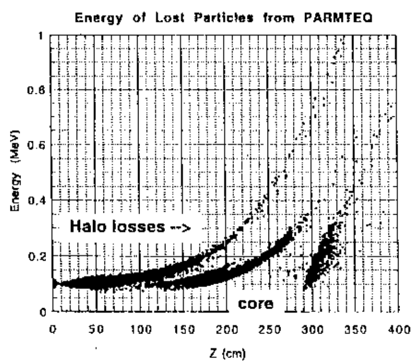


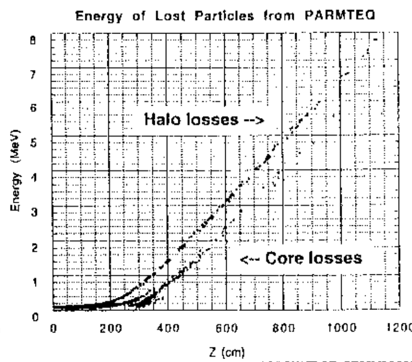
Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Energy of Particles Lost in the RFQ

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Most of lost current (~7 %) is from beam halo
  - predominantly lost very early in RFQ at 100-200 KeV
  - losses continue right up to full output energy of RFQ
- Remaining losses (~4 %) are from beam core





Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Side Study: RFQ Transmission vs. Input Emittance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Parameter sweep of input emittance and current was conducted
  - Idealized 1000 particle waterbag input distributions were used
  - Matched Twiss parameters were found with Trace in each case
  - Output current and emittance were found
- Goal was to find relaxed specifications for injector
- Three useful data points were obtained
- Results suggest that requirements on ion source can be relaxed slightly

D+ current (mA)	% current in halo	Input emit. cm-mR	Xmission of RFQ	RFQ Output Emittance cm-mR	RFQ Output Emittance Deg-MeV	RFQ Output Current (mA)
144	10	0.026	96.6	0.032	0.277	125.2
149	10	0.047	94.1	0.053	0.312	126.2
155	10	0.052	90.5	0.057	0.309	126.2

Bechtel - Northrop Grumman - Westinghouse

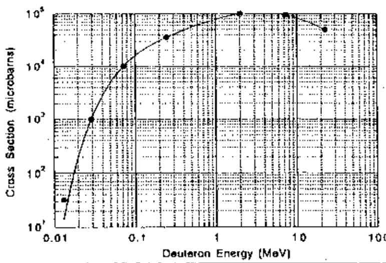
NORTHROP GRUMMAN

Cross-Sections for Neutron Production via Deuterium Loss

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

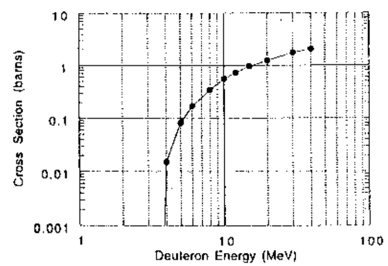
- Two nuclear reactions considered: D+D --> n+He; D+Cu --> n+p+Cu
- Cross sections were obtained from data in the literature
- Functional fits were obtained so the cross section could be integrated

Cross Section for D-D Neutron Production



y = exp(m1+m2*ln(m0)+m3*ln(m0)^2+m4*ln(m0)^3+m5*ln(m0)^4+m6*ln(m0)^5)	Value	Error
m1	11.272	0.0010886
m2	0.43552	0.001314
m3	-0.10268	0.00087898
m4	-0.029702	0.0006723
m5	-0.0080024	0.00010905
m6	0.0028626	6.43e-05

Cross Section for Deuterium on Copper Stripping



y = m1+m2*log(m0)+m3*log(m0)^ 2+m4*log(m0)^ 3	Value
m1	0.92339
m2	-3.8655
m3	4.5452
m4	-1.0543

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Calculating the Neutron Source Resulting From Beam Loss

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- We numerically integrated the cross sections over the range of D in Cu:

$$\int_0^{R(E_i)} dx\ \sigma[E(x)] = \int_0^{E_i} dE\ \sigma(E)/S(E)\ ;\ S(E) \equiv \frac{dE}{dx}(E)$$

- For the D+D reaction, one must assess the D concentration in Cu
  - this has been addressed in the literature by Kim, Berkner and Bartle
- Full saturation ==> 1.7 e+22 cm^{-3} throughout the full range
- Work by Bartle indicates the time scale for diffusion >> 12 hours
- We employ the following physical picture:
  - uniform density is assumed throughout range of deuterium
  - density is assumed to build up linearly in time for 11 months until (if ever) full saturation density is attained
  - complete removal of deuterium during 1 month shut down is assumed (perhaps requiring that RFQ be flushed with small concentrations of hydrogen during this time)

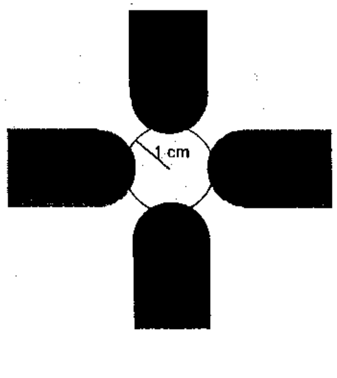
Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Saturated Deuterium Levels in the Copper RFQ Vanes

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Schematic of RFQ Vanes



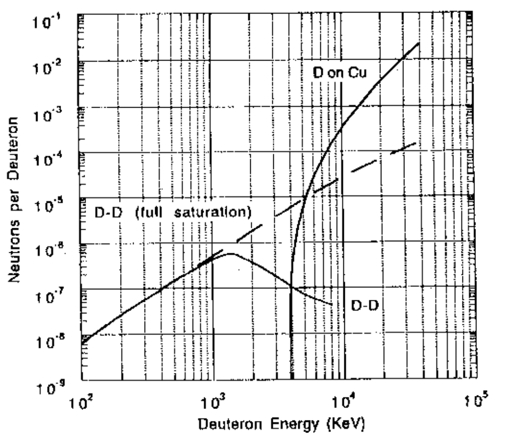
- At low energies, full saturation is quickly achieved and no assumptions are required
- For higher energy / low current loss:
  - In converting beam loss of mA/cm from PARMTEQ simulations to a loss density in mA/cm^2, an effective circumference of 2π * 1 cm was assumed
  - This assumption was used in determining the rate at which the lost current could build up the deuterium density in the copper
- On the whole, our assumptions have been very conservative
- Neutrons from D+D are swamped by neutrons from D on Cu at high energy in any case

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Neutrons per Deuteron: both D-D and D on Cu

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

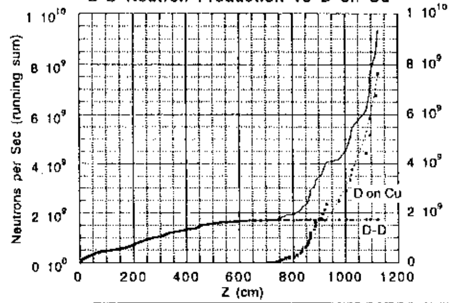


- Dashed curve shows D-D neutrons per deuteron, assuming full saturation of deuterium in copper
- Lower solid line gives D-D neutrons per deuteron, using estimated densities
- Upper solid line gives neutrons per deuteron arising from D / Cu reaction
- Cross-over for solid lines occurs at 4 MeV
- 6 orders of magnitude more neutrons per deuteron at 40 MeV than at 100 KeV

Bechtel - Northrop Grumman - Westinghouse

Running Sum of Neutron Source in RFQ; Functional Fit

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



D-D

y = 1.7263e+9-(1.7263e+9+m1*m0+m2*m0^ 2)*exp(-m3*m0)		
	Value	Error
m1	5.822e+06	12872
m2	1.4635e+05	427.1
m3	0.010803	9.5371e-06

D on Cu

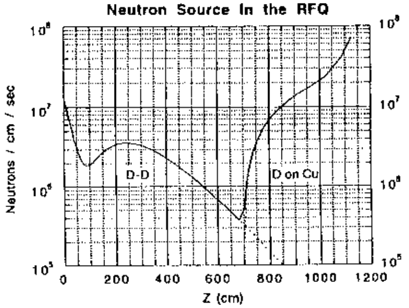
y = m1*(m0-700)^ 2+m2*(m0-700)^ 12		
	Value	Error
m1	33538	827.8
m2	4.50e-23	7.25e-24

- Data points to left show running sum of neutrons generated via D-D
- Data points to right show running sum for D on Cu
- Solid line shows the combined result.
- Dashed lines show fit of closed form expressions to data

Bechtel - Northrop Grumman - Westinghouse

Neutron source in RFQ

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



D-D

y = (m1+m2*m0+m3*m0^ 2)*exp(-m4*m0)		
	Value	Error
m1	1.2827e+07	0.0065688
m2	-2.298e+05	0.00033927
m3	1581	3.7154e-06
m4	0.010803	1.529e-11

D on Cu

y = m1*(m0-700)+m2*(m0-700)^ 11		
	Value	Error
m1	87072	0.00032592
m2	5.4e-22	3.745e-30

- Initial drop in D-D curve occurs, because current loss is falling, and all lost particles are at ≈ 100 KeV
- Rise occurs as energy of lost particles begins increasing
- Final exponential decrease occurs as deuterium density in the copper falls along with the beam loss
- D on Cu curve rises sharply once 3.5 MeV threshold is crossed.
- We have an order of magnitude more neutrons at end of RFQ
- Neutrons at entrance are isotropic with energy of 2.5 MeV
- Others are less well characterized

Bechtel - Northrop Grumman - Westinghouse

Neutron Source in LEBT

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- TOPKARK simulations indicate that roughly 3% of the beam is lost uniformly along the last meter of the LEBT
- We have not assessed the difference between imbedding of deuterium in an aluminum beam tube vs a copper structure
  - literature indicates chemical bonding occurs (copper hydride)
  - 1.7 e+22 cm^{-3} corresponds to 1 D nucleus for every 5 Cu nuclei
- Conservative to assume "full saturation" of beam tube with deuterium
- This implies a neutron source of 1.8 e+6 N / sec / cm

Bechtel - Northrop Grumman - Westinghouse

Conclusions Regarding Beam Loss

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Conservative assumptions have been made throughout
- Loss of beam halo early in RFQ is consistent with observations of actual RFQ vanes
- Up to ~ 1 MeV, the number (and energy / angular distribution) of neutrons is well understood
  - all come from D+D fusion reaction
  - copper is fully saturated with 1.7 e+22 deuterons/cm^3
  - approximately isotropic distribution of ~2.5 MeV neutrons
- At higher energies, situation is more complicated
  - very poor statistics for lost current
  - anisotropic distribution of higher-energy neutrons
  - for D+D neutrons, assumptions regarding density of deuterons in copper must be made
  - other D+D reactions become possible
  - The D on Cu reaction has been included in this study, but --
    - » resulting energy / distribution of neutrons not yet determined

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Conclusions For Low Energy Neutron Activation (<4 MeV)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Access to injector for routine repair during system shutdown:
  - Gomes (ANL) results indicate residual radiation levels of 0.1 - 2 mrem/hr in the low energy area outside of LEBT, first RFQ section
  - Residual contact doses as high as 6 mrem/hr will require some respect
- Access to injector during operation (or test):
  - Operational doses are much higher (up to 32 Rem/hr)
  - Design of an effective shield still in progress
- These conclusions are based on preliminary low-energy beam loss data that were provided to ANL
  - Numbers could increase somewhat due to superposition of transported radiation from higher energy deuteron losses.

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Some Lessons Learned From FMIT: DTL Activation

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- **Configuration/materials**
  - **35 MeV, 100 mA, 80 MHz, - RFQ made of copper plated mild steel**
  - **Copper drift tubes with mild steel tank shell**
- **Beam loss assumption/resulting neutron flux**
  - **2.1 μa per drift tube, uniform over drift tube bore (~ 2.5 μa/m)**
  - **Fast neutron flux in drift tubes: 1•10^8 n/cm^2-s**
  - **Fast neutron flux in DTL tank shell: 4•10^6 n/cm^2-s**
  - **Thermal neutron flux: 2% of fast flux**
- **Activation issues**
  - **Deuterons: activate copper, make Zn-65 (1.11 MeV γ emitter, $T^{1/2}$ = 244 d, threshold 4.49 MeV)**
    - **+ Substitute 0.005-0.025 cm gold inserts to make Hg-195m [0.56 MeV, 20% γ emitter, $T^{1/2}$ = 9.5 h]**
    - **+ Reduces direct deuteron activation 3-fold (with much shorter half life)**
  - **Secondary Neutrons: make Mn-54 [$T^{1/2}$ = 300 d], Cu-64 [$T^{1/2}$ = 13 h]**
- **Typical dose results @35 MeV**
  - **10.6 mrem/hr (30 cm from linac tank wall, after 20 yr ops + 24 Hr decay)**
  - **62% from d+Au, 38% from neutron activation.**

Ref. #618, 625 — Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Some Lessons Learned From FMIT: HEBT Activation

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- **Configuration/materials**
  - **Aluminum beam tubes**
  - **Iron + copper magnets**
- **Beam loss assumptions**
  - **10 μa per bending/switching magnet**
  - **3 μa/m linear throughout the HEBT system**
- **Activation issues**
  - **Deuterons: activate iron, make radioactive cobalt (various)**
    - **+ Substitute aluminum**
    - **+ Reduces direct deuteron activation ~10-fold (with much shorter half life)**
  - **Secondary Neutrons: make Na-24 [$T^{1/2}$ = 15 h]**
- **Typical dose results @35 MeV**
  - **≤6 Rem/hr (30 cm from loss point in magnet, after 20 yr ops + 16 Hr decay),**
  - **Reduced to 5-250 mrem/hr after 1 week (copper windings are dominant here)**
  - **FMIT analysis concludes remote maintainabnce can be avoided with copious use of:**
    - **+ lead γ shields**
    - **+ borated polyethylene neutron shields**

Ref. #615 — Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Some Lessons Learned From FMIT: Other

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

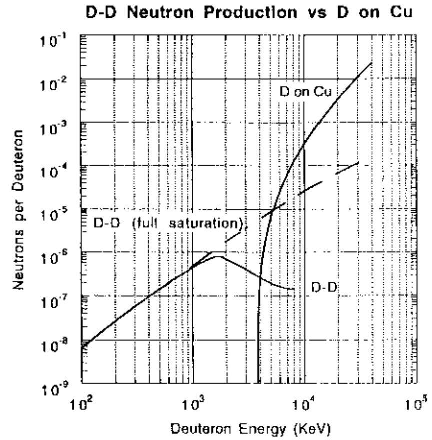
- Activation of corrosion products in water coolant was very low
- 1 m borated concrete provided reasonably effective shielding for component protection

Ref. #644, 615 — Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Looking Toward Evaluation Of Higher Energy Activation (>4 MeV)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- New reactions will become important. Must be modeled.
  - d+Cu, d+Au?
  - direct deuteron products
  - fast neutrons, new products
- Assumption on deuteron loss will be most important
  - 20 mA/m @100 keV ~ 1 mrem/hr
  - 20 nA/m @35 MeV > 1 mrem/hr?
  - 2 μA/m @ 35 MeV > 100 mrem/hr?
- Which approach shall we take?
  - Specify acceptable radiation dose
  - Specify achievable beam loss



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Northrop Grumman Perspective On

Deuterium Performance/Scaling For Positive Ion Injectors

Dave Berwald for Joe Sredniawski
Northrop Grumman Corp.
Bethpage, NY

Presentation At IFMIF Design Integration Meeting
Tokai, Japan

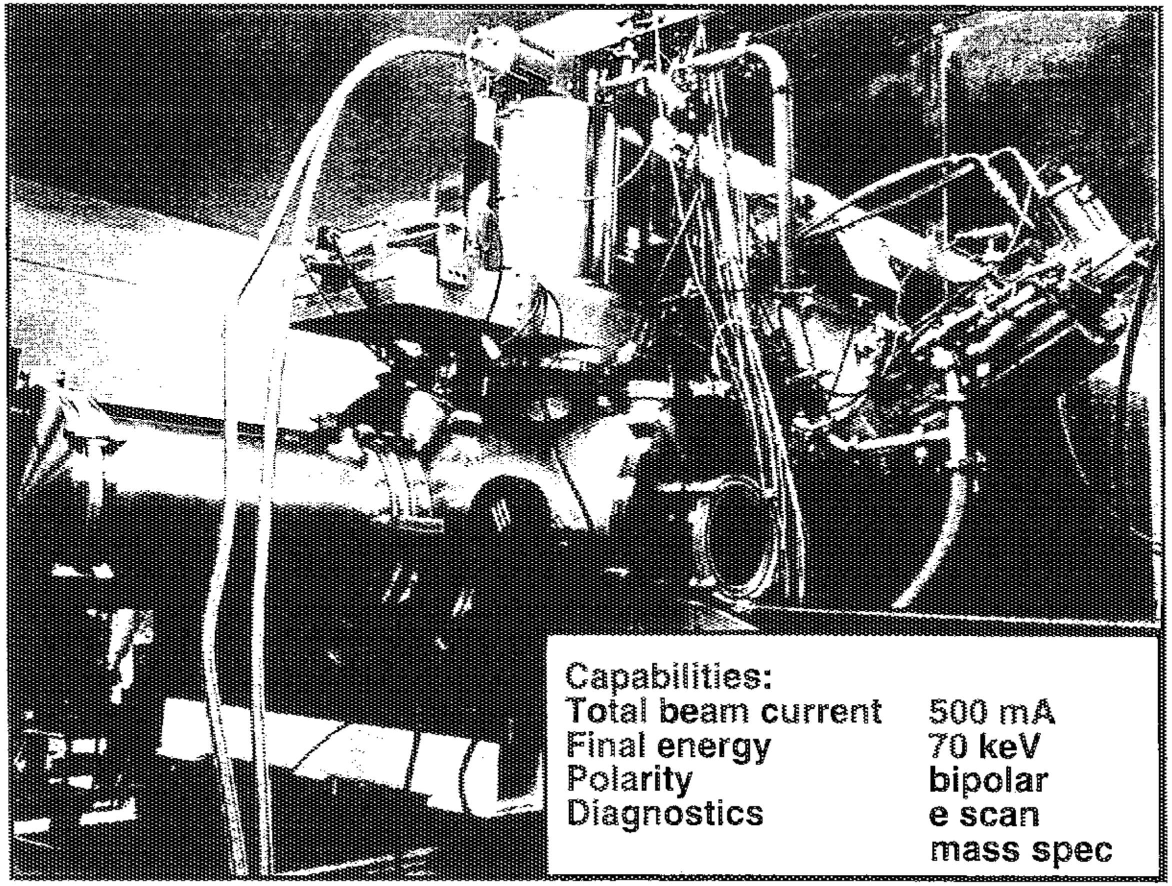
20-25 May, 1996

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

CW Test Stand (Plant 26)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Applicable to ion sources, low energy beam transport and diagnostics



Capabilities:

Total beam current	500 mA
Final energy	70 keV
Polarity	bipolar
Diagnostics	e scan mass spec

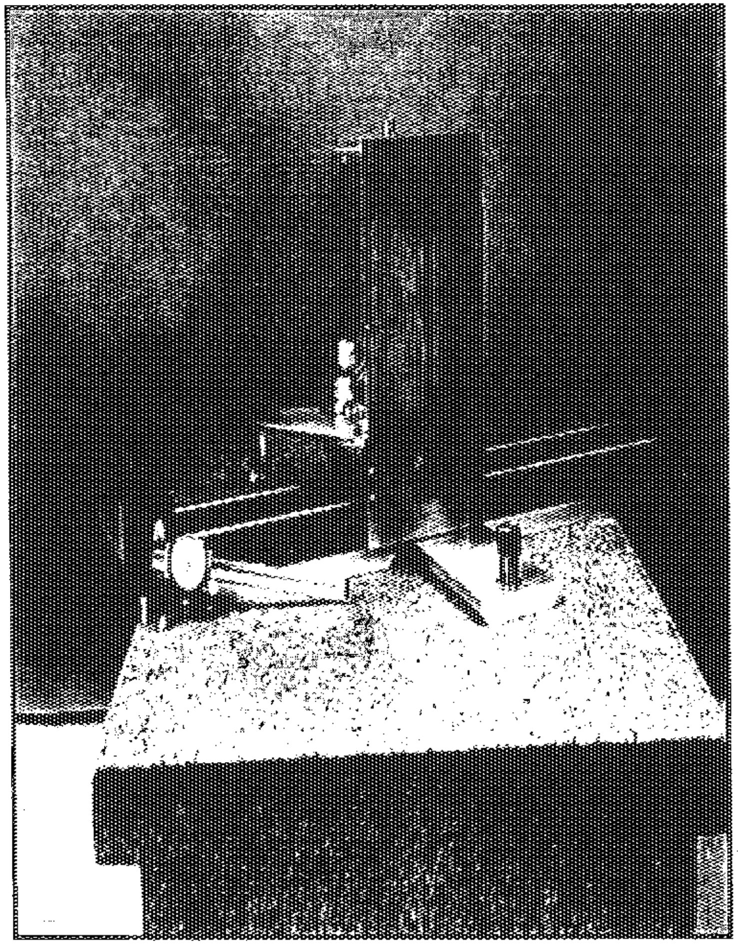
Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

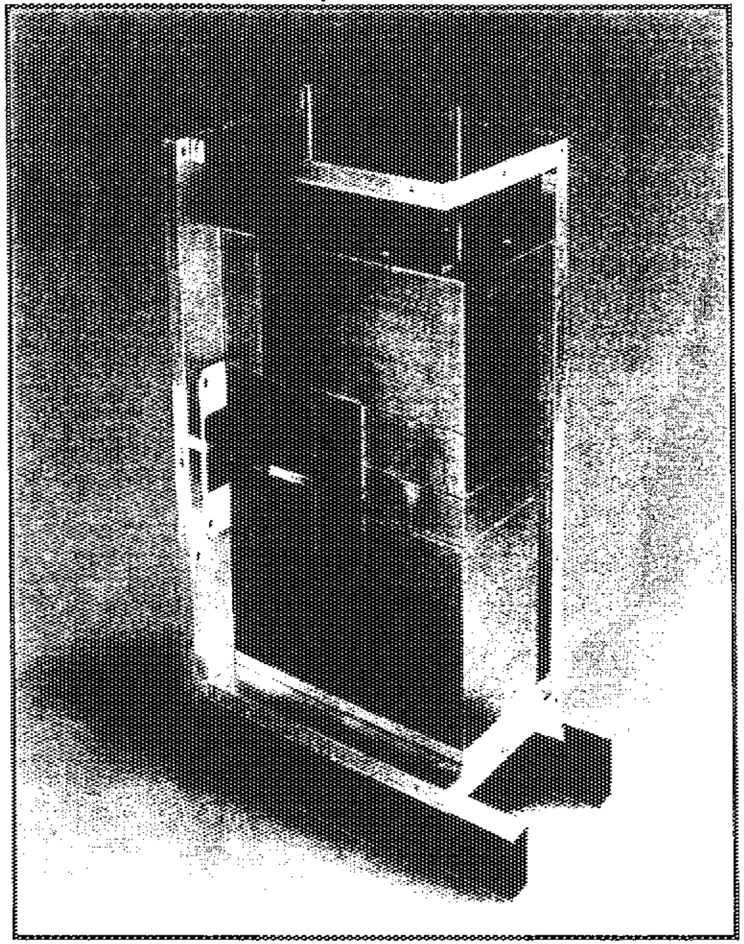
CW Beam Diagnostics On Test Stand

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Emittance Scanner



Mass Spectrometer



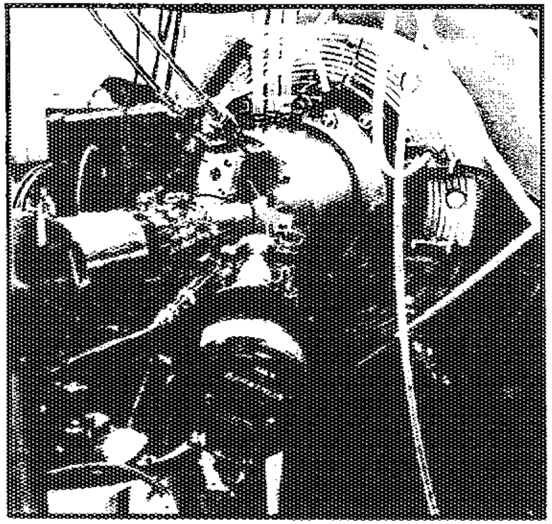
NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Sources for High Current Positive Ion Beams

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

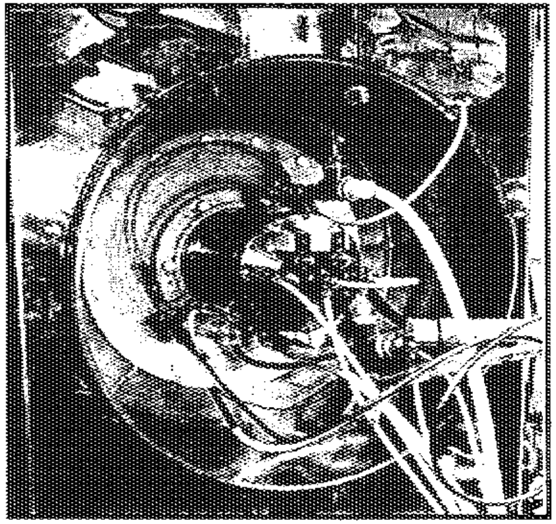
LBL Type RF Volume



Features:
- Highest output shown in pulsed mode (850 mA/cm^2)
- Long life at low power demonstrated (260 hr.)

Issue:
- Antenna survivability at high power uncertain

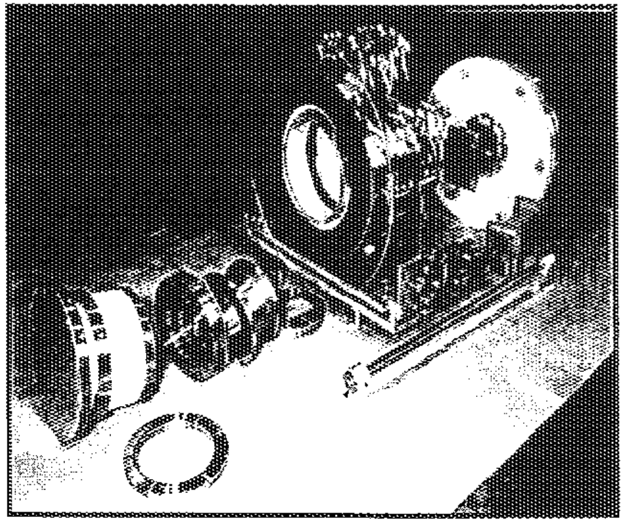
CDS Type Filament Volume



Feature:
- Advanced version on CDS shows good filament life of 5 to 6 weeks with H^- currents $\geq$ 12 mA

Issue:
- Positive ion output is presently unknown

Chalk River Type ECR



Feature:
- Demonstrated APT CW current @ LANL

Issue:
- Long term operating reliability and fault recovery
- Scalability to IFMIF due to plasma power & aperture limits

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Northrop Grumman's Positive Ion Source Development Program

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Goal
  - Select the best candidate for high current positive ion production (125 mA H^+ for APT, 145 mA D^+ for IFMIF)
  - Engineer to optimize output, reliability and maintainability
- Approach
  - Continue testing of RF multicusp source in higher power regime
  - Set up ECR source on separate stand and test in parallel for reliability and D^+ scaling
  - Consider CDS filament driven derivative as an alternative (include CDS experience)

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

Recent Progress

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

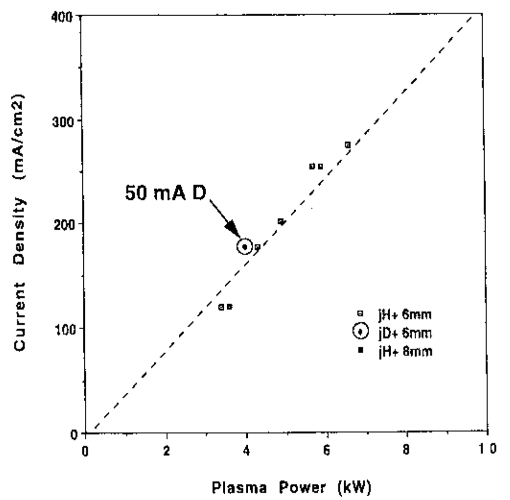
- Identified primary causes of CW RF source failure:
  - Instabilities in 35 kW RF amplifier at low power (≤ 10 kW)
  - External HV breakdown in RF isolation transformer (35 keV)
  - Upgraded test stand equipment on order (RF ampl, isol. matching)
- Began testing RF sources with deuterium
  - Limited 4 kW CW operation of 10 cm source
  - Total current power scans with pulsed 7 cm source
  - Initial results are encouraging
- ECR ion source is in-house and build up is ready to start
- Our CDS experience with TRIUMF filament source indicates long lifetime and reliable operation in H^- mode
  - Typically a good H^- multicusp source is a good H^+ source
  - Testing in positive ion mode is required

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

CW Performance of RF Multicusp Source

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Measured on 10 cm Diameter Source With 80 Gauss Filter Field



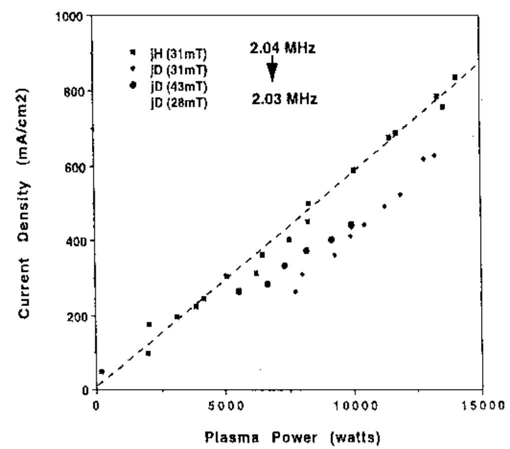
The limited data obtained so far with the RF driven multicusp source shows that total beam current density is constant over small changes in aperture diameter and that D^+ density is comparable to H^+ density

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

Recent Data With Pulsed RF Source

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Measured on 7 cm Source With 110 Gauss Filter and 3.6 mm Aperture *



The data confirms our assumption that total D output can be optimized in terms of RF match, and gas pressure to be about the same as H output

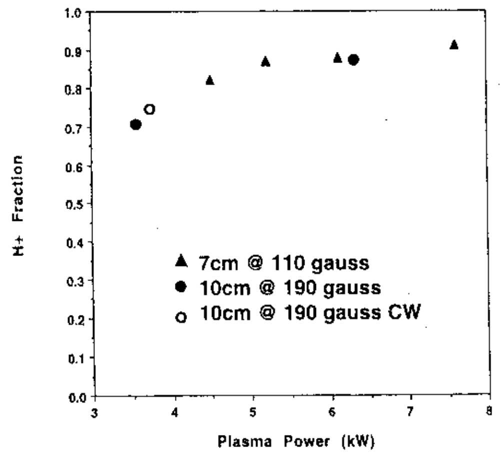
* Original electron separation collar in place, which significantly reduces output

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

Comparison of RF Multicusp Sources

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Measured Data From Pulsed & CW Operation



The data shows that the smaller source has H+ fractions comparable to the larger source but at lower filter field thereby permitting higher beam current density

This is explained from the higher plasma power density within the smaller source

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

A Path to IFMIF Source Requirements (RF Volume)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

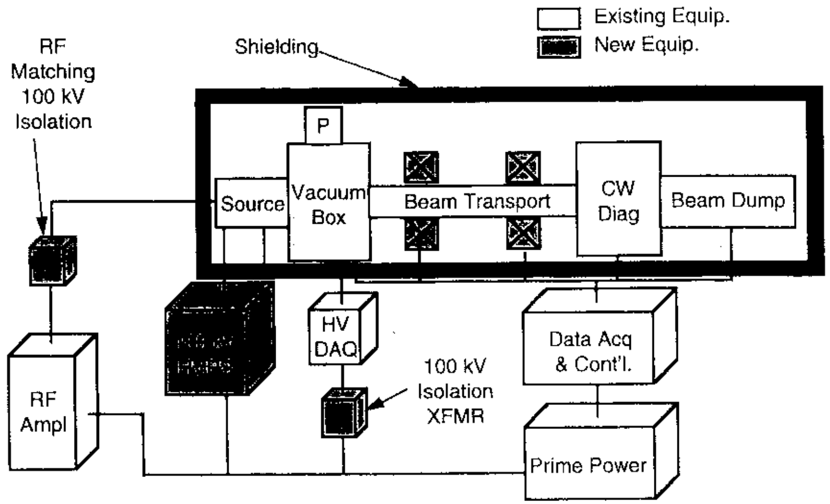
- The 7 cm source may be best due to higher operating efficiency ($mA/cm^2/kW/cm^3$) over 10 cm source
  - Demonstrated in pulsed mode
- Based upon a modest plasma power of 5 kW CW:
  - Assume D^+ fraction = H^+ fraction = 0.86 (from the previous chart)
  - jD = 300 mA/cm^2 (scaled from pulsed source data and should even be higher without aperture collar)
  - Therefore: jD^+ = 258 mA/cm^2
  - The aperture is: I_{D+}/j_{D+} = 145/258 = 0.562 cm^2 (8.5 mm dia)
- Verify scaling and CW operation of 7 cm source in 1996 under IRAD program
  - Consider options for higher D^+ fraction (i.e. H_2O, higher power)

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

IFMIF Injector Demo Block Diagram

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

The 8th advanced beam dynamic workshop on

Space Charge Dominated Beams
and Applications of High Brightness Beams

Bloomington, Indiana, USA
October 11-13, 1995

Nonlinear resonances, chaos and halo formation in space-charge dominated beams

J-M Lagniel

Commissariat à l'Energie Atomique - Direction des Sciences de la Matière
Groupe d'Etudes et de Conception d'Accélérateurs
(CEA-DSM-GECA)

CEA Saclay - Laboratoire National Saturne
91191 Gif-sur-Yvette Cedex - FRANCE

1

Nonlinear resonances, chaos and halo formation in space-charge dominated beams

J-M Lagniel

Commissariat à l'Energie Atomique - Direction des Sciences de la Matière
Groupe d'Etudes et de Conception d'Accélérateurs
(CEA-DSM-GECA)

CEA Saclay - Laboratoire National Saturne
91191 Gif-sur-Yvette Cedex - FRANCE

- Abstract -

A significant breakthrough in the understanding of the mechanisms leading to charge redistribution and halo formation in space-charge dominated beams has been achieved in the past few years. The first aim of this paper is to summarize the main results which have been obtained in recent studies. The nonlinear resonances excited by space charge forces are analysed, then it is shown that they can induce chaotic trajectories, therefore halo formation. The second objective is to present some ideas in order to try to promote new successful studies, as well as to point out the ambiguous character of some theories used in this field without any serious justification.

- I - Introduction.

In numerous nonlinear dynamical systems studied in various disciplines (fluid dynamics, celestial mechanics, chemistry, biology, ecology, economy...), chaotic (stochastic) motions are generated by the dynamics itself whereas no random force is present. The chaotic behaviour of particle trajectories has been studied for a long time in the accelerator field to understand the beam-beam effects in colliders and to determine the dynamic apperture of storage rings (see ref.[1] for example). During the 1972 linac conference [2], A. Sessler writted :

> "one can conjecture that the phenomenon studied in [Numerical calculations of the effects of space charge..., R. Chasman] is the result of nonlinear space charge forces causing particles to be above the stochasticity limit. It would be most illuminating to undertake analyses, analogous to those in [Research concerning the theory of non-linear resonance and stochasticity, B.V. Chirikov] and [Non-linear space charge effects, E. Keil, Arnol'd diffusion lifetime in storage rings, E. Keil]".

2

Nevertheless, nobody followed this idea at that time (it could be interesting to analyse the reason why), and it was only 21 years later that the stochastic (chaotic) behaviour of the particle trajectories induced by space charge force has been demonstrated for the first time [3].

The first aim of this paper is to summarize the main results which have been obtained from recent studies on unbunched beams evolving in continuous focusing and FODO channels. The nonlinear resonances excited by space charge force are analysed in section II, then it is shown how these nonlinear resonances can induce chaotic trajectories in section III. Charge redistribution and halo formation are analysed in section IV. Numerical simulation results showing the particle diffusion (due to the presence of nonlinear resonances and enhanced in the chaotic areas) are presented. On the basis of these studies, some ideas are also proposed in order to try to promote new succesful studies, as well as to point out the ambiguous character of ideas sometimes applied to this field without any real justification.

- II - Nonlinear resonances induced by space charge.

For azimuthally symetric beams evolving in a continuous focusing channel, the dimensionless equations of motion for both beam core envelope and individual (test) particles depend only on the space-charge tune depression $\eta = \sigma_t / \sigma_{0t}$ where σ_t and σ_{0t} are the phase advances *per unit length* respectively with and without space charge [4]. When the beam is mismatched, resonances between the particle motion and the space-charge force (a "nonlinear oscillating perturbing force") can be characterized by the tune $\nu = \sigma_{particle} / \sigma_{core}$. The core envelope oscillation being characterized by $\sigma_{core} = \sqrt{2(\sigma_{0t}^2 + \sigma_t^2)}$, the tunes are given by :

$\nu_t = \sigma_t / \sigma_{core} = \eta / \sqrt{2(1+\eta^2)}$ for particles injected inside the core for uniform distributions, or for particles traveling near the axis of nonuniform beams if σ_t is the phase advance on the axis,

$\nu_\infty = \sigma_{0t} / \sigma_{core} = 1 / \sqrt{2(1+\eta^2)}$ for particles injected further and further from the core because the influence of the space-charge force becomes smaller and smaller [5].

For beams with uniform or monotonically-decreasing distributions, the tune of the test particles is then such that $\nu_t \le \nu < \nu_\infty$. Figure 1 (from Ref.[5]) gives the tune spread of the particles versus the space-charge tune depression η, then the range of nonlinear resonances which are excited by the beam core oscillation for a given η value. This analysis already presented in Ref.[5] and rediscovered in Ref.[6] shows that the strong $\nu = 1/2$ resonance is always present. For beams evolving in a continuous focusing channel, the excitation of these resonances is a function of the mismatching level.

3

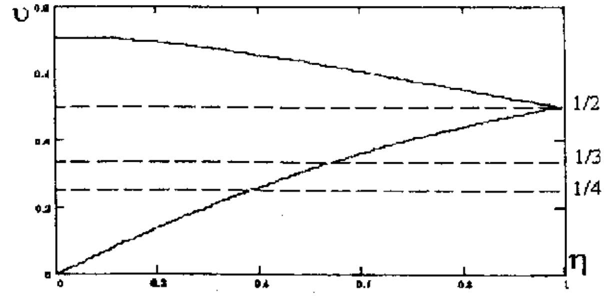


Fig. 1 : Tune spead of the particles versus space-charge tune depression

Figure 2 (from Ref.[5]) shows calculations of phase advances ($\sigma = 2\pi\nu$) for $\eta = 0.1$ and $\eta = 0.5$. To establish this figure, the evolution of particles injected with increasing amplitudes and x'= 0 is computed over one beam-core oscillation, then σ is calculated. The results are given for both uniform (KV) and Gaussian distributions with the same particle density on the axis. Obviously, the nonlinear resonances can be excited into the beam core for nonuniform densities.

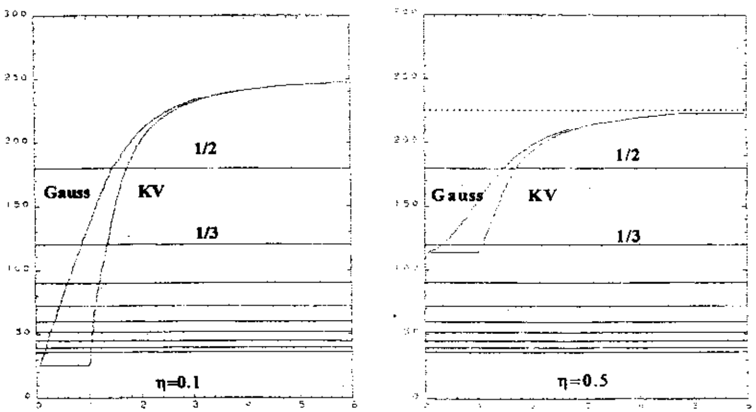


Fig.2 : Phase advances : $\sigma = 2\pi\nu$ (°) vs the particle amplitude for $\eta = 0.1$ (left) and $\eta = 0.5$ (right) for KV and Gaussian distributions with Ro = Rrms = 1. The nonlinear resonances 1/2, 1/3 ... are also ploted.

4

For a matched beam in a FODO channel [7-8-9], again both order and number of resonances are determined by the choice of the phase advances *per focusing period* σ_{0t} and σ_t. For uniform or monotonically-decreasing distribution functions for which the phase advance on the axis is σ_t, the tune of the particles which travel near the axis is close to $\nu = \sigma_t / 2\pi$. When the transverse energy of the test particles is increased, the space-charge effect becomes more and more negligeable, the tune of the particles which travel far from the axis is then close to $\nu_\infty = \sigma_{0t} / 2\pi$. The parametric resonances which are *excited by the FODO channel* when the beam is matched are then in the range :

$$\sigma_t / 2\pi \leq \nu < \sigma_{0t} / 2\pi$$

For mismatched beams in a FODO channel, the main nonlinear resonances excited by the beam modulation due to the quadrupolar focusing are still present and, in addition, new resonances are excited by the two eigen frequencies of the mismatched envelope oscillation [9].

For weak mismatches, the envelope equations in smooth approximation can be linearized and, following I. Hofmann [10], the two eigen modes (even and odd) can be calculated. They are given by :

$$\sigma_e = \sqrt{2(\sigma_{0t}^2 + \sigma_t^2)} \text{ and } \sigma_o = \sqrt{\sigma_{0t}^2 + 3\sigma_t^2}$$

The rms envelope equations have been numerically integrated (without smooth approximation) for $\sigma_{0t} = 62°, \sigma_t \sim 20°$, and a weak initial mismatch (10% in the (x,x') plane). The Fourier spectrum of the envelopes (figure 3) shows that, even for this weak mismatch, the amplitudes of the odd and even modes (the two peaks at low frequency) are already large compared to the one of the main mode (f=1). These eigen frequencies are very close to those calculated using the theoretical formulas derived using the smooth approximation. It must be pointed out that for large mismatches, the envelope oscillations become rapidly chaotic [11], a more complicated frequency spectrum can be observed.

Above the main resonances excited by the natural beam modulation due to the quadrupolar focusing system ($\sigma_t / 2\pi \leq \nu < \sigma_{0t} / 2\pi$), new resonances are then excited by the two eigen frequencies of the envelope oscillations when the beam is mismatched. These additional resonances are in the range

$$\sigma_t / \sigma_{e,o} \leq \nu_{e,o} < \sigma_{0t} / \sigma_{e,o}$$

then : $\eta / \sqrt{2(\eta^2+1)} \leq \nu_e < 1 / \sqrt{2(\eta^2+1)}$ for the even mode

and $\eta / \sqrt{3\eta^2+1} \leq \nu_o < 1 / \sqrt{3\eta^2+1}$ for the odd mode [9].

Figure 4 shows the range of resonances which can be excited by the two modes as a function of the tune depression η. As in the case of a continuous focusing channel, the strong $\nu = 1/2$ resonance is always present.

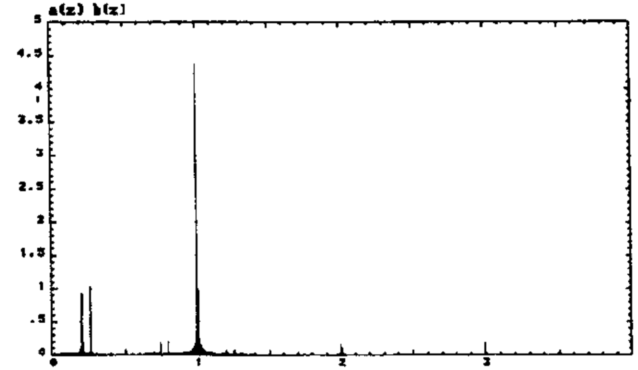


Fig.3 : Fourier spectrum of a mismatched beam envelope.
The frequency of the envelope oscillation induced by the quadrupoles is f = 1,
the two low frequency peaks are the two eigen frequencies
of the mismatched envelope oscillation.

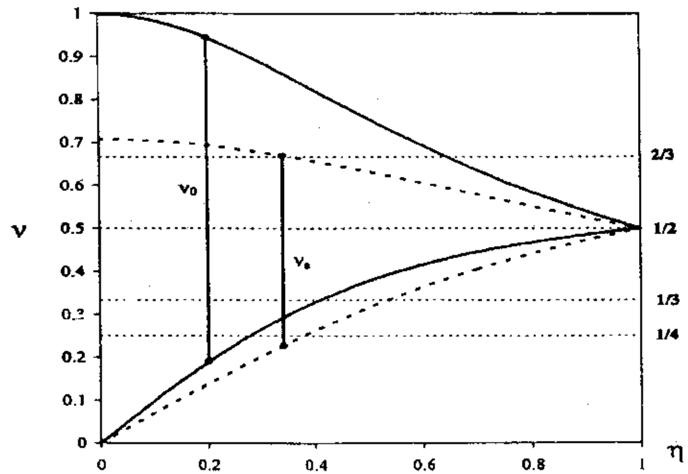


Fig.4 : Range of resonances excited by a mismatch versus η.
Each pair of curves defines the range of the nonlinear resonances
(ν=2/3, 1/2, 1/3...) which are excited by the odd (ν_o) and even (ν_e) modes.
For $\eta \leq 0.4$, the strong resonances ν = 2/3, 1/2, 1/3 and 1/4 are excited.

- III - Chaos induced by the nonlinear resonances -

The very first observation of chaotic particle trajectories has been presented in Ref.[3] for space-charge dominated beams evolving in a continuous focusing channel. These analyses [3] have been confirmed in Ref.[4] for different values of the tune depression and for a nonuniform distribution. This significant breakthrough in the understanding of the mechamisms leading to charge redistribution and halo formation in high-intensity beams has been achieved thanks to the Particle-Core Model (PCM) [12]. As usually done to study *complex systems*, the PCM is a simplified model which keeps the dominant properties of the real physical system and which allows an analysis of the basic phenomena.

In Ref.[3], it has been demonstrated that the *resonance overlap mechanism* can lead to the formation of a halo area where the particle trajectories are stochastic. This chaotic behaviour has been clearly observed using the Poincaré surface of section technique (figure 5). Sensitive dependance on initial conditions (figure 6) and intermittencies which characterize chaotic systems have also been shown. These results have been confirmed by analytical studies [13] as well as by numerous simulations done using multiparticle PIC codes [14].

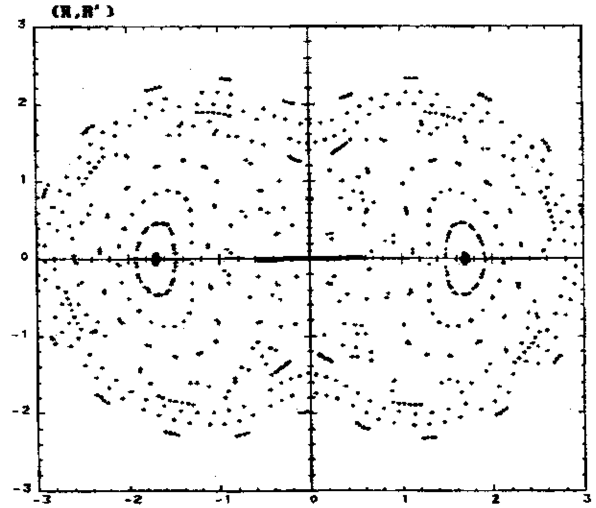


Fig. 5 : Poincaré surface of section for $\eta = 0$ (from Ref.[3])
The two $\nu = 1/2$ islands are localized around R = ± 1.7 and R' = 0.
The outer curves are "KAM surfaces" which limit the chaotic area.

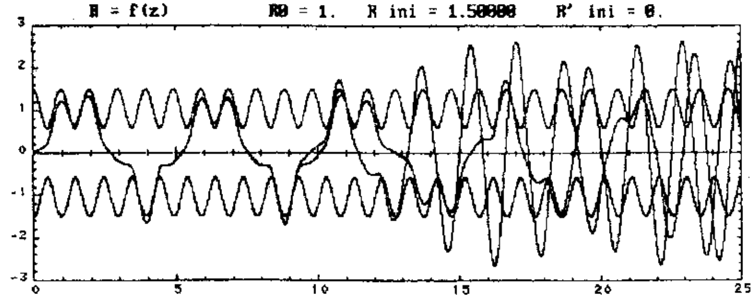


Fig. 6 : Sensitive dependence on initial conditions.
The trajectories of two particles injected at x = 0, x' = 0.10000 and 0.10001 (initial dx'/x' = 10^{-4}) are completely different after 10 beam core oscillations.

The PCM has also been used to study the behaviour of matched beams in a FODO channel [7-8-9]. The Poincaré surface of section technique is used again to analyse the phase space topology. Figure 7 clearly shows the position of some resonances in the (x,x') phase plane for uncoupled (y = y' = 0) particles.

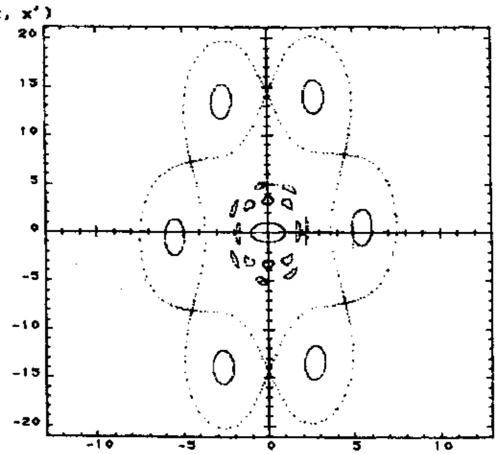


Fig. 7 : Poincaré surface of section (x,x') for $\sigma_{0t} = 62^{o}$ and $\sigma_t = 20^{o}$

As pointed out in section II, the $\nu = 1/6$ resonance is excited far from the beam core because it corresponds to a phase advance $\sigma = 60^{\circ}$ close to $\sigma_{0t} = 62^{\circ}$. The size of the chaotic areas is limited when the strong nonlinear resonances $\nu = 1/4$ and $\nu = 1/5$ are avoided, that is when $\sigma_{0t} < 72^{\circ}$. For the parameters choosen to draw figure 7, thin chaotic zones (not shown in this figure) are present only on the periphery of the uniform-density beam core.

To take into account the coupling force induced by space charge leads to the analysis of a nonautonomous system with N = 2.5 degrees of freedom : (x,x')+(y,y')+z. In this case, resonances form a dense "Arnol'd web" into which particles can diffuse (Arnol'd diffusion) as demonstrated in Ref.[8].

For mismatched beams in a FODO channel, additional resonances are excited by the even and odd modes of the envelope oscillations (see section II and figure 4). Figure 8 illustrates the fact that "The more there are oscillators, the more they couple between themselves, and the more one can anticipate chaos to be observed" [15]. Drawn with $\sigma_{0t} = 62^{\circ}$ and $\sigma_t = 20^{\circ}$ (same parameters as figure 7), figure 8 shows the wide chaotic area formed around the beam core for a weak mismatch (+10% in x, -10% in y) which excites only the odd mode. The $\nu_0 = 1/2$ resonance is clearely shown by this Poincaré section [9]. At a larger amplitude, the main resonance $\nu = 1/6$ (figure 7) is not affected by the weak mismatch.

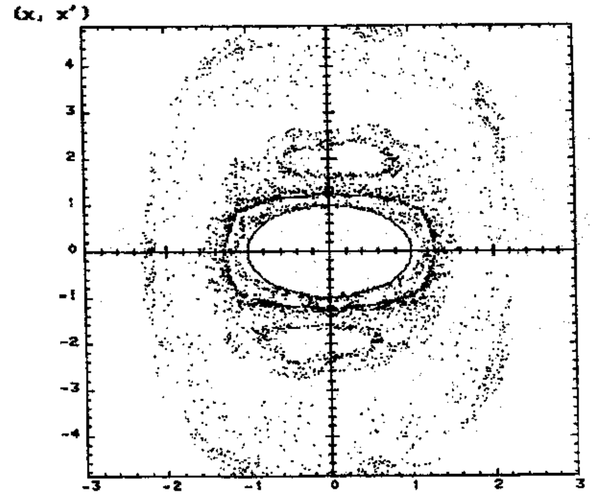


Fig. 8 : Poincaré section for an uncoupled particule, $\sigma_{0t} = 62^{\circ}$ and $\sigma_t = 20^{\circ}$ mismatch = +10% in x, -10% in y (odd mode only)

- IV - Halo formation induced by nonlinear resonances and chaos.

It is clear that nonlinear resonances can scatter particles around the beam core, this halo formation is highly enhanced when chaotic areas are formed :

Nonlinear resonances => Chaos => Halo formation

The links between these phenomena are now known : the resonance overlap mechanism explains the formation of stochastic areas, and diffusion in these stochastic areas (Arnol'd web for N > 2) increases particle redistribution and halo formation.

This knowledge has been used to find a way to avoid halo formation. The basic idea is simple : as halo comes mainly from particle diffusions in chaotic areas, halo formation will be avoided if the resonances do not overlap. This has been demonstrated in Ref.[8] where defocusing octupoles were used to cancel emittance growth and halo formation in a FODO channel tuned with $\sigma_{0t} = 100^{\circ}$. Other types of nonlinear correctors can also be used, modified octupoles have been proposed in Ref.[8], effects of duodecapoles are demonstrated in Ref.[16].

For realistic accelerator parameters ($\sigma_{0t} < 90^{\circ}$ and $\sigma_t > 0^{\circ}$ on the axis), we know that the stochastic web is thin, then the diffusion rates could be very low. Nevertheless, particle losses must be extremely low in the new generation of high-current accelerators. Arnol'd diffusion rates are low at large amplitude but relative losses lower than 10^{-7}/m must be achieved [17]. We must keep in mind that, for example, if one particle diffuses from an inner stochastic area to an outer one after 1000 or 10000 FODO periods, there is a high probability that one particle diffuses in few periods if the inner stochastic area is filled with 1000 or 10000 particles (ergodic hypothesis).

Anticipating *a priori* that such a type of diffusion is too slow to induce halo formation is not a scientific attitude. So, we have done a large number of simulations using the PCM to answer the question : can we observe diffusions along the Arnol'd web which drive particles from the beam core vicinity towards a resonance located far from it? To do this, up to 80000 test particles per simulation have been injected in the (x,y) plane (x' = y' = 0) and followed along 200 and 600 FODO periods. For each particule, the maximum radius (Rmax) reached during both 200 and 600 periods was stored in order to calculate Δ = (Rmax - Ro) / Ro which is a measure of the diffusion for a particle injected with an initial radius Ro. These studies have been done for different mismatching values and two tunes : $\sigma_{0t} = 62^{\circ}$ and $\sigma_t = 20^{\circ}$ for which the $\nu = 1/6$ resonance is located far from the beam core (see figure 7), $\sigma_{0t} = 75^{\circ}$ and $\sigma_t = 20^{\circ}$ for which, this time, the $\nu = 1/5$ ($\sigma = 72^{\circ}$) resonance is located far from the beam core.

Figure 9 gives a 3D representation of Δ versus the initial positions of the test particules in the ranges 0 < x <6 and 0< y < 6 with x' = y' = 0 and dimensions normalized with respect to the beam core radius. The large stochastic area located near the beam core and the $\nu = 1/6$ resonance area can be clearly localized but no diffusion from one area to the other can be observed.

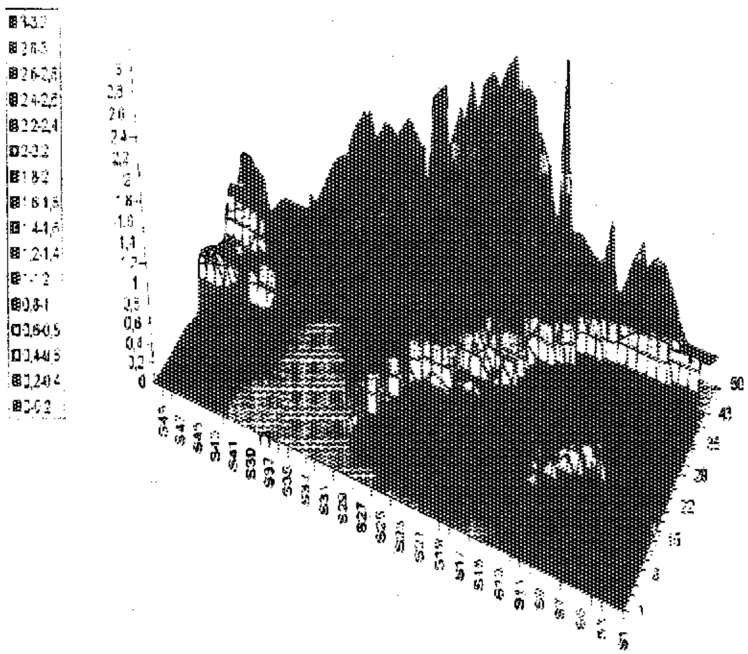


Fig. 9 : Example of simulation result for a mismatched beam in FODO channel
Δ (vertical axis), computed over 200 FODO periods, is ploted
versus the test particule initial position ($0 < x < 6$ and $0 < y < 6$ with Rcore ~ 1)
$\sigma_{0t} = 62°$ and $\sigma_t = 20°$, the mismatch is +10% in x and y

- IV - Conclusion -

Table 1 summarizes a large number of simulation results obtained using the PCM for weakly or strongly mismatched beams. The values of Δ which are reported in this table concern only the particules injected in the stochastic area surrounding the beam core ($1 < Ro < 2$, see figures 8 and 9). From this initial positions, Δ must reach values around 4 or 5 if the test particules diffuse towards the $\nu = 1/6$ or $\nu = 1/5$ resonances.

Δ for	$\sigma_{0t} = 62°$, $\sigma_t = 20°$		$\sigma_{0t} = 75°$, $\sigma_t = 20°$	
mismatch X-Y	# = 200	# = 600	# = 200	# = 600
1.1-1.1	0.8	0.8		
1.1-0.9	0.8	1.2		
1.3-0.7	1.0	1.4		
1.0-1.1	0.8	1.0	1.2	1.4
1.0-1.2	1.0	1.2	1.6	1.6
1.0-1.3	1.0	1.2	1.4	1.8
1.0-1.4	1.0	1.4	1.8	2.0
1.0-1.5	1.2	1.4 (zoom =1.8)	1.6	2.2

Table 1 : Values of Δ versus the mismatching factor for two tunes
is the number of FODO periods for the calculation of Δ

The main result of these studies is that we never observed particles jumping from the beam core vicinity to a strong resonance (1/6 or 1/5) located far from it. The maximum amplitude reached by particles injected close to the uniform beam core ($1 < Ro < 2$) is limited to approximatively 3 times the beam core radius. Nevertheless, a zoom showing the values of Δ in a narrow area located on the beam core border (figure 10) recalls us that the system we are studying is chaotic, therefore very sensitive to the initial conditions.

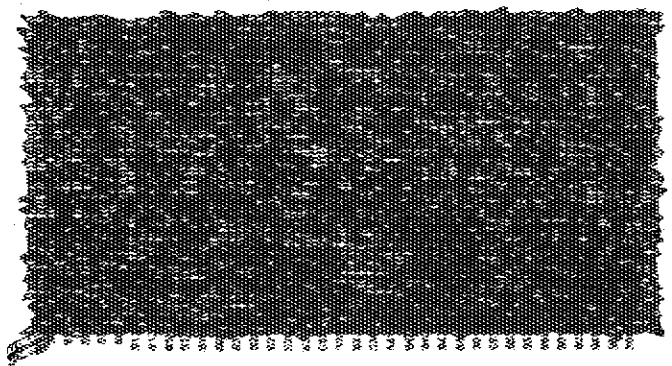


Fig. 10 : Zoom on initial positions $0.06 < x < 0.22$ and $1.05 < y < 1.12$
for $\sigma_{0t} = 62°$, $\sigma_t = 20°$, x mismatch = 1 (0%) and y mismatch = 1.5 (50%).
In this chaotic area, the Δ value ($0 < \Delta < 1.8$)
is very sensitive to the initial conditions.

Then, even with the PCM, our "toy model" which is used to simplify the studies, it is necessary to inject a very large number of test particles to check that a very low fraction ($\sim 10^{-7}$/m) of the beam does not diffuse at large amplitudes. An accurate code able to handle a very large number of particles ($>10^{6}$) is developed by R. Ryne at LANL. From the studies presented here, it seems that it is the only way to obtain the results needed for the next generation of high-current linacs.

Another remark can be made. For *collisionless* beams evolving in FODO channels (without acceleration), we are dealing with *conservative Hamiltonian systems*. With the nonlinear space-charge forces, these systems are *nonintegrable*. We have shown some characters which are common to this class of systems :

-1- The global properties of the system are determined by the location and the size of the nonlinear resonances and by the *resonance overlap* mechanism which leads to the formation of stochastic (chaotic) areas.

-2- Particle diffusion and halo formation are *enhanced* in the chaotic areas (Arnol'd web for N > 2).

-3- Beams which are not a priori unstables (beam current around 100 mA, $\sigma > 0$ on the axis) are in a *regime of weak chaos*. The system contains a mixture of *quasiperiodic (KAM) and chaotic orbits*, and a mixture of *stable and unstable periodic orbits* (fixed points).

-4- The flow is *ergodic only on a subspace* of the phase space (the chaotic regions) but isolated adiabatic islands exist in these regions. Fortunately, *the system is not in a regime of strong chaos.*

At this point, following J.D. Lawson [18], "it may be asked whether the concepts of statistical mechanics and thermodynamics can yield new insights or put on a more firm footing recent work on emittance growth" (and halo formation). This question addresses in fact one of the most challenging problems studied (since 150 years !) by theoretical physics : the bridge between dynamics and thermodynamics. This bridge is under construction on the basis of the chaos theory which shows that the structure of the equations of motion with "deterministic randomness" on the microscopic level emerges as irreversibility on the macroscopic level. In other words, Boltzmann irreversibility is a consequence of molecular chaos "superimposed" on the equations of dynamics; in a purely dynamical system, both randomness and irreversibility can be consequences of the equations of motion. But, the deterministic description in terms of Liouville equation can be transformed into a Markov chain *only* if the system is strongly chaotic. Then, it seems that the Fokker-Planck equation cannot be used to study the global evolution of beams which are not unstables. These arguments also push us to think that, as in the past, to regard the beam as a 'drifting gas' described in terms of thermodynamic variables will not lead to any new insights of practical value.

It must be added that particles evolving in an accelerator are usually accelerated. Then, the system becomes a *nonconservative nonintegrable system*. Its behaviour is very different from the one described here (to be published).

13

Bibliography

[1] L.R. Evans and J. Gareyte, "Beam-beam effects". 1985 CERN Accelerator School, CERN 87-03, 1987.

[2] A. M. Sessler, "Collective phenomena in accelerators", LINAC72 Conf. Proc., October 1972, p.291.

[3] J-M. Lagniel, "On halo formation from space-charge dominated beams", LNS/SM/93-35, August 1993 and NIM-A Vol.345 (1994) No.1, p.46.

[4] T.P. Wangler, "Dynamics of beam halo in mismatched high-current charged-particle beams", LA-UR-94-1135, March 1994.

[5] J-M. Lagniel and A-C. Piquemal, "On the dynamics of space-charge dominated beams", LINAC94 Conf. Proc., August 1994.

[6] see the works presented during this workshop by S.Y. Lee and A. Riabko.

[7] J-M. Lagniel, "Chaotic behaviour and halo formation from 2D space-charge dominated beams", LNS/SM/93-42, December 1993 and NIM-A Vol.345 (1994) No.3, p.405.

[8] J-M. Lagniel, "Chaotic behaviour induced by space charge", EPAC94 Conf. Proc., June 1994, p.1177.

[9] J-M. Lagniel and D. Libault, "Chaos, a source of charge redistribution and halo formation in space-charge dominated beams, PAC95, May 1995.

[10] I. Hofmann, "Transport and focusing of high-intensity unneutralized beams", in Applied charged particle optics (C), A. Septier, Academic press, 1983]

[11] C. Chen and R.C. Davidson, "Non-linear resonances and chaotic behavior in a periodically focused intense charged particle beam", Physical Review Letters, Vol.72 (1994), No.4, p.2195.

[12] J.S. O'Connell, T.P. Wangler, R.S. Mills and K.R. Krandall, "Beam halo formation from space-charge dominated beams in uniform focusing channels", PAC93 Proc, p.3657.

[13] R.L. Gluckstern, "Analytic model for halo formation in high current ion linacs", Physical Review Letters, Vol.73, No.9, August 1994.

[14] see T.P. Wangler, R. Ryne, A. Piquemal, C. Chen ..., this workshop.

[15] D. Ruelle, "Hasard et chaos", Editions Odile Jacob, 1991.

[16] see the works presented during this workshop by Y. Batygin

[17] J.R. Delayen et al., "Design considerations for high-current superconducting ion linacs", PAC93 Proc. p.1715 and earlier references therein.

[18] J.D. Lawson, "The emittance concept", High-brightness beams for advanced accelerator applications, AIP Conf. Proc. No.253, 1991.

14

HALOS AND CHAOS IN SPACE-CHARGE DOMINATED BEAMS

J-M. LAGNIEL

Commissariat à l'Energie Atomique
DSM-GECA, CEA-Saclay, LNS
91191 Gif-sur-Yvette Cedex, France

IFMIF meeting, JAERI, May 1996

(To be presented at EPAC96)

The first aim of this lecture is to summarize the main results obtained from both analytical studies and numerical simulations related to emittance growth and halo formation induced by space charge

1

I- Motivations for such studies

Particle accelerators able to deliver high-power beams as drivers for the production of high neutron flux

High-power proton beams (40...100 mA CW, 40...100 MW) for transmutation of radioactive waste, energy production, tritium production

~ 5 MW H^- beams with peak current greater than 100 mA for the new generation of pulsed spallation sources

two 125 mA CW deuteron beams accelerated up to 35 - 40 MeV for IFMIF (International Fusion Materials Irradiation Facility)

The most important aim
is to keep beam losses along the structure
below an extremely low threshold
in order to limit the radioactivity in the machine area

2

Maximum tolerable losses

Proton beams

Energy (MeV)	tolerable loss (nA/m)	relative level (ΔI/I /m) for I = 100mA
10	200	$2\ 10^{-6}$
20	15	$1.5\ 10^{-7}$
50	2.5	$2.5\ 10^{-8}$
100	1	$1\ 10^{-8}$
200	.2	$2\ 10^{-9}$
500	.05	$5\ 10^{-10}$
1000	.03	$3\ 10^{-10}$

Proton losses producing a gamma dose of 2.8 mrem/hr
at 1 m from the machine 1 hr after shutdown
(rough values from Fedotov and Murin & Golubeva *et al.*)

=> <u>from ~200 nA/m at 10 MeV to less than 1 nA/m at 1 GeV</u> <=

Deuteron beams

Dose rates at 30 cm from copper and niobium
35 MeV deuteron accelerators for a constant 1 nA/m loss :
~3.5 mrem/hr 8 hours after shutdown
~2.5 mrem/hr only just after 24 hours
(J.R. Delayen *et al.*)

=> **relative losses in the range $\Delta I/I \sim 10^{-6}$ /m to $\sim 10^{-9}$/m must be achieved**

3

A very low fraction of the total beam must not reach large amplitudes

emittance-growth studies (synchrotron injectors)

==>

"halo-formation" studies (High-power linacs)

diffuse "halo" of particles surrounding the central beam core
(numerical simulations and measurements of high-current beams)

Emittance growth and halo formation induced by space charge

different physics or two different manifestations of the same physics ?

Emittance-growth and halo-formation mechanisms

for

unbunched beams in continuous or periodic focusing channels

unneutralysed and <u>*collisionless*</u> ("Liouvillean beams")

(For beams with Markov process, see J. Struckmeier)

4

II- Emittance growth mechanism

Two key papers by Iñgo Hofmann (1983) and Tom Wangler (1991)

4 distinct emittance-growth mechanisms :

- rms-mismatch mechanism -

betatron frequency dependent of the particle amplitudes
=> filamented pattern in phase space

Equilibrium = *internally matched* state
for which the distribution isodensity contour = particle phase-space trajectories

Emittance growth formula considering that
the free energy available in the rms-mismatched beam => "thermal" energy

- charge-redistribution mechanism -

Affects beams which are rms-matched but internally mismatched

Internal plasma oscillations drive the nonuniform initial density towards
a central uniform core and a finite thickness boundary

Emittance growth formula (conversion of nonlinear field energy to thermal energy)

Coherent space-charge effects are considered to be the source of instabilities

- energy-transfer mechanism -

Emittance transfer between two degrees of freedom => energy equipartition

(P. Lapostolle, 1968, first demonstrated by M. Promé in computer studies, 1970)

While the collisionless character of the beam precludes any thermodynanical
equipartition of the temperature anisotropy

extensively studied after that by I. Hofmann, R.A. Jameson, T.P. Wangler, M. Reiser.....

I. Hofmann : *collective instabilities* can be excited and lead to equipartitioning

Instability thresholds

- structure-resonance mechanism -

Periodic structures induce envelope growth and excite *coherent modes*

$\sigma_{0t} < 90^{\circ}$ in order to avoid these instabilities

5

III- Incoherent space-charge resonances

Two papers presented at PAC93 :

J.S. O'Connell, T.P. Wangler, R.S. Mills and K.R. Krandall
R.A. Jameson

pointed out that the interactions of single particles with an oscillating beam core
can be resonant and drive the particles at large amplitude

incoherent space-charge effects

(by analogy with the incoherent beam-beam effect)

First : analyse the resonances which can be excited (J-M. Lagniel)

The envelope equations
(beam radius evolutions in the horizontal (a) and vertical (b) planes)
in smooth approximation :

$$\frac{d^2a}{ds^2} + \sigma_{0t}^2 a - \frac{\varepsilon^2}{a^3} - \frac{2K}{a+b} = 0$$

$$\frac{d^2b}{ds^2} + \sigma_{0t}^2 b - \frac{\varepsilon^2}{b^3} - \frac{2K}{a+b} = 0$$

σ_{0t} is the zero-current betatron phase advance

K is the generalised perveance

$\varepsilon = \varepsilon_x = \varepsilon_y$ is the total emittance

For weak mismatchs, (I. Hofmann)

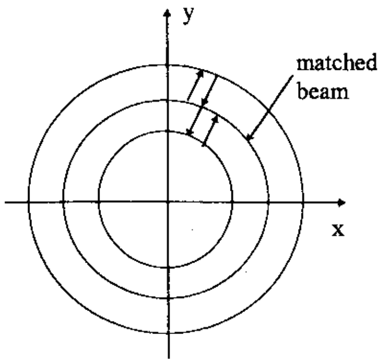
the two eigen modes (even and odd) of the envelope oscillations are characterised by :

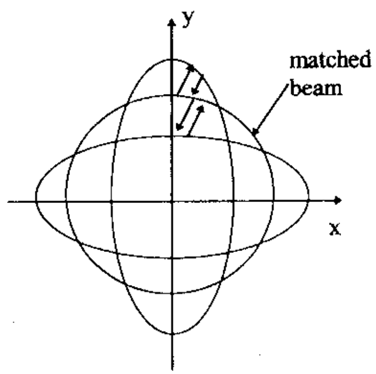
$$\sigma_e = \sqrt{2(\sigma_{0t}^2 + \sigma_t^2)} \qquad \sigma_o = \sqrt{\sigma_{0t}^2 + 3\sigma_t^2}$$

where σ_t is the betatron phase advance with space charge

6

The even and odd modes are also called "breathing" and "quadrupolar" modes



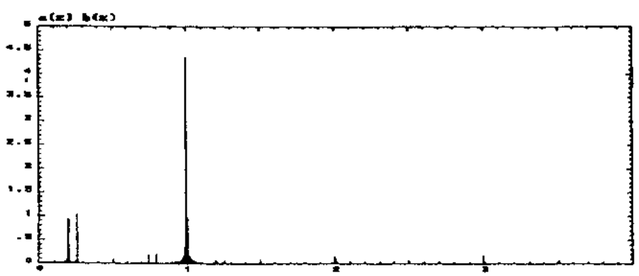


The envelope oscillations are function of the focusing system :

- for a *continuous focusing channel*
these two modes can be excited only if the beam is mismatched

- for a *periodic solenoidal channel*
the beathing mode is "intrinsically excited" for a matched beam $\sigma_i = 2\pi$
For a mismatched beam the two eigen modes σ_e and σ_o can be excited in addition

- for a *FODO channel*
the intrinsic quadrupolar mode ($\sigma_i = 2\pi$) is permanently excited
the two eigen modes are added when the beam is mismatched



Fourier spectrum of a mismatched beam envelope in a FODO channel

7

Incoherent space-charge effects can then be "excited"
even if the beam is matched
Beam mismatching is an additional source of excitation
but is not a *sine qua non* condition for emittance growth and halo formation

Resonant interactions between the particle motion and these oscillating forces can be characterized by the space-charge tune :

$$\nu = \sigma_{particle} / \sigma_{core} \quad \text{with} \quad \sigma_{core} = \sigma_i, \sigma_e \text{ or } \sigma_o$$

$\sigma_t \leq \sigma_{particle} < \sigma_{ot}$ => resonances excited by core oscillations in the range

$$\sigma_t / \sigma_{i,e,o} \leq \nu_{i,e,o} < \sigma_{0t} / \sigma_{i,e,o}$$

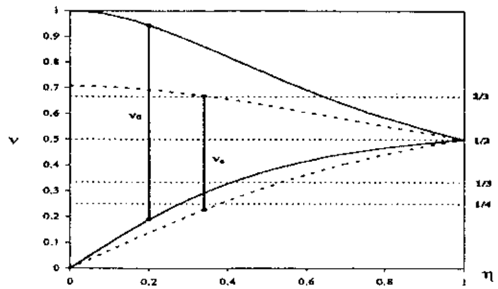
Range of intrinsic resonances (matched beam in a periodic focusing channel)

$$\sigma_t / 2\pi \leq \nu_i < \sigma_{0t} / 2\pi$$

Range of the additional resonances excited by a mismatched beam

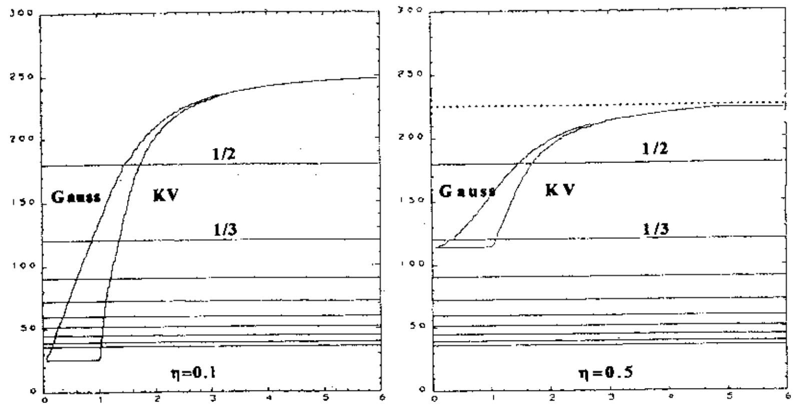
$$\eta / \sqrt{2(\eta^2+1)} \leq \nu_e < 1 / \sqrt{2(\eta^2+1)} \quad \eta / \sqrt{3\eta^2+1} \leq \nu_o < 1 / \sqrt{3\eta^2+1}$$

where $\eta = \sigma_t / \sigma_{0t}$ is the tune depression



$\nu_{e,o} = 1/2$ resonances are always excited, $\nu_{e,o} = 1/4$ is not present for $\eta > 0.4$

8



Even mode resonances vs particle amplitude
for η= 0.1 (left) and η= 0.5 (right)
in KV and Gaussian distributions with R and R_{rms} = 1

Incoherent nonlinear resonances can be excited
into the beam core of a nonuniform distribution

they can drive the nonuniform beam core towards an uniform distribution,
even if the beam is not strongly "space-charge dominated" (η ~ 0.4)

For a high-intensity beam accelerated by a linac (at relatively low energies)
the tune spread induced by space charge is large

Real accelerators designs (140 mA) =>

$\eta_t = \sigma_t / \sigma_{0t}$ rises as 0.40 0.62 0.91 at 20 200 1600 MeV
$\eta_l = \sigma_l / \sigma_{0l}$ falls as 0.50 0.24 0.08 at 20 200 1600 MeV
(R.A. Jameson, G.P. Lawrence, S.O. Shriber EPAC92)

difficult (indeed impossible) to avoid strong *incoherent space-charge resonance*,
at least at low energy (η IFMIF = ?)

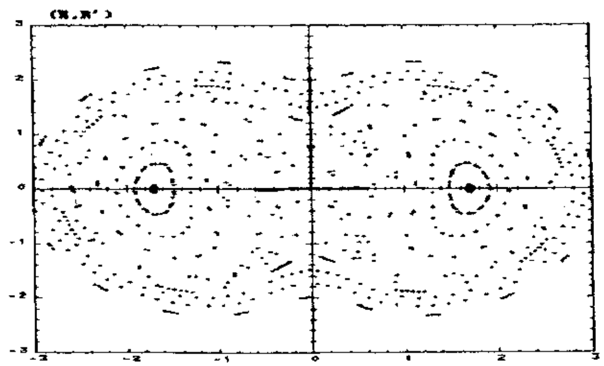
IV- Halos and Chaos

In order to get a meaningful insight of the physics underlaying any *complex system*,
models must be built geting rid of details of the real system
by seeking some hierarchy in the physical processes involved.
Simplifying assumptions are essential to understand the system dynamic properties,
an understanding which is imposible looking to computer simulations
done with a large number of particles.

Following this idea, the Particle-Core Model (PCM)
(J.S. O'Connell, T.P. Wangler, R.S. Mills and K.R. Krandall, PAC93)
is the best tool to study the *incoherent space-charge effects*

This is a two-step method :
- the *beam core* envelope evolution is first computed,
- the behaviour of *test particles* injected into or around the beam core is analysed.

The very first observation of chaotic particle trajectories (J-M Lagniel, 1993)
space-charge dominated beams in *continuous focusing channels.*



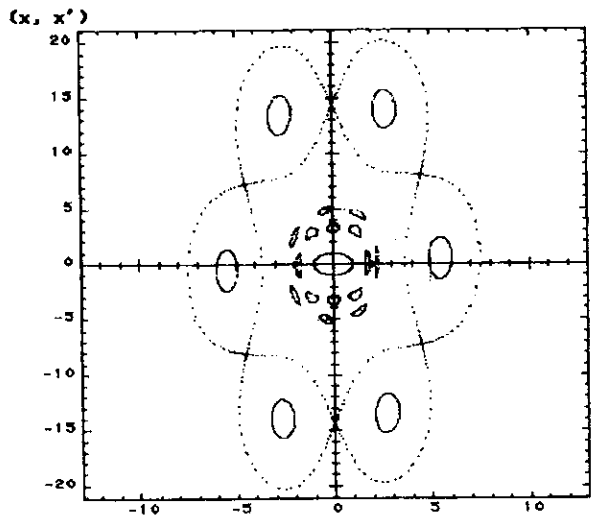
Poincaré surface of section
The two ν_c = 1/2 islands are surrounded by "KAM tori" which limit the chaotic area

This chaotic behaviour is induced by the *resonance overlap mechanism*

These analyses have been confirmed

* for different values of the tune depression and for a nonuniform distribution using the PCM T. Wangler 1994
* by analytical studies
  R.L Gluckstern, S.Y Lee et al. ....since 1994
* by numerous simulations done using multiparticle PIC codes
  see T.P. Wangler, R. Ryne, C. Chen, A.C. Piquemal ....
  The 8th advanced beam dynamic workshop on Space Charge Dominated Beams and Applications of High Brightness Beams

The PCM has also been used to study the behaviour of matched beams in a FODO channel (J-M. Lagniel 1993...)



Poincaré surface of section (x,x') for $\sigma_{0t} = 62°$ and $\sigma_t = 20°$

To take into account the coupling force induced by space charge leads to the analysis of a nonautonomous system with N = 2.5 degrees of freedom

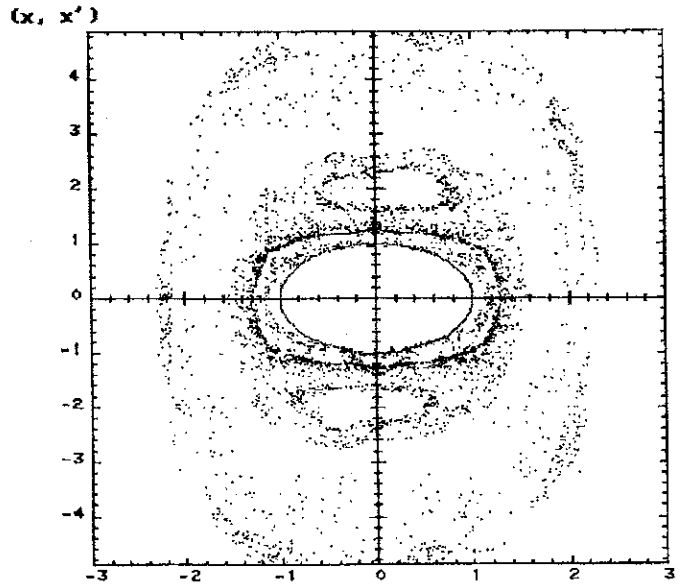
(x,x')+(y,y')+z

=> resonances form a dense "Arnol'd web" into which particles can diffuse

Arnol'd diffusion (J-M. Lagniel PAC94)

mismatched beams in a FODO channel (J-M. Lagniel - D. Libault PAC95)

additional resonances are excited by the even and odd modes of the envelope oscillations



Drawn with the same parameters as the previous figure

Wide chaotic sea formed around the beam core for a weak mismatch (+10%)

which excites only the odd mode ($\nu_o = 1/2$)

The intrinsic resonance $\nu_i = 1/6$ (larger amplitude) is not affected

Conclusions on Halo formation induced by *incoherent space-charge resonances* and chaos :

Incoherent space-charge nonlinear resonances
can scatter particles around the beam core
this halo formation is highly enhanced when chaotic areas are formed :

Nonlinear resonances => Chaos => Halo formation
=> weak chaos =>

The links between these phenomena are now known :
the resonance overlap mechanism explains the formation of stochastic areas
diffusion in these stochastic areas (Arnol'd web for N > 2)
increases particle redistribution and halo formation

This knowledge has been used to find a way to avoid halo formation
halo formation is avoided if the resonances do not overlap
Demonstrated for a FODO channel + octupoles tuned with $\sigma_{0t} = 100°$
=> neither emittance growth nor halo formation (Lagniel, EPAC94)
see also Y. Batygin (duodecapoles)

From a large number of simulations :

We never observed particles jumping from the beam core vicinity
to a strong resonance located far from it.

The maximum amplitude reached by particles injected close to the uniform beam core
is limited to approximatively 3 times the beam core radius

Nevertheless, the system we are studying is chaotic,
therefore very sensitive to the initial conditions .
=> difficult to say if 1 particle / 10^9 do not reach larger amplitudes

large number of Theoretical work and simulations
done only for continuous beams (without acceleration)

13

V- Accelerated beams

Previous sections deal with the transverse dynamics of continuous beams
=> analyse of a *nonintegrable conservative Hamiltonian system*
For accelerated beams
=> analyse of a *nonintegrable* ***nonconservative*** *Hamiltonian system*

Following are some preliminary reflexions on additional effects
which can be induced by the longitudinal motion.

When the beam is accelerated :

a- The most obvious effect is that the particles being bunched,
the peak current increases by almost a factor ten (100 mA = 1 A).

b- There is a strong synchro-betatron coupling induced by space charge
but also by the defocusing effect of the RF field.

c- Acceleration is done by a sinusoidal RF voltage,
the longitudinal focusing force is nonlinear.

d- We are dealing with a Hamiltonian system which is no longer conservative
« the motion appears to be damped » (G. Dôme, CAS85)

Point b- should be studied carefuly because
synchrobetatron coupling is a strong source of chaos

Point c- the sinusoidal accelerating voltage increases the system nonlinearities
and gives a possibility for particules to escape the potential well
then to diffuse far from the beam core.

Point d- the deep character of the dynamics is modified.
A damping term must be introduced in the equation of motion then,
the assymptotic behaviour is characterized
by a bassin of attraction and simple or strange attractors.

14

<u>Equation of motion in the longitudinal plane :</u>

$$\frac{d^2\delta\phi}{ds^2} + A(s)\frac{d\delta\phi}{ds} + B(s)(\delta\phi - k\delta\phi^2) + SC(\delta\phi, s) = 0$$

A(s) = damping term : $A(s) = \frac{3}{m_0 c^2 \beta_s^2 \gamma_s} \frac{dW_s}{ds}$

B(s) = "synchrotron frequency" : $B(s) = \frac{-2\pi . tg(\Phi_s)}{m_0 c^2 \lambda \beta_s^3 \gamma_s^3} \frac{dW_s}{ds}$

k = nonlinear term : $k = \frac{-1}{2 . tg(\Phi_s)}$ (k = 0.87 for Φ_s = -30°)

SC = space-charge "force"

15

With suitable scaling of "displacement and time"
the equation without SC can be reduced to the standard form

$$x'' + \alpha x' + x - x^2 = 0$$

where the damping term α =

α 5 MeV = 0.15 α 20 MeV = 0.10 α 50 MeV = 0.087
α 100 MeV = 0.15α 500 MeV = 0.067 α 1000 MeV = 0.073
for protons, 1 MeV/m, Φ_s = -30°, 352 MHz

In order to estimate how the longitudinal behaviour
is affected when a perturbing forces are added (SC or others),

(get the feeling of the sensibility to perturbations)

we can study

$$x'' + \alpha x' + (1 + F \cos(\omega z))\, x - x^2 = 0$$

$$x'' + \alpha x' + (1 + F \cos(\omega z))\,(x - x^2) = 0$$

(Nonlinear Mathieu's equations)

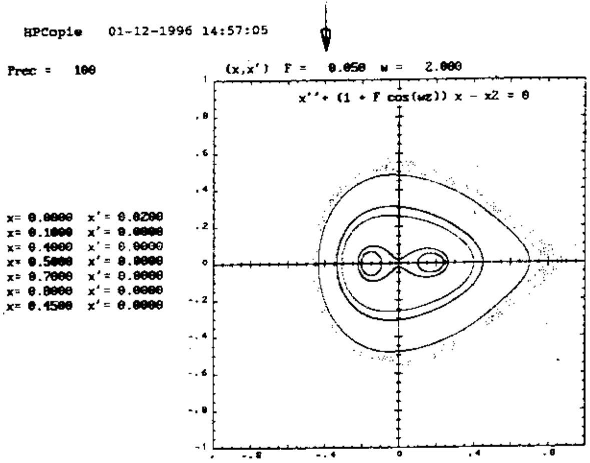
$$x'' + \alpha x' + x - x^2 = F \cos(\omega z)$$

(Duffing's like equation)

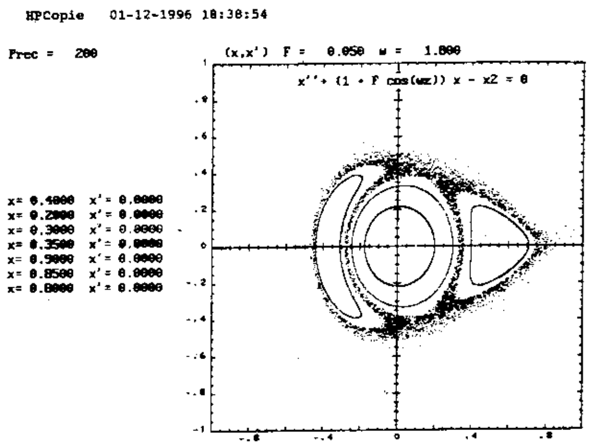
(Model for capsizing of ships in waves J.M.T. Thompson et al. 1982....)

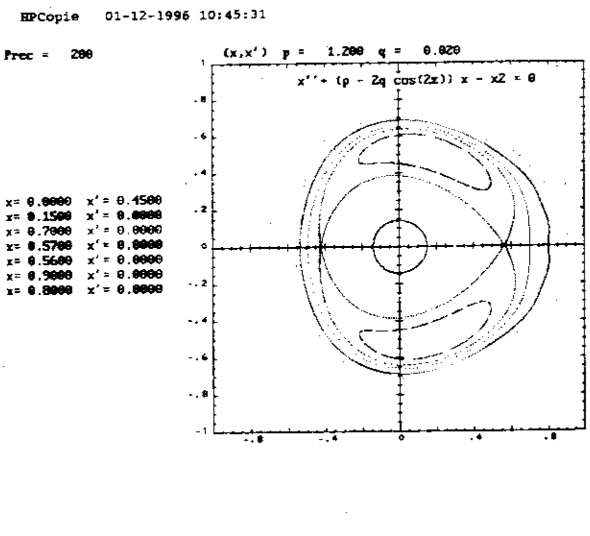
16

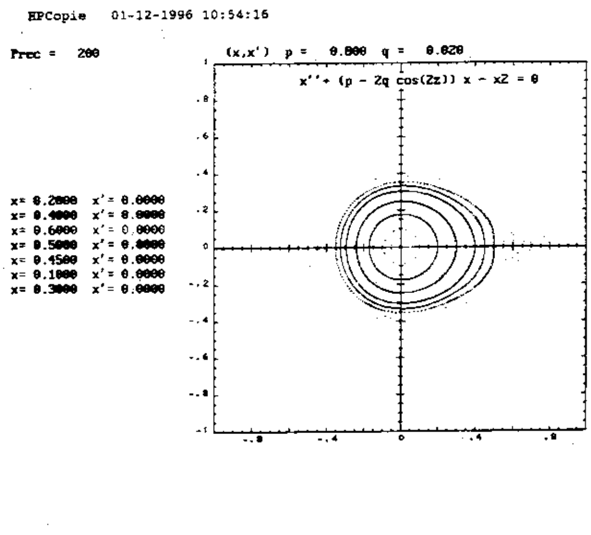
$\alpha = 0$



$\alpha = 0$



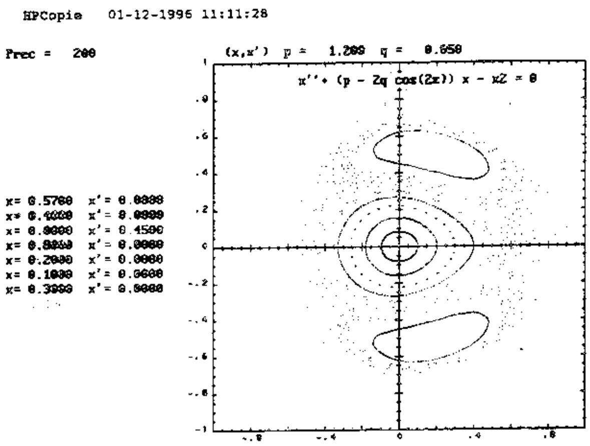


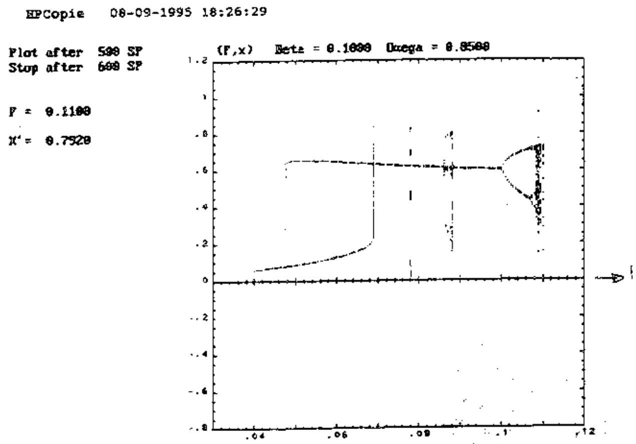


$$x'' + \alpha x' + x - x^2 = F \cos(\omega z)$$

$\alpha = 0.1$

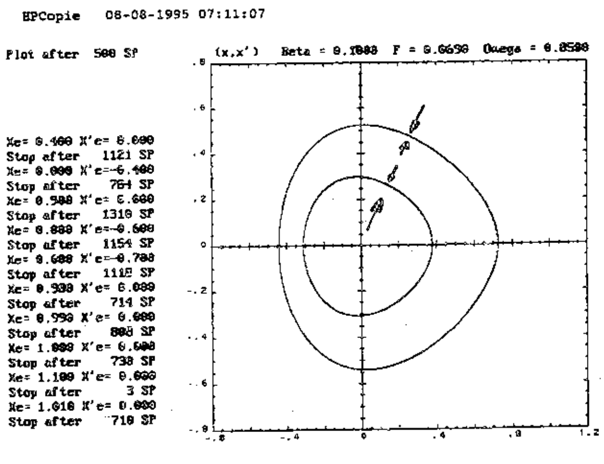
$\omega = 0.85$

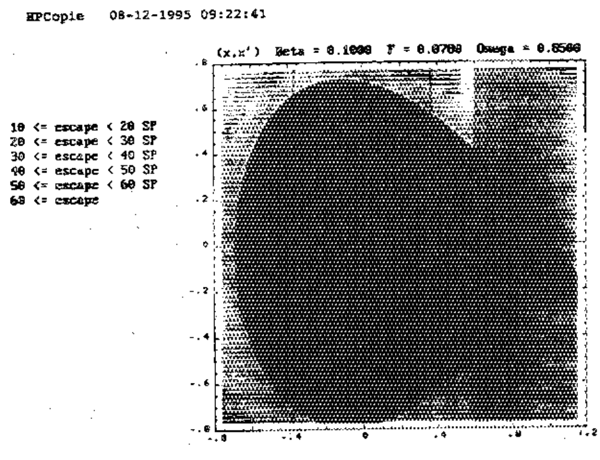




BIFURCATION DIAGRAM

FIRST PERIOD DOUBLING AT F=0.0472





Position of the two attractors
for F = 0.069
(perturbing force = 6.9 % of the main force
(unnormalized)
⇒ longitudinal emittance will not decrease
as expected !

BASSIN OF ATTRACTION
FOR F = 0.078

VI- Conclusion

Beam dynamics is governed by simple laws,
however, as usual in Nature,
the basic laws are simple but the consequences are incredibly rich.

For beams with space charge,

The incoherent space-charge resonances induced by both matched (intrinsic) and mismatched (even and odd modes) beams seem to be the major source of emittance growth and halo formation

Halo formation is highly enhanced when chaotic seas are formed

Even a weak mismatch (10%) strongly increases the chaotic area (near the core)

<u>General system properties :</u>

Beams which are not a priori unstables (linac with 100 mA) are in a *regime of weak chaos*.
The system contains a mixture of *quasiperiodic (KAM) and chaotic orbits*, and a mixture of *stable and unstable periodic orbits* (fixed points).

The flow is *ergodic only on a subspace* of the phase space (chaotic regions)
Isolated adiabatic islands exist in these regions.

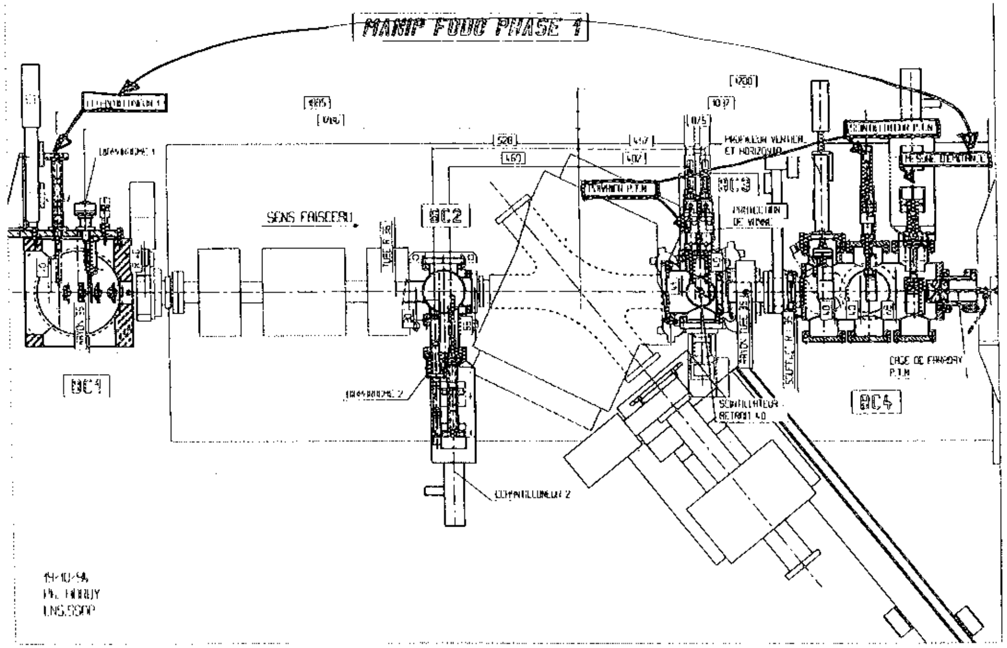
Accelerated beams must be analysed as *damped systems*.

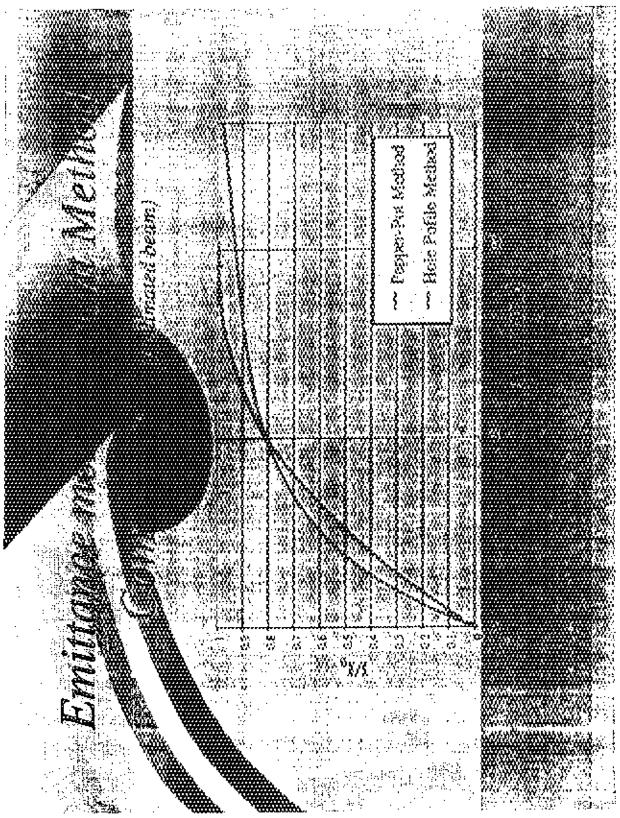
17

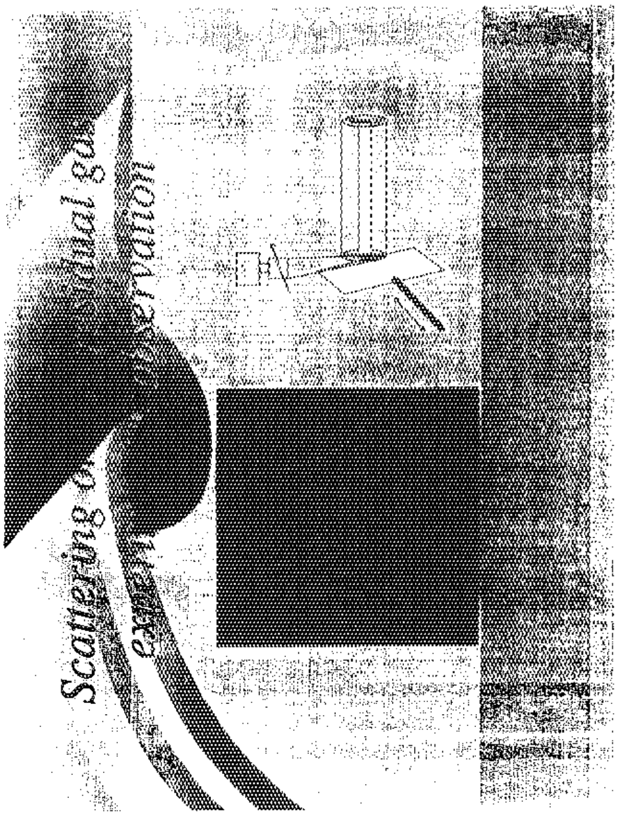
The FODO experiment

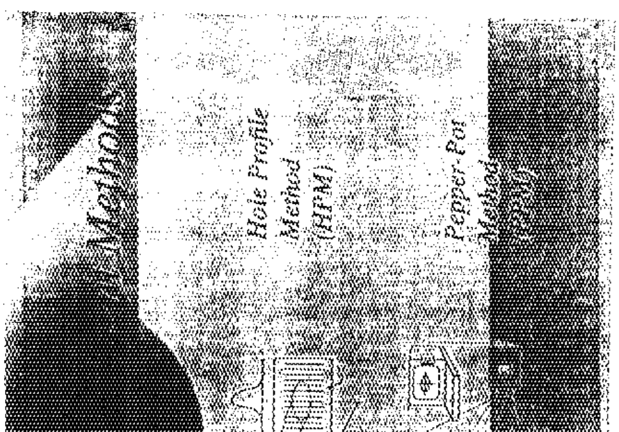
Phase 1 :
Beam emittance measurement,
Scattering study,
Study of the space charge neutralization effects,

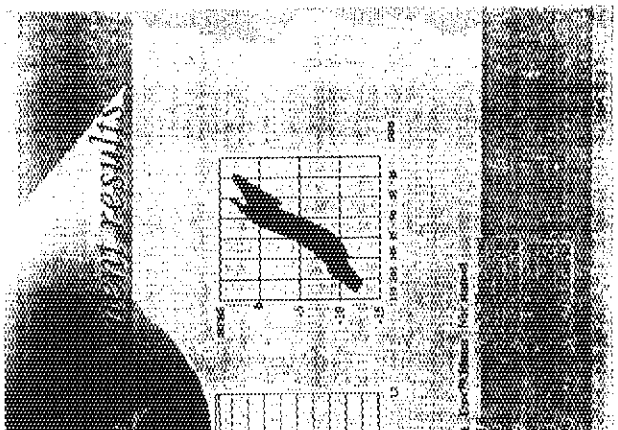
Phase 2 :
Goal and planning.

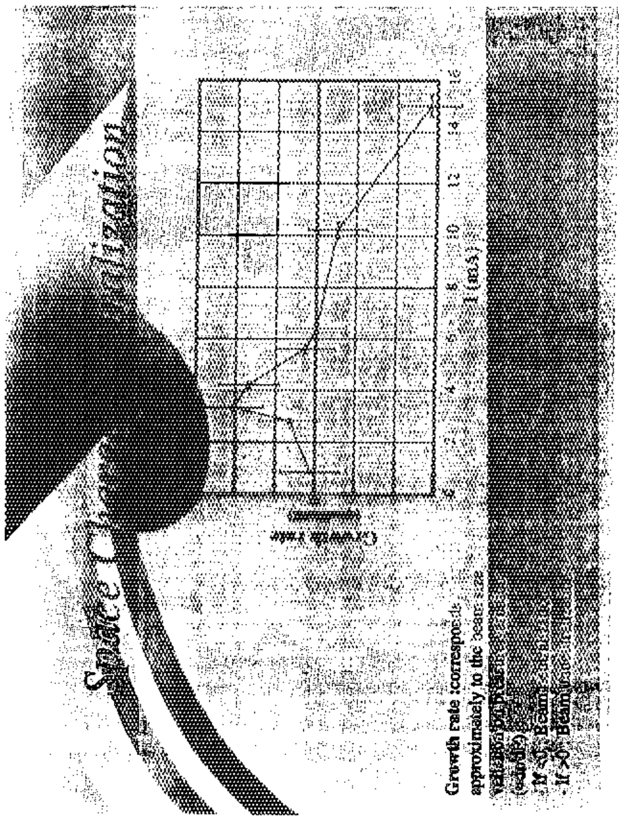


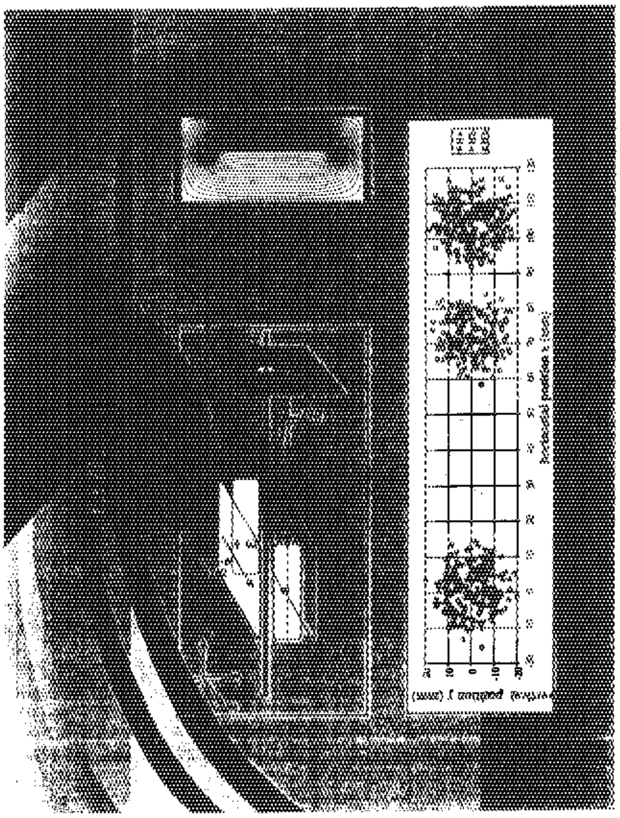

Pepper-Pot Method
Hole Profile Method

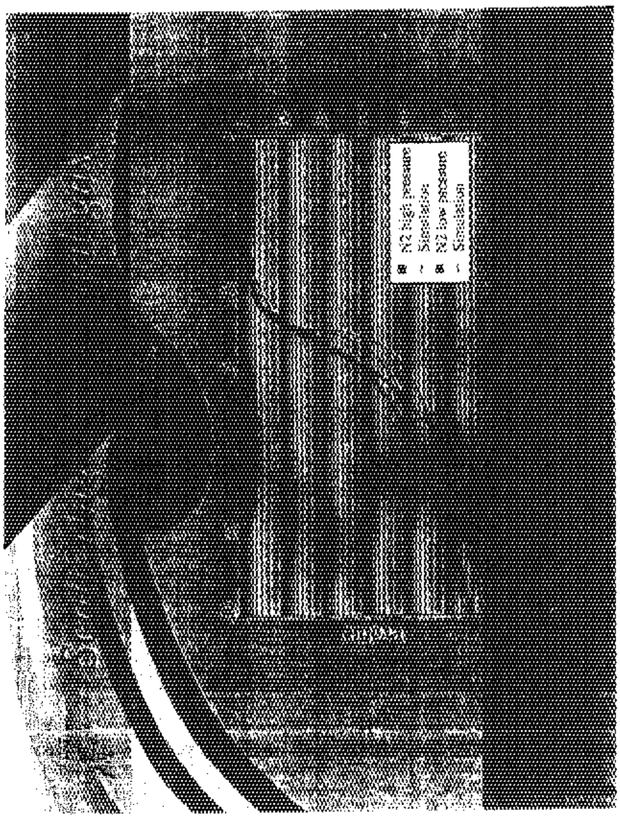


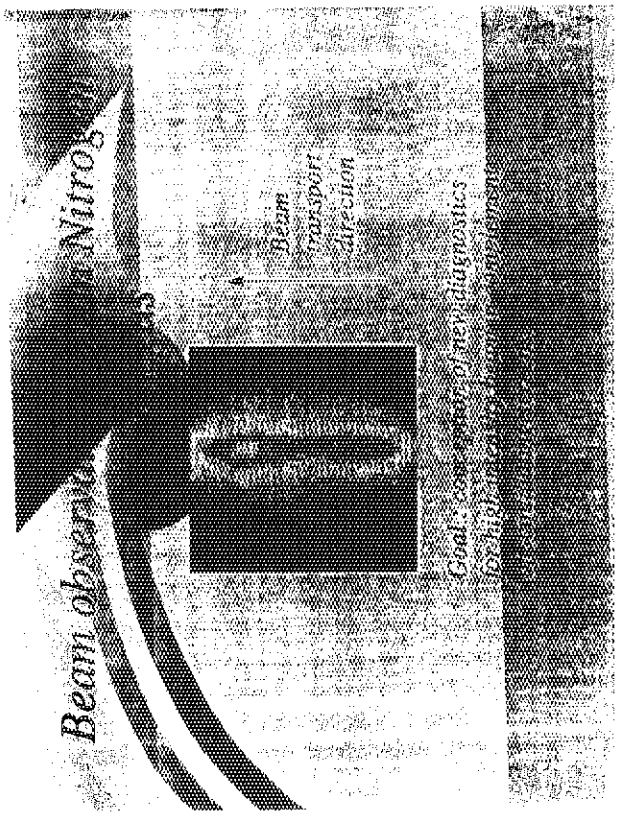

Hole Profile
Method
(HPM)
Pepper-Pot

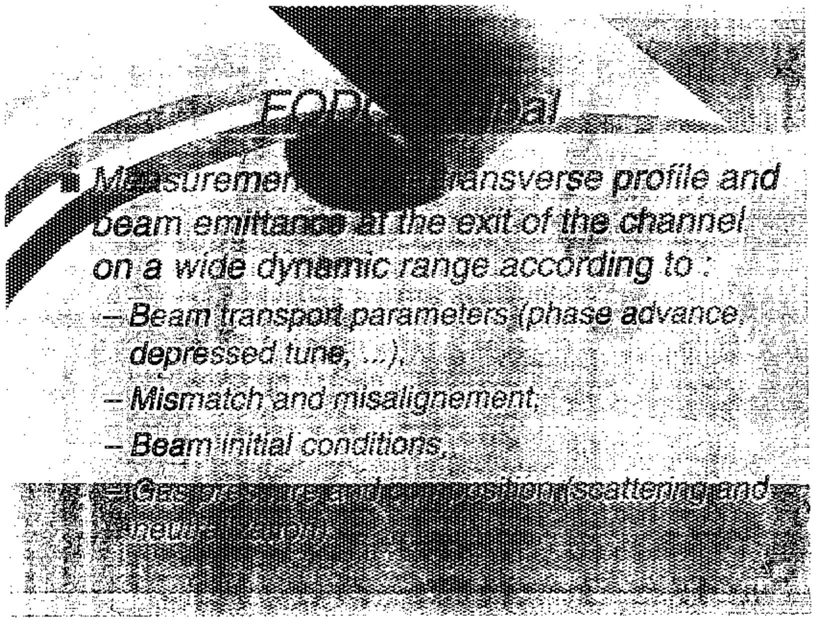












IFMIF RF SYSTEM

J-M. LAGNIEL

Commissariat à l'Energie Atomique
DSM-GECA, CEA-Saclay, LNS
91191 Gif-sur-Yvette Cedex, France

IFMIF meeting, JAERI, May 1996

I- Remarks on the data presented at the Santa Fe meeting

II- Comparison between EIMAC and THOMSON tubes

III- Conclusion

1

I- Remarks on the data presented at the Santa Fe meeting

At the Santa Fe meeting

(11-13 September 1995)

the EIMAC tube 4CM2500KG

has been choosen for

the accelerator rf system baseline amplifier

on the basis of some information

2

Princeton Physics Lab (TFTR)

??? 2 MW @ 64 MHz ???

Not really a long pulse operation
Pulse duration ~ 2 seconds
Mean Power ~ 15 kW

Japan Nat. Inst. for Fusion Science

??? 1 MW @ 201 MHz ???

The maximum frequency is 80 MHz
rf amplifiers used between 50 and 60 MHz
Test 1.6 MW / 1 hour at **50 MHz**

remark : NIFS uses / will use (?) TH525A TTE tetrodes (comparison?)

JAERI

??? 1.7 MW @ 131 MHz ???

BTA
frequency = 201 MHz
Duty cycle < 12%
Standard operation = 850 kW peak => ~ **100 kW CW**

JT60
frequency = 116 - 120 131 MHz
Used 1.4 MW with **3 sec pulses**
X2274 prototype 1.7 MW / 5.4 sec 1.8 MW => 50 ms

3

EIMAC 4CM2500KG Tube Characteristics

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Specifications

• Voltage	21 kV
• Max Power	1.3 MW
• Efficiency @ max power	73%
• Control Margin (for this configuration)	7%
• Low Voltage Power Supply Requirements	100.0 kW
• Gain	14.0 db
• Average Operational Life	10,000 hrs

Operational history (long pulse operation)

• Princeton Physics Lab	>2 MW @ 64 MHz
• Japan Atomic Energy Research Inst.	1.7 MW @ 131 MHz
• Japan National Inst. for Fusion Science	1.0 MW @ 201 MHz

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

THEN

IF our information is correct,

THE DATA PRESENTED BY THE US TEAM

AT THE SANTA FE MEETING

ARE WRONG

4

LAMIREL

II- Comparison between EIMAC and THOMSON tubes

Performance reached by the THOMSON tubes

During tests at Thonon for the JAERI projects (JT60 and BTA)

(with a participation of JAERI and SUMITOMO HI)

TH 526 A for BTA

first test :

1 MW peak / 200 MHz / 2 ms - 100 Hz during ½ hr
mean power = 200 kW

second test :

200 MHz - 2 ms
1.034 MW peak / 100 Hz during 40 mn then
1.228 MW peak / 60 Hz during 17 mn then
1.400 MW peak / 60 Hz during 6 mn then
1.617 MW peak / 60 Hz during 10 mn

TH 526 A for the Japan Nat. Inst. for Fusion Science

first test :

1.6 MW / 57 MHz during 40 min

second test :

1.6 MW / 57 MHz during 30 min

5

LAMIREL

Comparison 1 :

*** High frequency ***

Max mean power at 200 MHz in the BTA condition during test :
~ 200 kW TTE ~ 100 kW EIMAC

500 kW CW / 200 MHz for a TH 526A during 20 mn
no information for the EIMAC tube in CW

*** Medium frequency ***

long pulses / f ~ 120 MHz
1.4 MW - 10 sec for EIMAC 1.4 MW - 30 sec for TTE (TH526 for Tore Supra)

repetitive use / f ~ 120 MHz
1.4 MW - 3 sec - xx% for EIMAC 1.2 MW - 30 sec - 12% for TTE

*** Low frequency ***

> 2 MW - 2 sec - 64 MHz - Pmean ~ 15 kW
for EIMAC (TFTR)
2 MW - 210 sec - 80 MHz 1 pulse or 2 MW - 30 sec - Pmean = 240 kW
for TTE (TH525 Tore Supra)

1.6 MW ~ CW (1hr) 50 MHz for TTE and EIMAC

6

LAMIREL

Comparison 2 :

*** Experience ***

TTE seems to have a better experience for long-pulse operation

(work for TORE SUPRA and high-power UHF TV)

*** Tests for High-power CW operation ***

THOMSON :

Both computations and data accumulated
during a large number of tests
push Thomson to develop a new technology (diacrode)

They think that conventional tetrodes
can work at 175 MHz CW 1 MW
but
the reliabity will be low
and the life time will be short

EIMAC

??????????????????????

7

LAMIREL

RF Technology Trade Study For Baseline Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Objective:
  - Understand influence of rf power tube technology on system efficiency and cost
- Approach: Consider existing and proposed tubes suitable for operation at 175 MHz
  - Eimac CMG2500 tetrode: existing used in POD
  - Thomson Diacrode: in development
  - EEV IOT: proposed
- Special Considerations/Limitations:
  - IOT power limits ~500 kW require small tanks or two tubes per tank
- Result/Conclusions:
  - High power EIMAC tube minimizes tanking and reduces overall cost
  - Lower projected R&R cost of IOT would result in lowest 20 year NPV, but not by much

RF Power Tube Type	EIMAC Tetrode (POD)	Thomson Diacrode	EEV IOT
Power (kW)	1300	~1000	500
Efficiency (%)	73	73	72
Gain (db)	14	14	23
Estimated Lifetime (1000 Hr)	10	10	25
Number Of DTL Tanks/Tubes	6/6	8/8	8/16
DTL Length (m)	26.5	29.2	29.2
Accelerator Direct Cost ($M)	64.9	71.5	71.5
RF Power Direct Cost ($M)	47.9	52.1	51.8
RF System R&R Annual Cost ($M/yr)	3.44	3.59	1.43
Total O&M Annual Cost ($M/yr)	10.7	10.9	8.76
20 Year Net Present Value ($M)	297	314	284

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

VI- Conclusion

Technical conclusion :

1) We think that it is hazardous to extrapolate
   - results from pulsed mode to CW
   - results from low frequency to 175 Mhz

2) As there is no difference from the cost point of view, we must use 1 MW rf power stations

3) Even at 1 MW, our feeling is that classical tetrodes will lead to a poor reliability
==> Developments and tests of tubes using new technologies

Conceptual Design of Superconducting Linac for IFMIF

Yoshio Tanabe, Tomoko Ota, Akiko Yamaguchi,
Yoshihiro Wachi, Choji Yamazaki
and
Shoshi Kawatsu

Toshiba Corporation

2nd IFMIF-CDA Design Integration Meeting
May 20 - 27, 1996, JAERI, JAPAN

1. Introduction

This report presents the results of works carried out after the IFMIF-CDA accelerator team workshop held at Santa Fe last year. The following contents are summarized.

(1) To optimize a configuration of a superconducting (s/c) cavity electromagnetically.

(2) The magnetic field analysis for a superconducting (s/c) quadrupole magnet by using a three dimensional nonlinear computer code.

(3) Reconsideration of an s/c ICL (Independent Cavity Linac) system, taking into account the results from (1) and (2).

(4) Literature investigations of irradiation damages on Nb for the s/c cavity and NbTi for the s/c quadrupole magnet.

(5) Present status of a 100kW class solid state rf amplifier because it is very attractive for the s/c ICL system.

(6) Concept of an rf control system for the s/c ICL.

2. Superconducting main linac

2.1 Optimization of superconducting(s/c) rf cavity

The following principal conditions were considered for the design of the s/c rf cavity.

(1) Maximum rf window loading is 100 kW. Maximum accelerating gradient is limited by this rf window loading.

(2) The $\lambda/2$ coaxial cavity with two gaps is considered to be suitable for this s/c cavity. The $\lambda/4$ coaxial cavity is also a candidate but was excepted because its electric field is axially less symmetric.

(3) Since the s/c cavity can make its bore diameter large, the influence of beam halo can be reduced. The diameter of 60 mm is 2 or 3 times larger than that of a room temperature cavity.

(4) Allowable maximum surface electric field is 1 kp.(Kilpatrick's criterion) which is 14MV/m at 175MHz.

It is essential to accelerate the beam efficiently at low β and therefore optimization concerning the configuration of the coaxial cavity was done to improve the accelerating efficiency as high as possible at low β. Analysis was carried out using the three-dimensional electromagnetic analysis code "MAFIA". In order to evaluate the efficiency, the effective shunt impedance(Rsheff) was calculated on the assumption that the cavity was made of copper. Of course the high Rsheff means the high accelerating efficiency. The Rsheff was compared, varying the thickness of the inner conductor, t and the gap length, g. It was known from this comparison that the thickness t is smaller, the Rsheff becomes larger at low β. However, the cavity with the thin inner conductor unfortunately has the concentration of the electric field over 1kp. on the corner of the inner conductor.

In order to understand how much thickness is allowable from the viewpoint of the maximum electric field on the inner conductor, we calculated the maximum electric field at 100kW input. Fig. 2.1.1 shows the results of the calculation for various thickness and gap length. It is clear from Fig.2.1.1 that the smaller thickness requires the larger gap length not to exceed the 1 Kilpatrick's criterion represented by a dotted line. Because the thin inner conductor is preferable as above-mentioned, the thickness of 60mm was chosen in our design.

Three cavities that have the gap length(g) of 50mm,60mm and 70mm ,and the same thickness(t) of 60mm were considered. Fig.2.1.2 shows the dependence of the Rsheff on β for these three cases. The cavity with the g of 50mm has relatively high Rsheff at low β but this tendency becomes reverse at high β.

For these cases, we also calculated how many cavities are necessary in order to accelerate the beam from 8 MeV to 40 MeV using the Rsheff shown in Fig.2.1.2. In this calculation summarized in Table 2.1.1, it is assumed that the rf input power is 100 kW in the case of t60g70 but the power should be reduced less than 100kW in other two cases for the limit of the Kilpatrick's criterion.

The cavity with the thickness of 60mm and the gap length of 60mm was selected as an optimum configuration considering following reasons.

(1) As the case of t60g50 requires more cavities than other cases, this case was abandoned.

(2) The cases of t60g60 and t60g70 have the same number of cavities but the rf input power of the former case is lower than that of the latter case. This means that an antenna used in the former case can be operated in relatively lighter loading.

(3) As shown in Fig.2.1.2, Rsheff in the case of t60g60 is greater than that in the case of t60g70 at low β. It is important to make β as high as possible at low β region.

The schematic drawing of the optimized cavity is shown in Fig. 2.1.3. The cavity made of niobium (Nb) consists of an inner conductor and an outer conductor. Both conductors have the height of about $\lambda/2$ and the cross section of race track configuration. The length is 340 mm and the width is 180 mm. A Nb bellows is attached as a tuner on the top of the cavity. The resonant frequency is adjusted by changing the length of this bellows. The frequency tuning rate is approximately 102 kHz/mm (=175 MHz / (857×2mm)).

2

Main specifications are summarized in Table 2.1.2. Maximum average field gradient is 2.9 MV/m at the maximum transit time factor(Tmax) of 0.83. Q value and the shunt impedance(Rsh) are calculated on the assumption that the superconducting surface resistance of Nb is 50 n Ω. The beam loading of the cavity varies from 43kW to 91 kW and the maximum rf loss on the cavity wall is 7.0 W. The maximum magnetic field appears at the end of the inner conductor in case of the $\lambda/2$ cavity. When the average gradient is 2.9 MV/m, the maximum magnetic field is 405 Gauss which is enough below the critical magnetic field(Hc) of 1580 Gauss at 4.2 K.

The electric field distribution along the beam axis is shown in Fig.2.1.4. which corresponds to the average field gradient of 2.9 MV/m and the maximum electric field of 14 MV/m. Three dimensional (1/8 piece of the whole body) arrow plot of the electric field is shown in Fig.2.1.5. It is known from this plot that the maximum electric field appears at the round corner of the inner conductor.

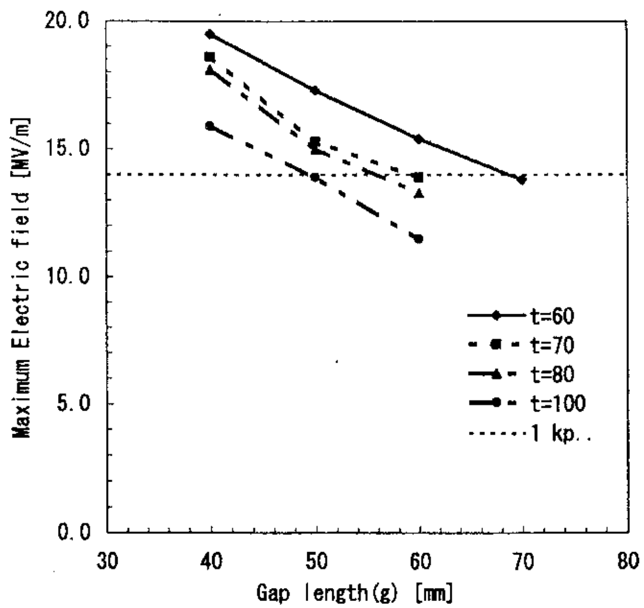


Fig.2.1.1 Maximum electric field on inner conductor

3

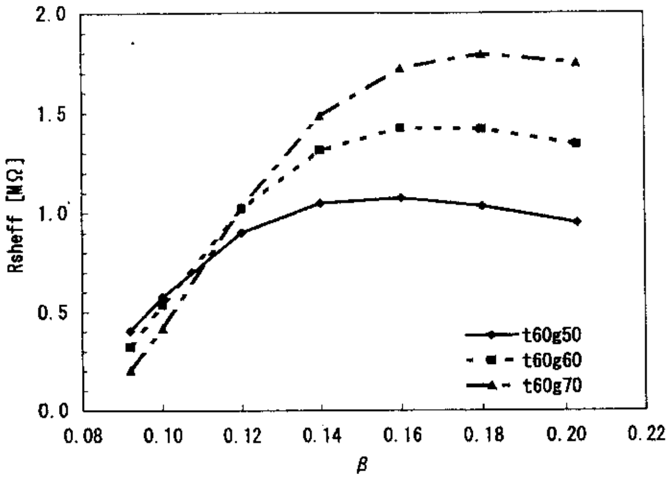


Fig. 2.1.2 Rsheff of cavities with thickness(t) of 60 mm

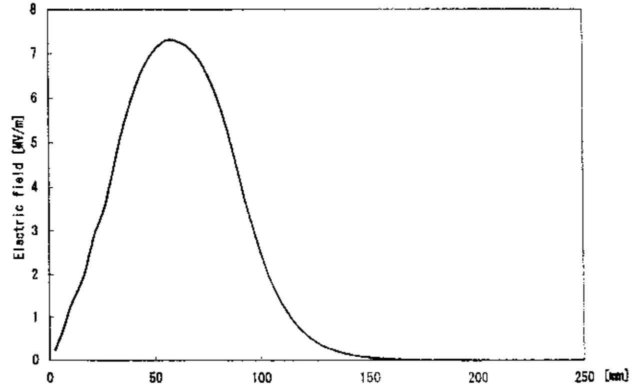


Fig. 2.1.4 Electric field distribution along beam axis

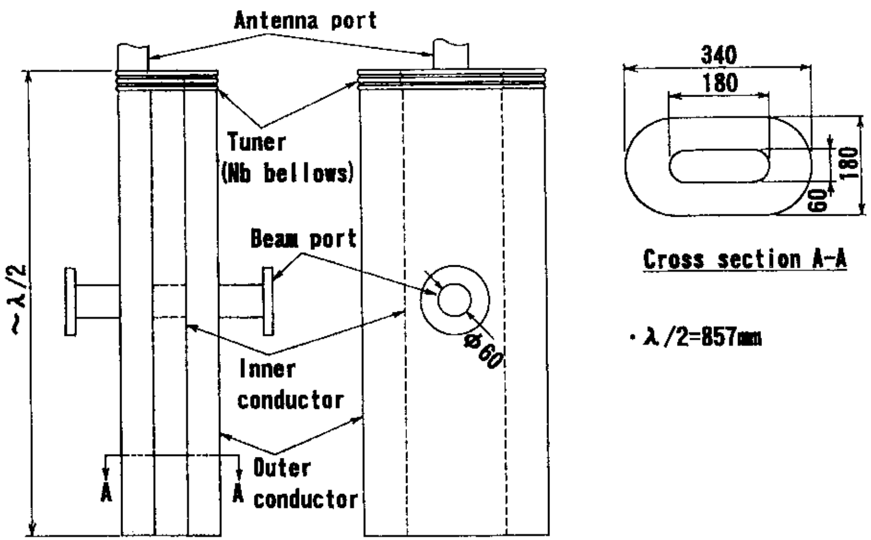


Fig. 2.1.3 Optimized s/c cavity

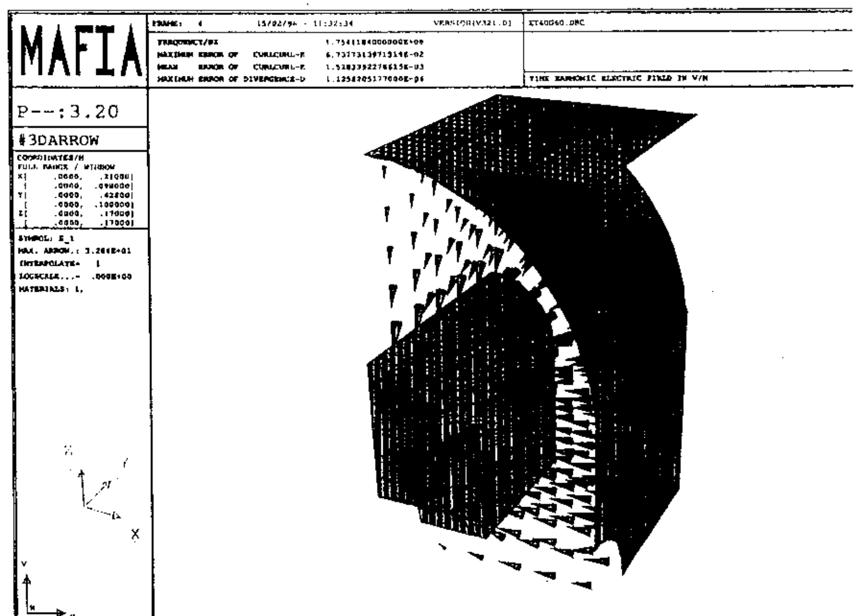


Fig. 2.1.5 Arrow plot of the electric field

4

5

Table 2.1.1 Optimization of cavities with thickness of 60 mm

	t60g50	t60g60	t60g70
Number of cryounits	14	13	13
Number of s/c cavities	56	52	52
Beam loading [kW]	49 ~ 81	43 ~ 91	33 ~ 100
Average accelerating field : Eacc* [MV/m]	1.7 ~ 2.8	1.4 ~ 2.9	1.0 ~ 3.0
Maximum electric field : Emax [MV/m]	14.0	14.0	14.0

* $Eacc=Vacc/(\beta * \lambda)$

$Vacc=Pb/(T*ib*\cos\phi s)$

Table 2.1.2 S/C cavity specifications

Material	Nb
Frequency	175[MHz]
Thickness of the inner conductor	60[mm]
Gap length	60[mm]
Width of the outer conductor	180[mm](=60+60*2)
Maximum transit time factor Tmax	0.83 (at β=0.168)
Maximum average field Eaccmax	2.9[MV/m]
Unloaded Q value*	$7.5*10^9$
Shunt impedance Rsh*	$1.5*10^{11}$[Ω]
Maximum effective shunt impedance Rsheff*	$1.0*10^{11}$[Ω]
Beam loading	43~91[kW]
RF loss on wall*	7.0[W]
Maximum electric field	14.0[MV/m]
Maximum magnetic field	405[Gauss]

*** The surface resistance of Nb is assumed as 50n Ω**

2.2 Magnetic field analysis of superconducting quadrupole

Three dimensional magnetic field analysis was carried out by using the code " OPERA-3d" (Vector Fields). An iron core is employed to reduce the stray magnetic field. The following conditions are taken into account for this analysis

(1) Dimensions and required magnetic field gradient

a) Bore diameter 60mm

b) Magnet length 50mm

c) Magnetic field gradient max 50T/m

(2) Cross sectional configuration

A cross sectional configuration is shown in Fig. 2.2.1. A fat pole is chosen in order to make the good field region wide.

(3) Ferromagnetic material for a core

As the core is used at the complete saturation state, a ferromagnetic material having high magnetic saturation is preferable. Fe-Co alloy (Permendur) has high magnetic saturation of 2.4 Tesla but its magnetic characteristics probably degrades due to irradiation damage. Therefore, iron (Fe) with magnetic saturation of 1.6 Tesla is applied as the core material instead of Fe-Co alloy. Magnetic properties of Fe at 4.2 K are nearly as the same as those at room temperature.

(4) Superconductor for coils

NbTi is used as a superconducting wire. The critical current density(Jc) of NbTi is ~3000 A/mm^2 at 2.5T and the average critical current density ((Jc)ave) is $Jc/(1+\rho)$ ~430 A/mm^2 ,where ρ is the copper stabilizer ratio and assumed as 6. Therefore, the operating current density up to 215 A/mm^2 is possible with a double margin.

Results are summarized as follows.

(1) The mesh model (1/8 piece of the whole body) is shown in Fig 2.2.2 and total number of meshes is about 13000.

(2) An excitation curve is shown in Fig. 2.2.3. This curve becomes nonlinear over 20 A/mm^2 due to the magnetic saturation. 50T/m corresponds to 180A/mm^2 which is within the allowable current density. At the current density of 200 A/mm^2, the maximum magnetic field at the coil and in the core are 2.2T and 4.6T, respectively.

(3) The uniformity of the magnetic field gradient ($\Delta G/G$) on the median plane is shown in Fig. 2.2.4, where G is the field gradient at the magnet center and ΔG means a change of the field gradient from G. If $\Delta G/G$ of 0.5 % is allowed, the good field region of ±24mm is obtained in the case of non-saturation (12A/mm^2). However, it becomes smaller to ±15 mm in the case of saturation (200A/mm^2). Analyses of beam dynamics will determine the required width of the good field region.

(4) We should also pay attention to the uniformity of the magnetic field gradient ($\Delta G/G$) along the beam axis because the length of the quadrupole magnet is very short compared with its large diameter. As shown in Fig.2.2.5, the higher the current density becomes, the greater the change of $\Delta G/G$ becomes, due to the increase in the leakage of the magnetic field. $\Delta G/G$ at the magnet end (25mm) decreases as much as 25% and therefore this decrease should be considered for the beam dynamics analysis.

(5) A magnetic shield is located between the cavity and the quadrupole magnet. The magnetic shield is located 70mm apart from the magnet center and the magnetic field at that point is 2.5kGauss at 180A/mm^2. Therefore it is possible to shield the stray field by using ordinary ferromagnetic materials. Of course more detailed analysis should be carried out including the magnetic shield.

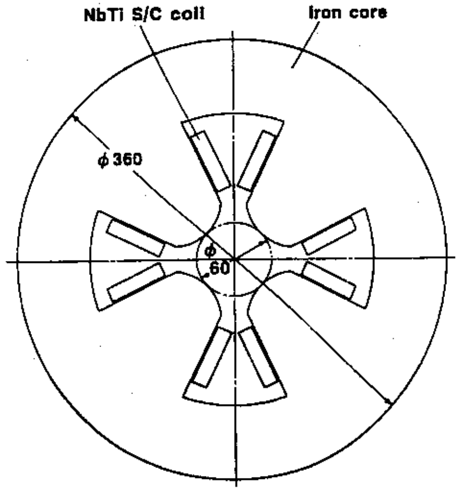


Fig. 2.2.1 Cross section of Quadrupole magnet

8

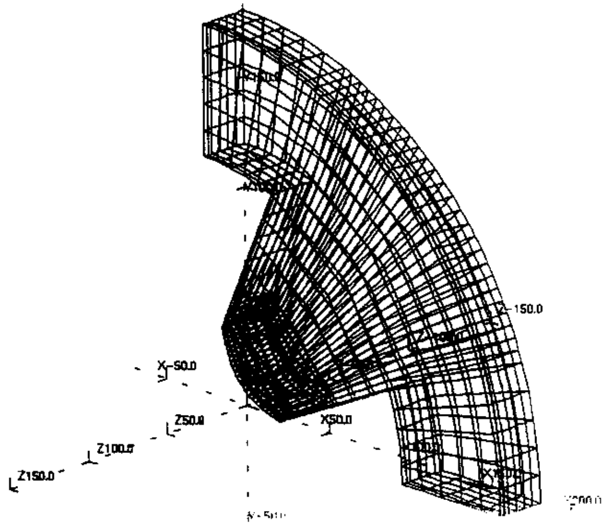


Fig. 2.2.2 Mesh Model

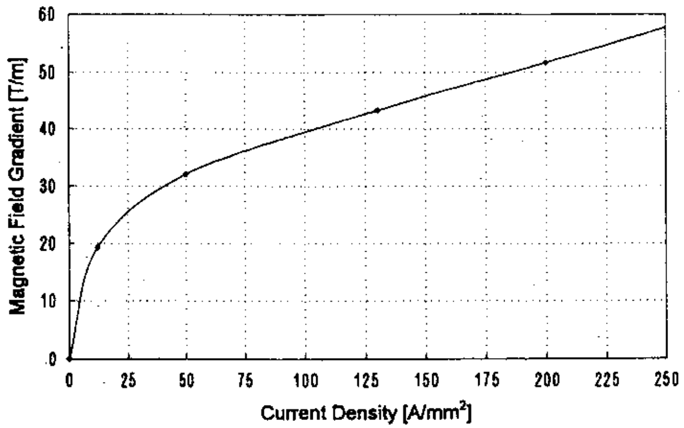


Fig. 2.2.3 Excitation curve

9

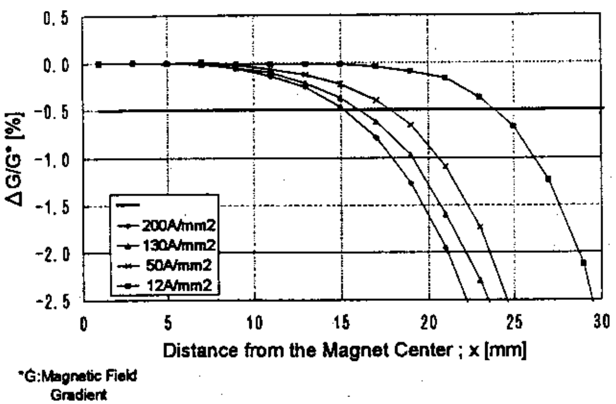


Fig. 2.2.4 Uniformity of magnetic field gradient on the median plane

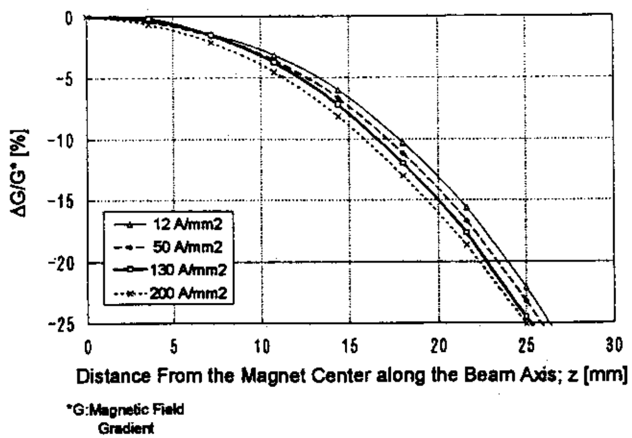


Fig. 2.2.5 Uniformity of magnetic field gradient along beam axis

2.3 Linac system

The schematic drawing of one cryounit is shown in Fig. 2.3.1. Four cavities are accommodated in one cryostat and each cavity has an antenna with an rf window. (The rf window is not shown in Fig. 2.3.1). The antenna has a coaxial structure and can move through stainless steel bellows to adjust its coupling coefficient to the cavity. It also should be so compact as to be installed in narrow space and to reduce its heat leakage as small as possible, while it should allow 100 kW power rating. The resonant frequency is kept constant by changing the length of the Nb bellows located at the top of the cavity. A tuner driver moves the Nb bellows tuner in response to a feedback control signal sent from a phase detector described below.

The cryostat is cooled at 4.2 K by LHe and thermally shielded by LN_2. This LN_2 shield is also used as a magnetic shielding for the terrestrial magnetism. The superconducting quadrupole magnet with the iron core is located both sides of the rf cavities. The stray magnetic field of the quadrupole magnet is shielded by a magnetic shield located outside the cavity.

The process of accelerating the beam from 8 MeV to 40 MeV is summarized in Table 2.3.1, where Win is the input beam energy, T is the transit time factor, Δ W is the beam energy gain in each cavity, and Pb is the beam loading. The linac needs 13 cryounits and the final output beam energy is adjusted by controlling the input rf power of the 13th cryounit.

Table 2.3.2 shows main specifications of the superconducting linac system. The superconducting linac consists of 13 cryounits, 52 cavities and 65 superconducting quadrupole magnets. The total beam loading is 4MW and the total wall loss of the cavities is 364 W. The total length is 32.5m which means that the average accelerating gradient is about 1MeV/m.

Table 2.3.1 Accelerating process from 8 MeV to 40 MeV

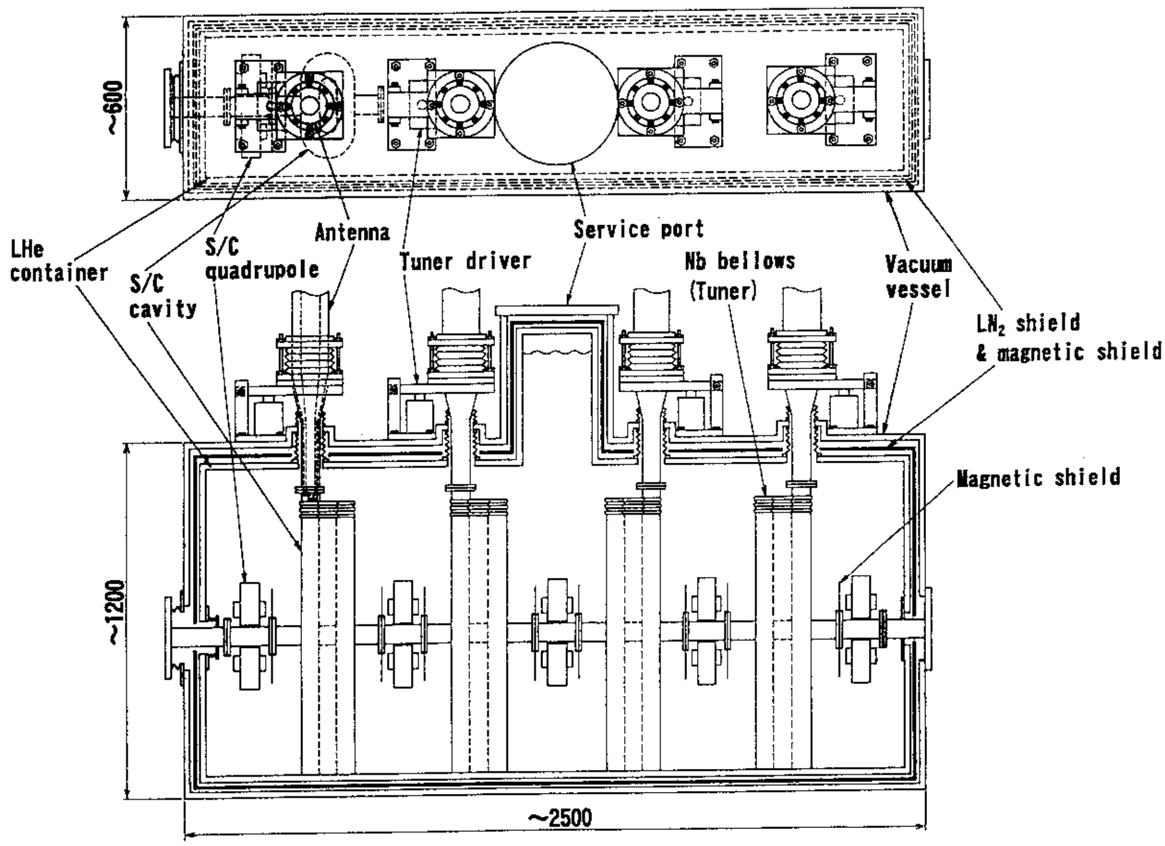
Cryounit No.	Win[MeV]	β	T	Eacc[MV/m]	ΔW[MeV]	Pb[kW]
1	8.000	0.092	0.3937	1.389	1.385	173.06
2	9.385	0.100	0.5071	1.788	1.783	222.91
3	11.168	0.109	0.6094	2.150	2.143	267.88
4	13.311	0.118	0.6868	2.422	2.415	301.91
5	15.726	0.129	0.7529	2.656	2.648	330.96
6	18.374	0.139	0.7917	2.792	2.784	348.02
7	21.158	0.149	0.8150	2.875	2.866	358.26
8	24.024	0.158	0.8260	2.914	2.905	363.10
9	26.929	0.168	0.8299	2.927	2.918	364.81
10	29.847	0.176	0.8283	2.922	2.913	364.11
11	32.760	0.184	0.8235	2.905	2.896	362.00
12	35.656	0.192	0.8162	2.879	2.870	358.79
13	38.526	0.200	0.8071	1.505	1.500	187.50

Final energy : 38.526 + 1.505 = 40.031[MeV]
Total beam loading : 4.0[MW]

Table 2.3.2 S/C linac system specifications

Number of cavities in a cryounit	4
Number of cryounits	13
Number of s/c cavities	52(=4*13)
Number of quadrupole magnets	65(=5*13)
Total length	32.5[m](=2.5*13)
Beam loading	4.0[MW]
Total rf loss on wall	364[W](=7.0*52)

13



12

Fig. 2.3.1 Schematic drawing of the cryounit

2.4 Cryogenic system

Outline of a cryogenic system was investigated based on the heat load summarized in Table 2.4.1. The total heat load is about 1.2kW at 4.2K. The refrigerator capacity of 1.2 kW at 4.2 K is the same as that of a refrigerator for the LCT(Large Coil Task) domestic test facility at JAERI. A block diagram of the system is shown in Fig. 2.4.1. The cryostat is cooled down from 300 K to 20 K using a refrigeration line and then LHe is transferred to the cryostat from a 20000 liter LHe dewar in order to cool down the cryostat up to 4.2 K and to fill it with LHe. LHe level is kept constant in a refrigeration mode during the steady state s/c cavity operation.

Required electricity is about 640 kW for 1.2 kW refrigeration capacity and it means that efficiency is 1.2/640=1/530 at 4.2 K.

Table 2.4.1 Estimation of heat load

S/C cavity	364[W] (=7.0[W]*52)
Antenna	520[W] (=10[W]*52)
Cryounit	130[W] (=10[W]*13)
Heat loss of transfer tube	140[W] (=2[W/m]*70[m])
Total heat load	1154[W]

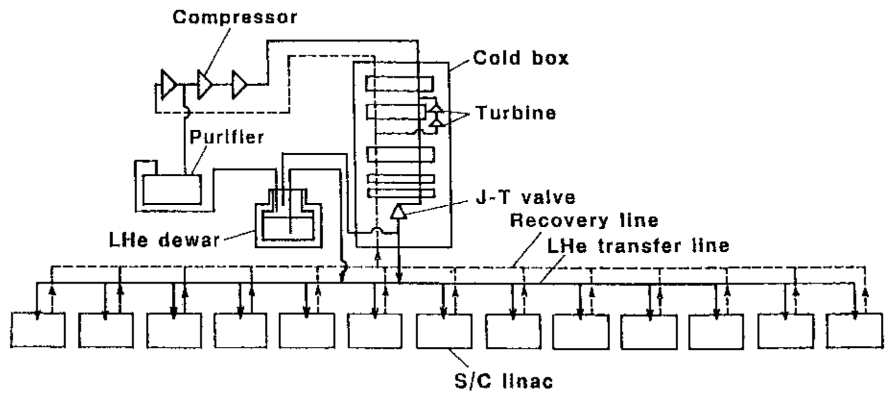


Fig. 2.4.1 Block diagram of cryogenic system

14

15

3. Irradiation damage on superconductors

Nb for the S/C cavity and NbTi for the S/C quadrupole are suffered from neutron irradiation. The data relating to irradiation damage are summarized and evaluated.

3.1 Superconducting cavity

As there were no data concerning Nb, direct evaluation is not possible. From the data shown in Table 3.1, the damage energy cross section <σ•T> of Nb is nearly the same as that of NbTi. Judging from these data, irradiation damage of Nb is considered to be similar to that of NbTi whose irradiation damage is trivial as below-mentioned.

3.2 Superconducting quadrupole

Fig.3.1 shows the relation between the critical current(Ic) and neutron fluence for NbTi and Nb_3Sn. Nb_3Sn is strongly affected by irradiation above fluence of 2.E18(n/cm^2) but NbTi is affected very little. However, irradiation damage for other magnet components such as conductor insulators and s/c stabilizers(Cu or Al) should be also evaluated. Moreover heating in the s/c coil due to neutron increases heat load of liquid He.

4. Solid state rf amplifier

There are some options for an rf amplifier. One is to use a high power tetrode such as EIMAC 4CM2500K(1.3MW) in order to reduce the cost of the rf amplifier. However, 175MHz-1.3MW CW operation is not achieved yet using the 4CM2500K. Moreover, the power distribution system is very complicated and much R&D efforts are required for many rf components such as a 1.3MW coaxial waveguide, a circulator and a 1.3MW divider. Instead of the 1.3MW circulator, a 100kW class circulator is installed in each 100kW line for the reflected rf power not to interfere in the phase of the inputted rf power which is used as a signal of an rf feedback control system.

The other option is a solid state rf amplifier. Its initial cost is probably higher than the tetrode rf amplifier but the solid state amplifier is very attractive for the S/C ICL due to the following reasons.

(1) A 100kW class solid state rf amplifier can be fabricated by existing technology which is commercially used for broadcasting power supplies.

(2) Easy operation and easy maintenance are expected.

(3) There is a possibility that the high initial cost can be compensated due to the long lifetime of the solid state.

Comparison of the two amplifiers is shown in Table 4.1. From this table, the solid state rf amplifier is recommended.

16

Table 3.1 Displacement damage energy cross sections $\langle\sigma \cdot T\rangle_E > 0.1$ MeV for different neutron sources and calculated fusion reactor designs, units in keV barn

Source Design	Ti	Nb	Nb-42wt%Ti	Nb-46.5wt%Ti	Nb-49wt%Ti	Nb-54wt%Ti
TRIGA-reactor,						
Vienna	81.5	70.7	76.9	77.4	77.7	78.2
IPNS/REF	64.9	62.0	63.7	63.8	63.9	64.1
RTNS-II	248.5	280.4	261.9	260.3	259.7	258.1
MARS,						
Yin-Yang region	58.3	62.9	60.3	60.1	59.9	59.7
STARFIRE	66.5	67.9	67.0	67.0	67.0	66.8

(Advances in Cryogenic Engineering, Vol.32, P.865 (1986))

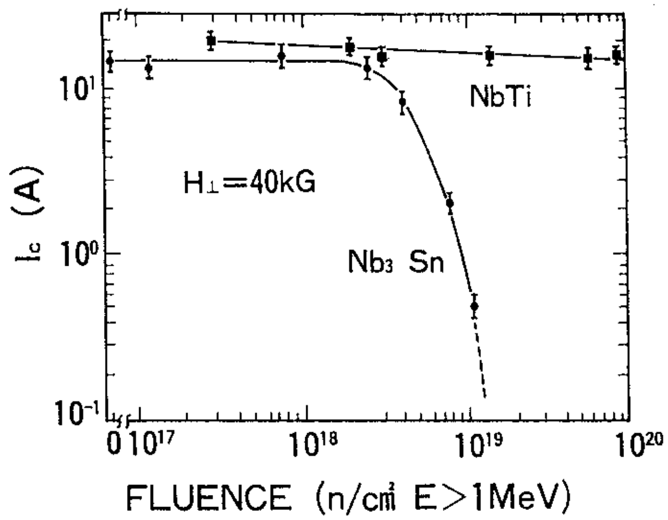


Fig. 3.1 Effect of neutron irradiation on the critical current in NbTi and Nb_3Sn

17

Table 4.1 Comparison of solid state amp. and tetrode amp.

Type	Solid state rf amplifier	Tetrode rf amplifier
Structure	•100kW is combined from 1kW units •Each 1kW unit has a circulator to bypass the reflected power to a dummy load •Phases among cavities are adjusted by PLL circuits •Block diagram Fig.4.1	•100kW is divided from 1.3MW high power tetrode (4CM2500K) •100kW circulator is required to bypass the reflected power to a dummy load •1kW,10kW and 100kW class amplifiers are used as drivers •Block diagram Fig.4.2
Features		
1)Phase control	PLL at low level	Coaxial phase shifter located near each s/c cavity
2)Amplifier	A unit commecially used in broadcasting stations is available	CW output of 1.3MW is not achievable yet using 4CM2500K
3)Transmission line	Structure is simple because each cavity has each transmission line.Standard coaxial waveguide ,WX-152D, is adoptable	Structure is complicated due to power distribution. R&Ds of coaxial waveguide, circulator and power divider are inevitable
4)Auxiliary facility	Simple due to the lack of high voltage devices	Complicated due to the high voltage power supply and the crawbar circuit
5)Efficiency	Approximately 35%	Approximately 50%
6)Maintenance	Easy maintenance because each 1kW unit can be replaced	Uneasy maintenance because the tetrode is large
7)Lifetime	Very long	Short(the tetrode and a vacuum tube in the crawbar circuit)
8)Reliability	It is possible to continue operating even if some 1kW units break down. Moreover, repair is also easy.	It is impossible to continue operating if the tetrode break down. Much repair time is required.

18

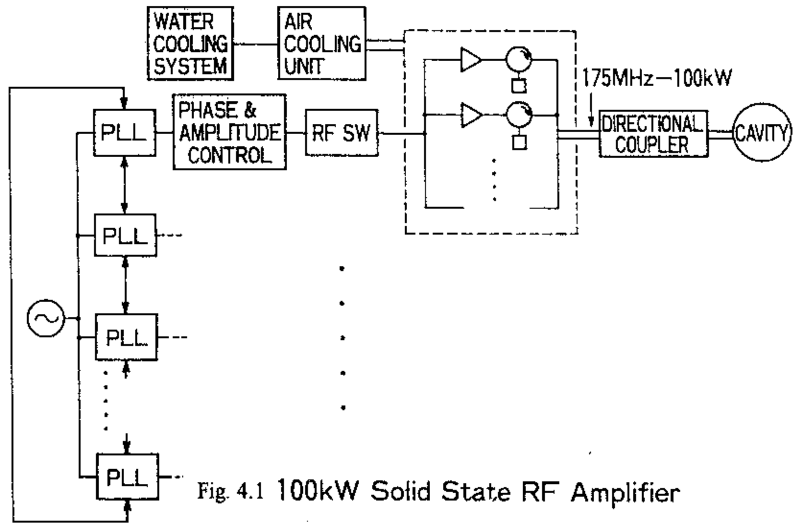


Fig. 4.1 100kW Solid State RF Amplifier

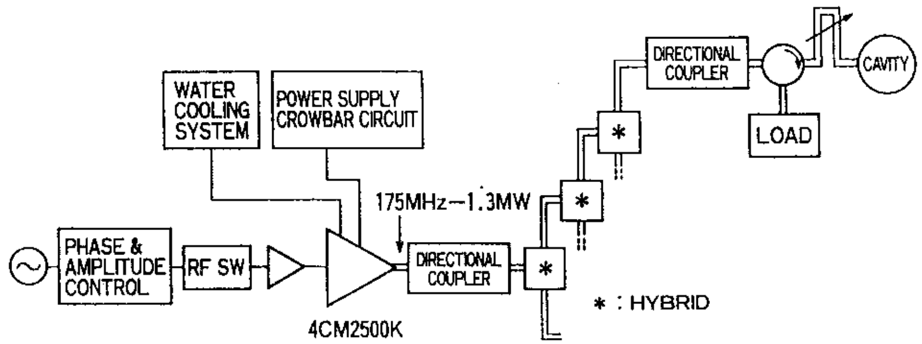


Fig. 4.2 1.3MW Tetrode RF Amplifier

19

5. RF control system

5.1 Main relations relating to an rf control system.

(1) β opt : optimum coupling coefficient between a cavity and an antenna in order to eliminate rf power reflection from the cavity in steady state operation,

$$\beta\ opt = 1 + Pb/Pc \quad \cdots(5.1)$$

,where Pb is the beam loading and Pc is the wall loss.

(2) Q_L: Loaded Q value of the cavity

$$Q_L = Q_0/(1+\beta\ opt) \quad \cdots(5.2)$$

,where Q_0 is unloaded Q value of the cavity.

(3) τ : The filling time of the cavity

$$\tau = 2Q_L/\omega \quad \cdots(5.3)$$

,where ω is $2\pi \times$(accelerating frequency, f).

(4) Δ f : FWHM (Full Width at Half Maximum) of the resonant curve of the cavity

$$\Delta f = f/Q_L \quad \cdots(5.4)$$

5.2 RF control system for the s/c linac system

Since Pb is 91kW and Pc is 7W from Table 2.1.2, β opt is as large as 13000. Therefore the rf power is perfectly reflected before the beam injection and circulators are required in order to protect the rf power supply from the perfect reflection.

Q_0 and f are 7.5E8 and 175MHz, respectively and Q_L becomes 5.8E4. Therefore τ and Δ f are 110 μ sec and 3kHz, respectively. The filling time of 110 μ sec is considered to be enough short in the initial transient stage. Moreover, Δ f is only 3kHz so we should develop a fine tuning system. One candidate is the system which uses the piezoelectric elements like the s/c cavity for TRISTAN.

A schematic diagram of an rf control system is shown in Fig.5.1. A signal from a pickup probe is divided into two feedback loops. One loop is for the phase control and the phase of the divided signal is campared with a phase reference through a phase detector. The phase difference is amplified to drive a phase controller and a tuner driver. Other loop is for the voltage control and the voltage of the divided signal is compared with a voltage reference. The voltage difference is amplified to drive a voltage controller.

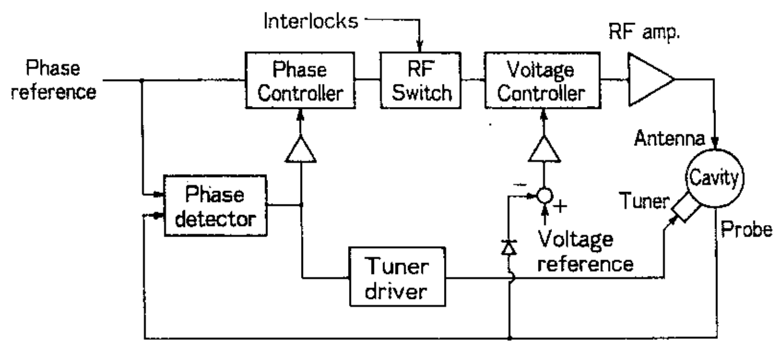


Fig 5.1 Schematic diagram of rf control system

6. Conclusion

The conceptual design of the s/c linac system was carried out as the main linac for the IFMIF. Main results are summarized as follows.

(1) The configuration of the s/c cavity was optimized for achieving the high accelerating efficiency at low β region. Because this optimized cavity has relatively high accelerating efficiency even at high β region, the same cavity was used at this region. It is beneficial from the viewpoint of compatibility to use the same cavity.

(2) It became clear from the three dimensional nonlinear magnetic field analysis that the s/c quadrupole magnet can generate the field gradient of 50T/m at 180A/mm^2. However, the distribution of the field gradient is not so good that it should be included in the analysis of beam dynamics.

(3) Total length of 13 cryounits is about 32m and that means the average accelerating gradient is about 1MeV/m. It is probably possible to reduce the total length through detailed system design.

(4) Irradiation damage data for Nb seems not to exist at present. Further investigation relating to the damage on superconductors are required.

(5) A 100 kW class solid state rf amplifier is available by the existing technology and is very attractive especially for the s/c linac system.

(6) The concept of rf feedback control system was considered. This system depends on the rf amplifier system and more quantitative study are necessary.

Further conceptual design activities will be focused on the following issues.

(1) Analysis of beam dynamics including the re-optimization of the s/c linac system.

(2) Investigation concerning how to fabricate the s/c cavity.

(3) Design of auxiliary devices for the cavity such as an antenna and a frequency tuner.

(4) Determination of the rf amplifier and the rf control system.

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

IFMIF Accelerator Interfaces

David Berwald

Northrop Grumman Corp.
Bethpage, NY

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Overview Of Presentation

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Summary of Accelerator Interfaces
- Test Cell Interfaces
- Target Interfaces
- Facilities Interfaces
- Central Control Interfaces

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

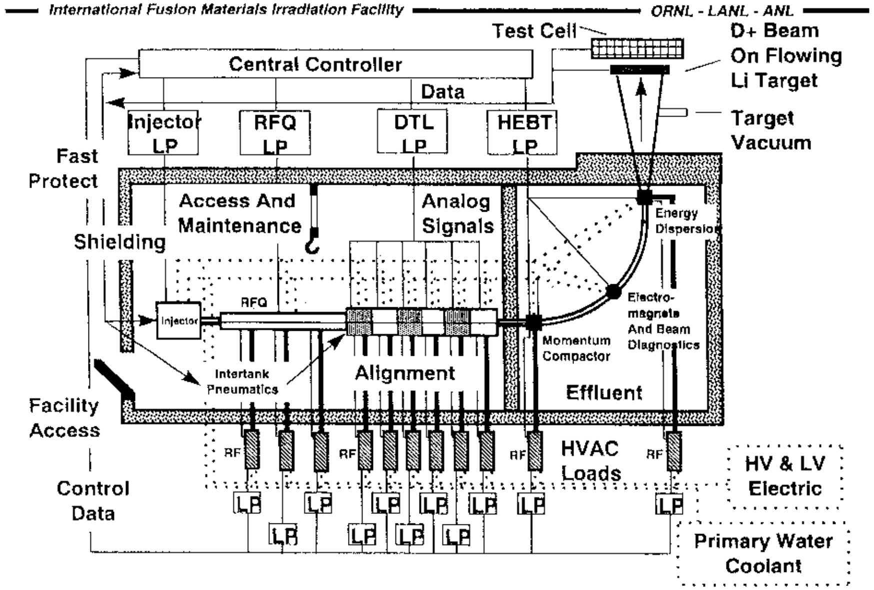
Summary Of Accelerator Interfaces

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator Interface Considerations

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Accelerator Interface Matrix

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

	Test Cell	Target	Conventional Facilities	Central Controls
Deuteron Beam	S	S	None	None
Physical	None	S	S	S
Electrical	None	None	P	None
Thermal Control	None	S	P	None
Vacuum	None	S	P	None
Control Data	S	P	None	P
Radiation Protection	None	None	P	None
Maintenance	None	None	P	X

Symbols: S - Interface requirements adequately defined for CDA
P - Interface requirement needs further discussion/development
X - Interface exists but not discussed in this briefing

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Related Presentations

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Test Cell, Target, Facilities, I&C Group presentations
- John Rathke's briefing on accelerator design updates
- David Bruhwiler/Itacil Gomes' briefings on beam loss/system activation
- Chris Piaszczyk's briefing on accelerator maintainability
- Stan Mendelson's briefing on instrumentation and control

Suggest IFMIF program establish interfaces working group to resolve issues, issue joint document

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Accelerator - Test Cell Interfaces

✓ Deuteron Beam
✓ Control Data

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Test Cell Interfaces: Deuteron Beam

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

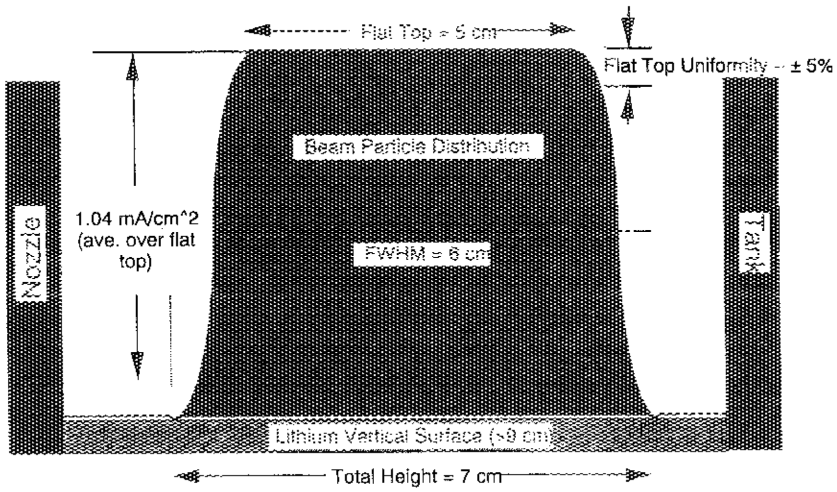
Design Objectives	Interface Requirement/Solution
Achieve optimal irradiation environment: - Flux level - Irradiation volume - Uniformity of irradiation	• Provide 125 mA current per beamline • Provide 5 cm x 20 cm rectangular beam profile • Provide high beam uniformity over flat top (+/- 5%) • Overlap two beams on target (<10° half angle)
Accurate determination of flux level at specific locations in test cell	• Provide beam centroid position tolerance less than +/- 1 mm at target
Ability to differentiate neutron damage due to high energy neutrons that can be generated in 40 MeV beam	• Provide 3 beam energies: 30, 35, 40 MeV
Avoid difficulties in interpretation of material damage that would result from kinetic effects (e.g., annealing) during beam outages	• Provide high enough accelerator reliability to make dual accelerator outage during scheduled operation highly unlikely (exact requirement TBD)

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Beam Profile Requirement : Vertical Direction

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



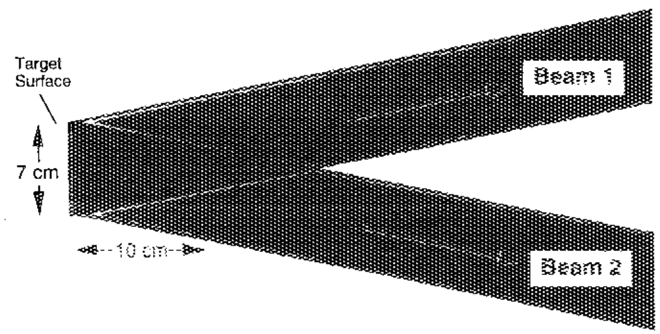
Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Divergence Of Neutron Source Geometry

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

(Target Distance Of 14 m, Beam Bending Angle Of 10°)



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Accelerator - Test Cell Interface Requirements: Control Data

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Design Objective	Interface Requirement/Solution
Provide rapid beam shutdown in response to critical test cell failure modes	• Provide Fast Beam Interrupt System (FBIS) with hard wired connection from test cell control substation to Ion injector power system

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Accelerator - Target Interfaces

✓ Deuteron Beam
✓ Physical
✓ Thermal
✓ Vacuum
✓ Control Data

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Accelerator - Target Interface Requirements: Deuteron Beam

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

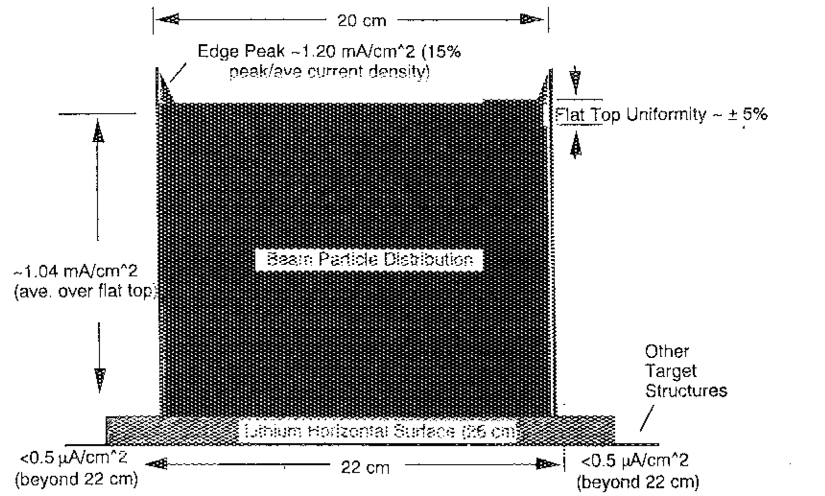
Design Objectives	Interface Requirement/Solution
Avoid overheating the lithium jet	• Minimize peak/average current density at horizontal edge of beam (<1.15) • Provide beam energy dispersion (+/- 0.5 MeV FWHM about final beam energy) to smear Bragg peak
Avoid thermo-mechanical shock to the lithium jet	• Avoid abrupt step increase in current density at vertical edges of beam (zero to full current over <1 cm) • During pulsed operation (e.g., startup), ramp current up to (and down from) flat top over 0.5 ms
Avoid overheating adjacent target surfaces	• Reduce beam current density beyond 11 cm from centerline of lithium jet to <20 w/cm² (< 0.5 μA/cm²)

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Beam Profile Requirement : Horizontal Direction

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



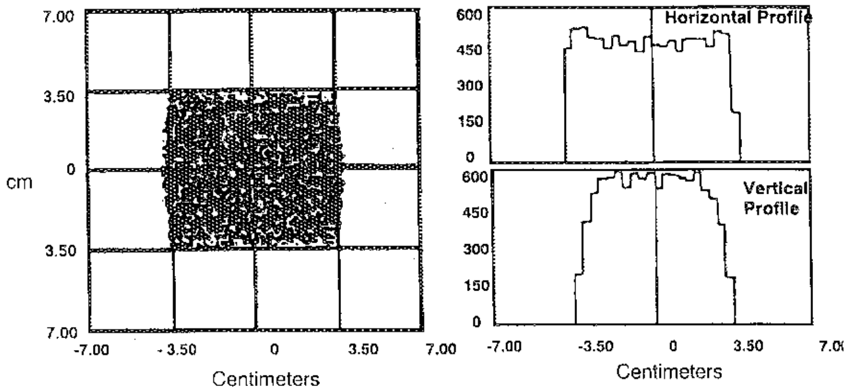
NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

PARMILA Simulation Of ESNIT Beam Profile On Target

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

(35 MeV, 100 mA, 7 cm x 7 cm, ± 0.5 MeV, 10000 particles)



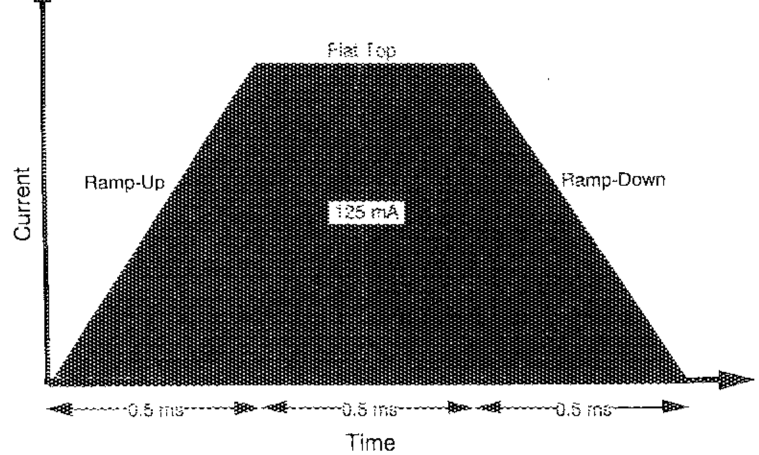
NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Typical Beam Pulse Form For Pulsed Operation

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

(2% Duty Factor, 20 Hz)



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Target Interface Requirements: Physical

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

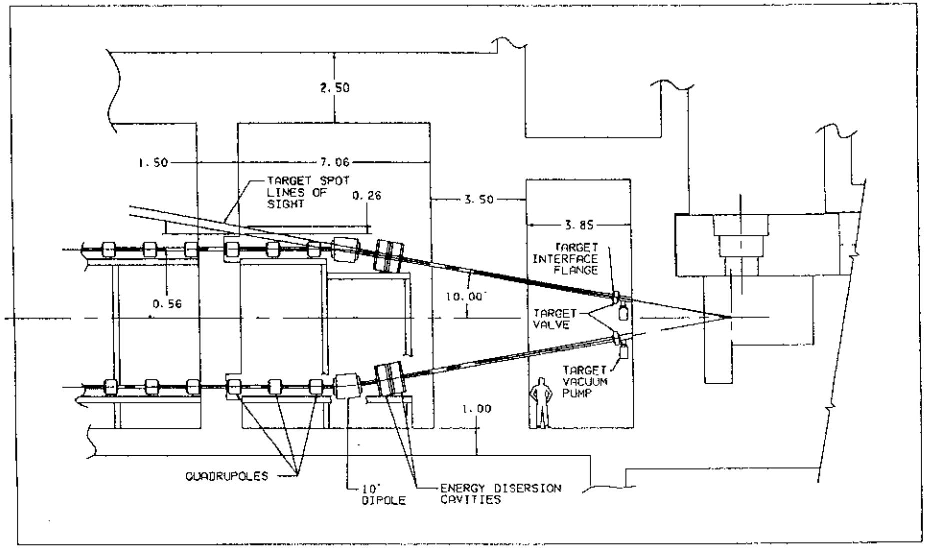
Design Objectives	Interface Requirement/Solution
Minimize neutron backstreaming and irradiation damage to final optical elements in beamline	• Transport expanding beam to target in square duct • Minimize free space on duct (~5 cm beyond edge of beam) • Maximize beam angle normal to target subject to test cell requirements (10° half angle)
Provide isolation of beamline and target for accident scenarios and routine maintenance	• Provide large gate valve on target side of interface flanges in final beam tubes • Provide small fast gate valve where beam is small near dispersion cavities

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator-Target: Physical Interface

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Accelerator - Target Interface Requirements: Thermal

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Beam Energy	30 MeV	35 MeV	40 MeV
Flat Top Area (cm^2)	100	100	100
Flat Top Power (MW)	6.25	7.29	8.33
Average Power Flux Over 5 x 20 Flat Top (W/cm^2)	62,400	72,800	83,200
Peak Power Flux At Horizontal Edge (W/cm^2)	71,700	83,700	95,700
Total Area Including Vertical Edges (cm^2)	110	110	110
Total Power (MW)	7.50	8.75	10.0

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Target Interface Requirements: Vacuum

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Design Objectives	Interface Requirement/Solution
Minimize routine incursions of vapors from lithium target into beamline RF cavities and other components ~12 m from target	• Provide ion pump on target side of target interface flange • Provide sufficient pump capacity to limit pressure immediately upstream of interface to <10^{-8} Torr
Minimize propagation of tritium effluent into the beamline	• Provide tritium pumping capability in final pump (above)

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Target Interface Requirements: Control Data

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Design Objective	Interface Requirement/Solution
Provide rapid beam shutdown in response to critical target failure modes	• Provide Fast Beam Interrupt System (FBIS) with hard wired connection from test cell control substation to ion injector power system and to fast acting valves in beamline

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Accelerator - Conventional Facilities Interfaces

- ✓ Physical
- ✓ Electrical
- ✓ Thermal
- ✓ Vacuum
- ✓ Radiation Protection
- ✓ Maintenance

X

<u>Separate Tabulations For:</u>
Accelerator Vault
Beam Turning Vault
Beam Steering Vault
Final Beam Calibration Vault
RF Power Hall
Auxiliary Power Hall

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Accelerator - Central Control Interfaces

- ✓ Physical
- ✓ Control Data ☛ I&C Presentation
- ✓ Maintenance

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Conclusions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- The IFMIF accelerator has many important interfaces
- We're attempting to capture them in the CDA report
- An overall coordination activity between IFMIF groups probably warranted

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Contents of the presentation

1. Beam dynamics study of IFMIF RFQ by the calculation codes RFQUIK, PARMTEQ, and CURLI.

   (1) I desigined two examples with the two kind of focusing strength in the same procedure.
   - B=5
   - B=6

   (2) The acceleration characteristics of these examples were compared with each other.

2. RF characteristics study of IFMIF RFQ by the calculation codes MAFIA and SUPERFISH.

   (1) RF characteristics of the coupled cavity RFQ were avaluated by MAFIA.
   - consideration about the optimum vane configuration
   - estimation of the RF poewr loss and the density

Specifications of the IFMIF RFQ shown by JAERI

Acceleration particle	D^+
Input energy	100keV
Output energy	8MeV
Output current	125mA
Frequency	175MHz

1. Beam dynamics study

1.1 RFQ Design procedure with RFQUIK, CURLI, and PARMTEQ

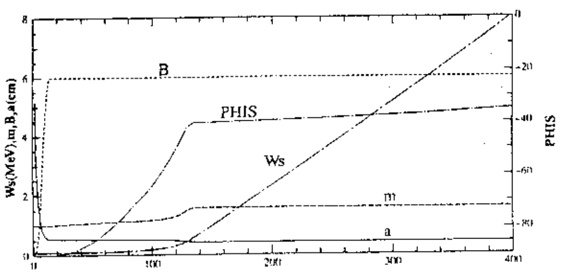
Many input parameters for RFQUIK were set in the manner listed below

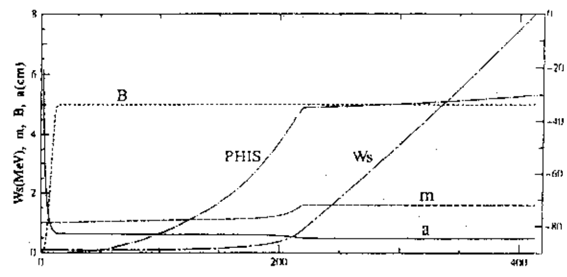
Input parameter	manner for parameter setting
B (focusing strength)	•Two values (B=5 and 6) were preset as independent constants.
Kilpatrick value	•The value were preset to 2.0 as an independent constant.
W_s (Beam energy at the shaper end)	•The value was set to maximize the phase advance of the betatron oscillation in the shaper section.
W_g (Beam energy at the gentle buncher end)	•The values were set to attain the transmission ratio about 100% for 0 mA curent input about 90% for 150 mA input.
A_g (Accrel. strength at the gentle buncher end)	•The values were set to satisfy the condotion that transversal current limit corresponds to longitudinal value.
$PHIS_g$ (synchronus phase at the gentle buncher end)	•The values were set to minimize the vane length.
$PHIS_A$ (synchronus phase at the accelerator end)	•The value was set to be slitly higher than the $PHIS_g$ to shorten the vane length.

1.2 Main parameters of the two examples

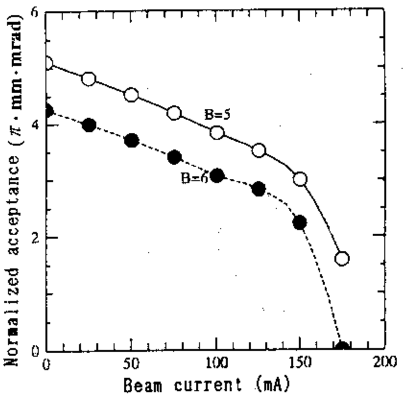
	B=6	B=5
Input energy (MeV)	0.1	0.1
Output energy (MeV)	8.0	8.0
Vane length (m)	16.05	13.38
cell no.	399	414
min. aparture radius(mm)	4.11	4.85
max. modulation	1.567	1.605
intervane voltage (kV)	111	133
ϕ at gentle buncher end	-40 deg	-35 deg
ϕ at accelerator end	-35 deg	-30 deg
Wall loss (kW)	1040	1190
Longi. current limit(mA)	178	191
Trans. current limit(mA)	174	189

1.3 Variation of the Cell parameters with cell no. for two examples





1.4 Dependency of the transversal acceptance on the input current



1.5 Transmission ratio for the two examples

input beam emittance = 0.5 x acceptance

Input current(mA)	B=6	B=5
0	99.7	100.0
50	95.0	97.7
100	91.0	94.7
150	88.7	90.0

1.6 Consideration on the beam dynamics

(1) From a view point of the theoretical calculation by PARMTEQ, it is possible to accelerate 125 mA beam up to 8 MeV with 175MHz RFQ.

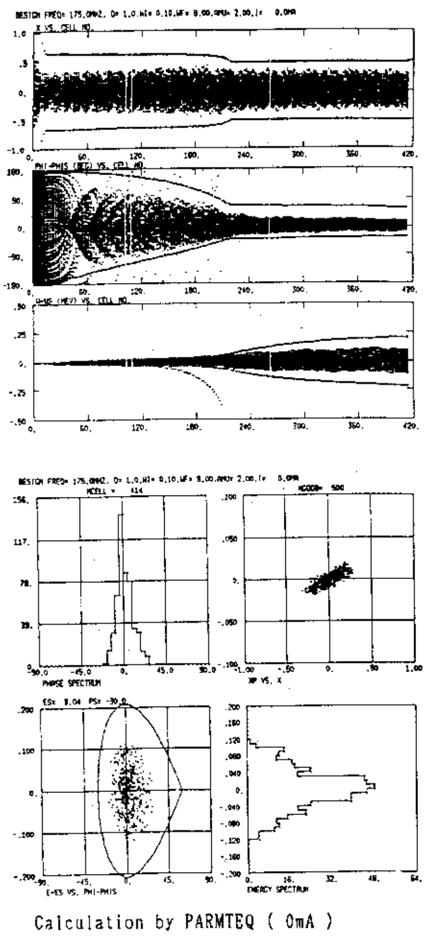
(2) From the comparision of the acceleration characteristics for the two examples, we can see that RFQ desigfed with lower focusing strength has a higher current limit, bigger acceptance, and shorter vane length.

(3) The example with B=5 is more suitable than another example(B=6).

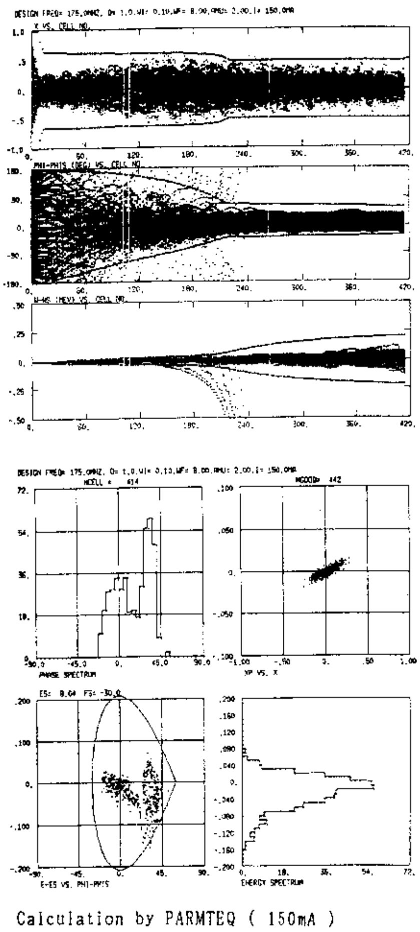
1.7 Concerning matter about the beam dynamics

(1) The value of the surface field (two times of Kilpatrick) in this study may be higher than the value we can attain stably. If we have to reduce this value, the reduction necessarily leads to the increase of the vane length to keep the acceleration current.

(2) There is no margin on the acceleration current in my both examples. Considering that no RFQ exists to accelerate the cw high current beam which is almost same as the current limit calculated by PARMTEQ or CURLI, some kinds of countermeasure to this probrem should be applied.



Calculation by PARMTEQ (0mA)

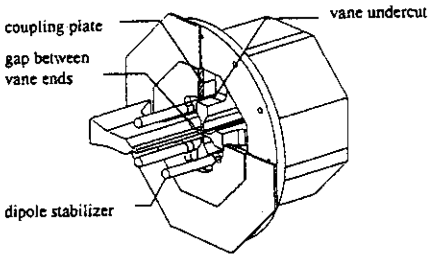


Calculation by PARMTEQ (150mA)

2. RF characteristics study

As shown in beam dynamics study, the length of the IFMIF RFQ reaches about 13 m. If we construct this RFQ in the conventional 4 vane type, it is almost impossible to attain an enough field flatness and stability of the RF quadrupole field, because field stability is proportional to $(\lambda/(\text{vane length}))^2$.

In order to overcome this problem, it is very useful to apply the resonance mode with nodes such as coupled cavity RFQ, 4 rod type, sprit coaxial RFQ, and so on. 4 rod type and SC-RFQ have a very low frequency so that only the coupled cavity RFQ is appliable to IFMIF RFQ.



2.1 Consideration about the optimum vane configuration

From a view point of attaining an enough field flatness along the beam axis, many parameters deciding the vane configuration (vane undercut shape, coupling plate shape, gap distance between vane undercut and coupling plate and so on) were optimized.

2.2 RF characteristics of IFMIF RFQ calculated by MAFIA

RF characteristics of IFMIF RFQ calculated by MAFIA is shown below. In order to evaluate the property as the cavity resonater, I calculated RF parameters about the 4 vane type by SUPERFISH. These parameters are also shown in the table.

	coupled cavity RFQ by MAFIA	4 vane type by SUPERFISH
intervane voltaze (kV)	133	133
vane length (m)	13.36	13.36
maximun field (MV/m)		27.82
kilpatrick value		1.99
Q value	13200	13200
power loss (kW)	1360	1450
beam loss (kW)	990	990
max. power loss density(W/cm²)	55.0	5.8

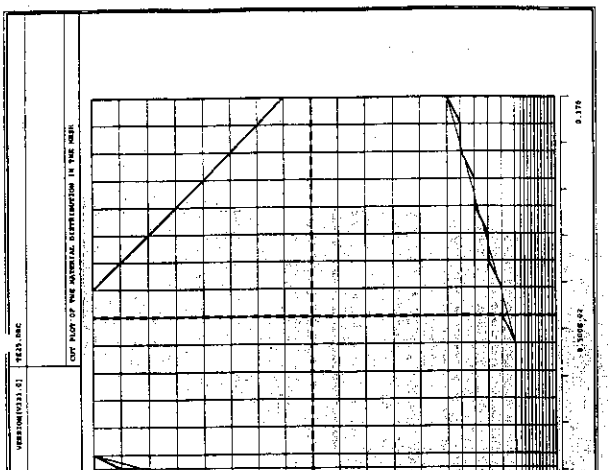
2.3 Consideration about the coupled cavity RFQ

(1) Q value and power loss are comparable to the values of the 4 vane type so that it is considered that coupled cavity RFQ has a superior RF characteristics.

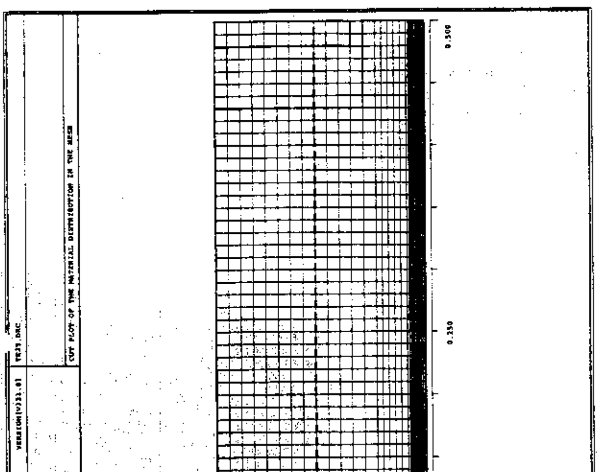
(2) It is supposed that coupled cavity RFQ is the only structure which is appliable to the IFMIF RFQ.

2.4 Concerning matter

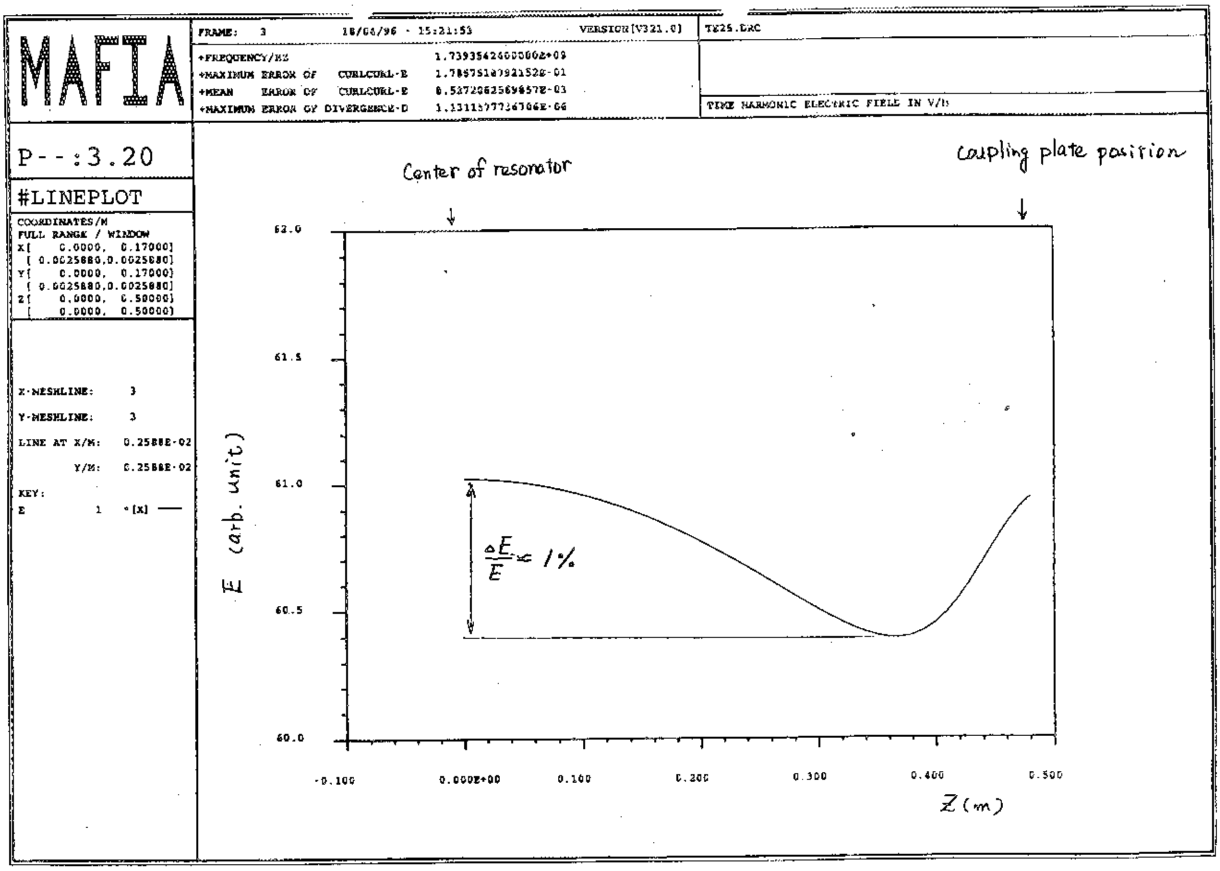
(1) Power loss density in the vane undercut region exceeds 50 W/cm², even in the case that Q value is equal to theoretical value, it is very difficult to remove the fever from the cavity.



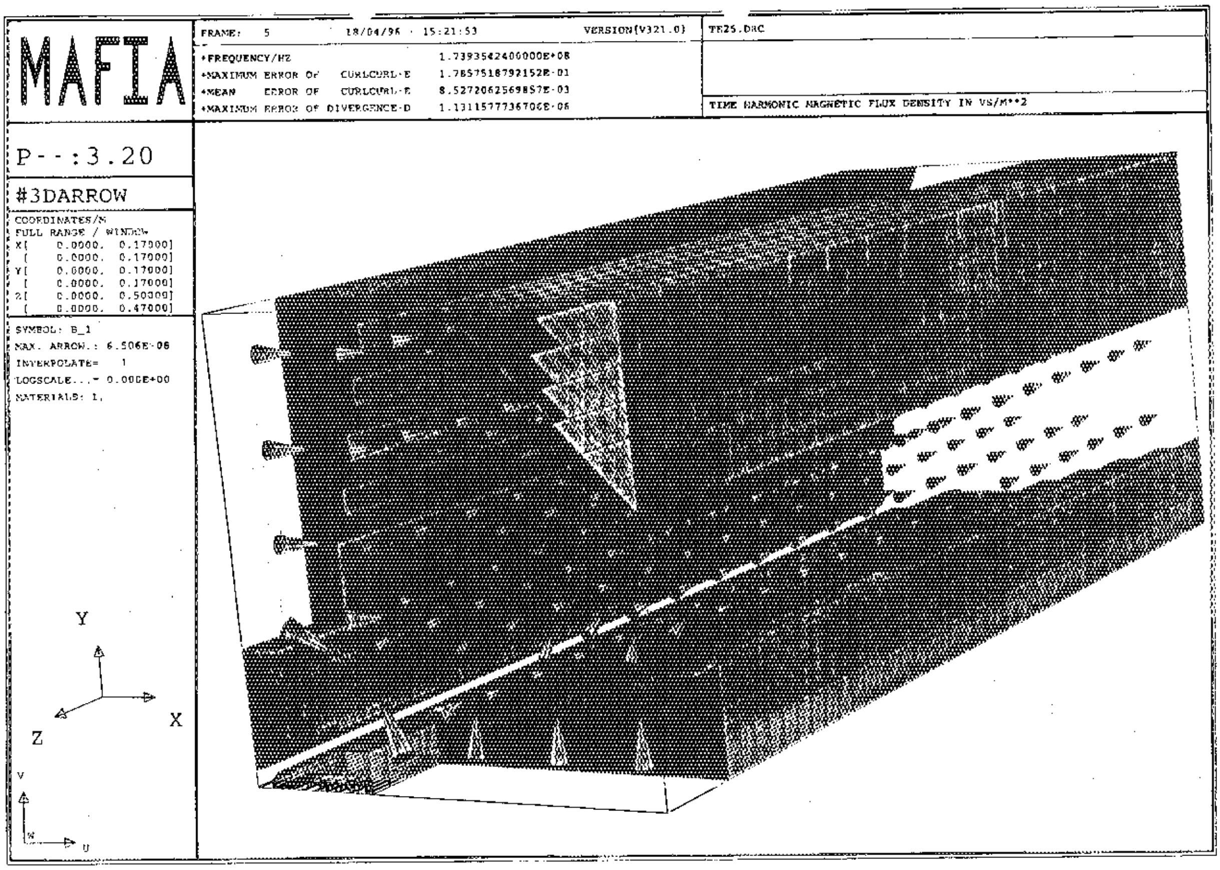
- 30 -



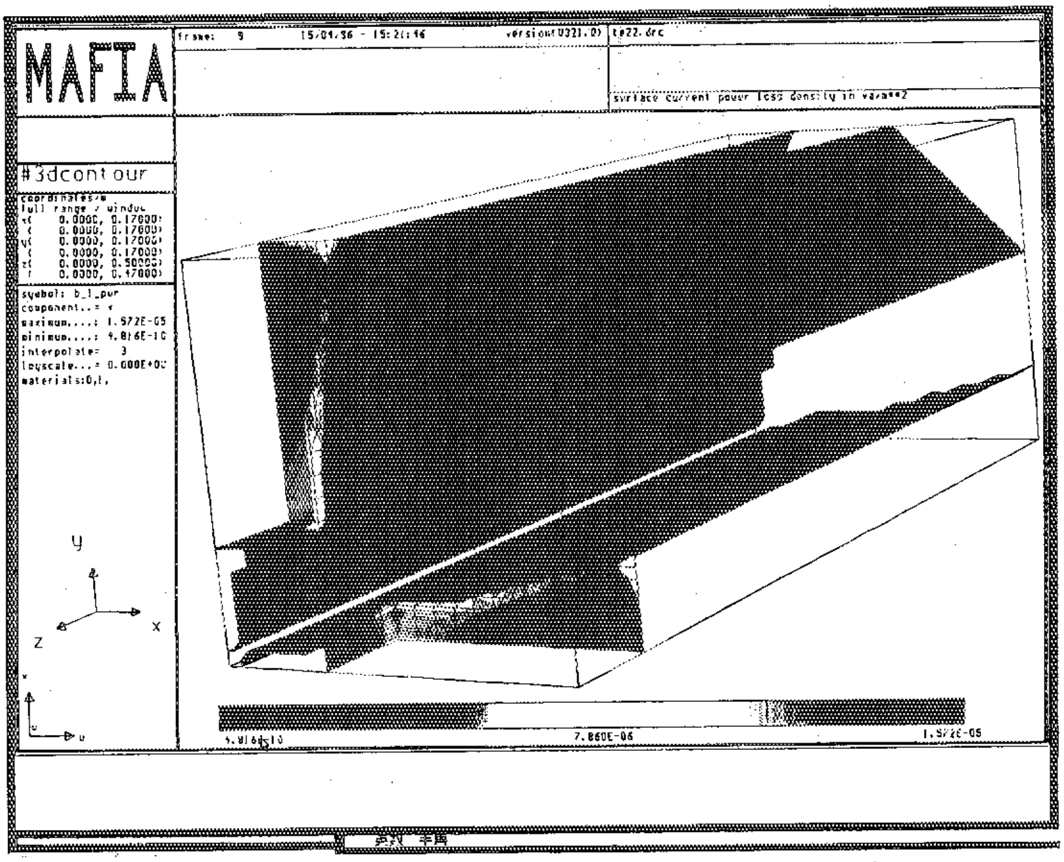
- 32 -



- 33 -



Arrow Plot of B



Power Loss Density of the RFQ under the condition that
Q value is equal to theoretical value

Comments on accelerating structures electrodynamical properties and RF systems

Measuring optical system for RFQ and DTL fine tunings are proposed; main principles are based on "Electromagnetic Field Precise Measurements in Accelerating Structures" paper. The modified method at equipotentials detecting principle can give high precision for segmented RFQ tuning under desired vane ends modulation implementation and under required setting in coincidence the axes of tuned segments. Projections forming and measuring optical system properties are presented also.

Conception of RF system for excluding different type transmission lines long feeders, undesirable modes eliminating under intense beam acceleration, matching of RF source, producing of RF control system supporting signals at directional selective coupling method are proposed, App.1 "Concerning RFQ structure and RF feed system design". Analysis of IFMIF segmented RFQ operating mode allowed to estimate the acceleration bore field distribution and the electrodes possible shapes in the inter-segment gape regions; electrostatic approximation of the fields for computer simulation of the beam dynamics is proposed, App.2 "Concerning segmented RFD structure inter-segment gaps design". These principles and main tuning method are based on "Portable 433MHz RFQ Linac RF System" article ideas, which are developed for IFMIF RFQ special properties.

Further works will be devoted to multimode beamloading at transient (nonstationary) operating conditions and to the basic principles of RF control system design. At consideration of generalized goal function (the main search problem) all the synthesis will be reduced to optimization problem for RFQ characteristics (at the beam dynamics simulation) in the meaning of the goal function extremum, but not in the beam divergence or equipartitioning principles usual senses in the general case.

Electromagnetic Field Vector Components Precise Measurements in Accelerating Structures

M. A. Chernogubovsky, M. F. Vorogushin
D.V. Efremov Research Institute of Electrophysical Apparatus, 189631 St Petersburg, Russia

Abstract

Precise method for resonator electric or magnetic vector components values and their space positions measurements, based on application of photosemiconductor plate with different configuration lighted images, formed by projections forming and measuring optical system of amplitude modulated light radiation, is presented. The optical system for 433 MHz RFQ accelerating structure is realized by means of serial producted micro-alignment telescopes; the method allows to descriminate the field axis fluctuations on micron level and provides several percents and tenths of percents precision for accelerating efficiency and modulation period measurements respectively.

I. INTRODUCTION

An electromagnetic field distribution measurements in accelerator resonant structures are usually carried out by perturbation method, the data processing gives the field vector modulus as averaged volumatric value on the perturbation object. The measurements accuracy is limited in principle by the object carrying system distortions and unperturbated resonant frequency reading inadequacy. Operative frequency rise as well as applied fields complication will cause inadmissible growth of these inaccuracies. Electro-optical principle is proposed to exclude these errors and to realize different vector components measurements of electric or magnetic fields distributions, the method and system development for RFQ structure is considered.

II. ELECTRO-OPTICAL PRINCIPLE

Perturbation object for the method is designed as a high resistivity photosemiconductor flat plate, that can be installed inside the resonator on a thin filament as before. Light radiation of amplitude modulated source passes through a controller of the light beam spatial position and lights up desired configuration region on the plate surface in required position. The resonant frequency difference between the readings in unlighting amplitude modulation half-cycle and in the next lighting one will determine the field in perturbated region. Electric field vector components measurements can be carried out by thin strip light configurations, oriented along the components; for the plate normal magnetic field component a closed-loop configuration is sutable; average properties can be determined by a spot of accordent space. A normal to electric field lighting minimizes the dark and light readings difference (that vanish for infinitesimal thickness of the normal), in quasistatic field it is equipotentials detection without quantity measurements.

Carrying system distortions are entirely excluded, because the perturbation is formed by exact strightforward light beam. The second mentioned error is excluded almost completely by the dark reading in any measurement point, because high-spead (acusto-optical, e.g.) devices allow to decrease amplitude modulation cycle up to the doubled transient duration. For all this, the precise measurement problem is reduced to implementation of correlated with the resonant mode light configurations.

III. RFQ MEASUREMENTS

The field symmetry axis can be detected by equal thin strips lighting on the round plate (II), fig.1. By (1) and (2) couple removing in OY direction the equal dark-light frequency differences for each strip can be achieved, i.e. E_y components in (1) and (2) regions are equal, the axis coordinate y_q is geometrical center of the couple; similar OX removing of (3),(4) gives x_q coordinate. Vanes curvature is determined by the strips turn refer O_qx and O_qy untill maximum (but a.m. equal) dark-light differences for (1'),(2'); (3'),(4') will be obtained – fig.1 presents symmetrical ψ bend; for a single element distortion the geometrical centers will not form straight lines under OX displacing of (1),(2) couple, (3),(4) – in OY direction. So, that kind positions research yields the field axis coordinates and symmetry destorting causes all information.

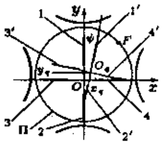


Figure 1: Lightings for RFQ measurements.

Obtainable precision analysis is conducted at known [1] electric field in the bore with modulation period l_m, accelerating efficiency θ, inner radius mean r_0:

$$\begin{aligned} E_x &= Ux(\Lambda - 1/r_0^2), \qquad \Lambda = 2\theta\kappa \sin\kappa z I_1(\kappa r)/\kappa r, \\ E_y &= Uy(\Lambda + 1/r_0^2), \qquad r = \sqrt{x^2+y^2}, \qquad (1) \\ E_z &= (U/\pi)2\theta\kappa \cos\kappa z \cdot I_0(\kappa r); \quad \kappa = \pi/l_m. \end{aligned}$$

Spatial selectivity is defined by frequency deviations ratio of interfluent and separated components, e.g. l length, $a_s \times a_s$ cross-section strip (4) E_x selectivity in (1) field according to [App.] is $\Pi_\perp = (\delta f_{E_z}/\delta f_{E_x}) \le 4\cdot 48(a_s/2l)^2(\ln 2l/a_s - 1)(r_0\theta/l_m)^2$ - the cylinder curcle perimeter is equal to square one. In the structure with $\theta \in [0.003; 0.5]$, $l_m \in [4; 20]$ mm, $r_0 = 3.5$ mm and operating frequency $f_n = (k_n/2\pi\sqrt{\varepsilon_0\mu_0}) = 433$ MHz for $0.1 \times 0.1 \times 2.5$ mm strip the averaged selectivity is $\Pi_\perp < 2\cdot 10^{-4}$, that is greatly less than instrumental resolution. The cavity analysis in the form of coupled shortcircuated sector radial waveguide sections, loaded by end capacitances, gives according to [App.(11)] the deviation

$$|\frac{\delta f_{E_x}}{f_n}| = M\left((\frac{x_0}{r_0})^2 + (s_1 - \frac{1}{4})(\frac{l}{r_0})^2\right), \quad (2)$$

$M \cong 5.52\cdot 10^{-6}$. An error in desired equality of deviations at RF phase measurements is determined by minimal phase count discrete $d\varphi_m$, and (2) result yields the strip displacement resolution $dx_0 \cong 2r_0(\pi MQ)^{-1}d\varphi_m$, Q - quality factor. For $d\varphi_m = 2\cdot 10^{-5}$, $Q = 5\cdot 10^3$ it is $dx_0 \simeq 1.6$ mkm, that cause the development of precise optical system for the images forming inside small aperture, lengthy ($L = 1445$ mm) bore without vanes lighting – the plate excitation by reflection phone is inadmissible. Autoreflective image forming in convergent rays of telescopic objective can be effected by micro-alignment telescope only by placing the light source beyond the graticule on the eyepiece side.

The system fig.2 comprises (4) and (5) micro-alignment telescopes [2]. Collimated image former (1) containes transparency (2) with adjustable in independent square directions transparent region; projective telescope (4) forms the image along its datum optical axis with displacements possibility by optical micrometers.

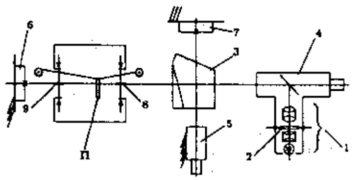


Figure 2: Images forming and measuring system.

Another telescope (5) is interconnected by pentaprism with wedge (3) for the image dimensions measurings on the plate (II). Alignment on the base datum targets (6),(7) sets optical axes of the former and both telescopes in coincidence; the resonator is fixed on the datum axis by (4) viewfinding on removable transparent targets (8),(9); and datum line of sight can be ascertained always by (5) viewfinding on (7) target after (3) removing. Transparency (2) is equipped by rotary device with 30″ count accuracy. The system allows to form rectangular images with variable $0.05\ldots 3$ mm sides, total error of the image coordinates is $\pm(3+2D)$ mkm, D - image distance, M, but the systematic error can be excluded, [2]. So, the strip position inaccuracy is 3.5 mkm and the field axis coordinates real error ≈ 4 mkm. The structure fine tuning properties θ, l_m are defined by the minimum dark-light deviation position detection under radial strip lighting refer to determined axis. According to [App.], this position corresponds to minimal integral value in (6) equation at the current distribution (7) for (1) field. Direct variation yields the minimum deviation angle α between Ox and the strip

$$\alpha = \frac{\arccos(G\theta \sin\kappa z)}{2}; \quad G = \frac{2(\kappa r_0)^2 \int_0^l I_1(\kappa z)F(z)\,dz}{\pi \int_0^l \kappa z F(z)\,dz},$$

$F(z) = kz - kl \sin kz \cdot \csc kl$, and it is enough to measure α under the plate removing along the structure for $\alpha^{max}, \alpha^{min}$ values and $\alpha = \frac{\pi}{4}$ positions determination, because

$$\theta = (\cos 2\alpha^{min} - \cos 2\alpha^{max})(2G)^{-1}. \quad (3)$$

Two counts phase method of α mesurment with rms error $(\delta\bar{\varphi}/\varphi) = 2\cdot 10^{-4}$ in (1) field gives inaccuracy $(\delta\alpha_m/\alpha) \le 1.7\cdot 10^{-6}$, but the phase dependence is not symmetric refer α (except $\alpha = \pi/4$), and systematic innacuracy $(\delta\alpha_s/\alpha) \le 4.4\cdot 10^{-5}$. Spatial selectivity is ample as before, sensitivity decreace is $2.5\cdot 10^{-3}$ only. The angle reading rms error of the optical system is $1.4\cdot 10^{-4}$, that determines real precision: for longitudinal coordinate count error $\simeq 5\cdot 10^{-3}$ the modulation period innacuracy is $(\delta l_m/l_m) \le 7.1\cdot 10^{-3}$, and (3) result gives accelerating efficiency with $(\delta\theta/\theta) \le 1.3\cdot 10^{-2}$ error.

Asymmetric positioning of R_d radius, T thickness, ε dielectric constant plate will distort investigating field (on fig.1: F is fastening point, $\sqrt{2}b$ – sag to 3 quadrant). But only transverse field components inside the plate are used, l_m accuracy under $\alpha = \pi/4$ position determination in 1 and 3 quadrants is not changed, because $\delta\alpha_m$ rise even to two orders due to sensitivity lowering will not exeed determinative value. The θ error electrostatic estimating for $R_d = l, \varepsilon = 10, T = 0.1$ mm, b $= 0.05$ mm gives $(\delta\theta_\varepsilon/\theta) \le 6\cdot 10^{-3}$, the efficiency error grow up to $1.5\cdot 10^{-2}$.

Photosemiconductor characteristics analysis by [App.] method yields optimized ratio of the active light-dark conductivity: for $\varepsilon \le 10$ the ratio is $125\ldots 130$, and CdS or CdSe materials suit perfectly well.

IV. CONCLUSION

Electro-optical principle and its application for RFQ structures precise measurements method have been developed. Designed optical system provides several micrometers accuracy not only for the field axis coordinates, but for geometrical shapes of the accelerating bore forming elements also - autoreflection method is effected by contact bore targets or master gauges fastening on the same filament. Developed balance technique (that excludes a field quantity measurements) for the structure fine tuning could be used for precise measurements in other types cavity resonators.

APPENDIX. Thin cylinder formfactor for RF nonhomogeneous fields

Use of retarded potential $\vec{A}$ field operator singularity for axially symmetric l length a radius longitudinal current $\bar{I}(z)$ yields on its circumference in ρ, ϕ, z local coordinates

$$\vec{A} = N(\rho)\cdot \bar{I}(z)\,|_{\rho=a}, \quad (4)$$

where $N(\rho) = (1/2\pi)[\ln(2/k\rho\gamma) + Ci(kl) - (\sin kl/kl)]$, $\gamma = 0,577\ldots$ - Euler's constant, $Ci(kl)$ - integral cosine. In two-component case (4) result inaccuracy will not exceed $(a/2l)^2$ even for equal longitudinal and transverse field components, that follows, e.g., from ellipsoid depolarization tensor principal values [3]; however, the practicaly used disposing along the supposed field vector will supplement decreace of inaccuracy to $3\ldots 4$ orders. Boundary conditions in external E_z^e field lead to

$$\frac{\partial I}{\partial z} = -\frac{i\omega\varepsilon_0\varphi(z)}{N(a)}; \quad \frac{\partial\varphi}{\partial z} = E_z^e - I(z)(i\omega\mu_0 N(a) + z_l), \quad (5)$$

where z_l - line active resistance of the cylinder material, φ - scalar potential of (4) field. Now a resonator ν-mode $\{\vec{E}_\nu, \vec{H}_\nu\}$ with ω_ν resonant frequency, Q_ν quality factor is excited by some source S together with the cylinder $\vec{j}$ current density, and magnetic h_ν, electric e_ν fields amplitudes equations are

$$h_\nu(\omega_\nu^2 - \omega^2) + \frac{i\omega\omega_\nu h_\nu}{Q_\nu} = S - \frac{\omega_\nu}{W_\nu}\int_{v}(\vec{j}, \vec{E}_\nu)dv, \quad (6)$$

$e_\nu = i\omega h_\nu/\omega_\nu$; where $W_\nu = \varepsilon_0 \int_{v_{re}} |\vec{E}_\nu|^2 dv$; v_{re}, v - resonator and cylinder volumes. Thus, for any $E_{\nu z}(z)$ function the $I(z)$ distribution is defined at $E_z^e = e_\nu E_{\nu z}(z)$ substituting in (5) equations:

$$\frac{\partial^2 I(z)}{\partial z^2} + k^2(1 - \frac{i\omega\varepsilon_0 z_l}{k^2 N(a)})I(z) = \frac{\omega^2\varepsilon_0}{N(a)\omega_\nu}E_{\nu z}(z)h_\nu, \quad (7)$$

boundary values are $I(0) = I(l) = 0$ for distant from the cavity walls cylinder. So defined $I(z)$ determines integral value in equation (6), forming the amplitude equation for only S excitation of the resonator with new resonant frequency ω_n and new quality factor Q_n, i.e. the formfactor is defined. Eigenfunctions means substantiate that the summary field of all other modes with gradient summand is described by cylinder own field (4), and only condition for exact measurements is excluding of other modes excitation by S source in the cylinder region.

Simplest homogeneous field analysis for $kl \le 0.1$ gives

$$Q_n \cong Q_\nu \frac{\omega_\nu}{\omega_n}\left(1 + \frac{\omega_\nu^2 - \omega_n^2}{\omega_\nu\omega_n}Q_\nu \frac{z_l l}{\sqrt{\frac{\mu_0}{\varepsilon_0}}N(a)}\frac{k_n l}{(k_n l)^2 + 10}\right)^{-1};$$

quality factor decrease due to finite coductivity of a thin $(N(a) > 1)$ cylinder even with $z_l l = 10$ Ohm will be in 4 order only. Therefore, $z_l = 0$ value can be used indeed, and for any kl the method yields (in conventional Slater's form writing):

$$\frac{\omega_n^2 - \omega_\nu^2}{\omega_n^2} = -\frac{[E_{\nu z}(z_0)]^2\varepsilon_0 v}{W_\nu}K, \quad (8)$$

where z_0 - coordinate of the field reading, $K = K_0$ - formfactor:

$$K_0 = \frac{(\frac{l}{a})^2}{\pi N(a)}\frac{2\tan\frac{k_n l}{2} - k_n l}{(k_n l)^3}. \quad (9)$$

Product vK_0 for $(a/l) \ll 1, k \to 0$ coinsides with the result of electrostatic analysis [3]. However, if the cylinder approaches the cavity walls (e.g. $z = 0$ endpoint is near the wall), $I(0) = 0$ value must be interchanged by $\varphi(0) = -I(0)/i\omega C_e$, or $I(0) = \beta(\partial I/\partial z)|_0$, C_e - the cylinder endwall and the cavity wall capacitance, $\beta = C_e N(a)/\varepsilon_0$:

$$K_w = K_0\left(1 + \beta k_n \frac{1 - 2\tan\frac{\tau}{2}\cot\tau}{(2\tan\frac{\tau}{2} - \tau)(1 + \beta k_n\cot\tau)}\right), \quad (10)$$

where $\tau = k_n l$. The end contiguity $(\beta \to \infty)$ yields $K_w \cong 4K_0$ for $kl \le 0.1$ and than K_w decreases up to K_0 for $\beta \to 0$ with the cylinder moving off, (10) general relation corresponds to electrostatic model [4].

Practicaly interesting results of nonhomogeneous field analysis are obtained at polinomial representation, e.g. for $E_{\nu z} = A_2 z^2 + A_1 z + A_0$ the method gives

$$K_p = K_0\left(\Upsilon + \eta\frac{4(4\eta s_2 + \frac{2\xi s_3 + s_4}{1+\xi}) - \Upsilon(\eta + 2)}{(1+\eta)^2}\right), \quad (11)$$

where $\Upsilon = 1 + (4s_1 - 1)(\frac{\xi}{1+\xi})^2$; $\xi = \frac{A_1 l}{2A_0}$, $\eta = \frac{A_2 l^2}{4A_0(1+\xi)}$ - normalised variability,

$$s_1 = \frac{\frac{\tau^2}{3} + \tau\cot\tau - 1}{\tau(\tau - 2\tan\frac{\tau}{2})}; \quad s_2 = \frac{\frac{\tau^2}{5} + \tau\cot\tau - \frac{2}{3}}{\tau(\tau - 2\tan\frac{\tau}{2})} + \frac{2}{\tau^2}(\frac{2}{\tau^2} - 1),$$

$$s_3 = \frac{1}{2} - \frac{2}{\tau^2} + \frac{\cot\frac{\tau}{2}}{\tau}, \quad s_4 = 1 - \frac{4}{\tau^2} - \frac{\frac{\tau}{3}}{\tau - 2\tan\frac{\tau}{2}};$$

and $K = K_p$, $z_0 = \frac{l}{2}$ in form (8).

References

[1] I.M. Kapchinsky, Theory of Linear Resonant Accelerators, Moscow, Energoisdat, 1982, pp. 130-143.

[2] Micro-Alignment Telescope ППС-11: Engineering Description, Optical Mechanical Enterprise LOMO, St Petersburg, 1994.

[3] L.D. Landau, E.M. Lifshitz, Electrodynamics of Continuous Media, Moscow, Nauka, 1992, pp. 38-46.

[4] J. Gao "The Precise Measurement of Electric and Magnetic Fields in a Resonant Cavity," Proceedings of the Linear Acc. Conf., Albuquerque, USA, September 1990, pp. 247-249.

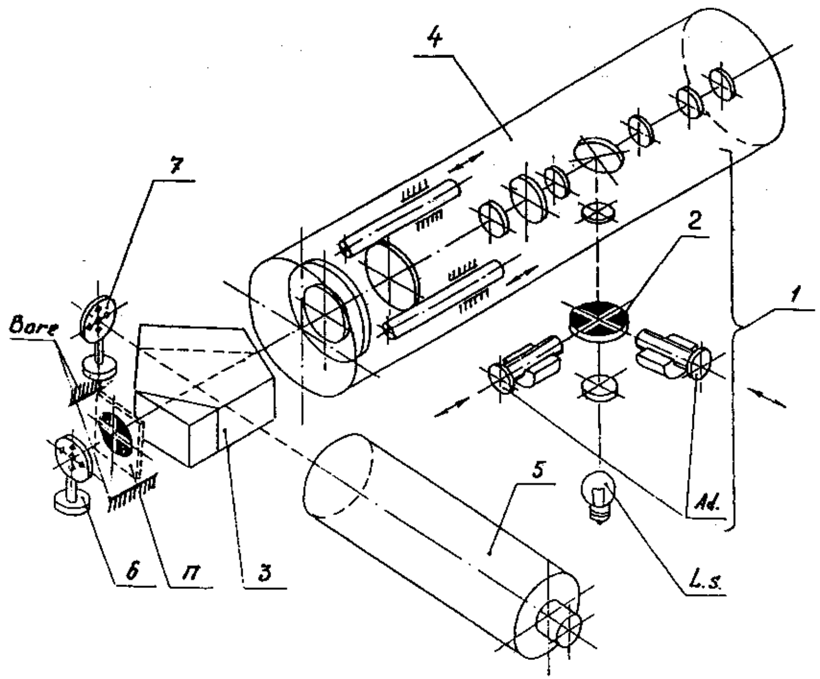


Figure 2. Projections forming and measuring optical system

APPENDIX 1

Concerning RFQ structure and RF feed system design

1 Analytical review of "An 8-Meter-long Coupled Cavity RFQ Linac" [1] and "Segmented Resonantly Coupled Radio-Frequency Quadrupole (RFQ)" [2] ideas

1.1. The [1] idea of undesirable mode frequencies moving "... farther away ..." from the "... fundamental RFQ quadrupole mode..." can not be effective for intense beam, in addition this "farther away" is only about two times greater than in ordinary RFQ (see [2]), just like at other methods, see References in [3]. Operating mode in [1,2] is not fundamental quadrupole, but the quadrupole with longitudinal alterations (p.2 in [1]), the number of alterations is equal to number of segments.

1.2. "Resonant coupling" elements are absent, it is not coupling by frequency depended devices. Explicit method of this structure analysis [3] reveals that the structure properties are not substantially dependent on the gap size between vane ends (capacity coupling element) if this size is commensurable with accelerating bore inner radius mean.

1.3. "The capacitance between the ends ... causes a splitting of the frequencies ..." (p.2 in [1]) - it is incorrect, because this effect does not depend on the capacitance value. "The additional stored energy ... at this point lowers the mode frequency" (p.2 in [1]) - it is not correct, because the mode field distribution is changed over all the resonator volume, so this point stored energy may be not "additional"; the stored energy of magnetic field is changed also, that can increase the resonant frequency. However, explicit method [3] reveals that in this case the mode frequency will be lowered indeed.

1.4. Indicated "RFQ mode" on Fig.2 in [1] does not correlate with description of operating quadrupole (p.2 in [1]) and "The most important feature ... the closed stopband ..." which " ... improves the longitudinal stability ..." can not be interpreted.

1.5. "Perturbations will tend to mix these modes with the operating mode equally but with opposite sign" (p.5 in[1]) - incorrect, because it is always possible to indicate many perturbations for different sign mixing. "... The effect of mixing ... is canceled by the other mode" (p5 in [1]) - it is the idea of two modes mutual cancellation. In any case two modes can cancel each other only in a point, or along a line, or in a plane, but not in finite space: otherwise, it would be possible to form analytic continuation of this field – zero field in all volume (two degenerative orthogonal mode's summary field satisfies Maxwell equations and can be in existence separately from all other modes). Thus, it is impossible to obtain a cancellation in accelerating bore – the main interest space for 3D particles dynamic in RFQ accelerator.

1.6. "Sensitivity to Perturbation" section in [1,2] does not contain detailed indication of the slug's positions, so it is possible, e.g., to obtain the same 22.5 KHz

1

deviation without substantial distortion of the field in accelerating bore or with the distortion. The field distribution is determined by means of magnetic field near the outer wall measurements, and the idea of the total field calculation under these measurements could be correct (in the general case) only for ideal cavity, so the section results can not be treated.

1.7. Adjacent dipole modes are not taken in consideration in [2], types of dipoles are not indicated in [1].

1.8 The waveguide feeding idea is excluded from [4,5] project, but it is noteworthy that [1] tapered section forms additional halfwave resonator, which quality factor can be commensurable with the RFQ, that leads to electric strength and tuning problems. It is impossible to have more than 1.3 MW power on 1/16 inch (1.58 mm) slot without breakdown - there is standing wave if RFQ is not exactly in resonance.

1.9 Transmission lines cross-sections on Fig.2.6.2-6 in [5] seems to be with excessive allowance: under nominal operating conditions for 8 cm coaxial loop ports the electric strength at full reflecting condition (even with 20% reserve) is provided by 19.2, 27.1, 38.4 cm coaxials instead of 23, 36, 48 cm (if all these lines wave impedances are equal). Some devices are not detailed and seem to be excessive also, e.g., DC (if it is directional coupler and HYBRID is hybrid bridge).

2 Resume

2.1. The strong advantage of [1,2] method is possibility of fabricating of relatively short segment RFQs, those can be tuned separately under setting the shortcircuators in the middle cross-sections of the "coupling plate" [1], Fig.1. In this case it will be two main problems:

2.1.1. Operating mode will be quadrupole with longitudinal alterations, so it is necessary to prove the proper beam particles dynamic possibility for this quadrupole field with mainly longitudinal fields in the gaps. Fig.7 in [1] can not be considered as the dynamic simulation result, because any beam perturbations in gap's positions are absent (Fig.7 is not mentioned in [1] text). It is possible to deform vane's ends near these short gaps, if it will be required for the dynamic.

2.1.2. The gap size must satisfy electric strength conditions, because gap voltages are equal to intervane ones, see [3] method for the mode physical property; [1] and especially [2] sizes seem to be excessively small (possible size is equal to intervanes minimal space).

2.2. Four drive loops feeding of IFMIF RFQ segments, as it shown on Fig.2.6.2-4 in [4], gives good possibility to apply RF system and method of tuning from [3]; in this case the "dipole stabilizer" rods (see Fig.1 in [1]) can be excluded, but "decoupled" tuning elements, analogous to "t" at the vane's undcuters (see Fig.1 in [3]) are to be provided. For operating longitudinal alterations quadrupole mode the A and C segment loops on Fig.2.6.2-4 are to be fed like Fig.1 in [3], but B segment loops must be replaced into adjacent quadrants ("90 deg. slew" of all 4 loop's positions in B segment), the nearest nonexcluded mode will be 9 longitudinal alternation's quadrupole. The system simplification can be obtained under the ring bridges installation on each segment in three cross-sections, that excludes many different types long feeders. Bridge's realization on square coaxial line is a simplest, central diameter will be about 0.8 M and there will be enough space between RFQ and the bridges for the square line with accordant electric strength; l_5, l_6 feeders will be about 1 M length, and $l_1 \ldots l_4$ lengths - 20 cm, Fig.1.

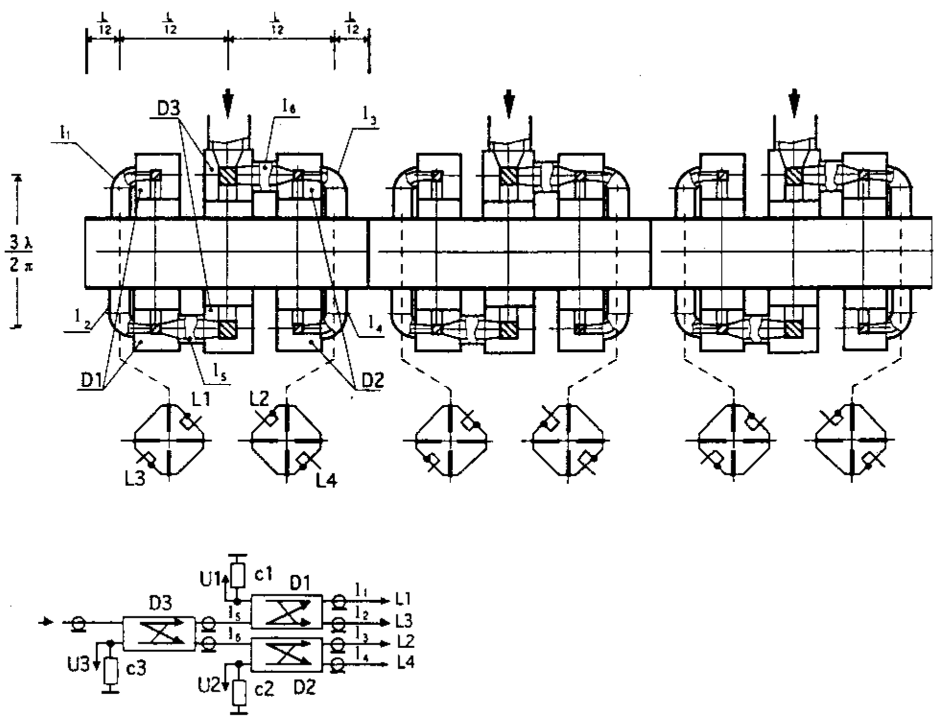


Fig.1. RF feed system (nonunirofm longitudinal scale, L - total length).

Apart from efficient elimination of undesirable modes and producing of control supporting signals (U1...U3 on Fig.1), the substantial item of [3] method is determination of the quadrupole field symmetry axis position with about 10 mkm accuracy, that will give the means for exact connection of the tuned segments (under precise tuning method [6] application the accuracy will be about 4 mkm). The same system can be applied for Alvarez type DTL feeding or especially for advantageous H-type DTL.

References

[1] L. M. Young, "An 8-Meter-long Coupled Cavity RFQ Linac", LAL Memorandum AOT-1: 94-199. A little compressed form: L. M. Young, "An 8-

Meter-long Coupled Cavity RFQ Linac", in Proc. of the 1994 International Linac Conf., (Tsukuba, Japan, August 1994), pp. 178-180.

[2] L. M. Young, "Segmented Resonantly Coupled Radio-Frequency Quadrupole (RFQ)", in Proc. of the 1993 PAC Conf., (Washington, May 1993), pp. 3136-3138.

[3] M. A. Chernogubovsky, A. G. Kurchavy, A. K. Liverovsky, "Portable 433 MHz RFQ Linac RF System", sent Nov.9, 1995 for NIM publication.

[4] M. Rennich (compiled), IFMIF Interim Conceptual Design Activity Report, Dec. 12, 1995.

[5] M. Rennich (compiled), IFMIF Interim Conceptual Design Activity Report, Oct. 27, 1995.

[6] M. A. Chernogubovsky, M. F. Vorogushin, "Electromagnetic Field Precise Measurements in Accelerating Structures", to be published in Proc. of the 1995 PAC and ICHEA, Dallas, USA, 1995.

APPENDIX 2

Concerning segmented RFQ structure inter-segment gaps design

1 General field properties in the gap region

According to the method of RFQ modes analysis [1] all quadrupole modes are delivered at electric (ideal metal) walls setting in II′ and II″ positions on fig.1 in [1]. For the segmented structure the longitudinally equidistant arrangement of two identical cuts of the vanes yields the symmetry conditions for electric or magnetic walls placing in these cut's midpoint $z1 = 0$, fig.1a; operating mode is delivered at electric walls (thick circle on fig.1a), that gives the possibility for separate segment consideration of RFQ fields and for separate tuning under real shortcircuiting plates setting.

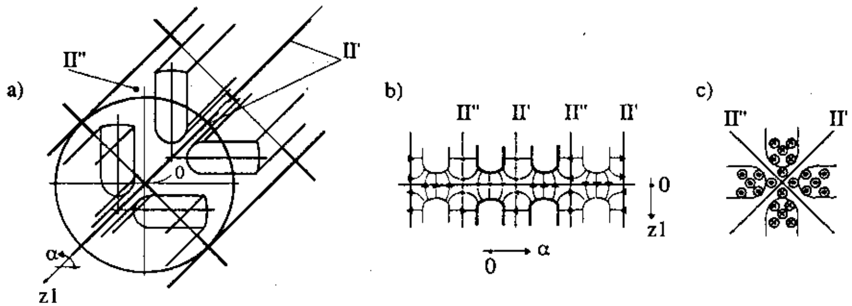


Fig.1. Inter-segment gap in segmented RFQ (electric walls are marked by thick lines) – a; electric field in radial cross-section – b, and in $z1 = 0$ plain – c.

Therefore the mode field properties do not depend on presence of thin diaphragm ("coupling plate" on fig.1 in [2]) in this position, much less on the diaphragm shape; however, the second mode (magnetic walls in the midpoints) properties will be dependent greatly. In contrast, the influence of the cut size on the mode frequencies splitting is rather weak, vanishing for long segments; these modes will be in existence even for a cut greater than wavelength size when coupling between the ends of the vanes is not "capacitative" at all (see 1.1 ... 1.3 in [3]). Radial propagating of quasi-TEM wave in four identical shortcircuited inhomogeneous coaxial (quasi-rectangular) transmission lines, loaded by electrode end – inter-wall corner capacitances, yields operating mode field distribution, fig1.b shows the gap field in radial cross-section. The voltages between the ends of the vanes do not depend on the cut size and are equal to inter-vane ones (TEM wave property); transverse cross-section field is shown on fig.1c. So, it is an alternating signs mainly longitudinal field in the midpoint region with zero field on the axis.

In inexact symmetry case the electric wall may be not a plane, it may be shifted from $z1 = 0$ position on fig.1a,b; electrode ends modulation will deform right angle between II′ and II″ walls near the corner and fig.1b,c distributions will be not completely symmetrical, nevertheless a.m. properties will remain as before.

Minimal distortion of proper beam dynamics by the gap field can be obtained by symmetrical field distribution on fig.1c, that leads to the gap design in electrodes without modulation region: p intervals on fig.2a.

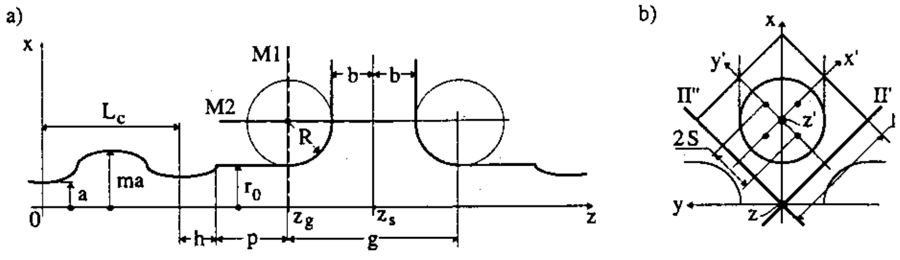


Fig.2. Possible shapes of the gap forming elements – a, $z = z_g$ cross-section – b.

Requirements on electric strength constrain desirable minimization of the gap size, and the same strength as in the main RFQ part can be realized at the same inter-surface distance under spherical shape of the vane corners and rounded edges, see fig.2a, at $b = ((r_0 + R)/\sqrt{2}) - R$. In this case there will be focusing quadrupoles before and after the gap with alternating mainly longitudinal field in beam aperture; p and h intervals can be different in the first and the second gap because of the different electrode modulations and accelerating conditions in the gap positions. The p space can be used for muster gauges or contact optical targets installation, which gives a convenient way for precise forming of the datum axis at RFQ segment fine tuning procedure and especially for desired setting in coincidence the symmetry axes of tuned RFQ segments.

2 Gap field

Transverse field orientation in p interval allows to place magnetic wall $M1$, and the beam aperture bounded region consideration allows to place magnetic wall $M2$, fig.2a. Therefore, continuos extension will coincide with the sphere in cube field in $x \le r_0 + R$, $z_g \le z \le z_s$ space, see fig.2b. Conventional electrostatic approximation of this field under equality of the sphere potential A_0 to uninterrupted electrode potential A_e at $z = z_g$ point (refer to zero potential of II′, II″ walls) yields the gap field at symmetrical continuation into other gap's spaces.

Sphere in cube electrostatic problem solution by mirror images method gives an advantage, since the result will already have just right symmetrical continuation for all the gap field. In local coordinates x', y', z', fig.2b, a charge q, located inside the cube in x'_0, y'_0, z'_0 point, sets up the potential

$$\varphi(x', y', z') = \frac{q}{4\pi\varepsilon_0 l} \cdot \Phi(x'_{0N}, y'_{0N}, z'_{0N}; x'_N, y'_N, z'_N); \qquad (1)$$

2

where $\Phi(x'_{0N}, y'_{0N}, z'_{0N}; x'_N, y'_N, z'_N) =$

$$\sum_{\substack{-\infty \\ (i)}}^{+\infty}\sum_{\substack{-\infty \\ (j)}}^{+\infty}\sum_{\substack{-\infty \\ (n)}}^{+\infty} \frac{(-1)^{i+j+n}}{\sqrt{(x'_N - i - (-1)^i \cdot x'_{0N})^2 + (y'_N - j - (-1)^j \cdot y'_{0N})^2 + (z'_N - n - (-1)^n \cdot z'_{0N})^2}},$$

all linear dimensions are normalized to l (except l itself) and denoted by index N, e.g., $x'_N = x'/l$. For satisfaction of the sphere surface conditions consider the normalized potential Φ_M of symmetrical set: one charge $6q\cdot\eta$ in the center with six charges q, disposed symmetrically on the axes at S distance (see fig2.b):

$$\Phi_M(x'_N, y'_N, z'_N) = 6\eta \cdot \Phi(0,0,0; x'_N, y'_N, z'_N) + \Phi_6(S_N, x'_N, y'_N, z'_N), \qquad (2)$$

$$\begin{aligned}\Phi_6(S_N, x'_N, y'_N, z'_N) = {} & \Phi(+S_N,0,0; x'_N, y'_N, z'_N) + \Phi(-S_N,0,0; x'_N, y'_N, z'_N) + \\ & \Phi(0,+S_N,0; x'_N, y'_N, z'_N) + \Phi(0,-S_N,0; x'_N, y'_N, z'_N) + \\ & \Phi(0,0,+S_N; x'_N, y'_N, z'_N) + \Phi(0,0,-S_N; x'_N, y'_N, z'_N). \qquad (3)\end{aligned}$$

Equality of Φ_M to Ψ_0 in three points: $P_1 = \{R_N, 0, 0\}$, $P_2 = \{R_N/\sqrt{2}, R_N/\sqrt{2}, 0\}$, $P_3 = \{R_N/\sqrt{3}, R_N/\sqrt{3}, R_N/\sqrt{3}\}$ (the form (2) evenness and permutative invariance refer to x'_N, y'_N, z'_N will give the same Ψ_0 in all other symmetrically disposed points) yields the equation for S_N value determination

$$\begin{aligned}\Phi_6(0,P_1)\cdot\Big(\Phi_6(S_N,P_3) - \Phi_6(S_N,P_2)\Big) + \Phi_6(0,P_2)\cdot\Big(\Phi_6(S_N,P_1) - \Phi_6(S_N,P_3)\Big) + \\ \Phi_6(0,P_3)\cdot\Big(\Phi_6(S_N,P_2) - \Phi_6(S_N,P_1)\Big) = 0 \qquad (4)\end{aligned}$$

since $6\Phi(0,0,0; x'_N, y'_N, z'_N) = \Phi_6(0, x'_N, y'_N, z'_N)$, and determines Ψ_0 and η values

$$\Psi_0 = \frac{\Phi_6(S_N,P_1)\cdot\Phi_6(0,P_2) - \Phi_6(S_N,P_2)\cdot\Phi_6(0,P_1)}{\Phi_6(0,P_2) - \Phi_6(0,P_1)}, \qquad (5)$$

$$\eta = \frac{\Phi_6(S_N,P_1) - \Phi_6(S_N,P_2)}{\Phi_6(0,P_2) - \Phi_6(0,P_1)}. \qquad (6)$$

Simulating for $R = r_0$ (one of the optimal cases, see [4]) estimates unique root $S_N = 0.14505$ of (4) equation, $\eta = -0.176856$, $\Psi_0 = 5.3304$. Analysis of $\Phi_M = \Psi_0$ equipotential shape in the form ${z'_N}^2 = (R_{N\varepsilon}(x'_N, y'_N))^2 - {x'_N}^2 - {y'_N}^2$ determines real accuracy, in fig.3 the radius deviation $(R_{N\varepsilon}(x'_N, y'_N) - R_N)/R_N$ is shown.

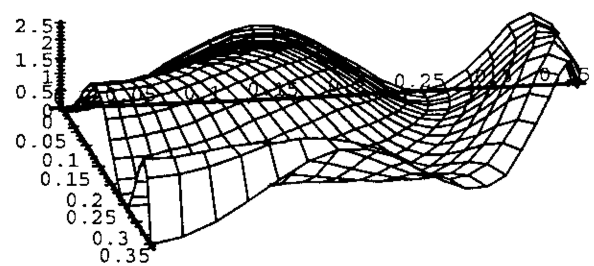


Fig.3. Radius normalized error absolute value $\times 10^4$ in a quadrant space.

3

The error does not exceed $2.5 \cdot 10^{-4}$, for $R = 8\,\text{mm}$ it corresponds to 2 mkm, that is less than fabrication tolerances; the cube walls boundary conditions satisfaction ensures exact field configuration in the beam aperture.

3 PARMTEQ input data

Within the accuracy of the RFQ field approximation in PARMTEQ code [5], the desired equivalence of $A_e = V/2$ to $A_0 = \frac{q}{4\pi\varepsilon_0 l}\Psi_0$ determines q value, and Φ_M transformation to PARMTEQ coordinates x, y, z, fig.2:

$$x'_N = \frac{x-y}{l\sqrt{2}} - \frac{1}{2}, \quad y'_N = \frac{x+y}{l\sqrt{2}} - \frac{1}{2}, \quad z'_N = \frac{z-z_g}{l},$$

yields the result for electric field components:

$$E_u = \frac{-V}{2\sqrt{2}\Psi_0 l} \cdot \sum_{\substack{-\infty \\ (i)}}^{+\infty}\sum_{\substack{-\infty \\ (j)}}^{+\infty}\sum_{\substack{-\infty \\ (n)}}^{+\infty}(-1)^{i+j+n}\Big(D_u(S_N,0,0) + D_u(-S_N,0,0) + D_u(0,S_N,0) + D_u(0,-S_N,0) + D_u(0,0,S_N) + D_u(0,0,-S_N) + 6\eta D_u(0,0,0)\Big), \qquad u = x,y,z; \tag{7}$$

where

$$D_x(\nu_1,\nu_2,\nu_3,) = (1 + i + (-1)^i\cdot\nu_1 + j + (-1)^j\cdot\nu_2 - \frac{x\sqrt{2}}{l}) \cdot D^{-\frac{3}{2}},$$

$$D_y(\nu_1,\nu_2,\nu_3,) = (-i - (-1)^i\cdot\nu_1 + j + (-1)^j\cdot\nu_2 - \frac{y\sqrt{2}}{l}) \cdot D^{-\frac{3}{2}},$$

$$D_z(\nu_1,\nu_2,\nu_3,) = \sqrt{2}\cdot(n + (-1)^n\cdot\nu_3 - \frac{z-z_g}{l}) \cdot D^{-\frac{3}{2}};$$

and

$$D = \left(\frac{x-y}{l\sqrt{2}} - \frac{1}{2} - i - (-1)^i\cdot\nu_1\right)^2 + \left(\frac{x+y}{l\sqrt{2}} - \frac{1}{2} - j - (-1)^j\cdot\nu_2\right)^2 + \left(\frac{z-z_g}{l} - n - (-1)^n\cdot\nu_3\right)^2.$$

So, accelerating bore field at L_c, h, p intervals (fig.2.a) is determined by (1) – (3) expressions in [5]; g field is defined by expression (7), multiplied by time-dependent factor $\sin\omega t$ or by $\sin z$ in accordance to PARMTEQ method (see eq. (6) in [5]). In (7) expression the S_N parameter is the root of equation (4) and Ψ_0, η values are determined by formulae (5),(6). Deviation of potential (3) from zero on the cube wall determines desired finite numbers of terms in (1) and (7) sums for required precision[1].

References

[1] M. A. Chernogubovsky, A. G. Kurchavy, A. K. Liverovsky, "Portable 433 MHz RFQ Linac RF System", sent Nov.9, 1995 for NIM publication.

[1] The best precision is obtained at $i \in [-(M+1); M], j \in [-(M+1); M], n \in [-N; N]$; $N \geq M$.

[2] L. M. Young, "An 8-Meter-long Coupled Cavity RFQ Linac", LAL Memorandum AOT-1: 94-199.

[3] M. A. Chernogubovsky, "Concerning RFQ structure and RF feed system design", Appendix 1 to Dec.1,1995 - Mar.1,1996 Periodical rep.

[4] I. M. Kapchinsky, Theory of Linear Resonant Accelerators, Moskow, Energoisdat, 1982, pp. 130-143.

[5] K. R. Crandall, T. P. Wangler, "PARMTEQ - A Beam-Dynamics Code For The RFQ Linear Accelerator", in AIP Conference Proceedings 177, New York, 1988, pp. 22-28.

Portable 433 MHz RFQ Linac RF System

M.A. Chernogubovsky, A.G. Kurchavy, A.K. Liverovsky
D.V. Efremov Scientific Research Institute of Electrophysical Apparatus
St Petersburg, 189631 Russian Federation

Abstract

Principle and experimental analysis of RF power feed system based on 3 db directional couplers for undesirable modes eliminating, divided power coupling with RFQ accelerating structure, matching of RF source are presented. The structure main tuning method and the system adjustment results are considered also.

1 Introduction

Ordinary used requirements to accelerator RF system concern constructing of high power feeder to accelerating structure, coupling devices and matching RF source nonreciprocal devices design; usual problem is electric strength. On the other hand, an application of four-vane RFQ structure sets a problem [1,2] of undesirable modes eliminating (stabilizing) and the structure precise tuning. Presenting RF system allows to obtain simultaneous solution of these problems instead of traditional separate consideration.

2 Directional selective coupling

Efficiency of a resonator modes selecting methods depends primarily on excitation sources characteristics - frequency spectrum, power, coupling. Accelerating beam keeps unbunched shape under focusing on one half or one third of the structure length, so this excitation has unbounded spectrum and the use of resonant frequencies difference seems to be ineffective in spite of the difference increasing in 2...4 times by reactive insertions [2,3], or by external resonance elements [4,5], but under RF source single harmonic spectrum excitation it allows to obtain about 2...4 reduction of the undesirable modes levels at similar quality factors and coupling. In the case of intense beam only the selecting modes quality factors lowering could be effective, however a few simplest external elements loading is inadequate since great majority of the modes are degenerate.

Explicit physical properties of the modes complete set and methods of tuning by t, a elements can be derived from the resonator symmetry, under placing in I or II position electric or magnetic walls in all possible combinations, fig.1. Both electric walls in II position at radial propagation form four identical waveguides (inhomogeneous coaxial rectangular transmission lines): quasi-T wave in these loaded by vane end - inter-walls corner capacitance shortcircuited lines yields operating quadrupole mode, TE and TM waves resonances describe quadrupole modes with longitudinal and azimuth alternations, radial resonances give high frequency quadrupoles with radial alternations. Magnetic and electric walls form twoconductor transmission lines: even

quasi-T wave resonance yields doubly degenerate diagonal dipole mode (magnetic wall II″ with electric II′ yield one, magnetic II′ with electric II″ - another mode from this pair), when end capacitance and wave impedance magnitudes are compared with those of odd wave, it is apparent that the frequency is greater than quadrupole one.

Adjacent dipole modes are derived at magnetic and electric walls in I position (rectangular lines with greater cross-sections); two magnetic walls yield already examined quadrupole, that reveals this doubly degenerate mode comparative properties. Vane ends modulation is of a little significance and manifests itself as some appropriate deformation of the walls planes near the corner.

Method of directional selective coupling is realized under the use of fields correlation in those regions, where RF source total coupling is maximal at operating mode and vanishes at undesirable ones; for longitudinal magnetic field components it is L1 - L4 regions, approximately one fourth structure length distant from the structure end-walls, fig.1; RF system contains three 3 db directional couplers $D1 - D3$, equal length feeders $l_1 - l_4$ and $l_5 - l_6$ to attain equal amplitudes cophased excitation at equal coupling loops spaces, fig.2. In the exact symmetrical case all mentioned undesirable modes except quadrupoles with even number of longitudinal alternations are not excited,

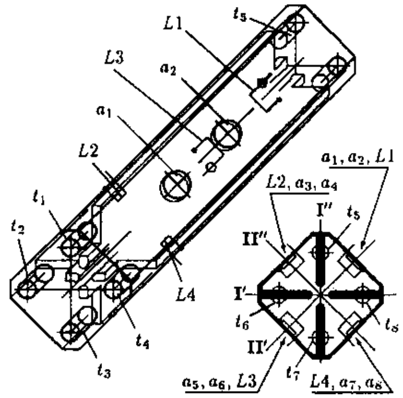


Fig.1. Symmetry planes, coupling loops and tuning elements of RFQ structure.

and feeders-loops matching on operating mode results in full decoupling of matched loads $c1 - c3$. At the beam excitation the loads remain decoupled at operating mode but all undesirable modes are loaded on appropriate loads $c1 \ldots c3$ (the maximum loading is attained just at 3 db transient attenuation of the couplers), while RF source is decoupled from these modes. In addition, the system assures RF source matching - e.g. in damage case in one of $l_1 \ldots l_4$ feeders or a loop breakdown the source feeder SWR will be 1.4 at short feeders and correlation of the high level signals $U1 - U3$ determines the damaged channel; in operating conditions deviations from amplitudes equality of all this low signals yield operating mode asymmetry. Real system loops can not be absolutely equal, so the signals are in proportion to the resonator reflectance, $U1, U2$ and $U3$ phases form supporting for automatic control system phase-lock loop. RF power dividing into four parts adequately alleviates the electric strength problems.

For all that, any frequency differences between operating and eliminating modes and even their coincidence are admissible at least over the directional couplers frequency band, the couplers central frequencies must be on the quadrupole mode resonance for additional loading minimization.

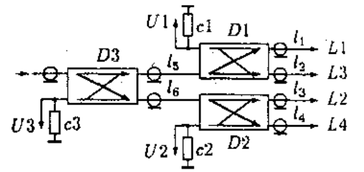


Fig.2. RF feed system devices.

Coaxial hybrid ring bridges are the best for the couplers when taking into account operating frequency range properties, coaxial type of the system feeders and in-phase output; adjusting of the feeders electric length and coupling loops spaces variation must be considered in the design.

2.1 Computer simulation

The system equivalent circuit includes resonator multimode scheme, decomposed hybrid ring bridges in form of different length transmission lines connection, $l_1 - l_6$ feeders. Frequency-domain analysis is carried out under 4 . . . 8 modes with calculated or measured characteristics, unequal lengths of feeders, inexact central frequency f_{ce} of the bridgers, faulty tuning of coupling loops spaces S_L. Computer simulating substantiates Ψ (relation of undesirable modes maximum voltages squares sum to operating mode maximum voltage square) global extremum for ideal parameters, and real tolerances of the elements for admissible growth of RF source feeder SWR up to 1.3 are $\Delta l_{1,2,3,4} = 8\,\text{cm}$, $\Delta l_{5,6} = 10\,\text{cm}$, $\Delta S_L/S_L = 0.16$, $\Delta f_{ce}/f_{ce} = 4.8 \cdot 10^{-2}$, or for the bridges central radius value $\Delta r_{ce} = 8\,\text{mm}$; losses in Ψ- factor are within 10%. Thus, a high degree of precision is not required for the system components realization.

2.2 RF system main tuning

The resonator modes identification is carried out under accordant turn of the system loops, that allows to excite any desired well-definable mode.

Degeneration property of adjacent dipole modes is used for resonator field symmetrization: when one-loop exciting, e.g. by L1, this pair will form zero magnetic field longitudinal component in II″ plane and the doubled field in II′ at ideal symmetry, fig.1; in real case the fields magnitudes are criterion of the symmetry. At inexact adjustment the frequency characteristics are bifurcated, but t elements tuning allows to accomplish degeneracy, and the only maximum value in L2, a_3, a_4 and L4, a_7, a_8 regions[1] can be minimized by a and t tuners, with analogous precise tuning at L2 excitation for the vanishing field value obtaining in 1,3 quadrants (real symmetry surfaces setting to II″, II′ forms by means of the tuners, see Appendix) the necessity for the other excitations will be avoided. Then any loop is tuned for SWR=7 on quadrupole mode resonance at matched-loaded the rest three loops, and symmetrization procedures are to be reiterated at setting of specified operating frequency value.

[1] Thin azimuth slots for field measurements are provided in a tuners.

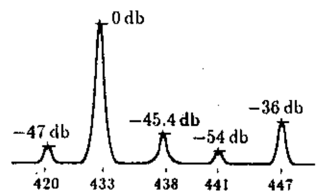
3

Quadrupole field symmetry axis can be determined[2] by the electric walls intersection points in input and output of accelerating bore; quasi-homogeneous longitudinal field distribution can be obtained by simultaneous adjustment of $t_1 - t_4$ or $t_5 - t_8$ elements with subsequent symmetrization and loops tuning under the field examination by bead perturbation method in parallel to the axis inside a quadrant.

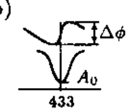
3 Experimental results

For the system with 1445 mm length, 3.5 mm inner radius mean aluminium RFQ structure the stated above spatial measurements are provided by optical device [7]; hybrid ring bridges are realized on coaxial square transmission lines, $\Delta f_{ce}/f_{ce}$ proved to be $\leq 2.4 \cdot 10^{-2}$; the feeders electric lengths are equalized within $(0.5 \pm 0.3)°$ by single shortening. Attained symmetrization accuracy is $-(38 \pm 1)$ db (ratio of a.m. vanishing to doubled values), that yields less than 1% error in operating field symmetry; the loops tuning SWR= 7 ± 0.1, error in specified operating frequency setting is $5 \cdot 10^{-6}$; frequency characteristics are presented in Fig.3. The field axis is determined by the use of $(0.1 \times 3 \times 15)$ mm strip, experimental resolution of the minimal deviation position at RF phase measuring ≤ 10 mkm; the axis coordinates reading accuracy is approximately the same for the strip with reflective side. Longitudinal field distribution is equalized only within 5% under the full use of $t_1 - t_4$ range limits[3], the field maximum is insignificantly shifted from the structure midpoint.

a)



b)



	A_0 [db]	$\Delta\phi$ [°]
U1	−68	63
U2	−60	54
U3	−63	72

Fig.3. Frequency characteristics: RFQ field in 400-450 MHz range – a); matched loads signals – b).

The source feeder SWR is 1.08 ± 0.06, loaded resonator quality factor 1930 ± 8. Thus, undesirable modes values are negligible, Fig.3a, the same effect would be attained with [2,3] principles at more than 180 times increasing of the frequencies difference.

4 Conclusion

Principle of directional selective coupling and its application for RFQ accelerating structure have been developed. Under experimental examination the RF system

[2] Uncertainty of the axis position in [4,6] method can lead to necessity of adjusting even though the structure is ideal, but all bead positions are displaced refer to the axis.

[3] The range is extended in the next construction design to obtain better results.

4

proved to be effective and not expensive, because RF source matching can be realized without ferrite devices. Moreover, hybrid ring bridges can be mounted on the structure in three cross-sections, so that four long feeders will be excluded and the system will be compact.

Acknowledgements

Authors are much obliged to Prof. M.F. Vorogushin for the work support.

APPENDIX

Perturbation in middle plane of vanishing field quadrant or the same in doubled value cause nearly equal deviations of the dipole modes summary field resonant frequency in spite of about 40 db difference of the values, that is evident at separate consideration of perturbed resonator modes, inasmuch as symmetric about the plane object in any one of quadrants forms identical resonators; however, the field consideration according to treatments [8-10] gives incorrect result.

For rigorous solution consider a resonator $\vec{E}$ field (V volume, complete mode set $\{\vec{E}_\nu, \vec{H}_\nu\}$, fundamental frequencies and quality factors $\{\omega_\nu, Q_\nu\}$, gradient field in form of one summand; $\nu=1$, $\nu=2$ pair can be degenerate) which is excited at the pair by some sources $S_1=s_1$, $S_2=s_2$ on ω frequency. Perturbation, e.g. conductive V_p volume object is assumed by current density $\vec{j}$:

$$\vec{E}=\frac{i\omega}{R_1W_1}\Big(S_1-\int_V(\vec{E}_1,\vec{j})dv\Big)\vec{E}_1+\frac{i\omega}{R_2W_2}\Big(S_2-\int_V(\vec{E}_2,\vec{j})dv\Big)\vec{E}_2+\vec{F}(\vec{j}), \qquad (1)$$

where

$$\vec{F}(\vec{j})=\sum_{\nu=3}^{\infty}\frac{-i\omega}{R_\nu W_\nu}\int_V(\vec{E}_\nu,\vec{j})dv\cdot\vec{E}_\nu-\mathrm{grad}\varphi,$$

$R_\nu=\omega_\nu^2-\omega^2+i\omega\omega_\nu(Q_\nu)^{-1}$, $W_\nu=\varepsilon_0\int_V(\vec{E}_\nu,\vec{E}_\nu)dv$, compliance with boundary conditions for (1) field yields unique solution for $\vec{j}$ distribution. In order to separate the perturbed modes let $\vec{j}_1$ is the solution for another source $S_1=s_1(1-\eta)$, $S_2=s_2\theta$, resonator field is $\vec{E}_{R1}$; $\vec{E}_{R2}$ is the field at $S_1=s_1\eta$, $S_2=s_2(1-\theta)$ excitation, $\vec{j}_2=\vec{j}-\vec{j}_1$, and $\vec{E}=\vec{E}_{R1}+\vec{E}_{R2}$. The use of convergence property in partial domain of $\vec{E}_{R1}$ and $\vec{E}_{R2}$ complete orthonormalized basis expansions with similar to [11] $\vec{j}_1,\vec{j}_2$ expanding reveals that the fields are linearly independent in $\{V-V_p\}$ space under $1-\eta-\theta\neq0$, and at the conditions $\vec{E}_{R1}\xrightarrow{\vec{j}_1\to0}\vec{E}_1\frac{i\omega}{R_1W}s_1$, $\vec{E}_{R2}\xrightarrow{\vec{j}_2\to0}\vec{E}_2\frac{i\omega}{R_2W}s_2$ the unique values $\eta=\theta=0$ are possible to form perturbed resonator modes, since each of $\vec{E}_{R1}$ and $\vec{E}_{R2}$ frequency characteristic contains one nonvanishing resonance pole $\omega_{R1}\xrightarrow{V_p\to0}\omega_1$ and $\omega_{R2}\xrightarrow{V_p\to0}\omega_2$. Thus, $\vec{j}_1$ is defined by

$$\vec{E}_{R1}|_{\tan}=\frac{i\omega}{R_1W}\Big(s_1-\int_{V_p}(\vec{E}_1,\vec{j}_1)dv\Big)\vec{E}_1|_{\tan}-\frac{i\omega}{R_2W}\int_{V_p}(\vec{E}_2,\vec{j}_1)dv\cdot\vec{E}_2|_{\tan}+\vec{F}|_{\tan}(\vec{j}_1)=0 \quad (2)$$

on the object surface. The same $\vec{j}_1$ obeys this equation for another object position with reversed $\vec{E}_2$ sign, for a position with opposite $\vec{E}_1$ the s_1 sign changing yields the same current and thus ω_{R1} values will be equal; comparison of $\vec{j}_2$ solutions gives ω_{R2} equality, and the the summary field frequency deviations will be equal also.

Final result for thin cylinder (radius a_c, length l) object can be obtained at reasonable assumption that ω lies in ω_1,ω_2 vicinity and all other modes frequencies are far from ω, so that $\vec{F}|_{\tan}(\vec{j}_1)$ is defined by the cylinder own field [7], and (2) equation in local coordinates for longitudinal current $\vec{e}_xI(x)$ in linear with x fields $\vec{E}_1=\vec{e}_x(a_1x+b_1)$, $\vec{E}_2=\vec{e}_x(a_2x+b_2)$ takes the form

$$\frac{\partial^2I(x)}{\partial x^2}+k^2I(x)=\frac{\omega^2\varepsilon_0}{N(a_c)}\Big(\frac{s_1-\int_0^l E_1I(x)dx}{R_1W}(a_1x+b_1)-\frac{\int_0^l E_2I(x)dx}{R_2W}(a_2x+b_2)\Big),$$

where $N(a_c)=(1/2\pi)[\ln(2/ka_c\gamma)+Ci(kl)-(\sin kl/kl)]$, $\gamma=0,577\ldots$ - Euler's constant, $Ci(kl)$ - integral cosine, $k=\omega\sqrt{\varepsilon_0\mu_0}$. At $I(x)\xrightarrow{s_1\to0}0$ with boundary values $I(0)=I(l)=0$ the solution is unique and $\vec{E}_{R1}$ field varies proportionally to

$$\frac{-i\omega s_1}{D}\cdot\frac{m(a_2l)t+2E_{10}f_2}{f_1[m(a_2l)^2+2E_{20}^2]+f_2[m(a_1l)^2+2E_{10}^2]-2f_1f_2-mt^2}, \qquad (3)$$

where

$$D=K_0\omega^2\varepsilon_0V_p,\quad K_0=\frac{(\frac{l}{a_c})^2}{\pi N(a_c)}\frac{2\tan\frac{\tau}{2}-\tau}{(\tau)^3}$$

- the cylinder formfactor in homogeneous field, $\tau=kl$, $t=(a_1l)E_{20}-(a_2l)E_{10}$,

$$f_{(1,2)}=\frac{R_{(1,2)}W}{D},\quad m=2\frac{\frac{\tau^2}{3}-\tau\cot\tau-1}{\tau(\tau-2\tan\frac{\tau}{2})}-\frac{1}{2}$$

- formfactor coefficient in linear field, $E_{(10,20)}=a_{(1,2)}\frac{l}{2}+b_{(1,2)}$ - the fields values in the cylinder midpoint. Analysis of nonvanishing pole in (3) characteristic and of similar result for $\vec{E}_{R2}$ field demonstrates that for constant E_{1x},E_{2x} signs in the cylinder region the perturbed modes can be degenerative only at degeneracy of unperturbed ones in two types of symmetry:

$$a_1E_{10}=-a_2E_{20} \qquad (4)$$

with deviation

$$\frac{\omega_{R1}^2-\omega_1^2}{\omega_{R1}^2}=-\frac{[E_{10}^2+E_{20}^2]\varepsilon_0V_p}{W}K_0,$$

and $a_1E_{20}=a_2E_{10}$ with deviation

$$\frac{\omega_{R1}^2-\omega_1^2}{\omega_{R1}^2}=-\frac{[E_{10}^2+E_{20}^2]\varepsilon_0V_p}{W}K_0\left(1+\frac{m}{2}\frac{(a_1l)^2}{E_{10}^2}\right);$$

these deviations do not depend on the fields signs. The latter symmetry is not available at RFQ adjacent dipoles, however (4) type is realized for symmetrically positioned cylinder perpendicular to the middle longitudinal plane in any point. With vanishing level of summary field in the plane the field characteristic will be without bifurcation not only at (4) condition, but at $|a_1|=|a_2|$, $|E_{10}|=|E_{20}|$ and $Q_1=Q_2$, giving the means for described symmetrization procedure.

It is notable that original [11] analysis is based on separate mode consideration in finite quality factor resonator, whereas [10] method ω,ω_1 coefficients have no fundamental frequency physical meanings except for single mode field.

References

[1] O. Takeda et al., "Design Study on an 80 MHz RFQ Linac for Heavy Ions", Proc. 3rd European Particle Accelerator Conf., Berlin, 1992, vol.2, (Edition Frontieres, Gif-sur-Yvatte, 1992) pp. 1334-1336.

[2] D. Howard, H. Lancaster, Vane Coupling Rings: a Simple Technique for Stabilizing a Four-Vane Radiofrequency Quadrupole Structure, IEEE Trans. Nucl. Sci. NS-30 (2) (1983) pp. 1446-1448.

[3] A. Ueno et al., "The π-Mode Stabilizing Loop for Four-Vane Type RFQs", Proc. 1990 Linear Accelerator Conf., Albuquerque, N.M., USA, vol. 1, (Los Alamos Nat. Lab., 1991) pp. 57-59.

[4] G. Spalek et al., "Azimuthal Stabilization of the Radio-Frequency Quadrupole with Loop – Coupled TEM Lines", Proc. 1990 Linear Accelerator Conf., Albuquerque, N.M., USA, vol. 1, (Los Alamos Nat. Lab., 1991) pp. 63-66.

[5] G. Spalek, A. Klapetzky, "A Coaxial Line Azimuthal Stabilizer for Radio Frequency Quadrupoles", Proc. 1990 Linear Accelerator Conf., Albuquerque, N.M., USA, vol. 1, (Los Alamos Nat. Lab., 1991) pp. 67-69.

[6] J. H. Billen, "Radio Frequency Measurement and Analysis Codes", Proc. of the 1993 Particle Accelerators Conf., Washington, D.C., vol. 2, (IEEE, 1993), pp. 793-795.

[7] M. A. Chernogubovsky, M. F. Vorogushin, "Electromagnetic Field Precise Measurements in Accelerating Structures", to be published in Proc. of the 1995 PAC and ICHEA, Dallas, USA, 1995.

[8] J. L. Altman, Microwave circuits, (Van Nostrand, Princeton, N.J., 1964) pp. 409-416.

[9] V. V. Nickolsky, Variational Methods for Interior Electrodynamical Problems [in Russian] (Nauka, Moscow, 1967) pp. 244-271.

[10] L. D. Landau, E. M. Lifshitz, Electrodynamics of Continuous Media [in Russian] (Nauka, Moscow, 1992) pp. 455-461.

[11] J. C. Slater, Microwave electronics, (Van Nostrand, Princeton, N.J., 1950) pp. 57-83.

Submitted to the 2nd IFMIF-CDA Design Integration Meeting, May 20-27, 1996

Japan RF System Work

Akiji MAEKAWA, Hitachi, Ltd.

Hitoshi BABA, Nihon Koshuha Co., Ltd.

Abstract

The IFMIF accelerator needs RF power sources of the 175MHz, 1MW-CW class. EIMAC tetrodes(4CM2,500KG) will be selected for the power tubes of the final amplifier stages. However, the tetrode has not yet been tested at frequencies of more than 150MHz, at RF power levels exceeding 1MW-CW or even in the long-pulse mode.

The prospects of available RF power levels induces a remarkable difference in the accelerator DTL designs between the United States and Japan.

Actual tube test should be started in the early R&D stage.

As for the alternative options, the possibilities of all solid state RF sources are reviewed. A solid state transmitter may be suitable for certain superconducting linac.

1. Introduction

The RF system for the ESNIT plan needs power sources of 120MHz, 1MW-CW RF and they are shown in the report [Maekawa(93/2)].

The Japanese designed RF system for the IFMIF is the ESNIT design modified to 175Mhz [Sugimoto(95/3)c]. It is shown in Ch.2.

The US-desiged RF system is shown in the reports of [Berwald(95/9)a], [Berwald(95/9)b], [Piechowiak(95/9)] and [Jameson(95/7)].

The EC-desiged RF system is shown in the report[France(95/9)].

The principal difference of the RF system design between the United States and Japan exists in the estimated output power level from the final amplifier tube(EIMAC 4CM2,500KG). The basis of the Japanese estimation is shown in Ch.3.

Alternatives to the electron tubes are the semiconductor elements. Possibilities of all solid state RF souces upto 1MW-CW are reviewed in Ch.4.

2. Japanese designed RF system for the IFMIF

Sheet-1 shows the specifications of the Japanese designed RF system [Sugimoto(95/3)c].

Sh.-2 shows the components of the RF power source and Sh.-3 shows the RF transmission line [Sugimoto(95/3)c].

Japanese designs of RFQs and DTLs for IFMIF are restricted to using the RF power units of less than 1MW-CW at 175Mhz [Sugimoto(95/3)a] [Sugimoto(95/3)b]. However, RF powers in the United States baseline designs need more than the 1MW-CW level, as shown on p.156 of [Bewald(95/9)a].

In addition, to obtain the stable operation of RF sources even during the accelerator beam current changing, circulators should be inserted in the transmission line between RF sources and acceleration tubes, though their insertion shows a power loss of the order of 10%(0.5dB). This reduces the available RF power level at the accelerator sections.

3. Power tubes for the final amplifier stages

EIMAC tetrodes 4CM2,500KG have been used at the various sites shown in Sh.-4 [Tornoe(95/11)]. Among them, the first CW operation data in the frequency range above than 10MHz were taken last October at the National Institute for Fusion Science(NIFS) in Japan, namely, 1.6MW-CW at 50Mhz for 5000 seconds [Mutou(95/12)]. Their apparatus works within the frequency band 25 to 90MHz. Data are shown in Sheets-5~7.

Only one known example in the 200Mhz range is the development in the JAERI Tokai. Its goal is the 1MW RF power generation in short pulses(1ms) [Hasegawa(95/10)][Mizumoto(95/2)].

The RF source used in the CW mode is quite different from the source in the short pulse mode. The situation is the same as for a tetrode.

In the frequency range above 150MHz, tetrode tube data of more than 1MW-CW RF power output does not exist, even in long pulse mode.
The tube test apparatus in such conditions does not exist anywhere in the world, also.

Therefore, I am afraid that the early report of Sh.-8 [Berwald(95/9)a] and Sh.-9 [Piechowiak(95/9)] might lead to a misunderstanding, as if the 200MHz,1MW-CW operation was done by the EIMAC tetrode. Japan NIFS have no 201Mhz plan(Sh.-8) and the point(200MHz,1MW) is the goal in 1ms-pulse (Sh.-9).

We don't know whether the EIMAC tetrode is really operatable at conditions of more than 1MW-CW,175MHz or not.

After the IFMIF accelerator goes into operation, tube test apparatus are necessary not only in the tube production factory, but also in the IFMIF site for the smooth maintenance of the tube.

Also, tube operation at the reduced power conditions is recommended, because tube operation at the maximum tested power conditions would bring shorter tube life. We need longer tube life in IFMIF design. In the report[Berwald(95/9)b]p.185, MTBF of the transmitter is expected to 10,000h.

Technically any RF system could be constructed with the reduced power conditions of elements(tubes, semiconductors etc.), but the excess margin to achieve the confidence in the RF power output value brings cost problem.

Actual tube tests should be started in the early R&D stage, because the decision on the available RF power level from the tetrode is necessary for the whole system design of the IFMIF accelerator.

4. Solid state amplifier

All solid state amplifier would be preferable from the point of view of low maintenance operation to the transmitter tube amplifier. Here, the designs of all solid state amplifiers are shown as options.

Recently, UHF TV transmitters of less than 50KW power level have been changed from tubes to the all solid state amplifiers[Tamura(89/2)].

The report shows that the old 50kW tube transmitter is replaced by 3 sets of 25kW, 230MHz solid transmitter. Among them, one set is for maintenance use. The dimensions of one set are 5m(W)X2.2m(H)X1m(D) and it needs a 70kW AC supply. It uses the MOS-FETs of 2SK1028, each of which is worked at the output RF power level of 65W. As power loss happens during the stacking process of power lines, the total number of the MOS-FET is 640 in a 25KW set.

Design of the 175MHz,100kW-CW solid state amplifier for the IFMIF accelerator is shown.

Overall system components are shown in Sh.-10. A solid state amplifier for accelerator use needs the addition of a circulator, because the reflected RF power from the accelerator tube would be more changeable than from a TV antenna and the semiconductor is apt to break.

Arrangement plan of the 175MHz, 100kW-CW RF source is shown in Sh.-11. The number of the 10KW power amplifier sections is 16.

The structure of the 10kW-CW power amplifier section is shown in Sh.-12.

The structure of the 1kW-CW power unit is shown in Sh.-13. Each print board(300W) has two MOS-FETs of MRF151G from Motorola.

Comparisons between the present 175MHz, 100kW-CW RF source and the 120kW-CW RF tube source in Sh.-2, are shown in Sh.-14. The initial cost and electricity cost would be expensive for the solid case.

Trial design of 175MHz, 1MW-CW all solid state RF source is shown in Sh.-15. Comparisons of electric efficiencies among the various power levels of all solid state 175Mhz RF sources are shown in Sh.-16.

Higher RF power output level reduces the efficiency value by the stacking loss. Because the RF power output of a single MOS-FET is limited to a low level, the situation could not be improved without a new development of MOS-FET.

An economic design for the solid state transmitter would be limited to the 100kW-CW RF power output level. The situation is the same as in the UHF TV transmitter case.

Solid state transmitter may be suitable for certain superconducting linac[Tanabe(95/9)], because the design is restricted to the use of unit RF power of less than 100kW-CW at 175MHz.

5. Conclusions

The principal difference of the RF system design between the United States and Japan exists in the estimated output power level from the final amplifier tube(EIMAC 4CM2,500KG). Actual tube tests above the frequency range of 175 Mhz are urgently required, for the deciding the available RF power value at the accelerator section.

Possibilities for all solid state 175Mhz RF power sources are shown at various RF power levels below the 1MW-CW condition. Higher RF power output reduces the electric efficiency by the synthesizing loss. An economic design would be below the 100kW-CW RF power output level. Solid state transmitters may be suitable for some superconducting linac.

This study was carried out by Hitachi,Ltd. with the cooperation of NIHON Koshuha Co.,Ltd. under the guidance of JAERI.

References

[Berwald(95/9)a]D.Berwald,et al.:Baseline DTL accelerator. Final progress report/IFMIF accelerator trade studies; LA-UR-95-4416,p.153-174

[Berwald(95/9)b]D.Berwald,et al.:Reliability, Availability, Maintainability (RAM) Budgets and Trades for Baseline accelerator. Final progress report/IFMIF accelerator trade studies; LA-UR-95-4416, p.182-194

[France(95/9)]A.France,et al.:IFMIF RF system; LA-UR-95-4416,p.441-452

[Jameson(95/7)]R.A.Jameson:Linac RF system design/with emphasis on control;LA-CP-95-175,88p. & LA-UR-95-4416,p.453-544

[LA-UR-95-1707(95/4)]Report of the IFMIF CDA Accelerator Team Meeting. Dallas,Texas,USA.30 April,1995.245p.

[LA-UR-95-4416(95/9)]IEA/Implementing Agreement for a Programme of Research and Development on Fusion Materials:Accelerator Team Meeting for the IFMIF-CDA. Santa Fe,New Mexico,USA;601p.

[Hasegawa(95/10)]K.Hasegawa,et al.:R&D status on the high intensity proton accelerator in JAERI;JAERI-Conf 95-021,233-235

[Maekawa(93/2)]A.MAEKAWA:RF source;ESNIT/International Advisory Meeting (JAERI,93/6)p.86-95

[Mizumoto(95/2)]M.Mizumoto:Present status of high intensity proton accelerator development;JAERI-Conf 95-017,9-20[in Japanese]

[Mutoh(95/12)]Takashi Mutoh and Ryuhei Kumazawa:Development of CW ICRF source;News from the National Institute for Fusion Science(65)1-3 (95/12);[in Japanese]

[Piechowiak(95/9)]E.Piechowiak:RF sources for the IFMIF accelerator; LA-UR-95-4416,p.421-440

[Sugimoto(95/3)a]Masayoshi Sugimoto:Preliminary design of drift tube linac for IFMIF;LA-UR-95-1707,p.103-129

[Sugimoto(95/3)b]Masayoshi Sugimoto:Preliminary design of RFQ linac for IFMIF;LA-UR-95-1707,p.131-148

[Sugimoto(95/3)c]Masayoshi Sugimoto:Survey of high power RF source for IFMIF;LA-UR-95-1707,p.149-162

[Tamura(89/2)]Shinichi Tamura,etc.:All solid state TV transmitter with output power of 50kW using high efficiency MOS FET;ITEJ Technical Report 13(10)7-12[in Japanese]

[Tanabe(95/9)]Yoshio Tanabe:Preliminary design of superconducting linac for IFMIF;LA-UR-95-4416,p.361-371

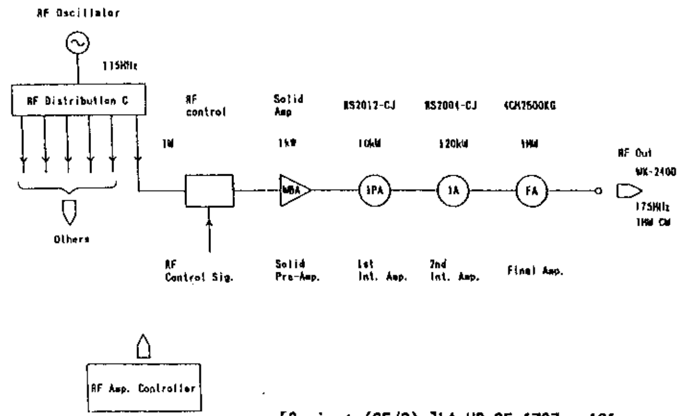
[Tornoe(95/11)]Robert N. Tornoe(CPI):private communication(95/12)

Specifications

frequency	120 / 175 MHz
output power	1 MW, CW
final amplifier	Tetrode or Diacrode
transmission line	coaxial guide, circulator, rf dummy

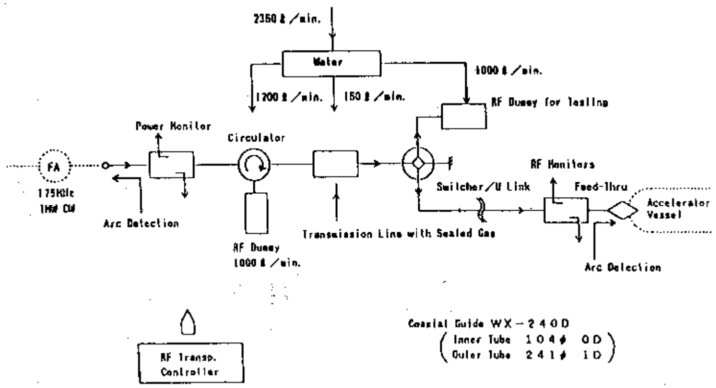
INS lab, JAERI [Sugimoto(95/3)c]LA-UR-95-1707, p. 156 Sh.-1

Fig. Schematic block diagram of the rf power source



INS lab, JAERI [Sugimoto(95/3)c]LA-UR-95-1707, p. 161 Sh.-2

Fig. Schematic block diagram of the rf transmission line



INS lab, JAERI [Sugimoto(95/3)c]LA-UR-95-1707, p. 162 Sh.-3

CPI Communications & Power Industries Eimac division

4CM2,500KG's Currently in Operation

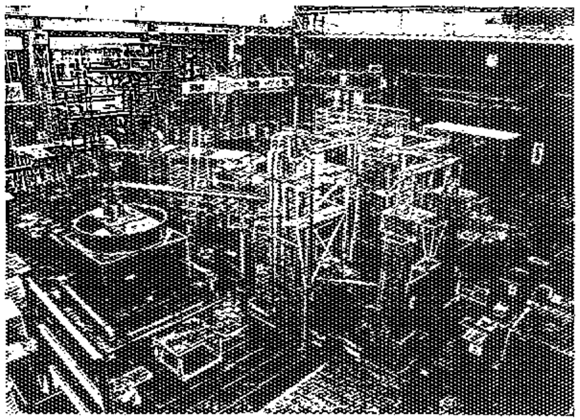
- At JAERI Tokai, operating in a SHI designed cavity at 201 MHz as an RF source for BTA-RFQ.
- Two tubes in operation at JAERI Naka (JT-60). They are used in the ICRH operating at 110 to 130 MHz, 750KW for 6 seconds.
- Two tubes are in the National Institute for Fusion Science ICRH 29 to 90 MHz. They have achieved 1.6 MW's for 1 hour and 23 minutes at 40 MHz.
- M.I.T. has three tubes which are used in ICRH. At 80 MHz they have operated at 1.8 Megawatts into a plasma with 1 second pulses. Their goal is 2.0 Megawatts.
- Princeton Plasma Physics Laboratory has two tubes in operation in ICRF operation into IFTR, 1.64 MHz at 2 Megawatts pulse.

[Tornoe(95/11)]private communication Sh.-4

融合科学研究

定常 ICRF

LHD 装置用のイオンサイクロトロン (ICRF) 加熱発振器の定常運転試験が当初の目標仕様を上回る高周波電力と連続運転時間で行われた。平成7年10月に、50メガヘルツの発振周波数において1.6メガワット、1時間超 (5000秒) の試験に成功した。これは一台の発振器の定常出力試験としては世界最高の値である。



NATIONAL INSTITUTE FOR FUSION SCIENCE

[Mutoh(95/12)]p.1　　Sh.-5

定常 ICRF 発振器の開発試験

武藤　敬、熊澤　隆平

イオンサイクロトロン (ICRF) 加熱装置は、LHD の加熱法の一つとして、3MW（メガワット）の定常加熱と 12MW 以上の大電力短時間加熱を行うことを目標として準備を進めてきた。ICRF 加熱装置は、構成要素として大電力発振器と伝送系、インピーダンス整合器、アンテナ系等があり、その各々について大電力の定常運転という目標のため開発試験 (R&D) を行ってきた。定常運転発振器は、テストスタンド用の先行機が、平成4年から土岐の加熱実験棟に設置され、発振器の開発を行うのと並行して、アンテナと伝送系の開発試験に使用されてきた。最近、大電力の定常運転による発熱に耐えるよう各部の冷却性能を向上させ、定常試験用のダミーロードの性能向上を行い、また終段増幅用の4極真空管付近の寄生振動を抑えることに成功した等の結果、大幅な運転性能の向上を見ることができた。安定に発振させるためにインターロックを含む制御系の改良も行い、信頼性の向上も併せて行っている。

LHD での ICRF 加熱は、広い磁場強度範囲での多様な実験に対応できるように、25MHz（メガヘルツ）から 100MHz までの周波数の RF 出力ができるよう計画された。通常の構造の発振器では、これだけの広い帯域をカバーできないので、特別に設計された2重同軸構造の出力キャビティ (空洞共鳴器) を持った増幅器を新たに開発した。この基本構造の試験のため、平成元年度に実物の約1/2サイズの出力キャビティを試作し、低電力での特性試験を経て採用を決定している。同軸とはいっても、作業性を考慮して最外側の断面形状は8角形、中間壁は16角形、内導体は真円形断面の構造をしている。キャビティの同調周波数は、基本モードに近いものを用いるため、円形断面を用いた解析値からの同調のずれは大きなものではないと予想されるが、低電力の試験で 25MHz から 100MHz までの周波数帯の同調が予定どおり取れている。出力及び入力キャビティと増幅用真空管の断面形状が図1に示されている。上半分の縦長の部分が出力側のキャビティにあたる。中央部のお釜を伏せたような形状の部分が増幅用の4極真空管である。

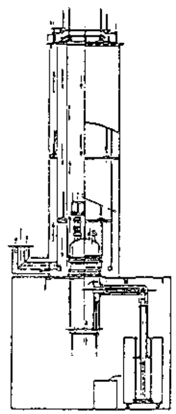


図1　定常大電力 ICRF 発振器終段増幅器の断面形状を示す。上側が出力キャビティで下側が入力キャビティ、球状のものが4極真空管である。

数十 MHz の周波数帯の発振増幅器で 100kW を超える電力を発生する場合、現在も大電力用の真空管を用いて機器を構成する他になく、ここで採用している4極管は米国 CPI 社製の Eimac 4CM2500KG 管と呼ばれるものである。高周波的には、グリッド接地型の励振機構を採用している。この真空管は、従来からよく用いられてきた同社の Eimac 8973 管をグレードアップしたもので、グリッドとスクリーングリッドの熱容量を増やすために特殊なグラファイト製とし、またプレートの熱容量をも大幅に増強するなどの改良を施したものである。世界的にも ICRF 加熱用の大型発振器では、この真空管と仏国トムソン CSF 社製の TH525 管が使われているものがほとんどである。4CM2500KG 管では、数秒のパルスモードで 2MW を超える高周波出力を出したという報告例があるが、実際に MW 級の定常運転の発振試験を行ったのは当研究所が最初である。

ICRF 加熱は、今まで数秒以下の短時間の加熱実験がほとんどであったため、耐電圧性能向上には、既存の発振器と伝送系の経験が役立ったが、定常運転での経験は、このような大電力領域ではほとんどもちあわせがなかった。まず熱を除くための冷却機能を大幅に付加する必要があり、設計段階ではできるだけ考慮してはいたものの、現実には真空管のコンディショニングとキャビティの調整をかねて出力を上げながら、パルス幅を伸ばし、熱的に弱いところを増強、改造しながら全体の性能を上げていくという方式を採ることになった。冷却性能の向上と並行して余分な熱発生の抑制を行うのも重要で、ICRF 発振器では、本来の高周波発振を行う部分とは別の場所で高周波のもれや発振が起こる。それが予想できない各所で部品の温度上昇を起こし、焼損

– 2 –　[Mutoh(95/12)]p.2　　Sh.-6

から絶縁破壊を引き起こすことが頻繁に起こった。これらのほとんどは、10秒程度のパルス運転であれば何の問題もなかったものであるが、定常運転になって大いに悩まされた点である。

いろいろな試行錯誤を経て、現在冷却のための送風を行っている経路をキャビティの概略図の図中に矢印で示す。図1には、大きな風の通り道を示しているが、これ以外に寄生振動防止用のフェライト片の空冷チャネルがあり、また大容量の冷却水の経路はプレート、グリッド、フィラメントに接続されている。これらの冷却システムの完成が、定常運転試験の必要条件の一つであった。

加熱装置のフルパワー試験には、その電力を吸収するダミーロードが重要な要素で、どの加熱装置でもある程度の苦労が要求される。通常ICRF用として、50MHzより高い周波数帯では、電解液を吸収体として用いたダミーロードが用いられている。我々は、25MHz付近の低周波数領域でも簡単に用いられるように、水冷のセラミック抵抗器を用いたダミーロードを製作した。大型のセラミック抵抗体を96本用いており、全体の大きさは直径2.8mで高さ2.6mという大きなものである。大電力を扱うため大きなものにすると、その結果高周波特性が悪くなるという反動があり、高周波特性を改善するために、入り口部に簡単なインピーダンス整合部をつけ加える工夫を行っている。

電力の主な吸収部は、水冷の抵抗体であるが、そこへ伝送するまでの同軸管部は空冷で冷やしている。空冷同軸管の内導体部は、冷却性能が低く、そのため定常運転では簡単に100度以上の温度になり、絶縁支持構造物の破壊が心配になる。同軸管の温度をモニターするために赤外線温度計を設置して測定している。発振器の内部を含めて同軸構造の内側部の高周波電流の流れる面の温度を測定する場合、強電磁場の影響が心配されたが、うまく測れているようである。

冷却能力の大幅な性能アップにより1.2MWレベルの30分程度の発振試験が可能になった。この時点でパワーの上限を制限していたのは、1.3GHz（ギガヘルツ、1GHz = 1000MHz）付近の寄生発振によるトラブルであった。増幅管である大型4極管では、管の構造から決まる1GHz付近の不要な寄生振動が問題になることが多く、これを抑える対策をキャビティ設計時から行っている。キャビティ周辺にある寄生振動防止用の吸収抵抗素子やフェライト吸収体の異常発熱と、4極管の管内でのガス発生とそれに伴う管内アークの発生等が具体的な発生現象であった。これらの寄生振動問題は、4極管使用時は常時つきまとう問題であるが、なかなか決まった対策がなく、苦労してきたところである。最近になり、出力キャビティと各バイアス電圧の調整を広い範囲で取り直すことにより、寄生振動の少ないチューニングポイントを探し出すことに成功した。この寄生振動成分の減少による性能の向上は著しく、パワーと発振時間の増加を得ることが出来た。これらの努力による試験性能の向上の様子が図2に示されている。

平成6年と7年の前半には、1MWで100秒の範囲であったが、今年の8月に冷却の増強とダミーロードの改造を行い、1.2MWで30分の定常運転に成功した。その後、上に述べた寄生振動の防止策を行ってから、1.6MWの5000秒の定常運転試験に成功した。伝送系、ダミーロードを含めて全系統が熱的には、平衡状態に達しており、より長い運転時間に対応することも可能である。10秒の短時間運転では、1.9MWの大電力の運転も行っている。これまでの範囲で特に運転に制限が現れたわけではないが、今後は他の要素の開発を行いながら、より大電力で長時間の運転試験を行う予定である。

加熱実験棟の冷却水設備は、クーリングタワーと熱交換器の能力がやや不足しがちで、実際に実験が行われたのは、夏を過ぎ外気温がやや涼しくなるのを待ってからであった。LHD本体棟の冷却水施設はもっとしっかりしたもののはずであるが、定常運転ではスタート時の初期温度が低いことは重要である。盛夏時より20度近く低いことは、外部の電源や発振器にとって相当に負荷が軽くなり、楽に運転が出来る。本実験でも定常モードは、涼しくなるのを待ってからというのがよさそうである。

(武藤　敬　プラズマ加熱研究系助教授
熊澤隆平　〃)

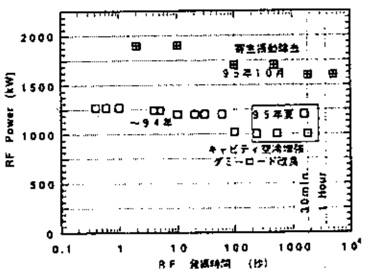


図2　出力パワーと連続発振時間の進展を示す。周波数50メガヘルツ、2号発振器の出力試験結果である。

EIMAC 4CM2500KG Tube Characteristics

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Specifications

- Voltage 21 kV
- Max Power 1.3 MW
- Efficiency @ max power 73%
- Control Margin (for this configuration) 7%
- Low Voltage Power Supply Requirements 100.0 kW
- Gain 14.0 db
- Average Operational Life 10,000 hrs

Operational history (long pulse operation)

- Princeton Physics Lab >2 MW @ 64 MHz
- ~~Japan Atomic Energy Research Inst. 1.7 MW @ 131 MHz~~
- Japan National Inst. for Fusion Science 1.0 MW @ 201 MHz

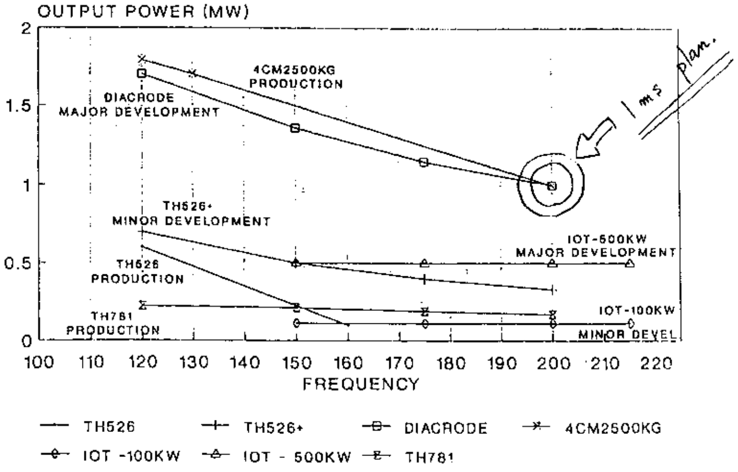
No plan.

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

[Berwald(95/9)a] LA-UR-95-4416, p. 159 Sh.-8

POWER vs FREQUENCY FOR TUBE CANDIDATES



HG:FMIFTET2.CHT

[Piechowiak(95/9)] LA-UR-95-4416, p. 424 Sh.-9

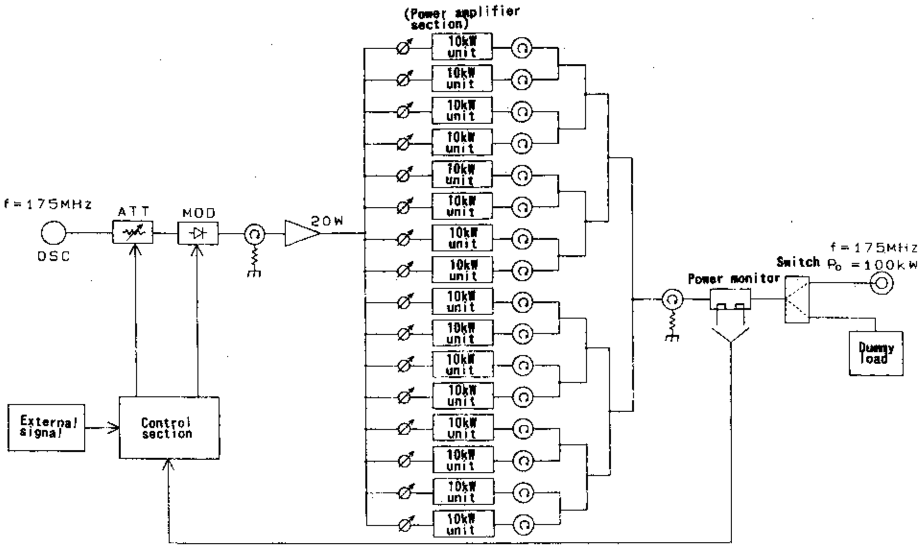


Fig. Overall system components of RF source (175MHz, 100kW-CW, solid state) Sh.-10

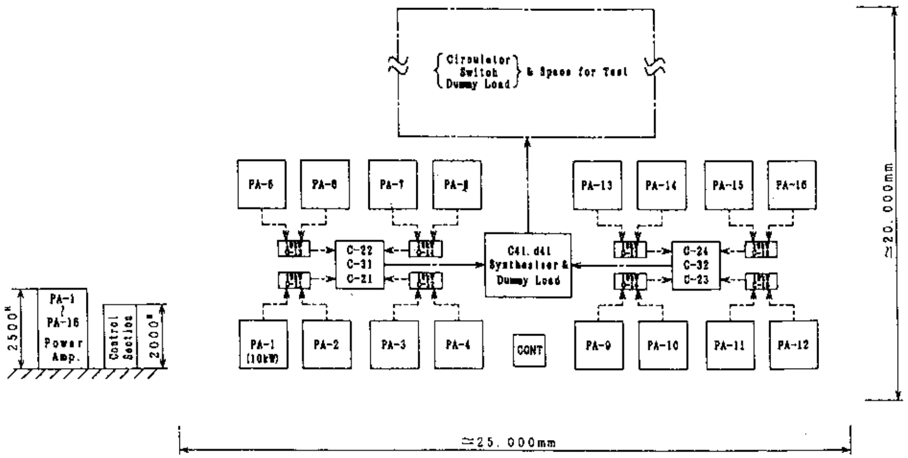


Fig. Arrangement plan of RF source (175MHz, 100kW-CW, solid state) Sh.-11

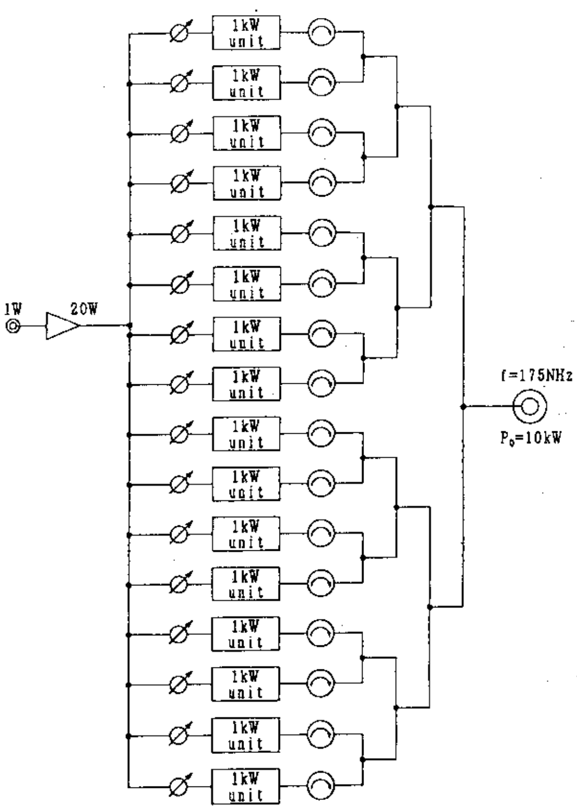


Fig. Power amplifier section(10kW-CW, 175MHz) Sh.-12

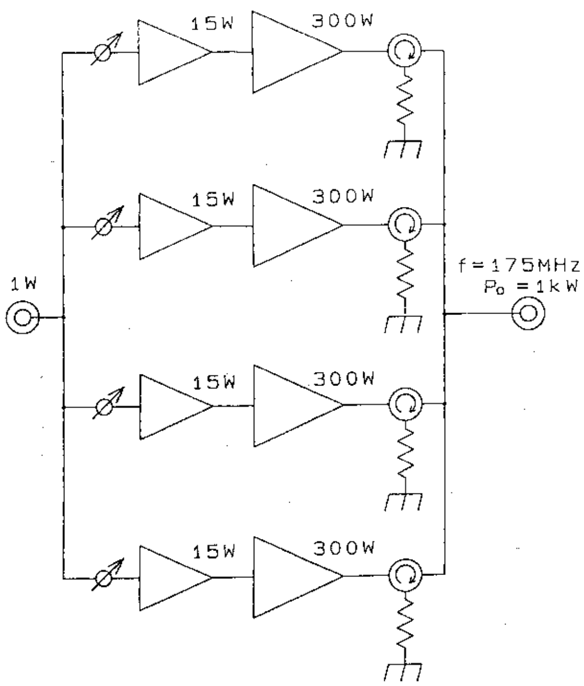


Fig. Fundamental Unit(1kW-CW, 175MHz) Sh.-13

Table Comparisons between 100kW-CW solid state and 120kW-CW tube RF sources(175MHz) Sh.-14

No.	Item	solid state	Tube
1	Frequency	175MHz	175MHz
2	RF output	100KW-CW	120KW-CW
3	Structure of components	PO=1KW(Fundamental Unit) ↓ (synthesizing 16 in parallel) PO=10KW ↓ (synthesizing 16 in parallel) PO=100KW	PO=1KW(Fundamental Unit) ↓ (Amplifiling in series) PO=10KW(IPA) ↓ (Amplifiing in series) PO=120KW(IA)
4	Amplifier components and their numbers	MOS·FET, MRF151G, × 8 ↓ 8 × 16=128 ↓ 128 × 16=2048	MOS·FET, MRF151G, × 8 ↓ Tetrode RS2012-CJ, 1 ↓ Tetrode RS2004-CJ, 1
5	AC power supplies		
5.1	RF amplifiers	1. per Fundamental unit 2.5KW(50V × 50A) 2. 2.5KWPS × 16=40KW 3. 2.5KWPS × 16 × 16 =640KW	1. per Fundamental unit 2.5KW(50V × 50A) 2. IPA, 20KVA 3. IA, 210KVA
5.2	AC line capacities	3 φ, AC200V, 750KVA 1 φ, AC100V, 10KVA 1 φ, AC115V, 10KVA	3 φ, AC200V, 300KVA 1 φ, AC100V, 10KVA 1 φ, AC115V, 10KVA
5.3	Electric efficieny	100KW/770KVA=13%	120KW/320KVA=38%
6	Cooling waters	Flow rate:500l/min Temperature:25℃~35℃ Pressure: ~5kgf/c㎡ Quality: (5k Ω-cm)	Flow rate:350l/min Temperature:25℃~35℃ Pressure: ~5kgf/c㎡ Quality:pure (1M Ω-cm)
7	Others		
7.1	Life	~20 years	Depend on the contract to supplier
7.2	Maintenanse	Easy (using plug-in Findamental units)	Prepare the spare tubes(Expensive and long delivery time)
7.3	Operation	Simple	Experiences
7.4	Price	Expensive	Reasonable
7.5	Cooling water	Ordinary	Pure water
7.6	Safety	Good	Danger to high voltage

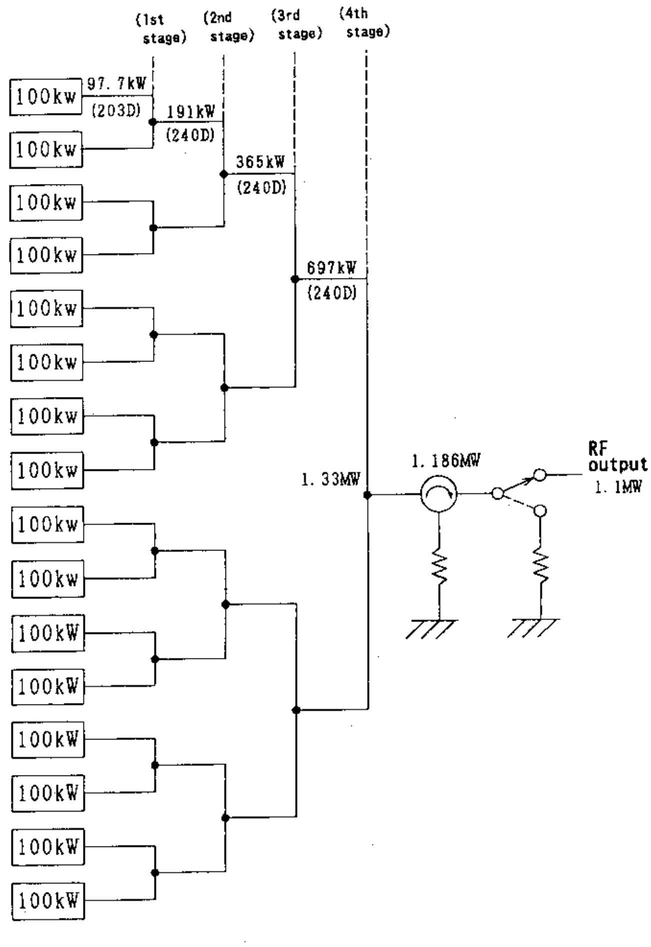


Fig. Trial design of RF source(175MHz, 1MW-CW, solid state) Sh.-15

Table Comparisons of electric efficiencies among the various power levels of all solid state 175Mhz RF sources

	RF power output	AC power supply	Efficiency
Print board	300W	600W	50%
Fundamental Unit	1KW-CW	2.5KW	40%
Power Amplifier	10KW-CW	40KW	25%
RF source	100KW-CW	640KW	16%
RF source	1MW-CW	10.24MW	10%

Sh.-16

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

Accelerator Design Progress

J. Rathke
Northrop Grumman Corp.
Bethpage, NY

S. Thomson
Bechtel Corporation

R. Jameson & B. Blind
Los Alamos National Laboratory

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

Bechtel - Northrop Grumman - Westinghouse *NORTHROP GRUMMAN*

September 1995 Configuration

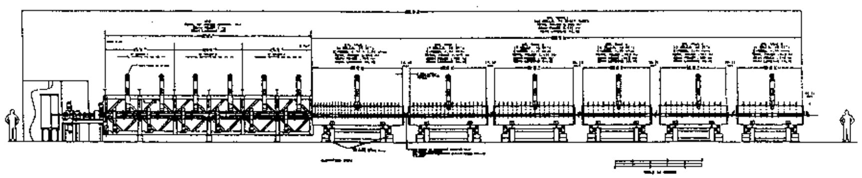
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

- Dual Injectors
  - Redundancy for Availability
  - Required Vault Access During Accelerator Operation
  - Long, Complex LEBT
  - Required Wide Vault
- Overhead Handling of Accelerator Components In-Vault
  - Required 25 ton Crane
  - Required Over-the-Wall Lift Capability
- RF Hall Next to Accelerator Vaults

Bechtel - Northrop Grumman - Westinghouse *NORTHROP GRUMMAN*

POD Accelerator - Sept 95

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

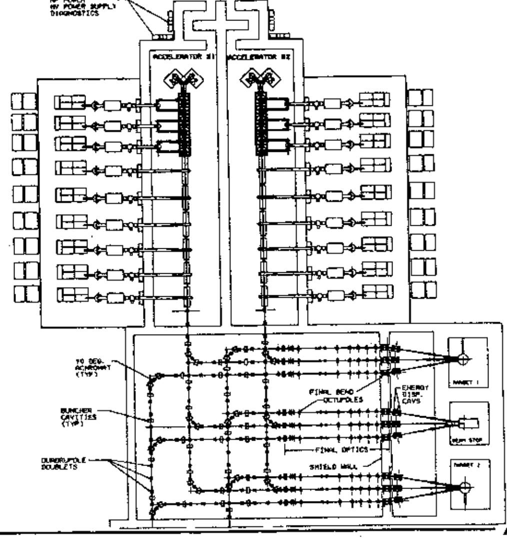


- Design Driver - Most Proven Technology, Power Efficiency
- System Length = 44.3m, System RF Power = 8.98 MW
- 175 MHz , FoDo Lattice
- DTL Matches RFQ Output at 1.4 MV/m and Ramps as β to 1.81 MV/m (First Tank)
- 3cm Drift Tube Bore Diameter with Rad Hard EM Quadrupoles
- 2 βλ Inter-Tank Space For Isolation Valves & Diagnostics

Bechtel - Northrop Grumman - Westinghouse *NORTHROP GRUMMAN*

Accelerator Plan View - 1995

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

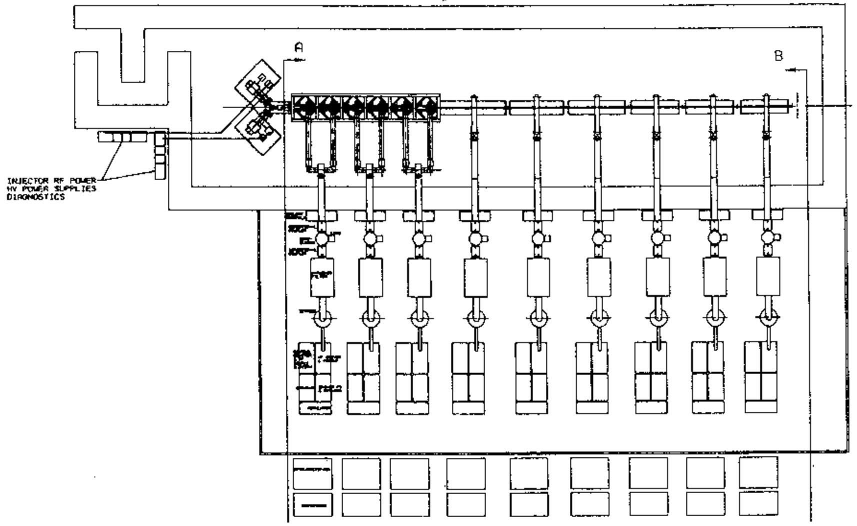


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System - 1995

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

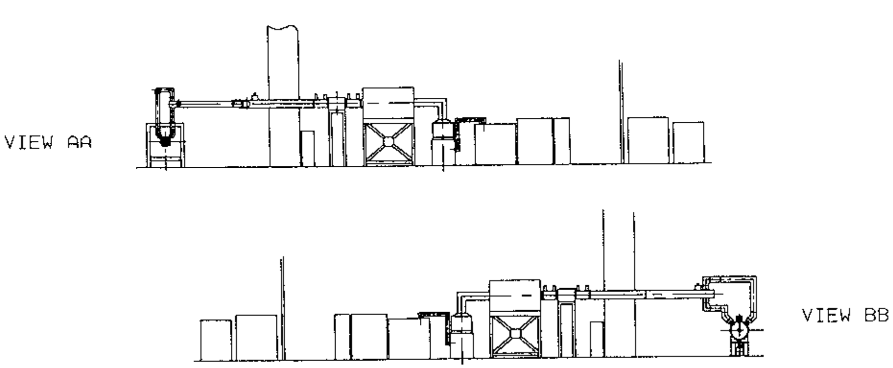


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System - 1995

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

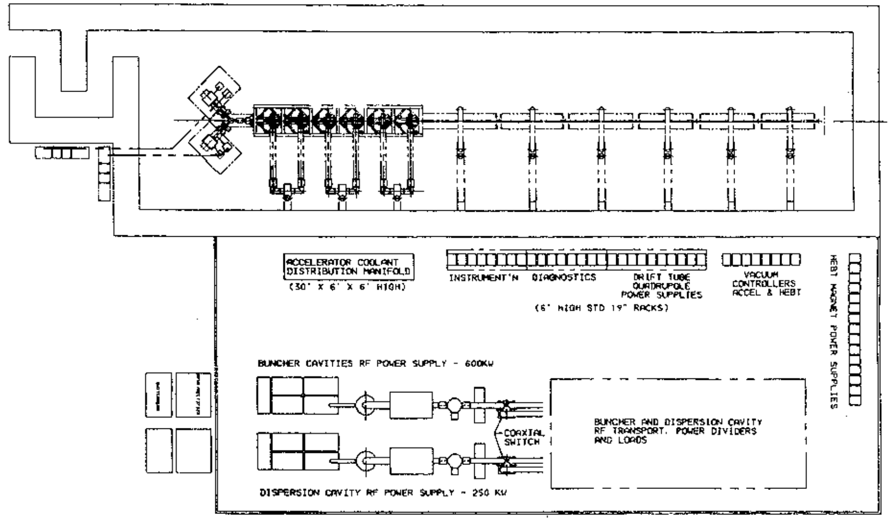


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF Second Floor - 1995

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Output of ORNL Design Integration Meeting

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- A Great Deal of Stress on Reducing the Plan Area
  - Try To Cut Down Vault Width
  - Put RF Power Above Accelerators (Earth Shielding)
- Desire to Eliminate Overhead Handling in Accelerator Vault
  - Reduce the Height Requirement of Vault
  - Eliminate Multiple 25 Ton Cranes
  - Side Handling Used At Many Installations for Heavy Items

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Maintenance Ground Rules and Assumptions

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- Vault Can Be Accessed Promptly After Accelerator Shutdown
  - Prompt Means Short Time Compared to Minimum MTTR Of Items
  - Access within 1 Hour Required for RF Antenna Replacement (2 Hour MTTR)
- Credible Maintenance Operations on the Accelerator Tanks Can Be Performed In-Vault
  - DT Replacement
  - Antenna, Extractor, and HV Equipment Replacement
  - RF Drive/Window Replacement (Modular)
  - Support Systems - Pumps, Cooling, Diagnostics
- Incredible Maintenance Will Be Done On Long Time Scale By Component Removal
  - Tanks Will Be Handled By Side Loading From Trolley Type Towed Carts
  - Tanks Will Be Lifted Up To The RF Floor Level For Major Work

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

May 1996 Configuration

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- Single Injector Designed for Rapid Maintenance
  - Beam Loss Study Indicates No Access Allowed During Operation
  - Allows Much Narrower Vault
- Simple, Short Dual Solenoid LEBT
  - Lessens Concern Over Space Charge Neutralization
- Accelerator Vaults Below Grade, RF Above
  - Common Central Pipe Chase Between Vaults For RF Coax and Services
  - Reduces Shielding Requirements for Vault Walls
- Accelerators Moved on Trolleys Over the Floor
  - Used For Initial Installation and Rare Case When Tank Must Be Removed
  - Saves Overhead Clearance and Reduces Crane Capacity to 5 Tons
  - Technique used at SLAC, Fermilab, and Others
- Accelerator Maintenance Area At RF Floor Level
  - 25 Ton Crane on RF Floor Lifts Accelerator Tanks When Necessary
  - Normal Accelerator Maintenacne Performed In-Place

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

May 1996 Configuration II

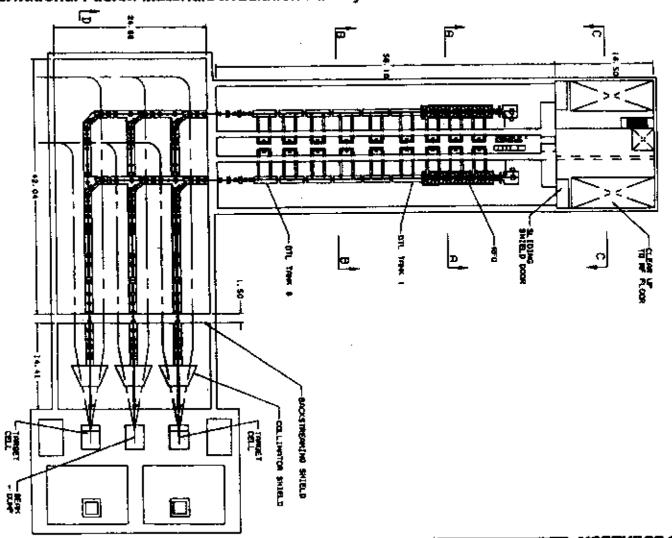
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- High Energy Beam Transport System Design Has Been Performed by Los Alamos
  - Not Optimized But Works End to End
  - Closely Conforms to the Overall Geometry Used Previously
  - Consists of:
    - > Four Quad DTL to HEBT Matching Section
    - > 2.4 Meter FDo Lattice With Bunchers Every 2nd or 3rd Cell (Before Bend)
    - > Achromatic Bend With Dual Bunchers
    - > 2.75 Meter FDo Lattice With Bunchers Every Other Cell (After Bend)
    - > Four Quad Plus Buncher Telescope Matching Section
    - > Nonlinear Expander (Oct-Quad-Quad-Oct)
    - > Six Quad Imager
    - > 10 Degree Dipole
    - > Two Energy Dispersion Cavities
- Bend to Target 2 Meters Greater Than Previously Shown

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Accelerator Plan View - 1996

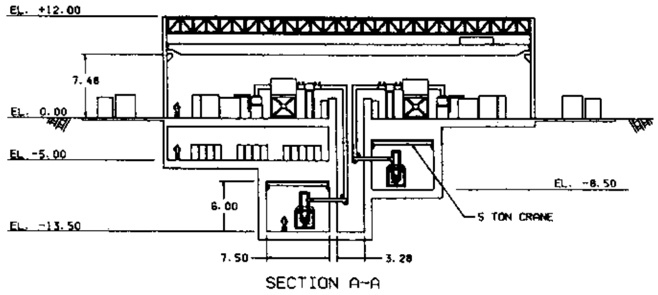
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Section Through Accelerators - 1996

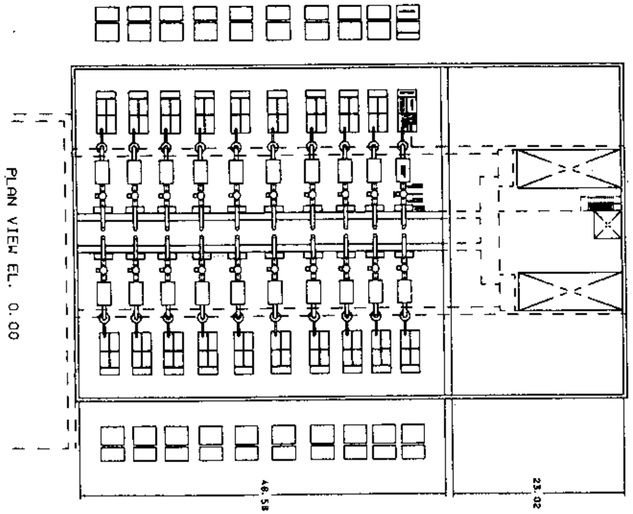
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

RF Floor - 1996

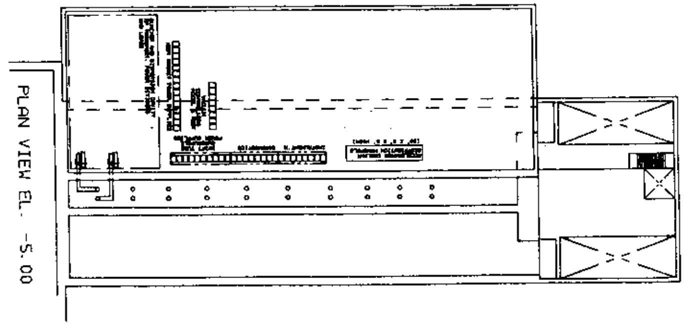
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Intermediate Floor Plan

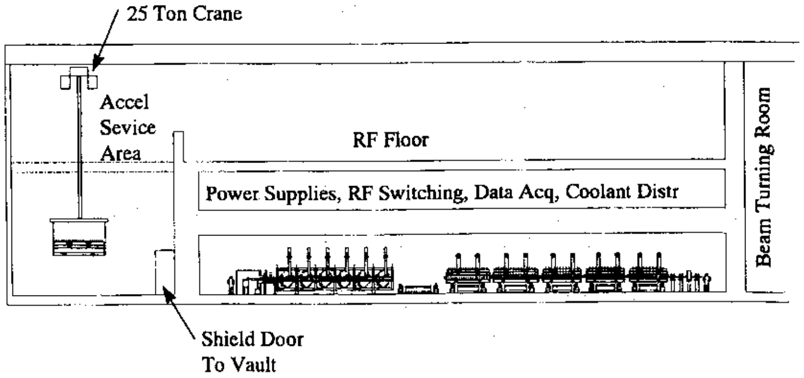
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Section Normal to Accelerators

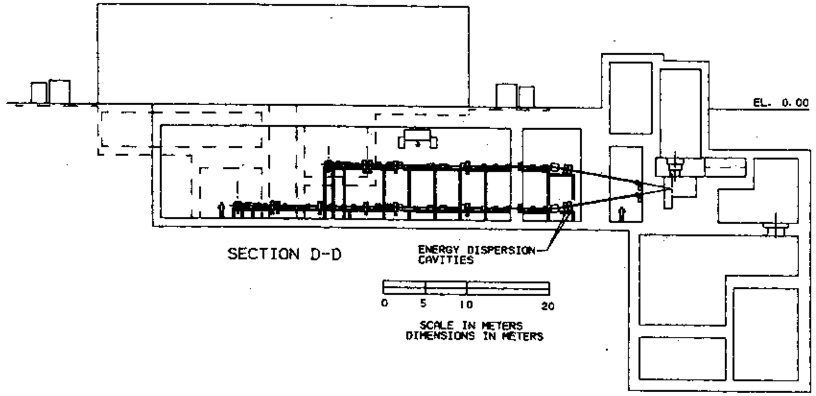
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

HEBT Elevation - 1996

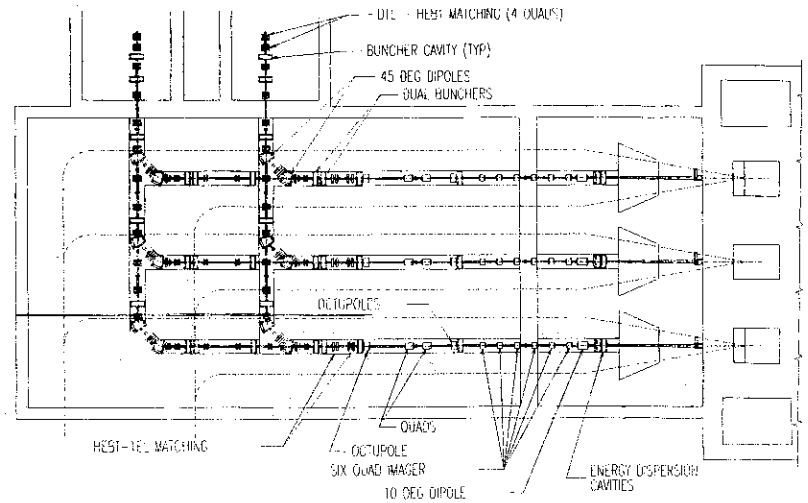
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

HEBT Plan View - 1996

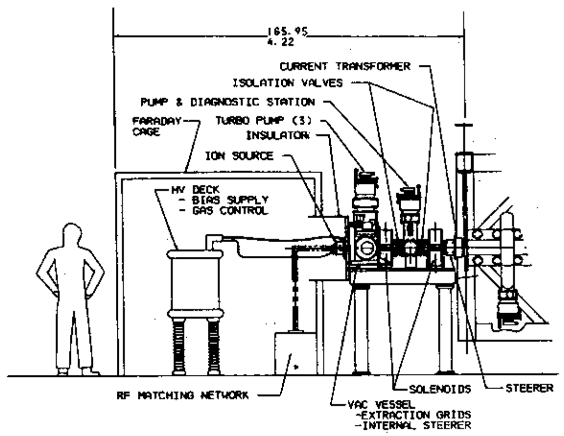
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Single Injector Configuration

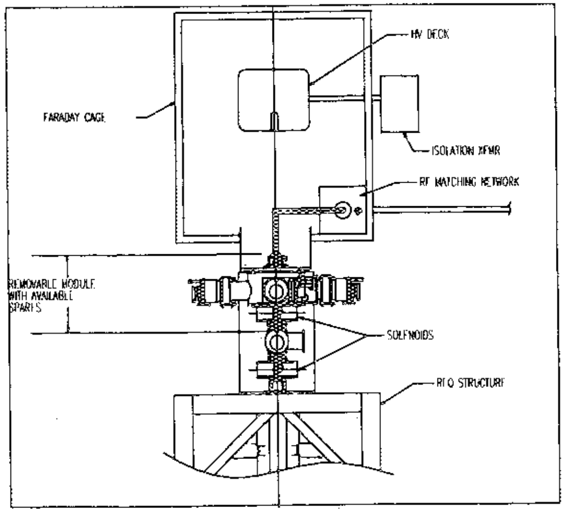
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Single Injector Plan View

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Injector Features

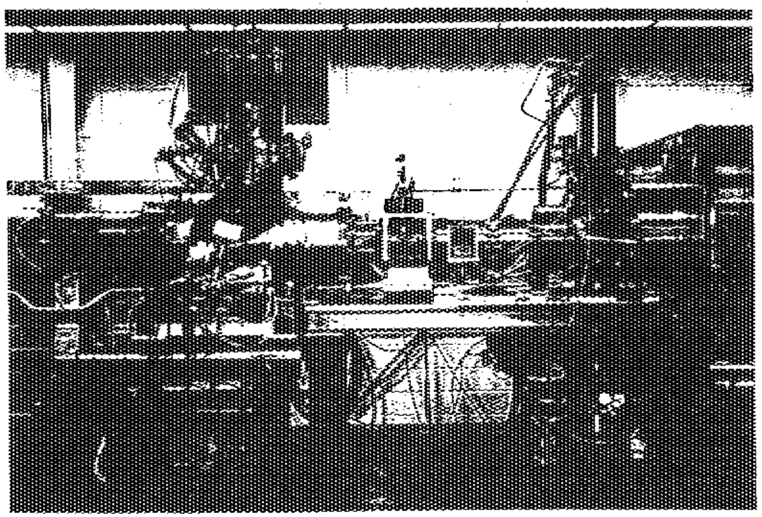
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- Quick Release Back Plate for Antenna Replacement
- Source, Extractor Grids, Pumping System, and First Solenoid Integrated in a Replaceable Module on Kinematic Base
  - Allows Rapid Replacement - Double Quick-Disconnect Valves
  - Pre-Aligned Assembly
  - Pre-Tested and Kept Under Vacuum
- Very Little, If Anything in HV Deck for RF Source
  - Bias Power Supply May Not Be Needed
  - Gas Supply Can Be Put at Ground
- ECR Should Have No HV Deck
  - Still Requires Faraday Cage
- All Other Services Can Be in Pipe Chase

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Palletized CW Injector

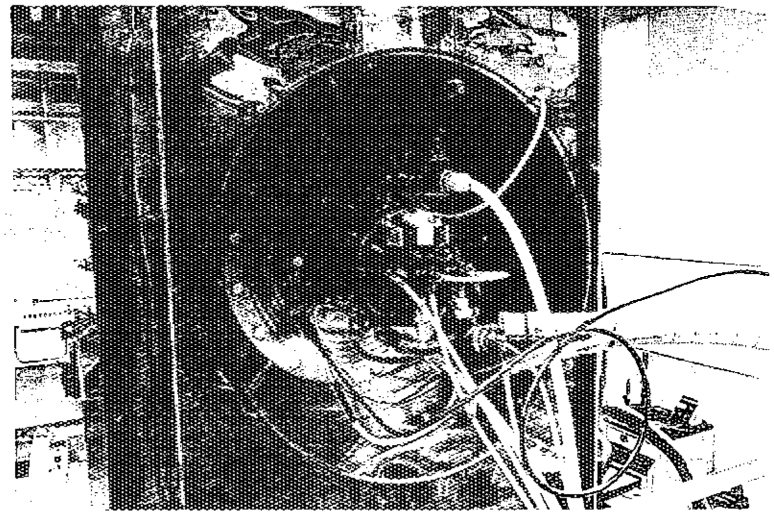
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Ion Source Installation

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL



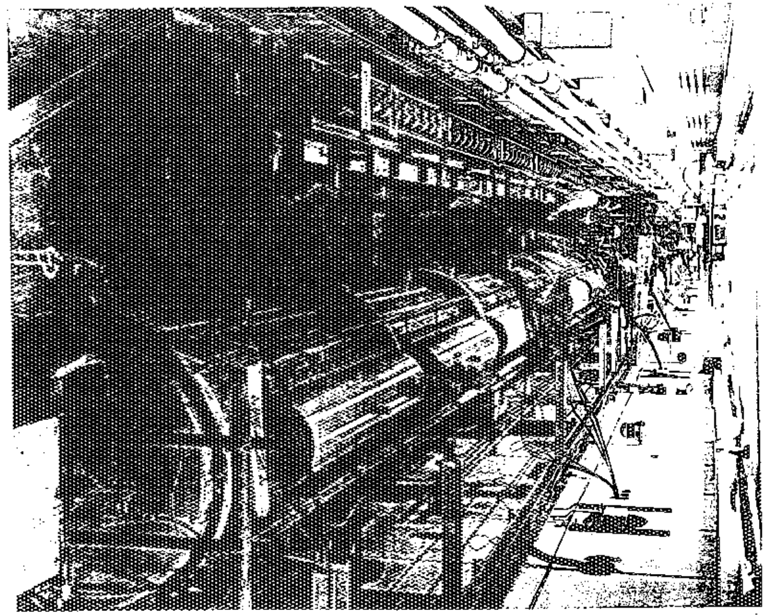
Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

EMQ's

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

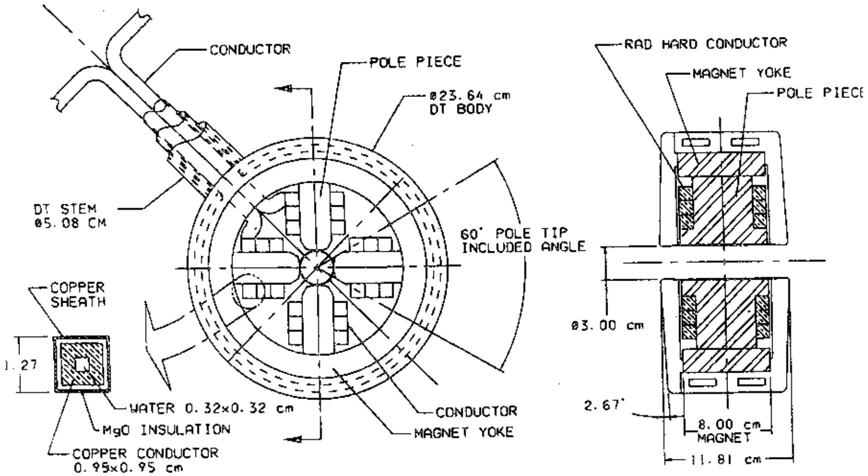
- Rad Hard Conductor Difficult to Use
  - Must Have Generous Bend Radii
    - > Much Greater Than Shown In Concept at Santa Fe
    - > Probably Not Possible With 175 MHz Drift Tube Diameter
  - Approx. 1100 Amps at .8 Volts, Requires 3.3 cm Square Bus Bar Feeds
  - Maintenance Problem
- Propose to Use LAMPF Type Approach
  - Standard Cooled Conductor Potted in Concrete
  - 4mm Sq Requires Approx. 145 Amps at 6 Volts
  - Can Use 2/0 Stranded Cable Feeds (Flexible)
- Using Conventional Conductor We Can Propose:
  - DTL Tank Can Be Moved Laterally to Gain Internal Access WITHOUT Disconnecting Power, Water or Tank Vacuum Plumbing
  - Use LAMPF Approach of Having A Set of Generic Drift Tubes That Can Fit Many Locations By Trimming Faces to Suit. Maybe Need 10 Spares.

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN



EMQ With Rad Hard Conductor

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

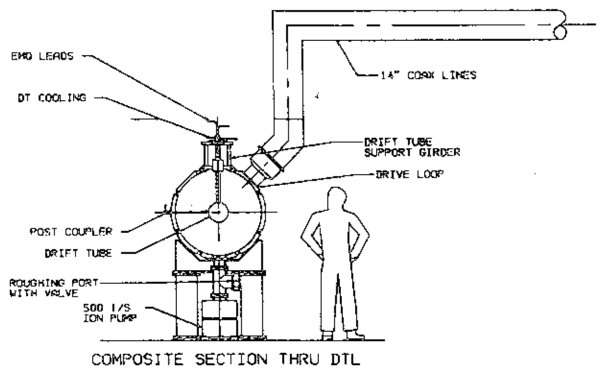


- At 6 MeV DT Length is 10.2 cm, At 4 MeV DT Length is 8.3 cm

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Drift Tube Linac Section

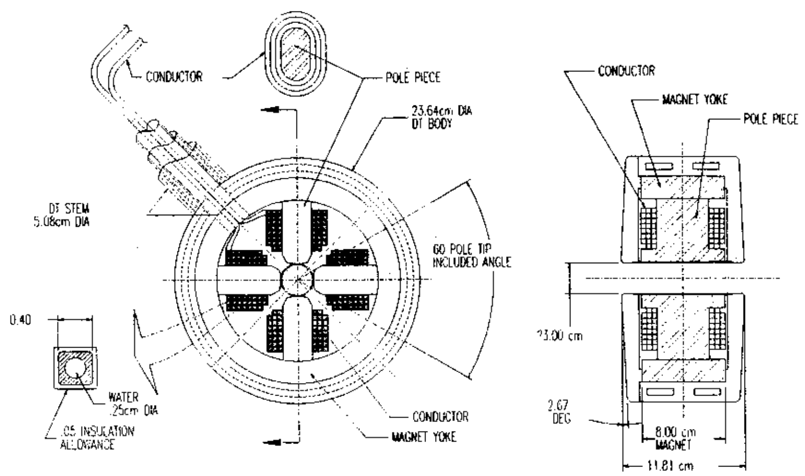
International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

EMQ With 4mm Conductor

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Accelerator Facility Cost, Schedule, and Manufacturing Flow Status Briefing

Timothy J. Myers

Northrop Grumman Corp.
Bethpage, NY

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Summary

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

- Design Tailored to Conform to Facility Requirements
  - Reduced Planform
  - Side Access and Handling
- Accessibility and Maintainability Considered in Overall Layout
  - Dual Injector Loses Because it Requires Access to Vault During Operation
  - Now Requires Prompt (1 hour) Access to Vault
  - Requires Accessibility to Internals Of DTL Tanks for Drift Tube Replacement -- 72 Hour MTTR
- Need to Re-Evaluate A&M After Further Activation Analysis

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Outline of presentation

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Acknowledgments**
- **Approach**
- **Accelerator schedule flowdown**
- **Work breakdown structure (WBS)**
- **Cost**
  - **comparison to Sept 95**
  - **projection for two accelerators**

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Contributors

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Name	Area of Responsibility
John Rathke	Overall engineering labor estimate (preliminary and final design, and manufacturing support)
David Bruhwiler/Alan Todd	Physic support labor estimate
Al Burger/Ed Peterson	Accelerator/HEBT manufacturing labor and material estimates
Ed Piechowiak/Eric Ulanowicz	RF power system engineering/manufacturing labor and material estimates
Mike Cole	Accelerator cavity tuning/installation labor and material estimates
Joe Sredniawski	Injector design and manufacturing labor and material estimates
Stephen Melnychuk	Injector startup labor and material estimates
Stan Mendelsohn	Accelerator Segment Instrumentation and control design and installation labor and material estimates
Ted Debiak	Accelerator/HEBT diagnostic labor and material estimate

- Coupled to over 90 component or service vendors supplying quotation in ~ 20 different technical areas

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

US Costing Approach - "Grass Roots"

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

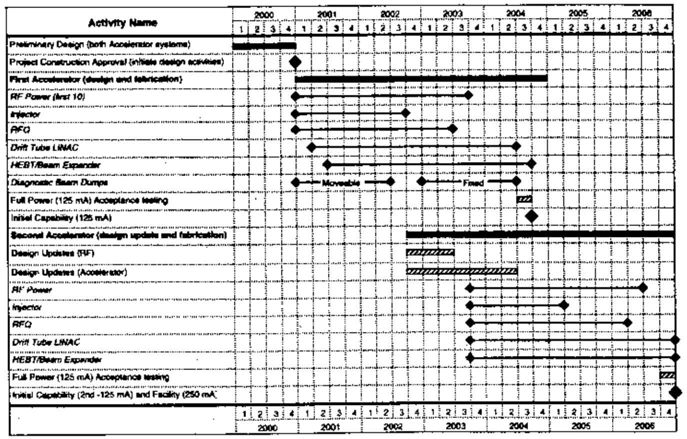
- **Develop lower level accelerator component activities from program master schedule**
  - » engineering design
  - » procurement/fabrication/manufacturing
  - » installation, assembly and checkout
- **Define each activity in terms of labor and material**
- **Compare results with similar programs/estimates**
  - » Contraband Detection System
  - » Continuous Wave Deuterium Demonstrator
  - » Accelerator Transmutation of Waste (ATW) and other high power accelerator programs

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Program Master Schedule - Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

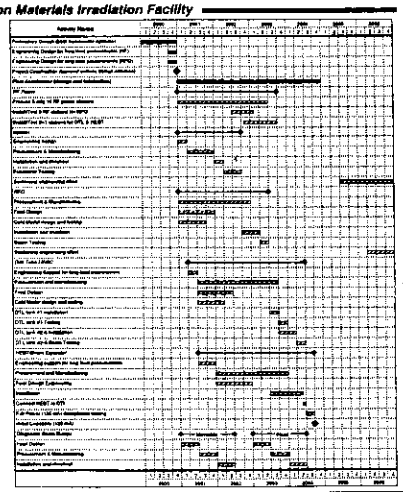


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

First Accelerator Detailed Master Schedule

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

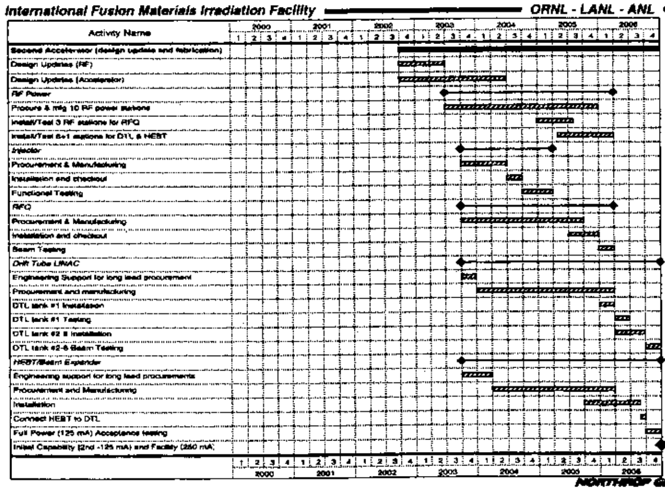


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Second Accelerator

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

Accelerator WBS General Comments

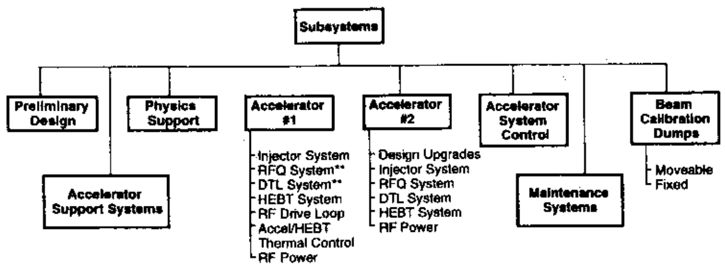
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- **Interim report level 2 structure maintained**
- **Level 3, and below, re-organized**
  - Accelerator Equipment Preliminary Design
  - Accelerator Equipment Physics Support
  - Accelerator #1 & Accelerator #2 segregated
    - most accelerator & RF power components at level 4 (individual DTL tanks at level 5)
    - HEBT & RF Power
  - Beam Calibration Dumps (includes fixed and moveable dumps)
  - Accelerator I&C *[included in accelerator & RF accounts]*
  - Accelerator Support Systems
  - Maintenance Systems *[not used]*

Bechtel - Northrop Grumman - Westinghouse

Subsystems Detail

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

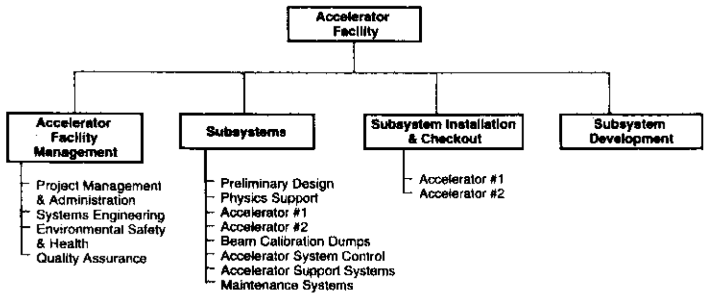


** - contains cold model activities

Bechtel - Northrop Grumman - Westinghouse

Accelerator Facility WBS

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

Subsystem Installation and Checkout

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Subsystems Installation and Checkout**
  - **Accelerator #1**
    - Injector System
    - RFQ System
    - DTL Tank #1
    - DTL Tanks #2-6
    - HEBT System
    - RF Power System
    - Beam Dumps
    - Full Power Acceptance Test (125 mA)
  - **Accelerator #2**
    - Injector System
    - RFQ System
    - DTL Tank #1
    - DTL Tanks #2-6
    - HEBT System
    - RF Power System
    - Full Power Acceptance Test (2nd-125 mA)

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Level 5 Detail

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Most level 5 accounts are comprised of:**
  - procurement support/seller surveillance
  - purchased material
  - fabrication labor
  - ⇒ *DTL system goes one level lower by tracking costs against each individual tank*
- **Accelerator #1 contains additional elements**
  - final design labor
  - cold models (RFQ & DTL)
  - sustaining labor efforts (Injector, RFQ, DTL)
    - » transition to Accelerator # 2 tasks

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

New WBS

Level 1.	2.	3.	4.	5.	6.	7.	Name
4.	0.	0.	0.	0.	0.	0.	Accelerator Facility
	1.	0.	0.	0.	0.	0.	Accelerator Facility Management
		1.	0.	0.	0.	0.	Project Managment and Administration
		2.	0.	0.	0.	0.	Systems Engineering
		3.	0.	0.	0.	0.	Environmental Safety & Health Documentation
		4.	0.	0.	0.	0.	Quality Assurance
	2.	0.	0.	0.	0.	0.	Subsystems
		1.	0.	0.	0.	0.	Accelerator Equipment Preliminary Design (injector thru HEBT)
		2.	0.	0.	0.	0.	Accelerator Equipment Physics (injector thru HEBT)
		3.	0.	0.	0.	0.	Accelerator #1 (Castor)
			1.	0.	0.	0.	Injector System
			2.	0.	0.	0.	Radiofrequency Quadrupole System
			3.	0.	0.	0.	Drift Tube Linac System
				1.	0.	0.	Cold Model Design & Test
				2.	0.	0.	Final Design Tanks #1-6
				3.	0.	0.	Tank #1
				4.	0.	0.	Tank #2
				5.	0.	0.	Tank #3
				6.	0.	0.	Tank #4
				7.	0.	0.	Tank #5
				8.	0.	0.	Tank #6
			4.	0.	0.	0.	HEBT System
			5.	0.	0.	0.	RF Drive Loop
			6.	0.	0.	0.	Accelerator & HEBT Thermal Control Engineering
			7.	0.	0.	0.	RF Power System
				1.	0.	0.	RF control
				2.	0.	0.	RF Pre-driver (first high gain stage - solid state)
				3.	0.	0.	RF Final Amplifier (including driver : Approx. 1.3 MW)
				4.	0.	0.	RF Transport
					1.	0.	RF station to RFQ
					2.	0.	RF station to DTL and Momentum Compactor
					3.	0.	RF station to Energy Dispersion Cavities
					4.	0.	Circulators (19" Y-junction)
					5.	0.	Filters (19")
					6.	0.	Low Power Couplers
					7.	0.	RF Dummy Loads
					8.	0.	Air pressurization and distribution
				5.	0.	0.	Cavity Resonance Control
				6.	0.	0.	Switchgear
				7.	0.	0.	Cooling
				8.	0.	0.	RF station Monitoring and Control
				9.	0.	0.	Integration Equipment
		4.	0.	0.	0.	0.	Accelerator #2 (Pollux)
			1.	0.	0.	0.	Design Updates
			2.	0.	0.	0.	Injector System
			3.	0.	0.	0.	Radiofrequency Quadrupole System
			4.	0.	0.	0.	Drift Tube Linac System
				1.	0.	0.	Tank #1
				2.	0.	0.	Tank #2
				3.	0.	0.	Tank #3
				4.	0.	0.	Tank #4
				5.	0.	0.	Tank #5
				6.	0.	0.	Tank #6
			5.	0.	0.	0.	HEBT System
			6.	0.	0.	0.	RF Power System
				1.	0.	0.	RF control
				2.	0.	0.	RF Pre-driver (first high gain stage - solid state)
				3.	0.	0.	RF Final Amplifier (including driver : Approx. 1.3 MW)
				4.	0.	0.	RF Transport
					1.	0.	RF station to RFQ

Page 1

New WBS

					2.	0.	RF station to DTL and Momentum Compactor
					3.	0.	RF station to Energy Dispersion Cavities
					4.	0.	Circulators (19" Y-junction)
					5.	0.	Filters (19")
					6.	0.	Low Power Couplers
					7.	0.	RF Dummy Loads
					8.	0.	Air pressurization and distribution
				5.	0.	0.	Cavity Resonance Control
				6.	0.	0.	Switchgear
				7.	0.	0.	Cooling
				8.	0.	0.	RF station Monitoring and Control
				9.	0.	0.	Integration Equipment
		5.	0.	0.	0.	0.	Beam Calibration Dumps
			1.	0.	0.	0.	Moveable Beam Dump
			2.	0.	0.	0.	Fixed Beam Dump
		6.	0.	0.	0.	0.	Accelerator System Control
		7.	0.	0.	0.	0.	Accelerator Support Systems
		8.	0.	0.	0.	0.	Maintenance Systems
	3.	0.	0.	0.	0.	0.	Subsystem Installation and Checkout
		1.	0.	0.	0.	0.	Accelerator #1 (Castor) Installation and Checkout
			1.	0.	0.	0.	Injector system.
			2.	0.	0.	0.	RFQ system
			3.	0.	0.	0.	DTL Tank#1 system
			4.	0.	0.	0.	DTL Tanks #2-#6 system
			5.	0.	0.	0.	HEBT systems ("Abel", "Baker", and "Charlie")
			6.	0.	0.	0.	RF power system
			7.	0.	0.	0.	Beam Dumps
				1.	0.	0.	Moveable Beam Dump
				2.	0.	0.	Fixed Beam Dump
			8.	0.	0.	0.	Full Power Acceptance Test (125 mA)
		2.	0.	0.	0.	0.	Accelerator #2 (Pollux) Installation and Checkout
			1.	0.	0.	0.	Injector system
			2.	0.	0.	0.	RFQ system
			3.	0.	0.	0.	DTL Tank#1 system
			4.	0.	0.	0.	DTL Tanks #2-#6 system
			5.	0.	0.	0.	HEBT systems ("Abel", "Baker", and "Charlie")
			6.	0.	0.	0.	RF power system
			7.	0.	0.	0.	Full Power Acceptance Testing (250 mA)
	4.	0.	0.	0.	0.	0.	Subsystem Development

Page 2

Cost Groundrules & Assumptions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- All technology feasibility issues resolved prior to preliminary design
- Cost complied without a separate milestone to commit funds for the second accelerator
- 1996 costs reported, no fee added
- Single shift operation (147 man-hours per man-month)
- Five labor grades considered
  - Program management: $150/hr
  - Physics support: $120/hr
  - Engineering (all disciplines): $100/hr
  - Technician: $82/hr
  - Craft: $25/hr
- 15% premium pay for work at IFMIF site
- Electric rate for installation and checkout: $0.04/kWe-hr
- 10% reduction in material expected at negotiation

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Cost Related Produceability Improvements - May 96

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

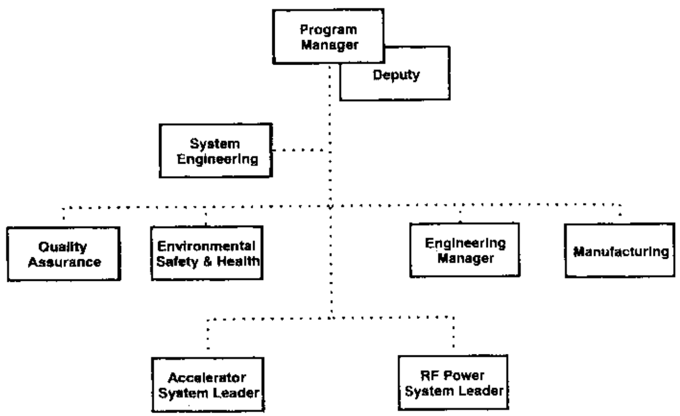
- Reduced RFQ sections from 12 ~1.0 m to 9 ~1.3m
  - » reduces machining and electroforming flow time
- Eliminated machining of DTL tank cavity coolant channels, with associated brazing steps
  - » utilize deep hole drilling techniques to create a passage the length of the cavity
- Utilize DTL end plates and sectioned DTL tank cavity to form HEBT buncher cavities
  - » saves design and tooling new cavities

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Project Management Organization

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Direct Cost Comparison (Sept 95 & May 96)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Sep-95	May-95	Delta
Injector	6.05	5.94	-2%
RFQ	14.10	13.91	-1%
DTL	28.03	23.14	-17%
Support Systems	8.43	2.12	-75%
Project Management	6.00	8.35	39%
RF Power (9 stations)	42.25	46.27	10%
Subtotal	**104.86**	**99.72**	**-5%**
RF drive Loop	0.00	2.12	
Accelerator cooling	0.00	1.94	
Control Computers**	0.00	4.01	
Accelerator Physics Support	0.00	3.27	
Total	**104.86**	**111.06**	**6%**

** - Included in Sept, now tracked in WBS 6.0 Central Control

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Additional Accelerator Segment Items (May 96)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

		Cost $M
• HEBT (including diagnostics)		19.91
– design	3.10	
– procurement/fabrication	1.70	
– purchased material	6.09	
– installation	3.89	
– RF power	5.14	
• Beam Calibration Dumps		7.89
• Testing at 125 mA		1.46
		29.26
Total Direct Cost		*$140.30M*

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Comparison of Overnight Costs - Two Accelerators

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

	Sept 95	May 96
• Accelerator&RF cost	$175M	$188M (7% increase)
• HEBT & RF	----	31
• Beam Dumps	----	8
• Full Power Testing	----	3
Subtotal Direct Cost:	$175M	$230M
• Construction Services	10	14
• Home Office Eng & Services	26	34
• Field Office Eng & Services	11	13
• Contingency	52 (@30%)	35 (@15%)
Total Overnight Cost:	$274M	$326M (19% increase)

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Direct Costs for Two Accelerator Systems

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	1st Accel	2nd Accel	% Change
Injector	5.94	2.31	-61%
RFQ	13.91	7.55	-46%
DTL	23.14	12.67	-45%
Support Systems	2.12	2.12	
Project Management	8.35	8.35	
RF Power (9 stations)	46.27	36.90	-20%
Subtotal	**99.72**	**69.90**	**-30%**
RF drive Loop	2.12	0.00	
Accelerator cooling	1.94	1.94	
Control Computers**	4.01	1.94	-52%
Accelerator Physics Support	3.27	3.27	
Subtotal	**111.06**	**77.05**	**-31%**
HEBT	19.91	11.27	-43%
Beam Calibration Dumps	7.89	0.00	
Testing at 125 mA	1.46	1.46	
Total	**140.30**	**90.01**	**-35%**

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Fee

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

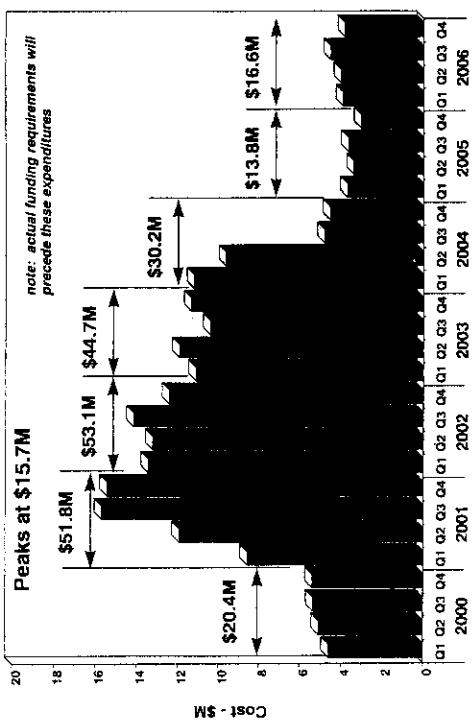
- **Corporate procedures prohibit including fee in engineering estimates**

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Spending Profile

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Two Accelerator Direct Cost Summary in Appendix C Summary Format

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

• **Facility Management:**		**$16.69M**
• **Off-IFMIF Site:**		**188.95**
– Industry Purchased Material	73.80	
– Industry Provided Labor	115.15	
– Institutional Labor (not estimated)	---------	
– AFI	---------	
• **On-Site at IFMIF:**		**20.76**
– Electricity	2.22	
– Industry Provided Labor	18.54	
– Institutional Labor (not estimated)	---------	
– AFI	---------	
• **Development (not estimated)**		**0.00**
• **Startup & Commissioning:**		**2.92**
TOTAL:		**$230M**

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

RF SYSTEM MODELING CODE DEVELOPMENT

Cavity Dynamics

Figure 11. illustrates the transimpedances used to convert input currents to klystron cavity voltages. The translator (see next section) takes the passed cavity attributes entered in a user-friendly form and translates them into the necessary constants needed by the cavity transimpedance models.

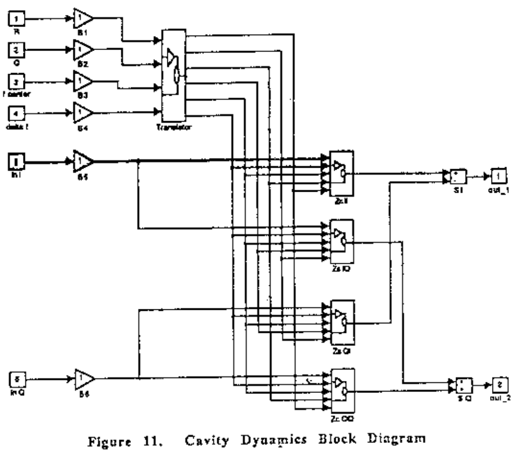


Figure 11. Cavity Dynamics Block Diagram

I/O Characteristics:

External inputs:	in_1	shunt resistance
	in_2	unloaded Q
	in_3	center frequency
	in_4	detuning frequency
	in_5	characteristic impedance
	in_6	coupling factor
	in_7	reflected I component
	in_8	reflected Q component
	in_9	input I component
	in_10	input Q component
Internal inputs:	none	
External outputs:	out_1	output I component

HEBT DESIGN

Features of Beamline

- small number of different components
  12-cm-long quadrupole (in periodic lattices)
  18-cm-long quadrupole (in achromatic bend and some matching sections)
  50-cm-long quadrupole (in expander and imager)
  45° dipole (in achromatic bend)
  10° dipole (in bend towards target)
  2.388° dipole (in bend towards target)
  first nonlinear element (in nonlinear expander)
  second nonlinear element (in nonlinear expander)
  buncher cavity (throughout HEBT)
- skew bend has undesirable properties and thus need vertical bend followed by horizontal bend in HEBT of accelerators 3 and 4
- ease of tuning:

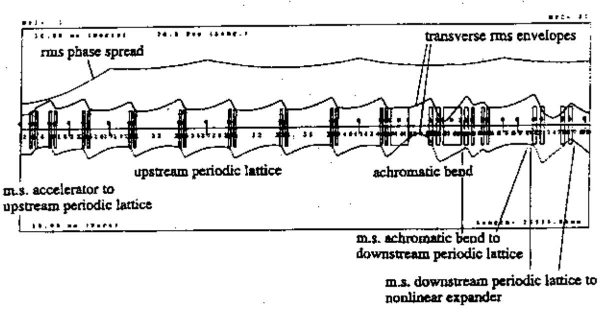
  all beamlines the same upstream of the imager

  imager tuned slightly different for HEBT of accelerators 1 and 2, as opposed to 3 and 4

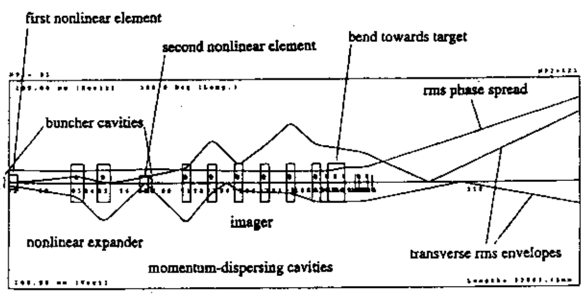
  distribution flatness at target adjustable in prescribed way with four-quadrupole matching section for nonlinear expander

  distribution size at target adjustable in prescribed way with last two quadrupoles of imager
- fit to building layout requirements

Exit Accelerator to Entrance First Nonlinear Element



Entrance First Nonlinear Element to Target



Modules of HEBT, in Beamline Order

- four-quadrupole, two-cavity matching section, to match between accelerator lattice and upstream periodic lattice
- upstream periodic lattice, 2.4-m cell length, cavity in every third cell
- 90° achromatic bend
- four-quadrupole, two-cavity matching section, to match between 90° achromatic bend and downstream periodic lattice
- downstream periodic lattice, 2.75-m cell length, cavity in every other cell
- four-quadrupole matching section, to produce transverse beam parameters for nonlinear expander
- nonlinear expander (two nonlinear elements, two quadrupoles) to fold beam in transverse phase space, with two buncher cavities to control momentum spread
- six-quadrupole imager to produce correct transverse beam sizes at target and beam waists in drift upstream of target, while preserving beam folding at target
- bend towards target
  accelerators 1 and 2: 10.000° vertical bend
  accelerators 3 and 4:
  2.388°vertical bend, 10.008° horizontal bend
- set of momentum-dispersing cavities

Features of Beamline

- small number of different components
  12-cm-long quadrupole (in periodic lattices)
  18-cm-long quadrupole (in achromatic bend and some matching sections)
  50-cm-long quadrupole (in expander and imager)
  45° dipole (in achromatic bend)
  10° dipole (in bend towards target)
  2.388° dipole (in bend towards target)
  first nonlinear element (in nonlinear expander)
  second nonlinear element (in nonlinear expander)
  buncher cavity (throughout HEBT)
- skew bend has undesirable properties and thus need vertical bend followed by horizontal bend in HEBT of accelerators 3 and 4
- ease of tuning:

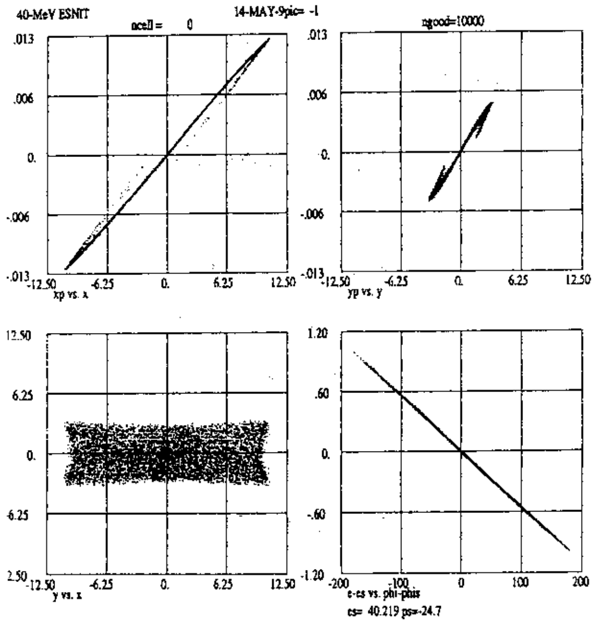
  all beamlines the same upstream of the imager

  imager tuned slightly different for HEBT of accelerators 1 and 2, as opposed to 3 and 4

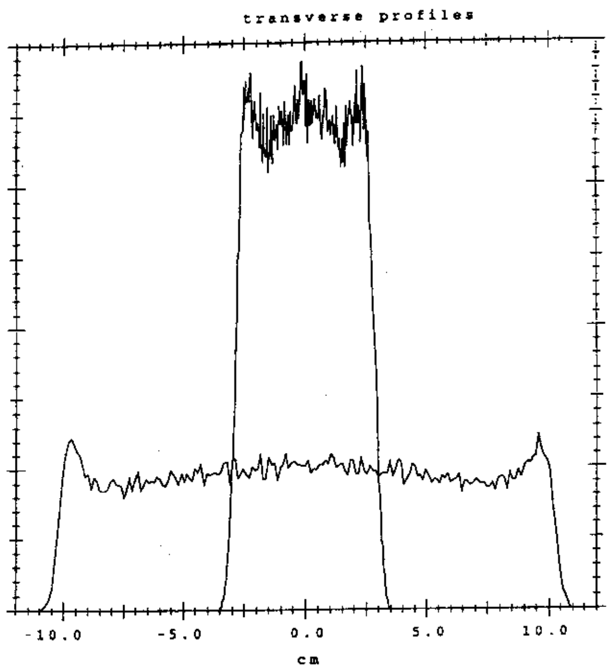
  distribution flatness at target adjustable in prescribed way with four-quadrupole matching section for nonlinear expander

  distribution size at target adjustable in prescribed way with last two quadrupoles of imager

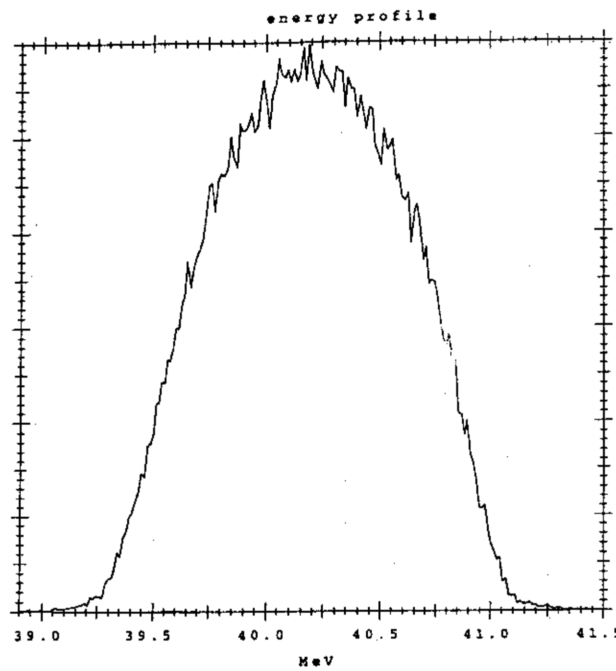
Beam Scatter Plots at Target



Beam Profiles at Target



Beam-Energy Distribution at Target



RFQ / DTL
MATCHING

INFLUENCE ON
DTL LATTICE
⇒ FDFD

END-TO-END RUNS

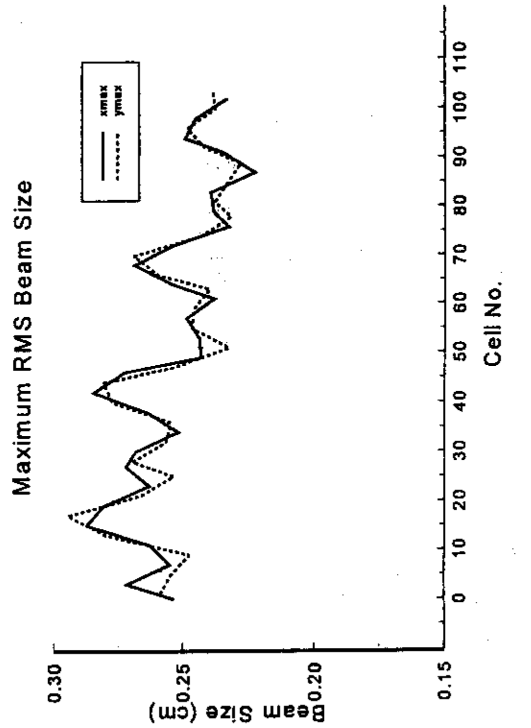


Fig. 3.1 Maximum rms beam size, (x and y) vs. the cell number for FOFODODO lattice

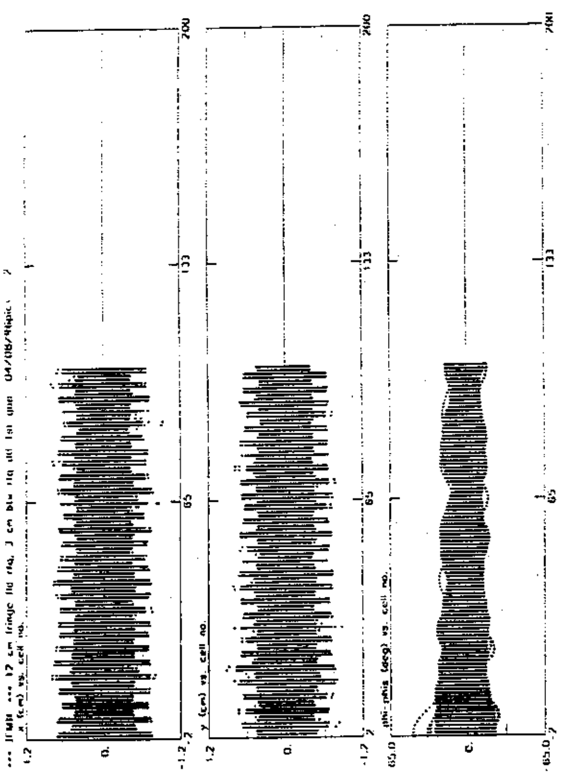


Fig. 3.2 Beam profile plots (x, y, φ) along the DTL (FOFODODO) for full current beam of 134 mA

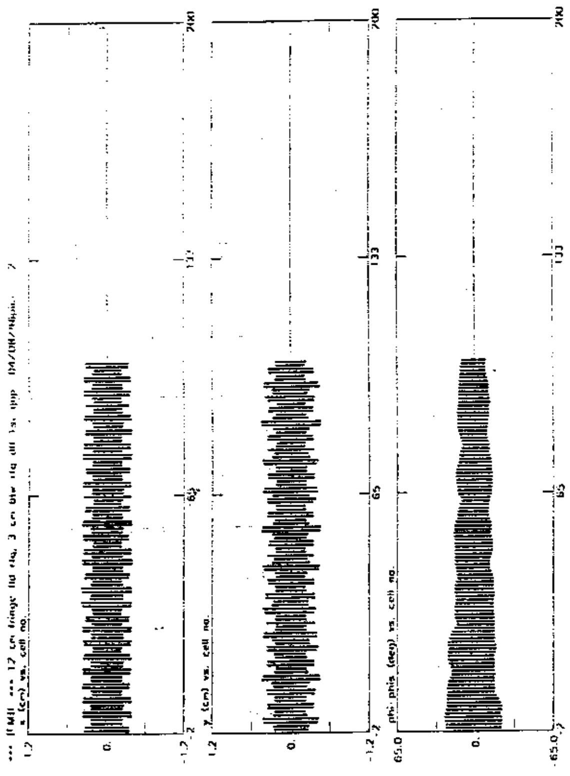


Fig. 3.6 Beam profile (x, y, φ) plots along the DTL (FOFODODO) for zero current

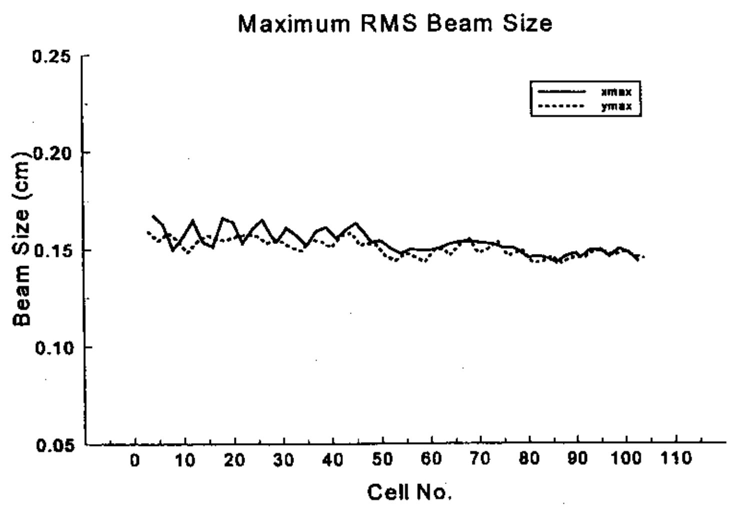


Fig. 3.10 Maximum rms beam size in both x and y vs. cell no in the DTL (FODO)

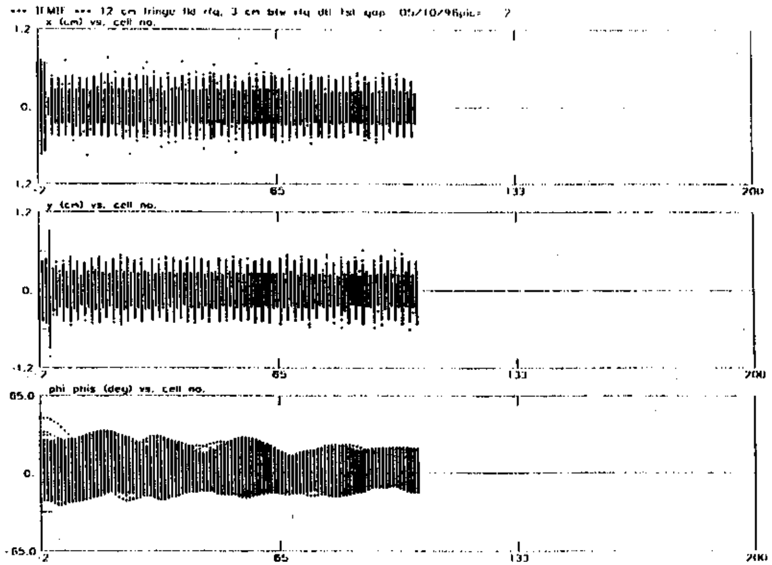


Fig. 3.11 Beam profile plots (x, y, φ) along the length of the DTL (FODO) for full current. All particles are plotted.

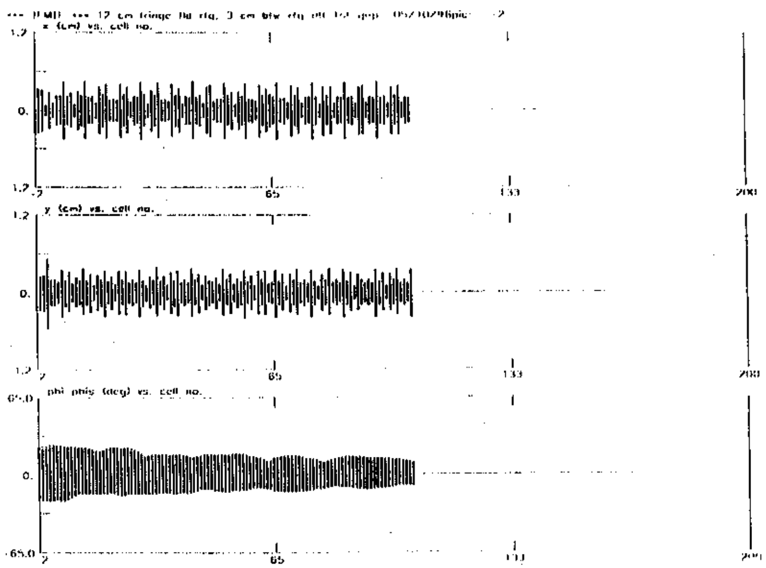


Fig. 3.12 Beam profile plots (x, y, φ) along the length of the DTL (FODO) for zero current. All particles are plotted.

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Perspective On Development and Test of High Power RF Windows at Northrop Grumman

David Berwald for Michael Cole

Northrop Grumman Corp.
Bethpage, NY

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

RF Window Development at Northrop Grumman

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

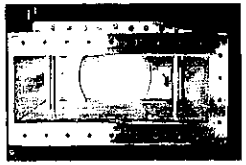
- Goal
  - Develop capability to design & fabricate CW high power windows
- Approach
  - Collaboration with Cornell University on the development of a new waveguide window for CESR
  - Collaboration with CEBAF on the improvement of their cryomodule cold window
  - Development planning for a new coaxial window for IFMIF

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Current And Proposed RF Window Development

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

CESR Window Development



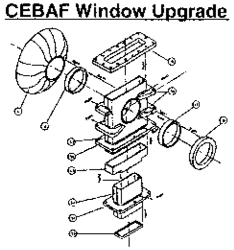
Current Thompson Window

Requirements:
- 600 kW CW @ 500 MHz
- Currently 300 kW CW

Issues:
- Thermal stresses due to losses in beryllia, coatings, and edges
- Multipacting at window face causes high local heat loads

Design Solutions:
- Beryllia window (higher thermal conductivity) may be used
- Stress optimized shaped ceramic
- Refined window coatings

CEBAF Window Upgrade



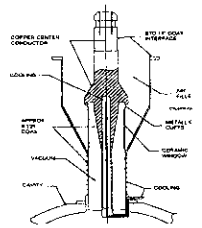
Exploded View (Window is Part 53)

Requirements:
- 50 kW CW design, 38 kW CW operation @ 1.497 GHz
- Currently 5.0 kW design, 2.8 kW CW operation

Issues:
- Exposure to field emitted electrons causes window degradation
- Multipacting

Design Solutions:
- Add wavguide bend
- Refined window coatings

IFMIF Coaxial Window



IFMIF Coax Window Design Concept

Requirements:
- 600 kW CW @ 175 MHz
- Test to 1200 kW CW

Issues:
- Impedance matching with minimum electric fields at window interface
- Thermal losses and stresses

Design Solutions:
- Cylindrical window at taper with non-intrusive attachment
- Cooled center conductor

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Cornell / NGC CESR RF Window Development Plan

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Concept Development
- RF analysis
- thermostructural
- produceablity
- interface w/suppliers

June 1996

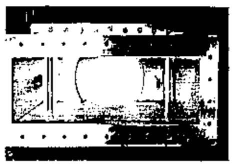
Preliminary Design
- concept downselect
- process prototypes
- cold modeling

Final Design & Construction
- detailed design
- long lead procurement
- assembly & low power test

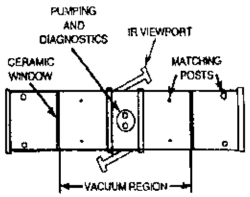
December 1996

High Power Test
- 600 kW off-line
- waveguide config.

Cavity Test
- install on CESR



Cornell/Thomson Window Tested to 300 kW CW

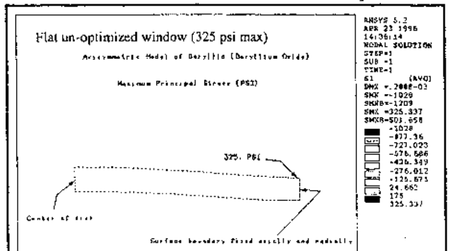


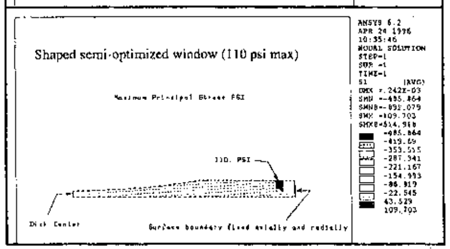
Planned Window Test Configuration

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Shaped Ceramic Stress Optimization (CESR)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*





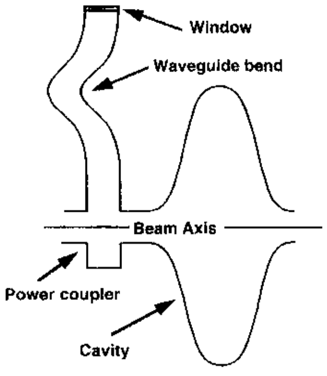
Configuration and Boundary Conditions:
- Ceramic is cooled via conduction at the edges.
- Circular window is thick enough to handle vacuum load

Achieving Minimum Stress:
- Minimizing the ceramic volume minimizes the total heat load (volumetric process)
- ANSYS optimizes the shape of the window to minimize internal stress

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Northrop Grumman Tasks for CEBAF Window Upgrade

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Modified CEBAF window includes a waveguide bend to eliminate the direct line of sight

- Work on ceramic coatings which would reduce multipacting
  - Refined application of titanium, titanium nitride, and chromium oxide
  - Measurements of RF losses and secondary electron emission as a function of coating type and thickness
- Perform 3D RF analysis of CEBAF modified waveguide configuration as a backup to CEBAF's HFSS analysis
  - Use MAFIA or SOPRANO
  - Validate minimal reflected power and minimum electric field

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

IFMIF Coaxial Window: Top-Level Requirements

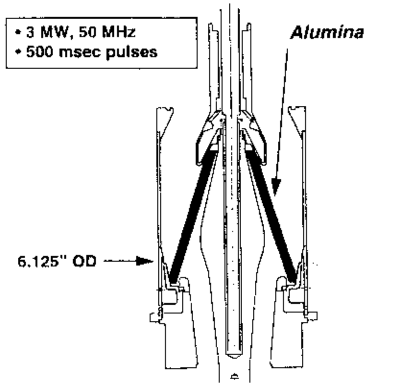
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- 175 MHz operating frequency
- 600 kW CW power requirement
- 14 in. to ~ 6 in. coax transition within window assembly
- Mean Time Between Failures (MBTF) = 20,000 hours
- Mean Time To Repair (MTTR) = 12 hours

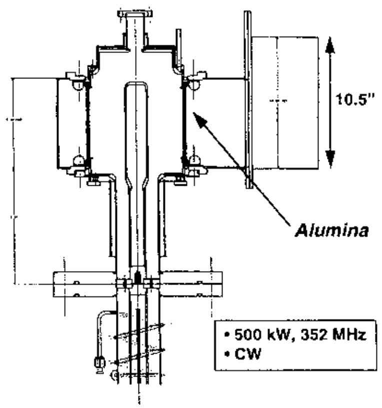
Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

Cylindrical RF Window Heritage

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



ICRH RF vacuum feedthrough designed by Grumman for PPPL in 1983. Installed and operated on PLT from 1984 until 1986.

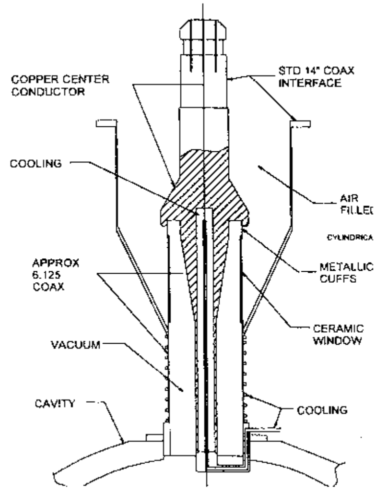


SLAC RF window used on the output of the PEP klystron tubes and input of the PEP cavities. Currently in use.

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

IFMIF Coaxial Window - Design Approach

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



- Window will nominally be a cylindrical ceramic, attaching to the inner conductor of the 14" coax and the outer conductor of the ~6" coax.
- Standard production ceramic would be our baseline, with a stress optimized, shaped cylinder being an option to be evaluated.
- We are considering novel methods of joining to the ceramic edges.

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

IFMIF Coaxial Window - Technical Approach

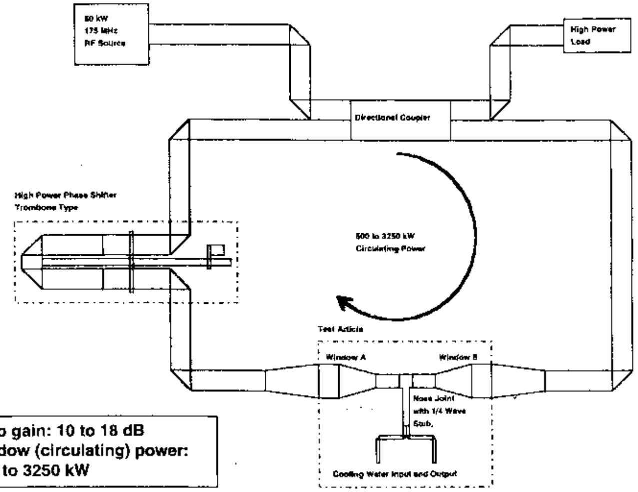
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- A 50 kW 175 MHz transmitter will be used to drive a resonant ring with a gain of approximately 10 to 18dB (existing capability at ORNL).
  - Test window at 500 - 1200 kW
- For the test, two windows would be joined nose-to-nose with a quarter wave stub at the middle to allow access for center conductor cooling.
  - Drive loop not to be tested: lower risk item than window, and logistically much harder to test
- Test article would be fully instrumented
  - IR camera for ceramic temperature measurement
  - Fiber optic probe for inner conductor temperature measurement
  - X-Ray detection for multipacting or arcing

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

IFMIF Window Test Setup

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



- Loop gain: 10 to 18 dB
- Window (circulating) power: 600 to 3250 kW

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Test Sequence

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

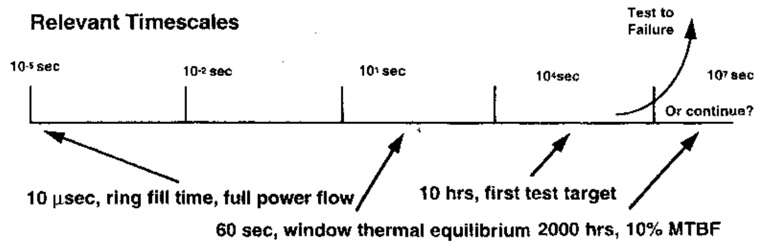
- Testing to begin in the preliminary design and carry on through the final design
  - Manufacturing prototype testing.
  - Ceramic attachment method testing.
  - Ceramics testing.
  - RF cold model testing.
- After fabrication the window assembly will be thoroughly characterized with low power testing.
- After low power testing the window will be installed in the ORNL resonant ring and tested at high CW power.
- High power testing will begin with gradual window conditioning up to 120% of nominal design power, followed by at least 10 hours continuous fault free operation at nominal design power
- Then gradually increase power to ~200% of nominal design power (i.e. 1200 kW)

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Window Test Duration

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Relevant Timescales



- The issue of long term testing needs to be considered.
- Given an MTBF of 20,000 hours test durations of >2000 hours are needed?
- Current proposed development program would not perform tests of such a duration
- Long duration test program may require periodic destructive inspection of test articles

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Statement of Work (NGC)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Northrop Grumman shall design, fabricate, and test a coaxial RF window test article. The RF window design will be compatible for use with an IFMIF coaxial drive loop. The effort shall be completed within 24 months ARO. The effort shall include:
  - Design of an RF window suitable for use in IFMIF
  - Construction of a window test article including two RF windows
  - Test of the window test article at ORNL (ORNL support required)
  - Post test analysis
- Deliverables shall include:
  - Test report containing test results, analysis of test results, and conclusions based on those results
  - Document outlining design recommendations for the IFMIF coaxial RF Windows

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Statement of Work (ORNL)

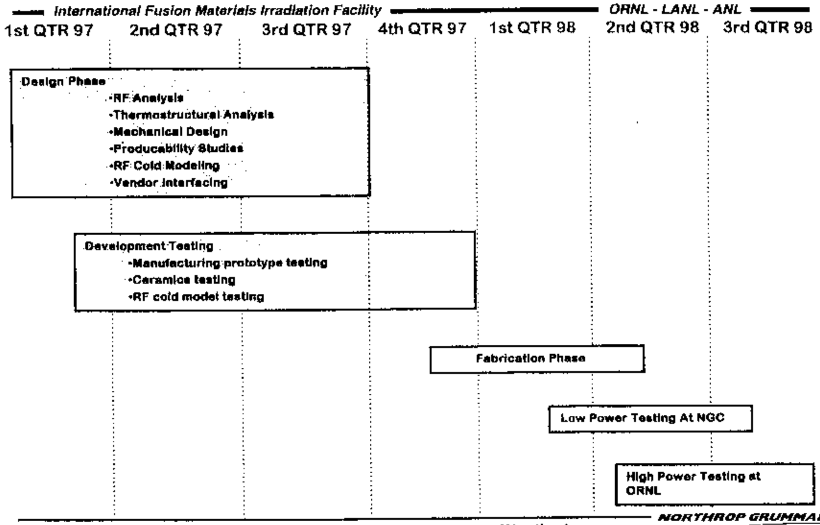
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Construct a resonant ring window test unit
  - 6" coax transmission line
  - Optimized directional coupler
  - Utilize available hardware
  - Water cooled center conductor
- 175 MHz, 50 kW transmitter system
  - Checkout transmitter
  - Setup transmission line
- Setup window test fixture
  - High vacuum system
  - Diagnostics
- Test windows
  - Investigate conditioning
  - Establish reliability
  - Power handling
- Electricity
  - ~$1 to $10 per hour

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Window Development and Test Program

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Unofficial ROM

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- NGC
  - Engineering — $151K
  - Materials and Fabrication — $94K
  - Testing — $61K
  - Grand Total — $306K
- ORNL
  - Staff — 400hrs
  - Technical support — 150hrs
  - Misc costs — $10K
  - Total — $75K

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Reliability, Availability, Maintainability

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Reliability, Availability & Maintainability

Christopher M. Piaszczyk

Northrop Grumman Corp.
Bethpage, NY

Presentation At IFMIF Design Integration Meeting

Tokai, Ibaraki, Japan

20-25 May, 1996

Bechtel - Northrop Grumman - Westinghouse

Outline

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Introduction
- Accelerator
- Target
- Test Cell
- Maintainability

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

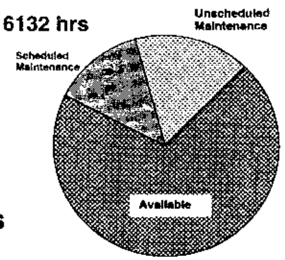
Introduction

Bechtel - Northrop Grumman - Westinghouse

Overall IFMIF System Availability Requirements

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Availability goal: 70% of calendar time
  - 365 days x 24 hrs x 0.70 = 8760 hrs x 0.70 = 6132 hrs
- Scheduled maintenance: 1160 hrs
  - 1 mo shutdown: 31x 24 = 744 hrs
  - 8 hr maint./wk: 52 x 8 = 416 hrs
- Scheduled operating time: 7600 hrs
- Required inherent availability: 6132/7600 = 0.8068



(This number is a budget, which assumes that on the average, over its design life, the machine may be down 1468 hours per year in unscheduled repairs due to randomly occurring failures that cannot be predicted deterministically neither from monitoring the wear and tear nor in any other way - for these failure modes only a statistical estimate is possible. Also, every repair leaves the system in exactly the same state as it was before the failure, i.e. no better or worse)

Bechtel - Northrop Grumman - Westinghouse

IFMIF Top Level Availability Allocation

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

• Accelerator Systems and Equipment	0.8800
• Injector	
• LINAC	
• LINAC RF System	
• HEBT	
• Target	0.9500
• Test Facility	0.9750
• Central I&C	0.9950
• Integrated Instrumentation and Controls	
• Operator Error	
•Conventional Facilities	0.9950
• Grid/Substation Electrical Systems and Equipment	
• Water Coolant Heat Rejection Systems and Equipment	
• Misc (HVAC, Compressed Air supply, Liquid Nitrogen Supply, etc.)	
• Power Outage, Fire, Earthquake, Sabotage, Strike, Riots	
• **Total IFMIF Facility**	**0.8068**

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

IFMIF Top Level Availability Summary

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

• Accelerator Systems and Equipment		0.8814
• Injector	0.9866	
• LINAC	0.9623	
• LINAC RF System	0.9630	
• HEBT	0.9694	
• Target		0.9508
• Test Facility		0.9752
• Central I&C		0.9950
• Integrated Instrumentation and Controls		
• Operator Error		
•Conventional Facilities		0.9950
• Grid/Substation Electrical Systems and Equipment		
• Water Coolant Heat Rejection Systems and Equipment		
• Misc (HVAC, Compressed Air supply, Liquid Nitrogen Supply, etc.)		
• Power Outage, Fire, Earthquake, Sabotage, Strike, Riots		
• **Total IFMIF Facility**		**0.8091**

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

RAM Budget Allocation For A Multi - Accelerator System

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Accelerator System Allocation = 0.88
- Operation of one accelerator : system "available" w/partial credit
- 2 Accelerators, with current I each:
  - => Total irradiation dose = 2I * A * (1-A) + 2I * A^2 = 2I * A
  - => Each Accelerator Availability Requirement = 88%
- N Accelerators, with current I each:
  - => Total irradiation dose = $I * \sum_{m=1}^{N} m \binom{N}{m} A^m (1-A)^{N-m}$ = N * I * A
  - => Each Accelerator Availability Requirement = 88%

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Reliability - General Comments

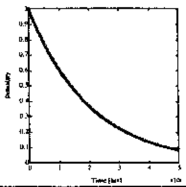
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Probability that the system survives the mission time**

—[R]—

For a single equipment:

R(MISSION TIME) = exp(-MISSION TIME/MTBF)



- **Reliability is difficult to achieve when**
  - MTBF is small
  - Mission time is long
- **Reliability for a system of equipments in series**

—[R_1]—[R_2]- - - - - -[R_n]—

$R = R_1 \times R_2 \times ... \times R_n$

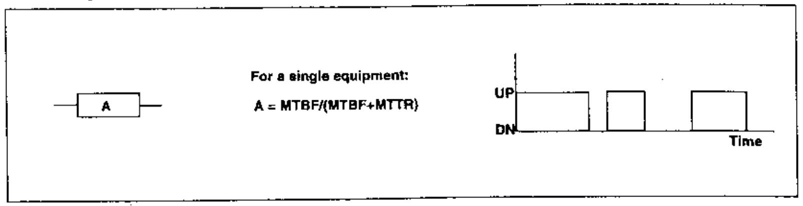
Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

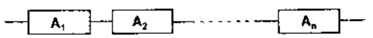
Availability - General Comments

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- **Proportion of time when system is usable**



- **Availability is difficult to achieve when**
  - MTBF is small
  - MTTR is large
- **Availability for a system of equipments in series**

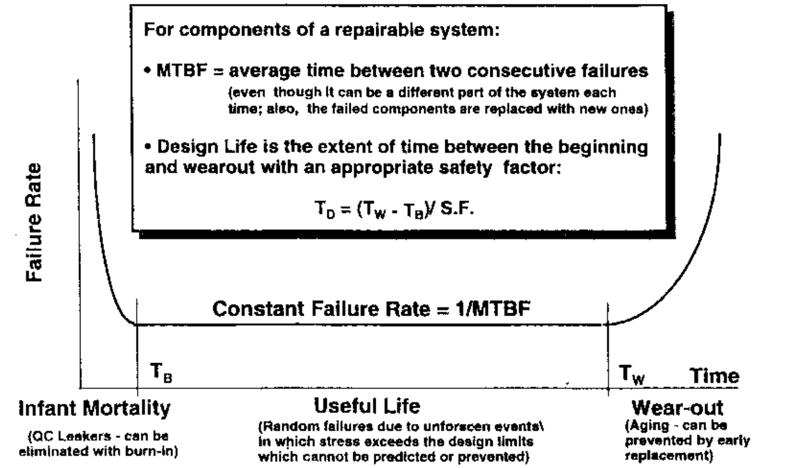


$A = A_1 \times A_2 \times \ldots \times A_n$

Bechtel - Northrop Grumman - Westinghouse

Bathtub Curve (Heuristic Arguments)

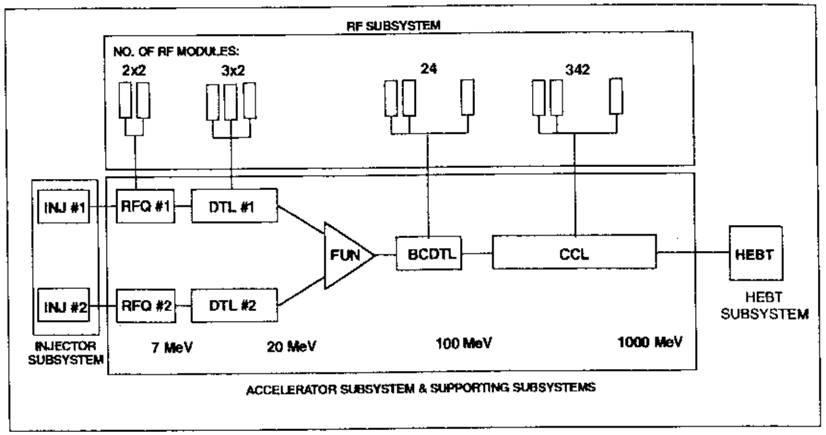
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

Accelerator System - Typical Configuration

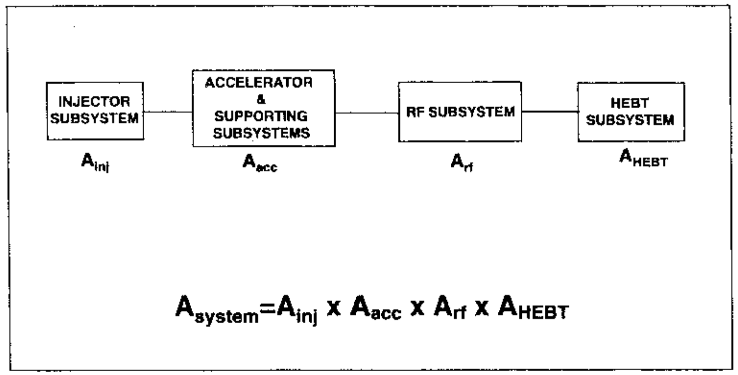
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

Accelerator System - Availability Configuration

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

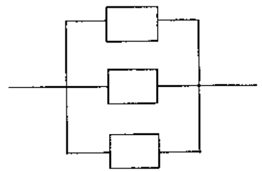


Bechtel - Northrop Grumman - Westinghouse

Injector and Accelerator Reliability Configuration

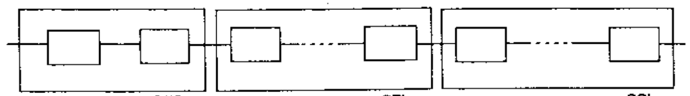
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Injector**



Cold Spares
w/on-line repair

- **Accelerator**

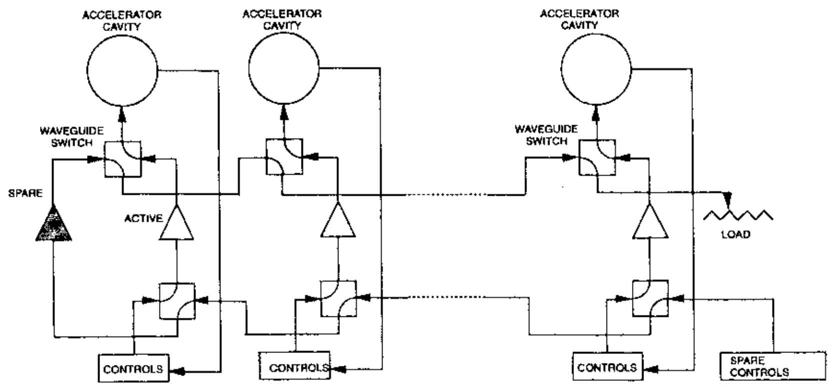


All equipments (accelerator tanks) in series. Superconducting linac tolerates failures beyond certain energy

Bechtel - Northrop Grumman - Westinghouse

RF System with Partial Redundancy - One Spare (Hot or Cold) per N

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

Steady State Availability - "Hot" Spares/On-line Repair

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

$$A^{hot}_{m/p} = \frac{\sum_{r=m-p}^{m} \binom{m}{r} \left(\frac{MTBF}{MTTR}\right)^{r}}{\sum_{k=0}^{m} \binom{m}{k} \left(\frac{MTBF}{MTTR}\right)^{k}}$$

- p=0: system of m equipments in series
- p=1: one spare per (m-1) equipments
- p=m-1: one equipment with (m-1) spares

Model assumptions:
1) number of repair crews =m
2) immediate repair policy (continuous monitoring & repair under operating conditions)

Bechtel - Northrop Grumman - Westinghouse

Steady State Availability - "Hot" Spares/Off-line Repair

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

$$A^{hot}_{m/p} = \frac{\sum_{r=m-p}^{m} \frac{MTBF}{r}}{\sum_{r=m-p}^{m} \frac{MTBF}{r} + MTTR}$$

- p=0: system of m equipments in series
- p=1: one spare per (m-1) equipments
- p=m-1: one equipment with (m-1) spares

Model assumptions:
1) number of repair crews =m

Bechtel - Northrop Grumman - Westinghouse

Steady State Availability - "Cold" Spares/On-line Repair

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

$$A_{m/p}^{cold} = \frac{\sum_{r=m-p}^{m} \frac{m!}{(m-r)!}\left(\frac{MTBF}{MTTR}\right)^{r}}{\sum_{k=0}^{m} \frac{m!}{(m-k)!}\left(\frac{MTBF}{MTTR}\right)^{k}}$$

- **p=1: one spare per (m-1) equipments**
- **p=m-1: one equipment with (m-1) spares**

Model assumptions:
1) number of repair crews = m
2) immediate repair policy (continuous monitoring & repair under operating conditions)

Bechtel - Northrop Grumman - Westinghouse

Steady State Availability - "Cold" Spares/Off-line Repair

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

$$A_{m/p}^{cold} = \frac{\frac{p+1}{m-p} MTBF}{\frac{p+1}{m-p} MTBF + MTTR}$$

- **p=1: one spare per (m-1) equipments**
- **p=m-1: one equipment with (m-1) spares**

Model assumptions:
1) number of repair crews = m

Bechtel - Northrop Grumman - Westinghouse

Reliability - "Hot" Spares/Off-line Repair

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

$$R_{m/p}^{hot}(t) = \sum_{k=0}^{p} \binom{m}{k} \left(e^{-\frac{t}{MTBF}}\right)^{m-k} \left[1 - \left(e^{-\frac{t}{MTBF}}\right)\right]^{k}$$

- **p=0: system of m equipments in series**
- **p=1: one spare per m-1 equipments**
- **p=m-1: one equipment with m-1 equipments**

Model assumptions:
1) number of repair crews = m

Bechtel - Northrop Grumman - Westinghouse

Reliability - "Hot" Spares/On-line Repair

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

$$R_{2/1}^{hot}(t) = \frac{s_1 \exp(s_2 t) - s_2 \exp(s_1 t)}{s_1 - s_2}$$

where

$$s_1 = -\frac{1}{2}\left[(3\lambda + \mu) + \sqrt{\mu^2 + 6\mu\lambda + \lambda^2}\right]$$

$$s_2 = -\frac{1}{2}\left[(3\lambda + \mu) - \sqrt{\mu^2 + 6\mu\lambda + \lambda^2}\right]$$

$$\lambda = 1/MTBF \qquad \mu = 1/MTTR$$

Model assumptions:
1) number of repair crews =2
2) continuous monitoring

Bechtel - Northrop Grumman - Westinghouse

Reliability - "Cold" Spares/Off-line Repair

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

$$R^{\text{cold}}_{m/p}(t) = e^{-\frac{(m-p)t}{\text{MTBF}}} \left[\sum_{k=0}^{p} \frac{\left((m-p)\frac{t}{\text{MTBF}} \right)^k}{k!} \right]$$

- p=0: system of m equipments in series
- p=1: one spare per (m-1) equipments
- p=m-1: one equipment with (m-1) spares

Model assumptions:
1) number of repair crews = m

Bechtel - Northrop Grumman - Westinghouse

Reliability - "Cold" Spares/On-line Repair

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

$$R^{cold}_{2/1}(t) = \frac{s_1 \exp(s_2 t) - s_2 \exp(s_1 t)}{s_1 - s_2}$$

where

$$s_1 = -\frac{1}{2}\left[(2\lambda + \mu) + \sqrt{\mu^2 + 4\mu\lambda}\right]$$

$$s_2 = -\frac{1}{2}\left[(2\lambda + \mu) - \sqrt{\mu^2 + 4\mu\lambda^2}\right]$$

$$\lambda = 1/\text{MTBF} \qquad \mu = 1/\text{MTTR}$$

Model assumptions:
1) number of repair crews =2
2) continuous monitoring

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Accelerator

Bechtel - Northrop Grumman - Westinghouse

IFMIF Accelerator Availability Allocation

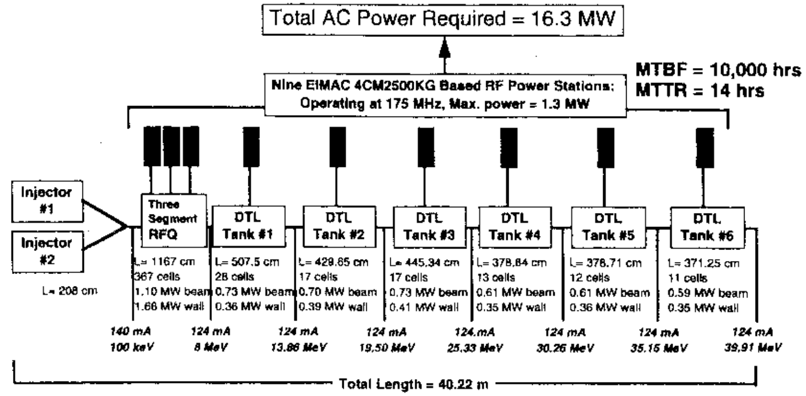
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

• *Accelerator Systems and Equipment*	*0.8800*
• *Injector*	
• *LINAC*	
• *LINAC RF System*	
• *HEBT*	
• Target	0.9500
• Test Facility	0.9750
• Central I&C	0.9950
• Integrated Instrumentation and Controls	
• Operator Error	
•Conventional Facilities	0.9950
• Grid/Substation Electrical Systems and Equipment	
• Water Coolant Heat Rejection Systems and Equipment	
• Misc (HVAC, Compressed Air supply, Liquid Nitrogen Supply, etc.)	
• Power Outage, Fire, Earthquake, Sabotage, Strike, Riots	
• Total IFMIF Facility	0.8068

Bechtel - Northrop Grumman - Westinghouse

IFMIF Baseline DTL Accelerator

Major Features Of IFMIF Baseline Accelerator



Major RAM Modeling Assumptions for IFMIF Baseline Accelerator

- **Injector:**
  - RF antenna replaced weekly, during scheduled maintenance
  - No redundant injector
- **RFQ: 0.075-8 MeV**
  - No redundancies in RF
- **DTL: 8-40 MeV**
  - No redundancies in RF
- **LINAC RF System:**
  - One HV Power Supply per Amplifier (no disconnect switches),
  - Tetrodes w/10000 hr MTBF used in main power amplifiers
  - Two stage Source & Driver System
  - RF Drive Loops (including vacuum windows) MTBF = 20000 hrs, MTTR = 12 hrs
- **HEBT:**
  - Features different MTTR values for similar components in low and high activity rooms

Changes (w/r to 10/95) in RAM Modeling Assumptions - I

- **Injector:**
  - Single injector instead of a redundant pair due to difficulties w/beam dynamics through the switching dipole with multiple ion species present (JR)
  - Changed MTBF/MTTR of RF antenna, RF generator, extractor, gas supply, HV pwr supply, support structure, LEBT magnets & their power supplies, gas neutralization, and diagnostics (EP & JR)
  - Redundancies in vacuum system eliminated (JR)
  - Individual cooling systems eliminated and cooling common to injector & linac adopted (JR)
- **RFQ: 0.075-8 MeV**
  - Single cavity instead of three physical segments in series (JR)
  - Changed MTBF/MTTR of cavity and support structure (JR)
  - No on-line repair for vacuum system (JR)
  - Corrected number of drive loops (JR)
  - Individual cooling systems eliminated and cooling common to injector & linac adopted (JR)
  - Beam diagnostics removed (JR)
- **DTL: 8-40 MeV**
  - Changed MTBF/MTTR of cavity and support structure (JR)
  - No on-line repair for vacuum system (JR)
  - Corrected number of drive loops (JR)
  - Individual cooling systems eliminated and cooling common to injector & linac adopted (JR)
  - Separate entry for drift tube leak added (JR)
  - Tolerance to quad failures beyond the first 30 quads removed (JR)
  - Redundancy in diagnostics introduced: 2 failures out of 6 tolerable, no on-line repair (JR)

Changes (w/r to 10/95) in RAM Modeling Assumptions - II

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **LINAC RF System:**
  - Tube cavity (MTBF = 100,000 hrs, MTTR = 10 hrs) added to HP Tube Support (EP)
  - MTTR for 2nd Stage Tube in Source and Driver reduced to 13 hrs from 14 hrs (EP)
  - MTTR for 2nd Stage Tube Cavity in Source and Driver reduced to 9 hrs from 10 hrs (EP)
  - MTTR for Source in Source and Driver reduced to 2 hrs from 10 hrs (EP)
- **HEBT:**
  - More detailed model for the buncher RF station added with the resulting MTBF and MTTR changed to 2156 hrs and 9 hrs from 5000 and 2, resp. (EP)
  - More detailed model for the dispersion Cavity RF station with the resulting MTBF and MTTR changed to 2156 hrs and 9 hrs from 5000 and 2, resp. (EP)
  - Drive loops added to the buncher and dispersion cavities (JR)
  - Cavity MTBF changed for buncher and dispersion cavities (JR)
- **Modelling changes: availability models w/repair off line added**
- **Bottom line system availability changed from 0.9066 to 0.8814 (still above 0.88 requirement but margin greatly reduced)**

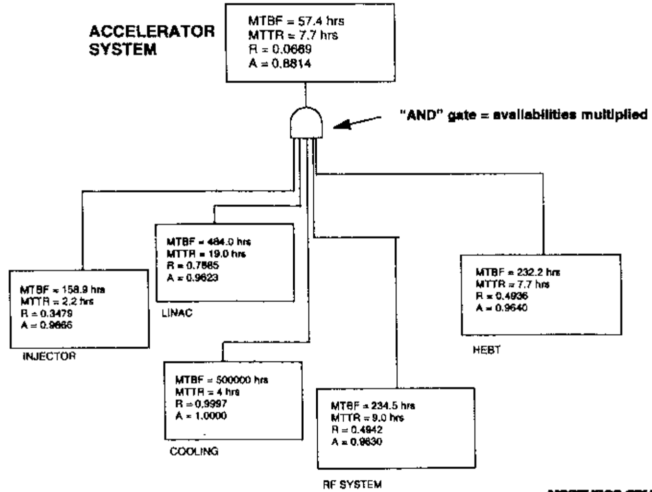
The changes were motivated by comments from Ed Pechowiak (EP) and John Rathke (JR) which are greatly appreciated

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

System RAM Budget For New IFMIF Baseline

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

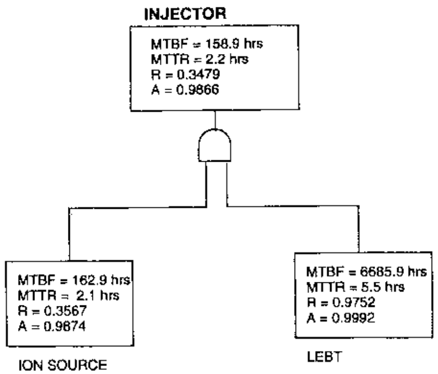


Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Injector RAM Budget For IFMIF Baseline

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

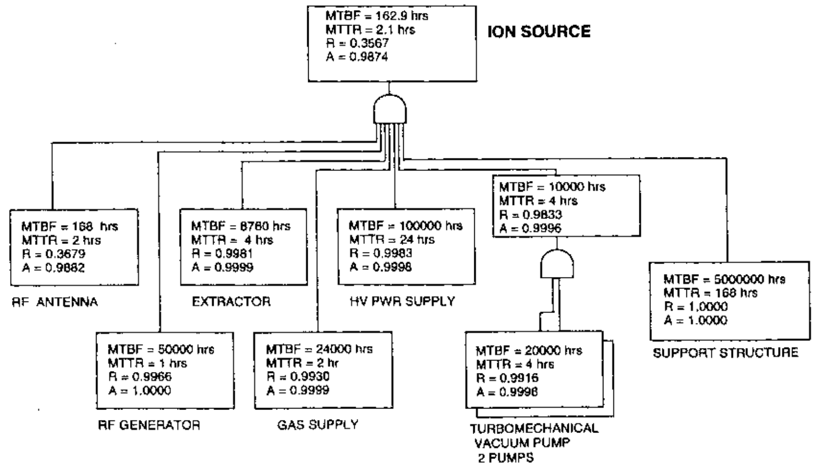


Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Ion Source RAM Budget For IFMIF Baseline

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

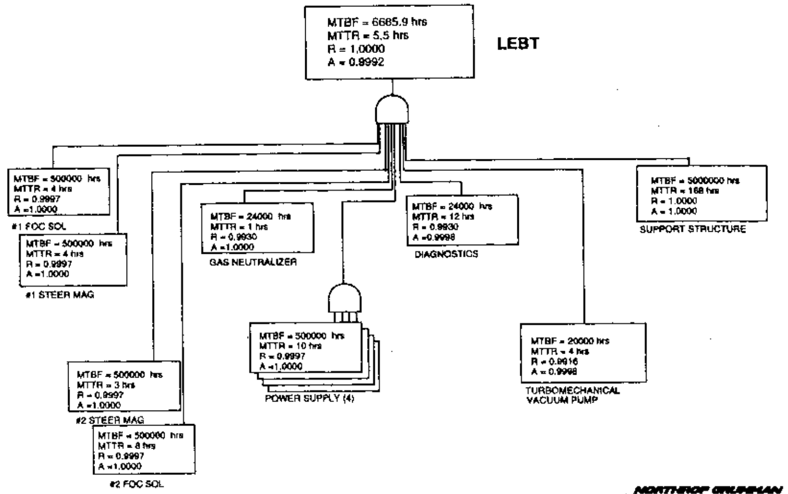


Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

LEBT RAM Budget For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse NORTHROP GRUMMAN

Injector - Availability Summary

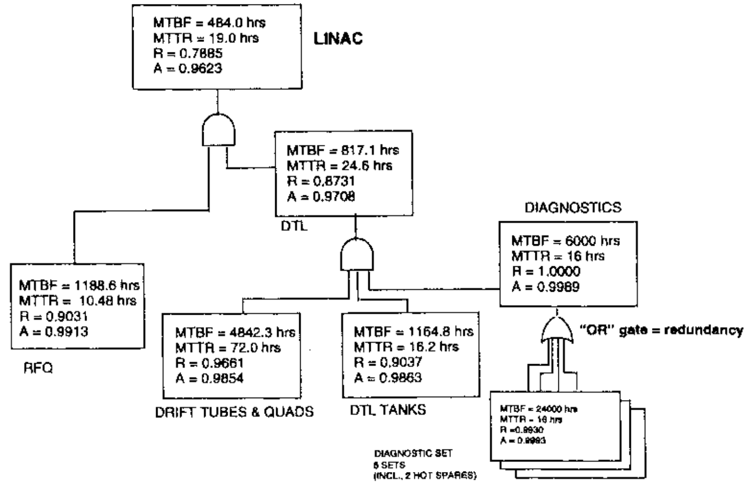
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
INJECTOR:																		
	Ion Source:																	
		RF Antenna		168	2	JR		1	0	0	0	0.0119	0.0060	52	104	0.98823529	168	0.36787944
		RF Generator		50000	1	EP		1	0	0	0	0.0000	0.0000	0	0	0.99996	168	0.99664564
		Extractor		87600	4	JR		1	0	0	0	0.0000	0.0000	0	0	0.99995434	168	0.99808403
		Gas Supply		24000	2	JR		1	0	0	0	0.0001	0.0000	0	1	0.99991667	168	0.99302444
		HV Pwr Supply		100000	24	JS		1	0	0	0	0.0002	0.0000	0	2	0.99976006	168	0.99832141
		Turbom vac pumps		20000	4	BA		2	0	0	0	0.0004	0.0001	1	4	0.99960012	168	0.98334033
		Support Structure		5000000	168	JR		1	0	0	0	0.0000	0.0000	0	0	0.9999664	168	0.9999664
	Total Ion Source			162.85	2.07	calc.						0.0127	0.0061	54	111	0.98742278	168	0.35672453
	LEBT:																	
		Focusing Solenoid#1		500000	4	JR		1	0	0	0	0.0000	0.0000	0	0	0.999992	168	0.99966406
		Steering Magnet#1		500000	4	JR		1	0	0	0	0.0000	0.0000	0	0	0.999992	168	0.99966406
		Steering Magnet#2		500000	3	JR		1	0	0	0	0.0000	0.0000	0	0	0.999994	168	0.99966406
		Focusing Solenoid#2		500000	8	JR		1	0	0	0	0.0000	0.0000	0	0	0.999984	168	0.99966406
		Magnet Power Supply		500000	1	JR		4	0	0	0	0.0000	0.0000	0	0	0.999992	168	0.9986569
		Gas Neutralization		24000	1	JS		1	0	0	0	0.0000	0.0000	0	0	0.99995834	168	0.99302444
		Turbom vac pumps		20000	4	BA		1	0	0	0	0.0002	0.0001	0	2	0.99980004	168	0.99163516
		Diagnostics		24000	12	JR		1	0	0	0	0.0005	0.0000	0	4	0.99950025	168	0.99302444
		Support Structure		5000000	168	JR		1	0	0	0	0.0000	0.0000	0	0	0.9999664	168	0.9999664
	Total LEBT			6685.92	5.49	calc.						0.0008	0.0001	1	7	0.99917922	168	0.97519132
TOTAL ONE INJECTOR				158.86	2.16	calc.		1				0.0135	0.0063	55	119	0.98661232	168	0.34787467
TOTAL INJECTOR SYSTEM W/SPARES:				158.86	2.16	calc.						0.0135	0.0063	55	119	0.98661232	168	0.34787467
ALL INJECTOR LEGS:				158.86	2.16	calc.	1					0.0135	0.0063	55	119	0.98661232		0.34787467

Bechtel - Northrop Grumman - Westinghouse NORTHROP GRUMMAN

Linac RAM Budget For IFMIF Baseline Accelerator

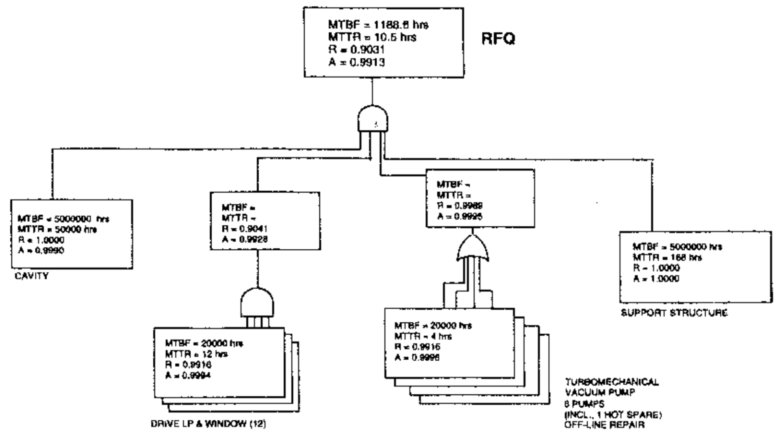
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse NORTHROP GRUMMAN

RFQ RAM Budget For IFMIF Baseline Accelerator

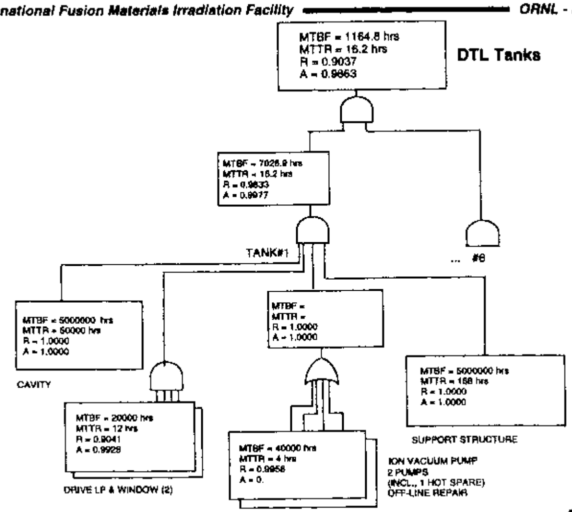
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse NORTHROP GRUMMAN

DTL Tanks

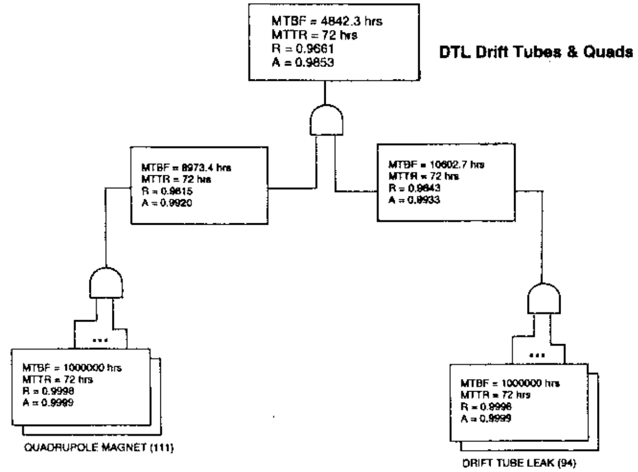
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

DTL Drift Tubes and Quads

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

LINAC - Availability Summary

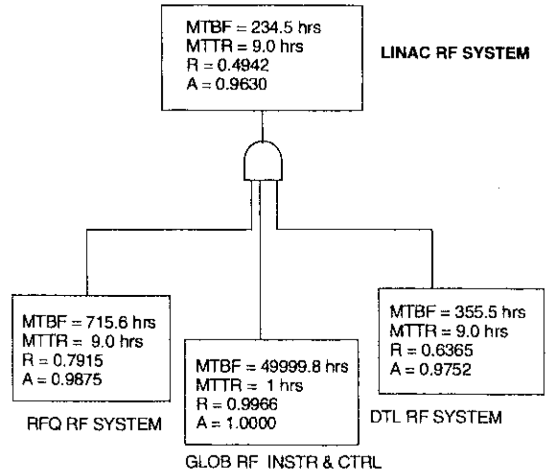
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
LINAC:																		
	RFQ:																	
		Cavity		5000000	5000	JR		1	0	0	0	0.0010	0.0000	0	9	0.999001	168	0.9999664
		Drive Loops		20000	12	JR		12	0	0	0	0.0072	0.0006	5	63	0.992828	168	0.90411384
		Turbom vac pumps		20000	4	BA		6	1	1	0	0.0012	0.0003	3	11	0.99945484	168	0.99997364
		Support Structure		5000000	168	CMP		1	0	0	0	0.0000	0.0000	0	0	0.9999664	168	0.9999664
	Total RFQ:			1168.67	10.48	calc.		1	0	0	0	0.0094	0.0009	8	83	0.99126215	168	0.9031252
	All RFQ Legs			1168.67	10.48	calc.	1					0.0094	0.0009	8	83	0.99126215		0.9031252
	DTL:																	
		Cavity		5000000	5000	JR		1	0	0	0	0.0010	0.0000	0	9	0.999001	168	0.9999664
		Drive Loops		20000	12	JR		2	0	0	0	0.0012	0.0001	1	11	0.99880108	168	0.98334033
		Vacuum Ion Pumps		40000	4	BA		2	1	1	0	0.0002	0.0001	0	2	0.99993334	168	0.99996243
		Support Structure		5000000	168	CMP		1	0	0	0	0.0000	0.0000	0	0	0.9999664	168	0.9999664
	Total one tank			7028.89	16.18	calc.		1	0	0	0	0.0024	0.0002	1	21	0.99770324	168	0.98325698
	All DTL tanks			1164.76	16.18	calc.		6	0	0	0	0.0146	0.0009	8	126	0.98629831	168	0.90385412
	Diagnostics			24000	16	JS		8	2	1	0	0.0040	0.0003	2	35	0.99882009	168	0.99998332
	Drift Tubes & Quadrupoles																	
			Drift Tube Leak	1000000	72	JR		1	0	0	0	0.0001	0.0000	0	1	0.99992801	168	0.99983201
		Drift Tube Chain w/0 failures tolerable		10602.72	72.00	calc.		94	0	0	0	0.0068	0.0001	1	59	0.99325509	168	0.98433204
			Quadrupole magnet	1000000	72	JR		1	0	0	0	0.0001	0.0000	0	1	0.99992801	168	0.99983201
		Quad Chain w/0 failures tolerable		8973.38	72.00	calc.		111	0	0	0	0.0080	0.0001	1	70	0.99204014	168	0.9815248
	Total Drift Tubes & Quadrupoles			4842.31	72.00	calc.						0.0148	0.0002	2	129	0.98534692	168	0.98614631
	Total DTL:			817.08	24.58	calc.						0.0334	0.0014	12	292	0.97079846		0.87305626
	All DTL Legs			817.08	24.58	calc.	1					0.0334	0.0014	12	292	0.97079846		0.87305626
TOTAL LINAC				484.02	18.95	calc.						0.0428	0.0023	20	375	0.96231577		0.78847911
ALL LINAC LEGS:				484.02	18.95	calc.	1					0.0428	0.0023	20	375	0.96231577		0.78847911

Bechtel - Northrop Grumman - Westinghouse

LINAC RF System RAM Budget For IFMIF Baseline Accelerator

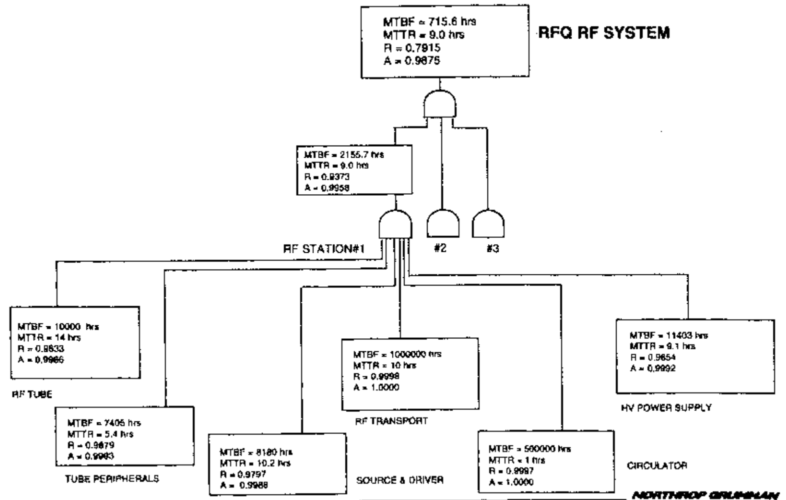
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

RFQ RF System RAM Budget For IFMIF Baseline Accelerator

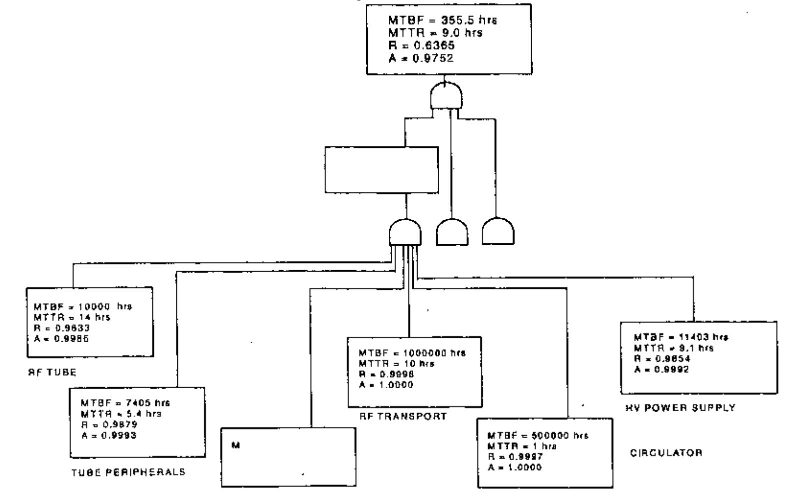
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

DTL RF System RAM Budget For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

LINAC RF System - Availability Summary

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Sources of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0 = off line 1 = on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
RFQ	RF STATION:																	
			High Power Tube	10000	14	EP		1	0	0	0	0.0014	0.0001	1	12	0.99860196	168	0.98334033
			High Power Tube Peripherals	7405	5.36	calc.		1	0	0	0	0.0009	0.0002	2	8	0.99927696	168	0.97756737
			RF Transport	1000000	10.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
			Source & Driver	8180	10.24	calc.		1	0	0	0	0.0013	0.0001	1	11	0.99875	168	0.97967137
			Circulator	500000	1.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.999998	168	0.99966406
			HV Power Supply	11403	9.09	calc.		1	0	0	0	0.0008	0.0001	1	7	0.99920368	168	0.98537462
		RF STATION TOTAL:		2155.73	9.03	calc.						0.0044	0.0005	4	36	0.99562696	168	0.927499
		All RF Stations		715.57	9.03	calc.		3	0	0	0	0.0132	0.0015	13	115	0.98753311	168	0.79152359
RFQ	TOTAL RF STATIONS:			715.57	9.03	calc.						0.0132	0.0015	13	115	0.98753311	168	0.79152359
ALL RFQ LEGS:				715.57	9.03	calc.	1					0.0132	0.0015	13	115	0.98753311		0.79152359
DTL	RF STATION:																	
			High Power Tube	10000	14	EP		1	0	0	0	0.0014	0.0001	1	12	0.99860196	168	0.98334033
			High Power Tube Peripherals	7405	5.36	calc.		1	0	0	0	0.0009	0.0002	2	8	0.99827696	168	0.97756737
			RF Transport	1000000	10.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
			Source & Driver	8180	10.24	calc.		1	0	0	0	0.0013	0.0001	1	11	0.99875	168	0.97967137
			Circulator	500000	1.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.999998	168	0.99966406
			HV Power Supply	11403	9.09	calc.		1	0	0	0	0.0008	0.0001	1	7	0.99920366	168	0.98537462
		RF STATION TOTAL:		2155.73	9.03	calc.						0.0044	0.0005	4	36	0.99562696	168	0.927499
		All RF Stations		355.54	9.03	calc.		6	0	0	0	0.0263	0.0029	26	230	0.97522185	168	0.6265096
DTL	TOTAL RF STATIONS:			355.54	9.03	calc.						0.0263	0.0029	26	230	0.97522185	168	0.6265096
ALL DTL LEGS:				355.54	9.03	calc.	1					0.0263	0.0029	26	230	0.97522165		0.6265096
		ALL RF STATIONS:		235.54	9.03	calc.						0.0395	0.0044	38	346	0.96306367		0.49589713
GLOBAL RF CONTROLS																		
		Master Oscillator		100000	1	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99832141
		Phase Reference Distribution		100000	1	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99832141
TOTAL GLOBAL RF CONTROLS				49999.75	1.00	calc.						0.0000	0.0000	0	0	0.99998	168	0.99664564
TOTAL RF SYSTEM				234.46	9.00	calc.						0.0395	0.0044	38	346	0.9630444	168	0.49423371
ALL LINAC LEGS:				234.46	9.00	calc.	1					0.0395	0.0044	38	346	0.9630444		0.49423371

Bechtel - Northrop Grumman - Westinghouse

RF Tube Peripherals - Availability Summary

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

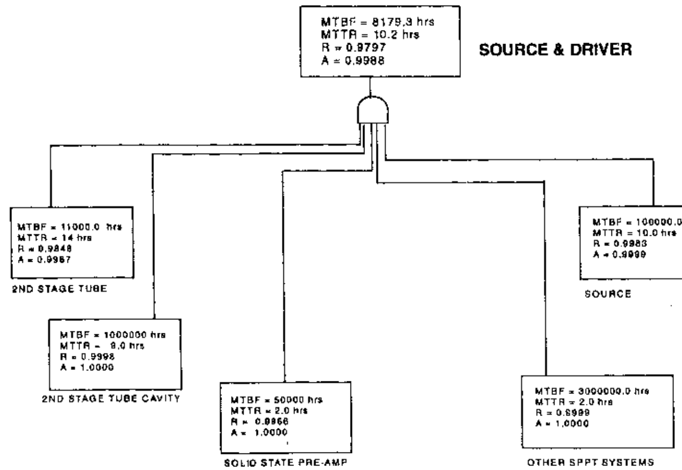
System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
		HIGH POWER TUBE PERIPHERALS:																
x		HP RF Tube																
x			Unchilled Cooling	20000	2	BA		2	1	2	1	0.0002	0.0001	1	2	1	168	0.99999917
			Tube Cavity	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x		Total HP RF Tube		27271.36	2.73	calc.						0.0003	0.0001	1	3	0.99990001	168	0.99832056
x		Local Controls & Monitoring																
x			Directional Couplers	1000000	10	ML		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
x			Reflectometer	1000000	10	ML		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
x			System Controls	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x			System Diagnostics	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x			Resonance Control	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x			Cavity Tuning Controls	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x		Total Local Controls & Monitoring		23805.66	10.00	calc.						0.0004	0.0000	0	4	0.99958011	168	0.99296884
x		Local Ph & Amp Controls		100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x		LV Power Supply		100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x		Structure and Cabling		3000000	10	CMP		1	0	0	0	0.0000	0.0000	0	0	0.99999567	168	0.999944
		TOTAL HPTP:		7404.77	5.36	calc.						0.0009	0.0002	2	8	0.99927686	168	0.98792072

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Source & Driver (2-Stage) RAM Budget For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Source & Driver Availability Summary

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

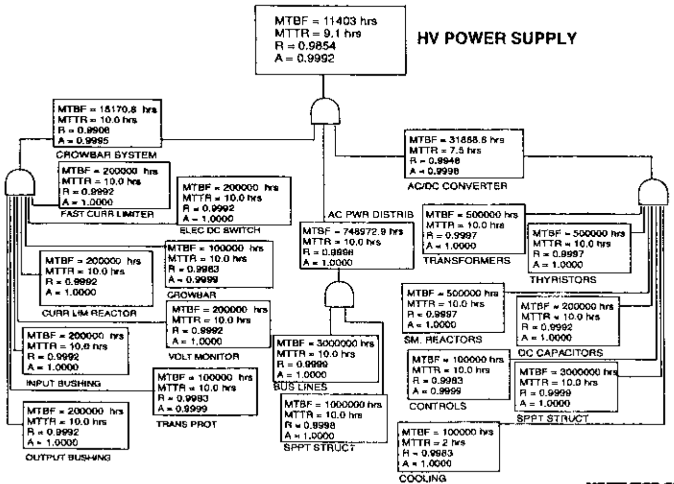
System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
		SOURCE & DRIVER - OPTION #2 (FOR TETRODES)																
x			2nd Stage Tube	11000	13	EP		1	0	0	0	0.0012	0.0001	1	10	0.99881958	168	0.98484331
x			2nd Stage Tube Cavity	1000000	9	EP		1	0	0	0	0.0000	0.0000	0	0	0.999991	168	0.99983201
x			Solid State Pre-Amp	50000	2	EP		1	0	0	0	0.0000	0.0000	0	0	0.99996	168	0.99664564
x			Source	100000	2	EP		1	0	0	0	0.0000	0.0000	0	0	0.99998	168	0.99832141
x			Other Support Subsystems	3000000	2	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999933	168	0.999944
x		Total Source and Driver (no redundancy)		8179.92	10.24	calc.						0.0013	0.0001	1	11	0.99875	168	0.97967272
x		Source and Driver with one hot spare		12269.88	10.24	calc.		2	1	1	0	0.0025	0.0002	2	22	0.99916632	168	0.99958675
x		Source and Driver with one cold spare		16359.84	10.24	calc.		2	1	2	0	0.0025	0.0002	2	22	0.99937461	168	0.99979196
		TOTAL SOURCE & DRIVER #2		8179.92	10.24	calc.						0.0013	0.0001	1	11	0.99875	168	0.97967272

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HV Power Supply RAM Budget For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HV Power Supply - Availability Summary

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

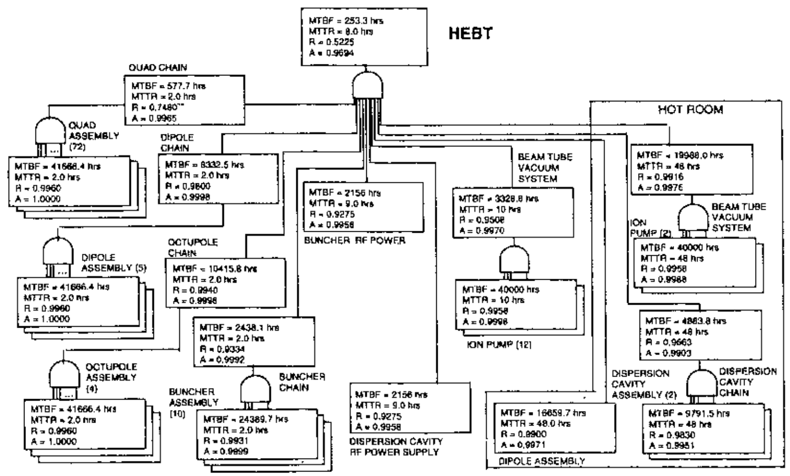
System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
		HIGH VOLTAGE POWER SUPPLY:																
x	x	AC Power Distribution																
x	x		Bus Lines	1000000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
x	x		Support Structures	3000000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999667	168	0.999944
x	x	Total AC Power Distribution		749998.12	10.00	calc.						0.0000	0.0000	0	0	0.99998667	168	0.99977603
x	x	AC/DC Converter																
x	x		Transformers	500000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99998	168	0.99966406
x	x		Thyristor Valves	500000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99998	168	0.99966406
x	x		Smoothing Reactor	500000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99998	168	0.99966406
x	x		DC Capacitor	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Controls	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x	x		Cooling	100000	2	EP		1	0	0	0	0.0000	0.0000	0	0	0.99998	168	0.99832141
x	x		Support Structure	3000000	10	EP		1	0	0	0	0.0000	0.0000	0	0	0.99999667	168	0.999944
x	x	Total AC/DC Converter		31912.14	7.45	calc.						0.0002	0.0000	0	2	0.9997667	168	0.99474983
x	x	Crowbar Systems																
x	x		Fast-Current Limiting Fuse	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Electronic DC Switch	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Crowbar	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x	x		Current Limiting Reactors	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Voltage Monitor	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Current Monitor	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Input Bushing	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Output Bushing	200000	10	EP		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99916035
x	x		Transient Protection Circuits	100000	10	EP		1	0	0	0	0.0001	0.0000	0	1	0.99990001	168	0.99832141
x	x	Total Crowbar Systems		18177.44	10.00	calc.						0.0006	0.0001	0	5	0.99945017	168	0.99060256
		TOTAL HIGH VOLTAGE POWER SUPPI		11402.67	9.09	calc.						0.0008	0.0001	1	7	0.99920368		0.98537993

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HEBT RAM Budget For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HEBT Low Activity Room (I of II) - Availability Summary

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
Low Activity Room																		
		Quadrupole Assembly																
			Electromagnet	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electrical Power Supply	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electromagnet Cooling	50000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.99996	168	0.99664564
		Total Quadrupole Assembly		41666.38	2.00	calc.						0.0000	0.0000	0	0	0.999952	168	0.99597612
		Quadrupole Chain		677.71	2.00	calc.		72	0	0	0	0.0035	0.0017	15	30	0.99655002	168	0.74803613
		Dipole Assembly:																
			Electromagnet	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electrical Power Supply	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electromagnet Cooling	50000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.99996	168	0.99664564
		Total Dipole Assembly		41666.38	2.00	calc.						0.0000	0.0000	0	0	0.999952	168	0.99597612
		Dipole Chain		8332.48	2.00	calc.		5	0	0	0	0.0002	0.0001	1	2	0.99976003	168	0.98004165
		Octupole Assembly:																
			Electromagnet	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electrical Power Supply	500000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.999996	168	0.99966406
			Electromagnet Cooling	50000	2	JR		1	0	0	0	0.0000	0.0000	0	0	0.99996	168	0.99664564
		Total Octupole Assembly		41666.38	2.00	calc.						0.0000	0.0000	0	0	0.999952	168	0.99597612
		Octupole Chain		10415.84	2.00	calc.		4				0.0002	0.0001	1	2	0.99980802	168	0.98400136

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HEBT Low Activity Room (II of II) - Availability Summary

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
		Buncher Cavity Assembly:																
			Cavity	5000000	8	JR		1	0	0	0	0.0000	0.0000	0	0	0.9999984	168	0.9999664
			Drive Loop	20000	12	JR		1	0	0	0	0.0006	0.0001	0	5	0.99940036	168	0.99163518
			Vacuum Ion Pump	40000	2	JR		1	0	0	0	0.0001	0.0000	0	0	0.99995	168	0.99580881
		Total Buncher Cavity Assembly		13297.24	8.65	calc.						0.0007	0.0001	1	5	0.99934879	168	0.98744587
		Buncher Cavity Chain		1325.83	8.65	calc.		10				0.0065	0.0008	7	57	0.99350698	168	0.88131867
		Buncher Cavity RF Power Supply																
			High Power Tube	10000	14	EP		1	0	0	0	0.0014	0.0001	1	12	0.99860196	168	0.98334033
			High Power Tube Peripherals	7405	5.36	calc.		1	0	0	0	0.0009	0.0002	2	8	0.99927696	168	0.97756737
			RF Transport	1000000	10.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
			Source & Driver	8180	10.24	calc.		1	0	0	0	0.0013	0.0001	1	11	0.99875	168	0.97967137
			Circulator	500000	1.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.999998	168	0.99966406
			HV Power Supply	11403	9.09	calc.		1	0	0	0	0.0008	0.0001	1	7	0.99920368	168	0.98537462
		RF STATION TOTAL:		2155.73	9.03	calc.						0.0044	0.0005	4	38	0.99582698		0.927499
		Buncher Cavities RF Power Supply		2156	9.03	calc.		1				0.0044	0.0005	4	38	0.99582698		0.927499
		Beam Tube Vacuum System																
			Ion pump	40000	10	EA		1	0	0	0	0.0003	0.0000	0	2	0.99975006	168	0.99580881
		Ion pump chain		3328.75	10.00	calc.		12				0.0030	0.0003	3	26	0.99700487		0.95084901
		Dispersion Cavity RF Power Supply																
			High Power Tube	10000	14	EP		1	0	0	0	0.0014	0.0001	1	12	0.99860196	168	0.98334033
			High Power Tube Peripherals	7405	5.36	calc		1	0	0	0	0.0009	0.0002	2	8	0.99927695	168	0.97756737
			RF Transport	1000000	10.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.99999	168	0.99983201
			Source & Driver	8180	10.24	calc.		1	0	0	0	0.0013	0.0001	1	11	0.99875	168	0.97967137
			Circulator	500000	1.00	calc.		1	0	0	0	0.0000	0.0000	0	0	0.999998	168	0.99966406
			HV Power Supply	11403	9.09	calc.		1	0	0	0	0.0008	0.0001	1	7	0.99920368	168	0.98537462
		RF STATION TOTAL:		2155.73	9.03	calc.						0.0044	0.0005	4	38	0.99582698		0.927499
		Dispersion Cavity RF Power Supply		2150	9.03	calc.		1				0.0044	0.0005	4	38	0.99582698		0.927499
		Total Low Activity Room		2156	9.03	calc						0.0222	0.0040	35	194	0.9785		0.5200

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

HEBT High Activity Room - Availability Summary

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

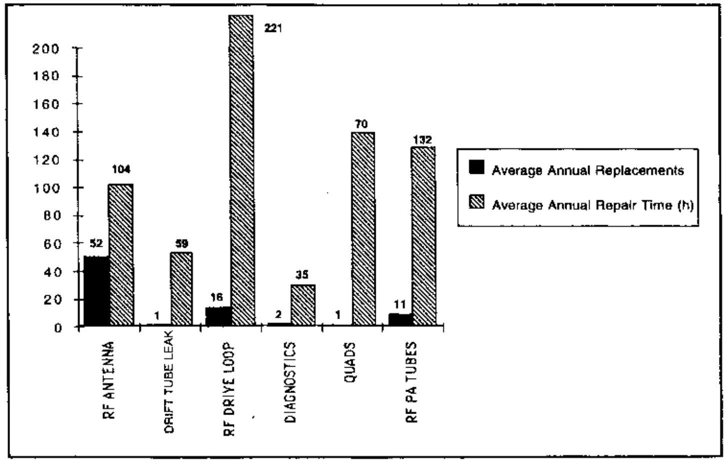
System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0 = off line, 1 = on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
	High Activity Room																	
		Dipole Assembly:																
			Electromagnet	200000	48	JR		1	0	0	0	0.0002	0.0000	0	2	0.99976006	168	0.99916035
			Electrical Power Supply	200000	48	JR		1	0	0	0	0.0002	0.0000	0	2	0.99976006	168	0.99916035
		Total Dipole Assembly		99988.00	48.00	calc.						0.0005	0.0000	0	4	0.99952017	168	0.99832141
		Dipole Chain		99988.00	48.00	calc.		1				0.0005	0.0000	0	4	0.99952017	168	0.99832141
		Dispersion Cavity Assembly:																
			Cavity	5000000	48	JR		1	0	0	0	0.0000	0.0000	0	0	0.9999904	168	0.9999664
			Drive Loop	20000	48	JR		1	0	0	0	0.0024	0.0001	0	21	0.99760575	168	0.99163518
			Vacuum Ion Pump	20000	48	JR		1	0	0	0	0.0024	0.0001	0	21	0.99760575	168	0.99163518
		Total Dispersion Cavity Assembly		9968.01	48.00	calc.						0.0048	0.0001	1	42	0.99520767		0.98330729
		Dispersion Cavity Chain		4972.03	48.00	calc.		2				0.0096	0.0002	2	84	0.99043831		0.96689323
		Beam Tube Vacuum System																
			Ion pump	40000	48	BA		1	0	0	0	0.0012	0.0000	0	11	0.99880144	168	0.99580681
		Ion pump chain		19988.01	48.00	calc.		2				0.0024	0.0001	0	21	0.99760431		0.99163518
		Cooling		20000	48	JR		1	0	0	0	0.0024	0.0001	0	21	0.99760575	168	0.99163518
	Total High Activity Room			3201.15	48.00	calc.						0.0149	0.0003	3	131	0.98522088		0.94918914
TOTAL HEBT				232.20	8.67	calc.						0.0371	0.0043	37	325	0.96401485	168	0.49361357
ALL HEBT LEGS				232.20	8.67	calc.	1					0.0371	0.0043	37	325	0.96401485		0.49361357

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Predicted Repair Frequencies For IFMIF Baseline Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

System Availability Trade Studies For IFMIF Baseline Accelerator - Sensitivities To Key MTBF & MTTR Assumptions (Has to be updated)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Component	MTBF (h)	MTTR (h)	MTBF Sensitivity*	MTTR Sensitivity*	Comment
RF Antenna Or Window (redundant)	48	0.75	0.0028	-0.0032	MTBF based on laboratory tests with current technology. Improvements will increase this value, but since injector configuration is redundant, the overall system gain expected is small.
Extractor (redundant)	4000	12	0.0005	-0.0006	The extractor is the second largest contributor to the low injector availability, primarily due to its relatively long MTTR.
RFQ Drive Loop	20000	24	0.0327	-0.0359	The rf drive loop is the largest factor in linac availability. Its failure is a single point failure mechanism, with a very long MTTR.
DTL Drive Loop	20000	24	0.0654	-0.0719	Same as above, except the effect is doubled due to the doubled number of drive loops in the system.
Source & Driver 2nd Stage Tube	11000	14	0.1041	-0.1143	This item is significant because it is encountered in every rf station. If necessary, the source and driver can be configured redundantly to minimize their effect on the overall system.
Source & Driver 1st Stage Tube	11000	2	0.0033	-0.0036	Significantly lower sensitivity in comparison with above item due to much higher component availability of this component and position on flatter part of curve.
RFQ High Power Tube	10000	14	0.0381	-0.0419	Similar to source and driver in its effect on the system. The sensitivity is larger, due to the slightly smaller availability of the individual item.
DTL High Power Tube	10000	14	0.0763	-0.0838	As above, except that the effect is doubled due to the doubled number of equipments.

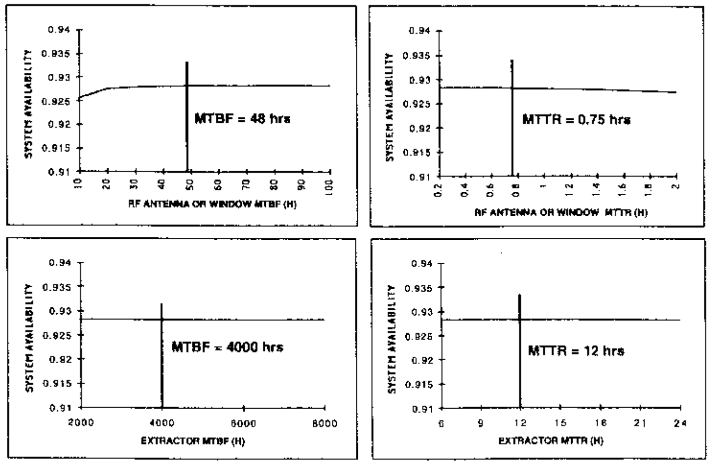
* DA/A (%) referenced to 10% change in MTBF or MTTR

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

System Availability Sensitivities For IFMIF Baseline Accelerator With Respect To Injector Parameters (Has to be updated)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

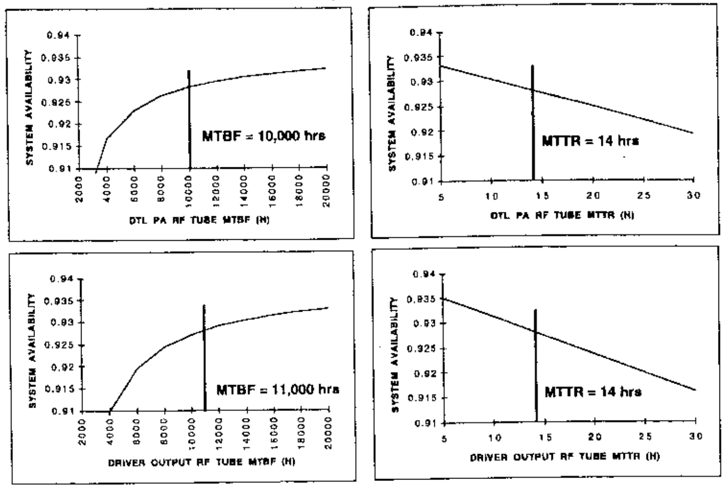


Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

System Availability Sensitivities For IFMIF Baseline Accelerator With Respect To RF Power Parameters (Has to be updated)

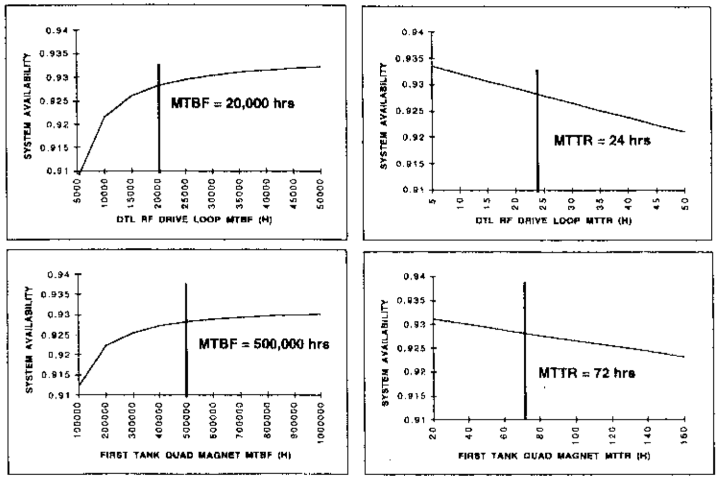
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

System Availability Sensitivities For IFMIF Baseline Accelerator With Respect To LINAC Parameters (Has to be updated)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

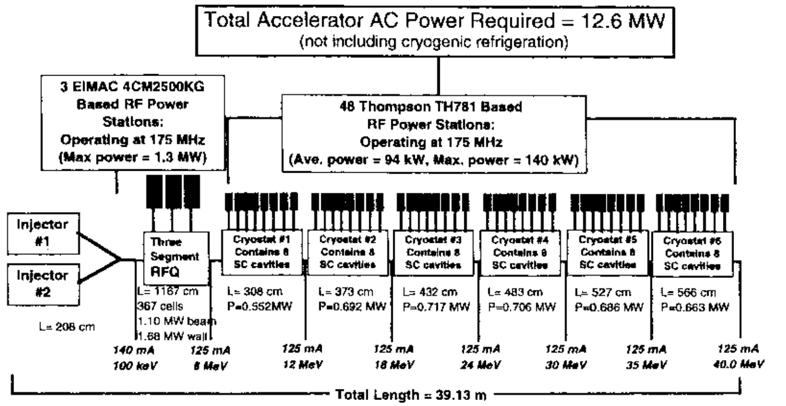
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

IFMIF Superconducting POD

Bechtel - Northrop Grumman - Westinghouse

Major Features Of IFMIF Superconducting POD

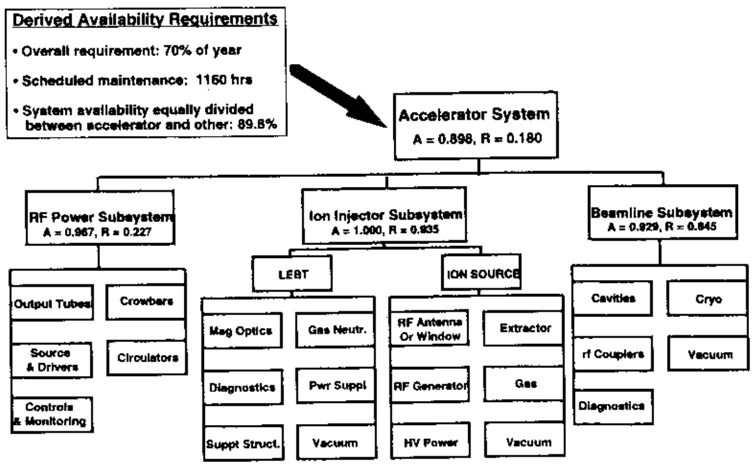
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD Availability & Reliability Budget

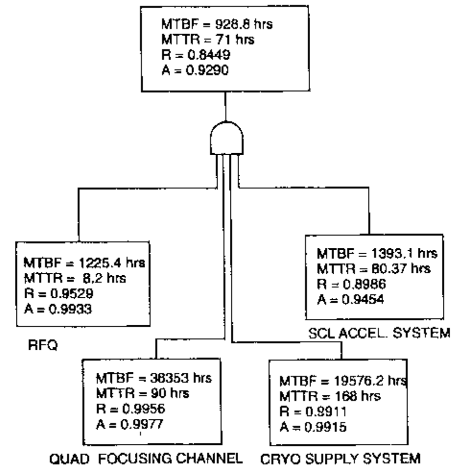
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD LINAC System RAM Budget

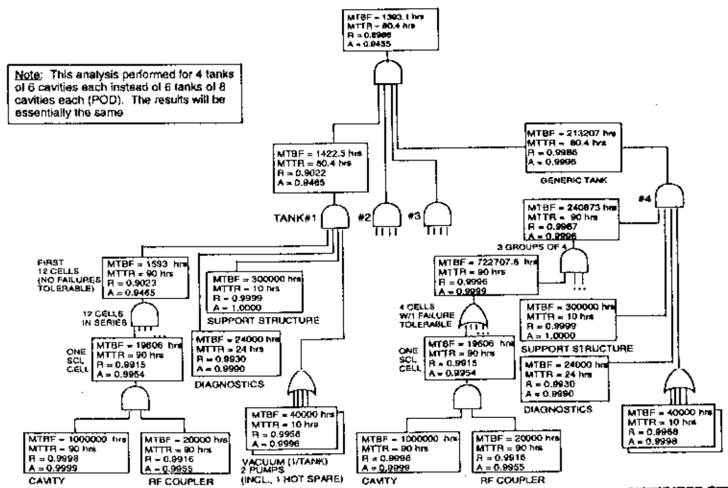
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD Accelerator RAM Budget

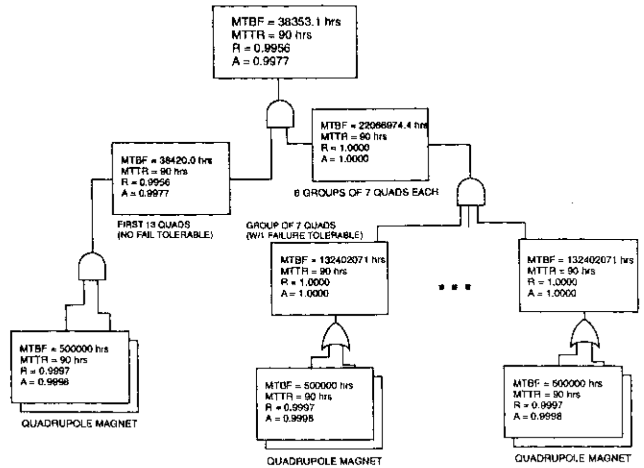
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD Quadrupole Magnets RAM Budget

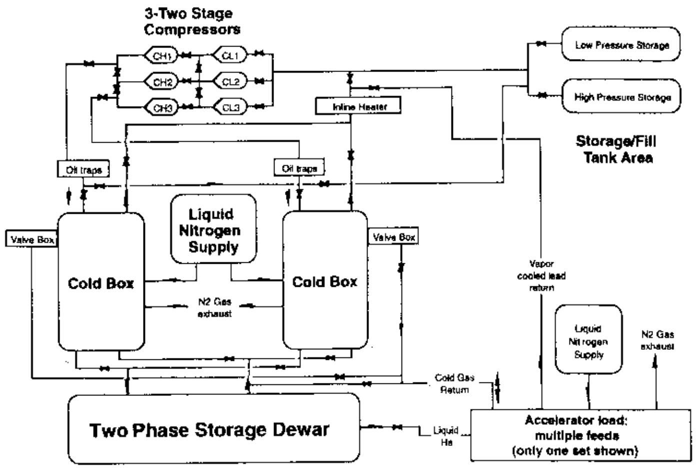
International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

Cryogenic Refrigeration System Configuration

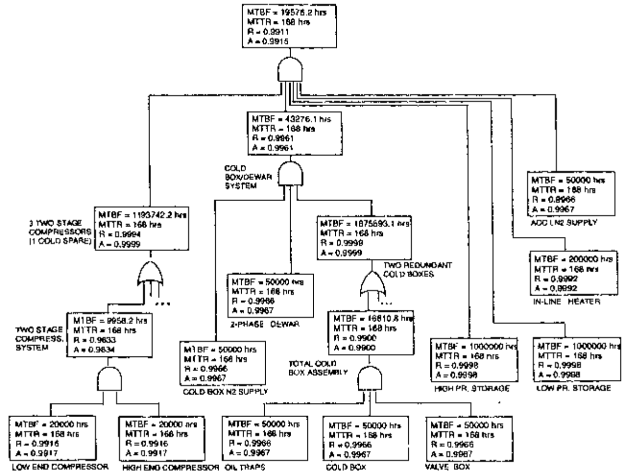
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD Cryogenic Supply RAM Budget

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

CEBAF Cryogenic Experience* - IFMIF Perspective

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Existing CEBAF:

- Achieved 96.5% availability between 6/94 & 3/95 (10 mo.)
- 35,000 hrs accumulated
- Initial commissioning difficulties caused by design problems and deficient installation

Planned CEBAF upgrades:

- Availability goal: 98%
- Redundant set of cold compressors and controllers to enable on-line repair
- Redundant cold box system
- 4K to 30K exchangers to be replaced
- Continuing improvement of repair times

IFMIF Cryo Availability:

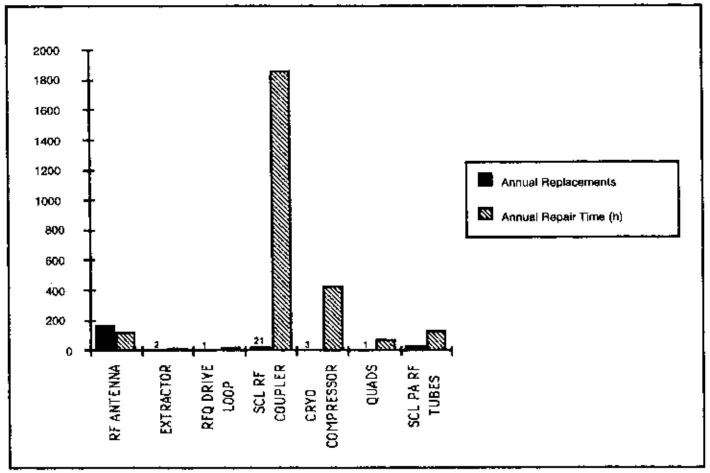
- Goal: 99.1 %
- System similar to CEBAF with redundancies already included:
  - redundant compressors
  - redundant cold boxes
  - cryogen storage
- No separate 2K loop

*Based on "CEBAF Cryogenic System", by Claus H. Rode, CEBAF, Newport News, VA 23606, USA

Bechtel - Northrop Grumman - Westinghouse

Predicted Repair Frequencies For IFMIF Superconducting POD

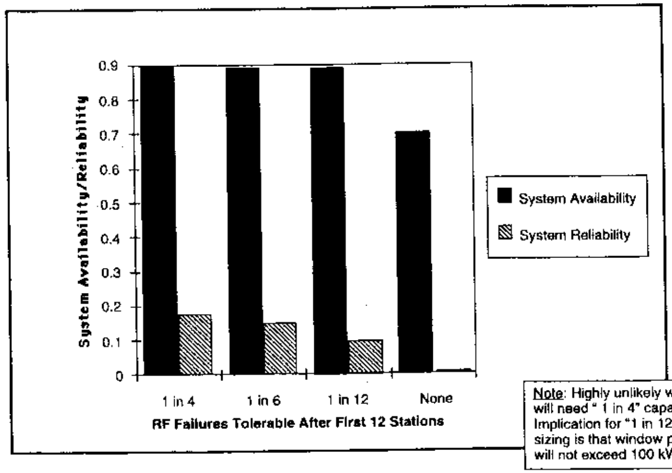
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

IFMIF Superconducting POD Availability- Sensitivities To Key Assumptions On RF Station Failures

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



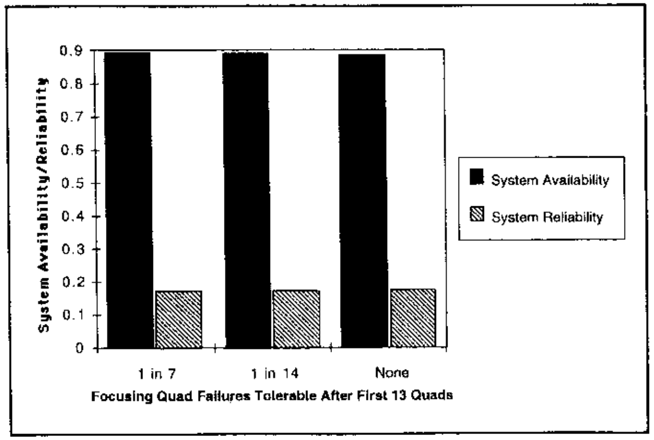
Note: Highly unlikely we will need " 1 in 4" capability. Implication for "1 in 12" sizing is that window power will not exceed 100 kW.

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

IFMIF Superconducting POD Availability - Sensitivities to Key Assumptions On Focusing Magnet Failures

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

IFMIF S/C Availability - Sensitivities to Key MTBF and MTTR Assumptions

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Component	MTBF (h)	MTTR (h)	MTBF Sensitivity*	MTTR Sensitivity*	Comment
RF Antenna (redundant)	48	0.75	0.0028	-0.0032	Same comment as for RT POD
Extractor (redundant)	4000	12	0.0005	-0.0006	Same comment as for RT POD
RFQ Drive Loop	20000	24	0.0327	-0.0359	Same comment as for RT POD
SCL RF Coupler (redundant)	20000	90	0.5091	-0.5587	Effect is magnified due to increased number of rf couplers in the SC accelerator.
Source & Driver 2nd Stage Tube (redundant)	11000	2	0.0252	-0.0277	Same comment as for RT POD
Source & Driver 1st Stage Tube (redundant)	11000	2	0.0252	-0.0277	Same comment as for RT POD
RFQ High Power Tube	10000	3	0.0082	-0.009	Same comment as for RT POD
SCL High Power Tube (redundant)	10000	3	0.0334	-0.0367	Effect is magnified due to the increased number of tubes in the SC accelerator
Cryo Compressor (redundant)	20000	168	0.0012	-0.0014	2 out of 3 cold redundancy. MTBF comparable to values experienced at Torr Supra. Long MTTR due to time associated with system cool down after repair.
Accelerator LN2 Supply	50000	168	0.0305	-0.0335	Large MTTR, associated with the long time required to cool the system down after repair, is the primary reason for large sensitivity

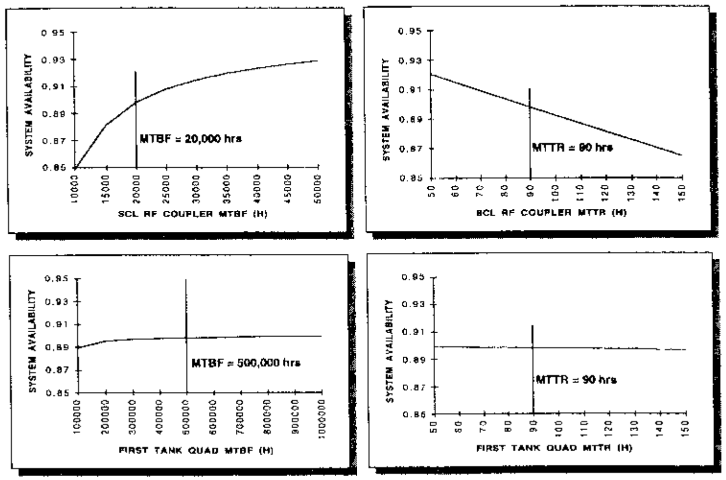
* ΔA/A (%) referenced to 10% change in MTBF or MTTR

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

IFMIF Superconducting POD Availability Sensitivities - Specific Examples

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

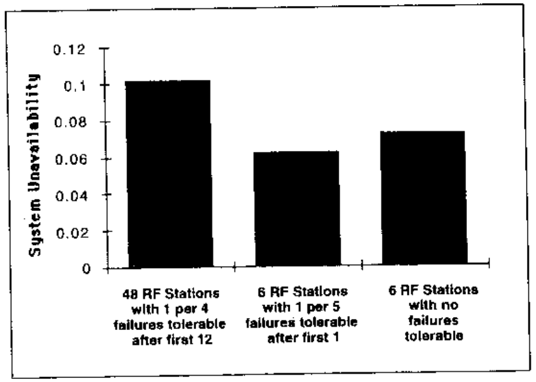


Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Availability Effect Of Grouping RF Stations

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

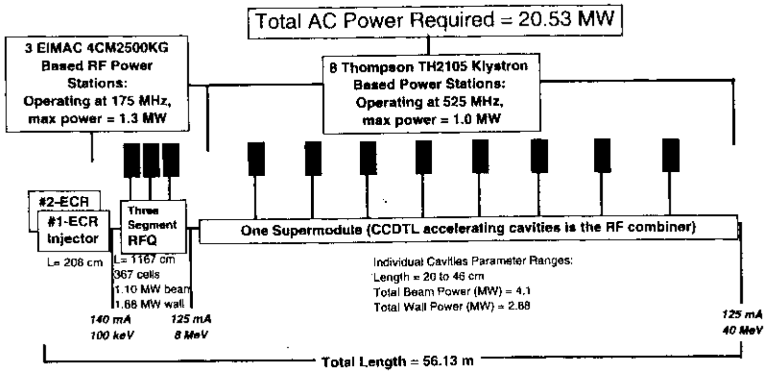
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

525 MHz IFMIF CCDTL POD

Bechtel - Northrop Grumman - Westinghouse

Major Features Of IFMIF CCDTL POD

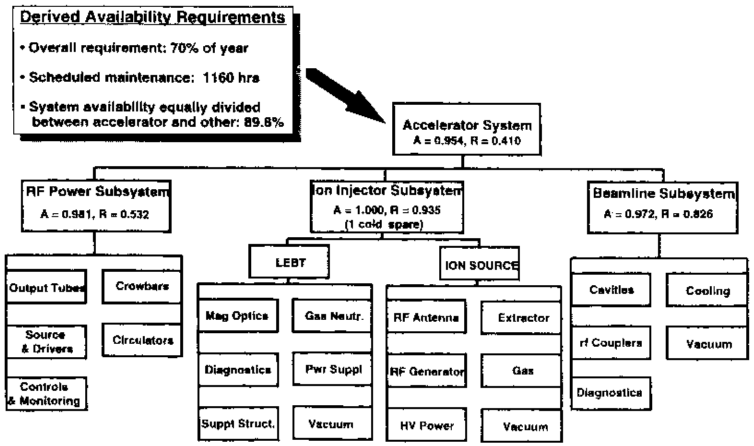
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

IFMIF CCDTL POD Availability & Reliability Budget

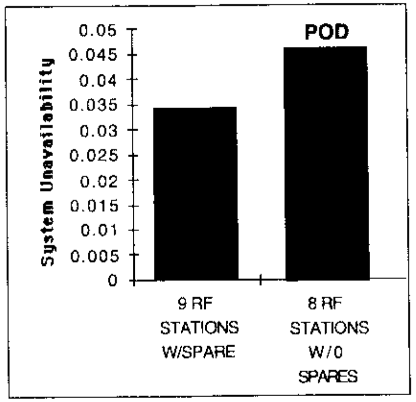
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

IFMIF CCDTL POD Unavailability Versus RF Station Redundancy

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Target

Bechtel - Northrop Grumman - Westinghouse

IFMIF Top Level Availability Allocation

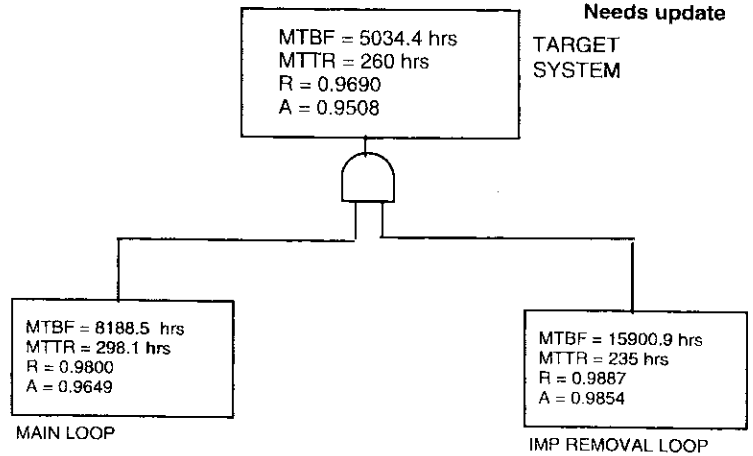
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

• Accelerator Systems and Equipment	0.8800
• Injector	
• LINAC	
• LINAC RF System	
• HEBT	
• *Target System*	*0.9500*
• Test Facility	0.9750
• Central I&C	0.9950
• Integrated Instrumentation and Controls	
• Operator Error	
•Conventional Facilities	0.9950
• Grid/Substation Electrical Systems and Equipment	
• Water Coolant Heat Rejection Systems and Equipment	
• Misc (HVAC, Compressed Air supply, Liquid Nitrogen Supply, etc.)	
• Power Outage, Fire, Earthquake, Sabotage, Strike, Riots	
• Total IFMIF Facility	0.8068

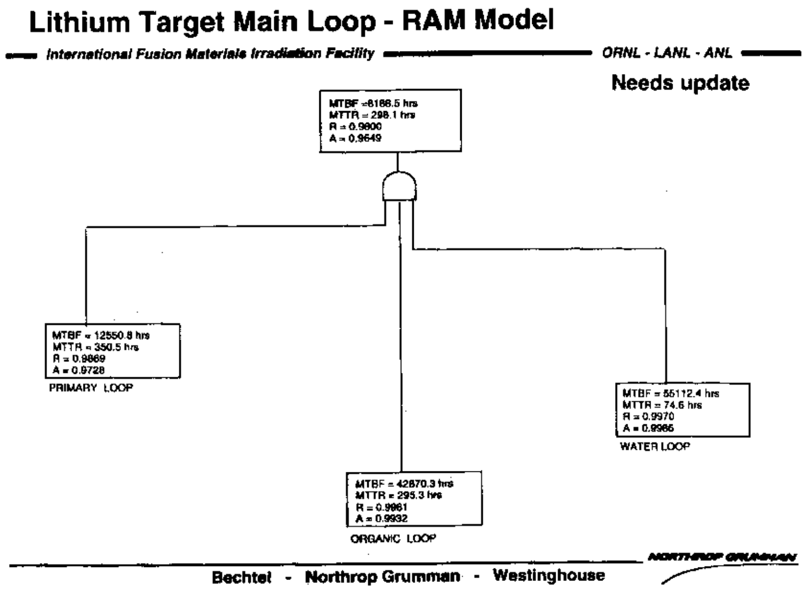
Bechtel - Northrop Grumman - Westinghouse

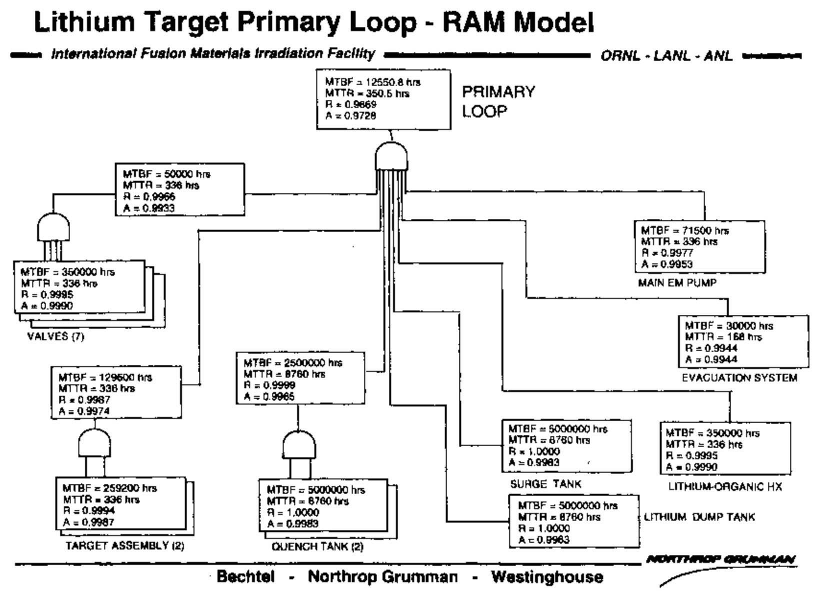
Lithium Target System - RAM Model

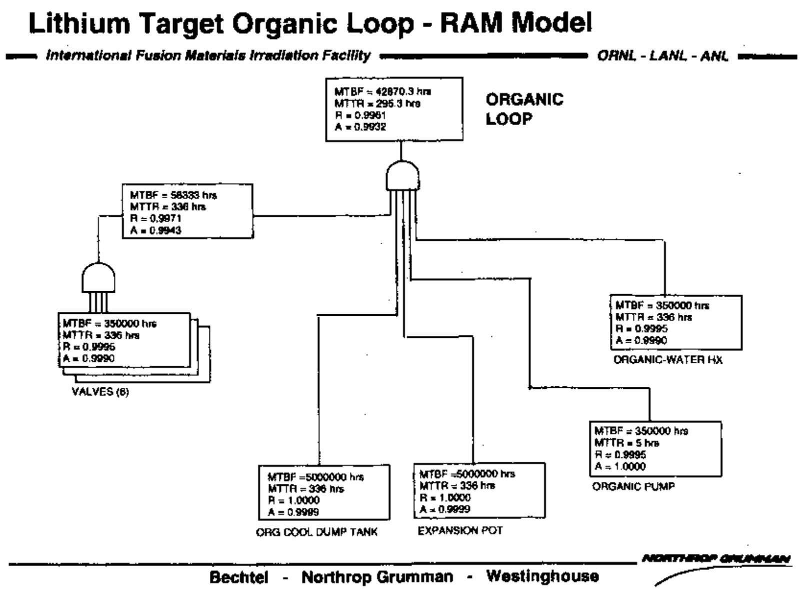
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

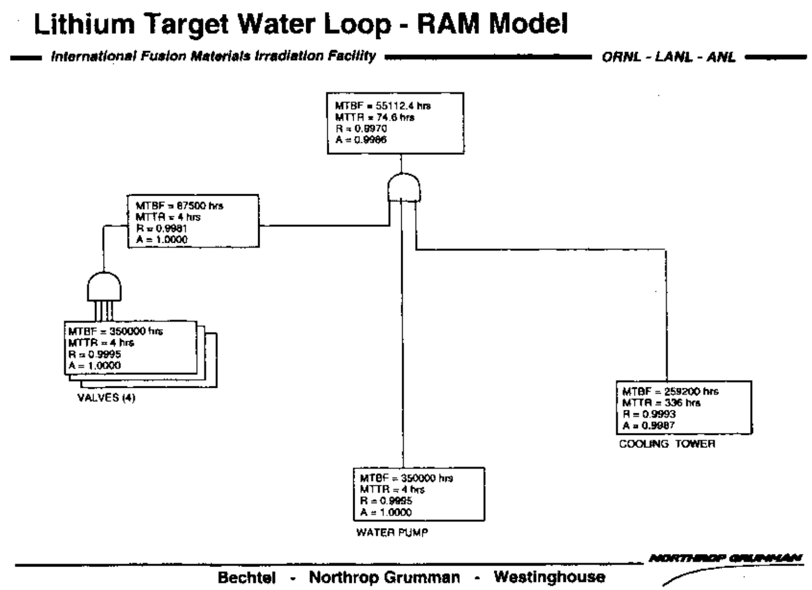


Bechtel - Northrop Grumman - Westinghouse


Lithium Target Main Loop - RAM Model
International Fusion Materials Irradiation Facility
ORNL - LANL - ANL
Needs update
MTBF =6188.5 hrs
MTTR = 298.1 hrs
R = 0.9800
A = 0.9649
MTBF = 12550.8 hrs
MTTR = 350.5 hrs
R = 0.9869
A = 0.9728
PRIMARY LOOP
MTBF = 42870.3 hrs
MTTR = 295.3 hrs
R = 0.9961
A = 0.9932
ORGANIC LOOP
MTBF = 55112.4 hrs
MTTR = 74.6 hrs
R = 0.9970
A = 0.9986
WATER LOOP
Bechtel - Northrop Grumman - Westinghouse

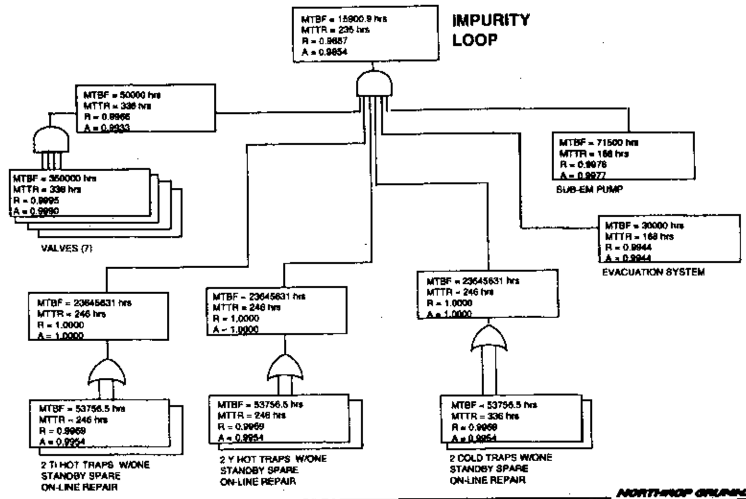

Lithium Target Primary Loop - RAM Model
International Fusion Materials Irradiation Facility
ORNL - LANL - ANL
MTBF = 12550.8 hrs
MTTR = 350.5 hrs
R = 0.9869
A = 0.9728
PRIMARY LOOP
MTBF = 50000 hrs
MTTR = 336 hrs
R = 0.9966
A = 0.9933
MTBF = 350000 hrs
MTTR = 336 hrs
R = 0.9995
A = 0.9990
VALVES (7)
MTBF = 129600 hrs
MTTR = 336 hrs
R = 0.9987
A = 0.9974
MTBF = 259200 hrs
MTTR = 336 hrs
R = 0.9994
A = 0.9987
TARGET ASSEMBLY (2)
MTBF = 2500000 hrs
MTTR = 8760 hrs
R = 0.9999
A = 0.9965
MTBF = 5000000 hrs
MTTR = 8760 hrs
R = 1.0000
A = 0.9983
QUENCH TANK (2)
MTBF = 71500 hrs
MTTR = 336 hrs
R = 0.9977
A = 0.9953
MAIN EM PUMP
MTBF = 30000 hrs
MTTR = 168 hrs
R = 0.9944
A = 0.9944
EVACUATION SYSTEM
MTBF = 5000000 hrs
MTTR = 8760 hrs
R = 1.0000
A = 0.9983
SURGE TANK
MTBF = 350000 hrs
MTTR = 336 hrs
R = 0.9995
A = 0.9990
LITHIUM-ORGANIC HX
MTBF = 5000000 hrs
MTTR = 8760 hrs
R = 1.0000
A = 0.9983
LITHIUM DUMP TANK
Bechtel - Northrop Grumman - Westinghouse


Lithium Target Organic Loop - RAM Model
International Fusion Materials Irradiation Facility
ORNL - LANL - ANL
MTBF = 42870.3 hrs
MTTR = 295.3 hrs
R = 0.9961
A = 0.9932
ORGANIC LOOP
MTBF = 58333 hrs
MTTR = 336 hrs
R = 0.9971
A = 0.9943
MTBF = 350000 hrs
MTTR = 336 hrs
R = 0.9995
A = 0.9990
VALVES (6)
MTBF =5000000 hrs
MTTR = 336 hrs
R = 1.0000
A = 0.9999
ORG COOL DUMP TANK
MTBF =5000000 hrs
MTTR = 336 hrs
R = 1.0000
A = 0.9999
EXPANSION POT
MTBF = 350000 hrs
MTTR = 5 hrs
R = 0.9995
A = 1.0000
ORGANIC PUMP
MTBF = 350000 hrs
MTTR = 336 hrs
R = 0.9995
A = 0.9990
ORGANIC-WATER HX
Bechtel - Northrop Grumman - Westinghouse


Lithium Target Water Loop - RAM Model
International Fusion Materials Irradiation Facility
ORNL - LANL - ANL
MTBF = 55112.4 hrs
MTTR = 74.6 hrs
R = 0.9970
A = 0.9986
MTBF = 67500 hrs
MTTR = 4 hrs
R = 0.9981
A = 1.0000
MTBF = 350000 hrs
MTTR = 4 hrs
R = 0.9995
A = 1.0000
VALVES (4)
MTBF = 350000 hrs
MTTR = 4 hrs
R = 0.9995
A = 1.0000
WATER PUMP
MTBF = 259200 hrs
MTTR = 336 hrs
R = 0.9993
A = 0.9987
COOLING TOWER
Bechtel - Northrop Grumman - Westinghouse

Lithium Target Impurity Removal Loop - RAM Model

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



NORTHROP GRUMMAN
Bechtel - Northrop Grumman - Westinghouse

Li Target - Main Loop - RAM Summary Table

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
MAIN LOOP																		
	Primary Loop																	
		Target Assembly		259200	336	YK	2	0	0	0	0.0026	0.0000	0.1	23	0.99741244	168	0.99870454	
		Quench Tank		5000000	8760	FMIT	2	0	0	0	0.0035	0.0000	0.0	31	0.99650519	168	0.9999328	
		Lithium Dump Tank		5000000	8760	FMIT	1	0	0	0	0.0018	0.0000	0.0	15	0.99825106	168	0.9999664	
		Main EM Pump		71500	336	FMIT	1	0	0	0	0.0047	0.0000	0.1	41	0.99532268	168	0.99765311	
		Valves		350000	336	YK	7	0	0	0	0.0067	0.0000	0.2	59	0.99330573	168	0.99664564	
		Surge Tank		5000000	8760	FMIT	1	0	0	0	0.0018	0.0000	0.0	15	0.99825106	168	0.9999664	
		Evacuation System		30000	168	BA	1	0	0	0	0.0056	0.0000	0.3	49	0.99443119	168	0.99441565	
		Lithium-Organic HX		350000	336	YH	1	0	0	0	0.0010	0.0000	0.0	8	0.99904092	168	0.99952012	
	Total Primary Loop			12550.94	350.48	calc.					0.0276	0.0001	0.7	242	0.97263405	168	0.98886666	
	Organic Loop																	
		Organic Coolant Dump Tank		5000000	336	FMIT	1	0	0	0	0.0001	0.0000	0.0	1	0.9999328	168	0.9999664	
		Organic Pump		350000	5	YH	1	0	0	0	0.0000	0.0000	0.0	0	0.99998571	168	0.99952012	
		Expansion Pot		5000000	336	FMIT	1	0	0	0	0.0001	0.0000	0.0	1	0.9999328	168	0.9999664	
		Organic-Water HX		350000	336	YH	1	0	0	0	0.0010	0.0000	0.0	8	0.99904092	168	0.99952012	
		Valves		350000	336	YK	6	0	0	0	0.0058	0.0000	0.2	50	0.9942593	168	0.99712414	
	Total Organic Loop			42870.26	295.34	calc.					0.0069	0.0000	0.2	60	0.99315806	168	0.99610042	
	Water Loop																	
		Water Pump		350000	4		1	0	0	0	0.0000	0.0000	0.0	0	0.99998857	168	0.99952012	
		Valves		350000	4		4	0	0	0	0.0000	0.0000	0.1	0	0.99995429	168	0.99808184	
		Cooling Tower		259200	336		1	0	0	0	0.0013	0.0000	0.0	11	0.99870538	168	0.99935206	
	Total Water Loop			55112.36	74.60	calc.					0.0014	0.0000	0.2	12	0.99864831	168	0.99695649	
TOTAL MAIN LOOP				8168.50	298.12	calc.					0.0358	0.0001	1.1	314	0.964872	168	0.98002647	

NORTHROP GRUMMAN
Bechtel - Northrop Grumman - Westinghouse

Li Target - Impurity Removal Loop (RAM Summary Table)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
IMPURITY REMOVAL LOOP																		
	Sub-EM Pump			71500	168	FMIT	1	0	0	0	0.0023	0.0000	0.1	21	0.99765586	168	0.99765311	
	Valves			350000	336	YK	7	0	0	0	0.0067	0.0000	0.2	59	0.99330573	168	0.99664564	
	Evacuation System			30000	168	BA	1	0	0	0	0.0056	0.0000	0.3	49	0.99443119	168	0.99441565	
	Cold Trap Assembly																	
		Cold Trap		100000	168	FMIT	1	0	0	0	0.0017	0.0000	0.1	15	0.99832282	168	0.99832141	
		Valves		350000	336	YK	3	0	0	0	0.0029	0.0000	0.1	25	0.99712552	168	0.99856104	
	Total Cold Trap Assembly			53756.46	246	calc.					0.0046	0.0000	0.2	40	0.99545316		0.99688486	
	2 Cold Trap Assemblies w/redundancy			23645630.99	246	calc.	2	1	2	1	0.0091	0.0000	0.3	80	0.99998962	168	1.00000638	
	Y Hot Trap Assembly																	
		Y Hot Trap		100000	168	FMIT	1	0	0	0	0.0017	0.0000	0.1	15	0.99832282	168	0.99832141	
		Valves		350000	336	YK	3	0	0	0	0.0029	0.0000	0.1	25	0.99712552	168	0.99856104	
	Total Y Hot Trap Assembly			53756.46	246	calc.					0.0046	0.0000	0.2	40	0.99545316		0.99688486	
	2 Y Hot Trap Assemblies w/redundancy			23645630.99	246	calc.	2	1	2	1	0.0091	0.0000	0.3	80	0.99998962	168	1.00000638	
	Ti Hot Trap Assembly																	
		Ti Hot Trap		100000	168	FMIT	1	0	0	0	0.0017	0.0000	0.1	15	0.99832282	168	0.99832141	
		Valves		350000	336	YK	3	0	0	0	0.0029	0.0000	0.1	25	0.99712552	168	0.99856104	
	Total Ti Hot Trap Assembly			53756.46	246	calc.					0.0046	0.0000	0.2	40	0.99545316		0.99688486	
	2 Ti Hot Trap Assemblies w/redundancy			23645630.99	246	calc.	2	1	2	1	0.0091	0.0000	0.3	80	0.99998962	168	1.00000638	
TOTAL IMPURITY REMOVAL LOOP				15900.87	235	calc.					0.0420	0.0002	1.6	368	0.98542801	168	0.988773	
TOTAL IFMIF LITHIUM TARGET SYSTEM				5034.43	260	calc.					0.0778	0.0003	2.6	682	0.950812	168	0.969024	
LITHIUM TARGET SYSTEM AVAILABILITY GOAL (MINIMUM)															0.95			

NORTHROP GRUMMAN
Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Test Cell

NORTHROP GRUMMAN
Bechtel - Northrop Grumman - Westinghouse

IFMIF Top Level Availability Allocation

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

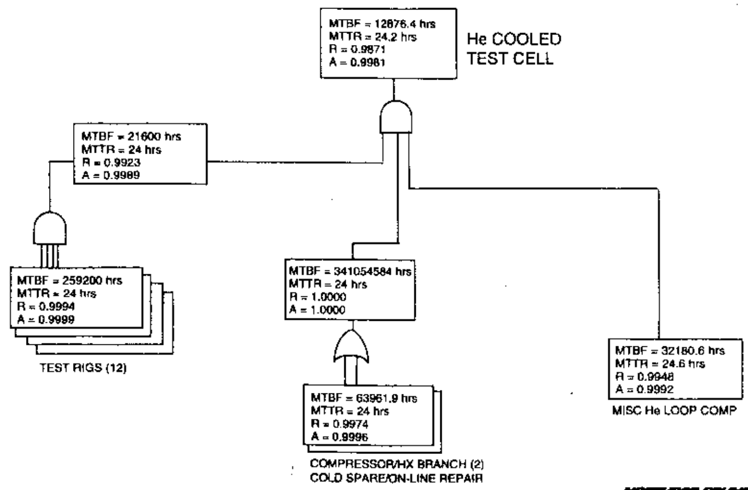
• Accelerator Systems and Equipment	**0.8800**
• Injector	
• LINAC	
• LINAC RF System	
• HEBT	
• Target System	**0.9500**
• Test Facility	***0.9750***
• Central I&C	**0.9950**
• Integrated Instrumentation and Controls	
• Operator Error	
•Conventional Facilities	**0.9950**
• Grid/Substation Electrical Systems and Equipment	
• Water Coolant Heat Rejection Systems and Equipment	
• Misc (HVAC, Compressed Air supply, Liquid Nitrogen Supply, etc.)	
• Power Outage, Fire, Earthquake, Sabotage, Strike, Riots	
• Total IFMIF Facility	**0.8068**

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

He Cooled Test System - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

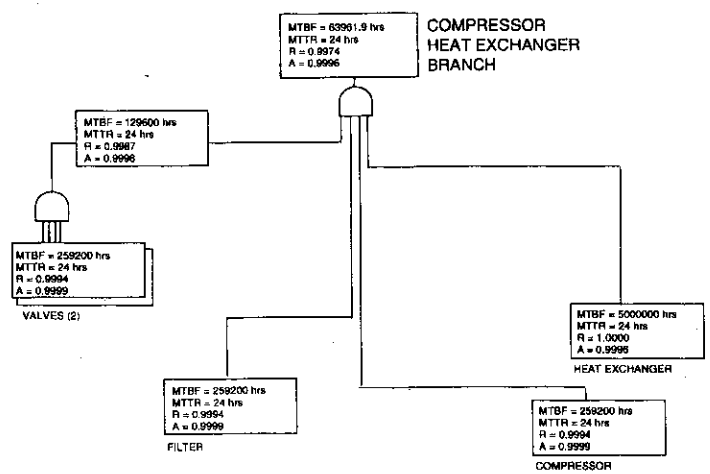


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

He Cooled Test System - Comp/HX Branch - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

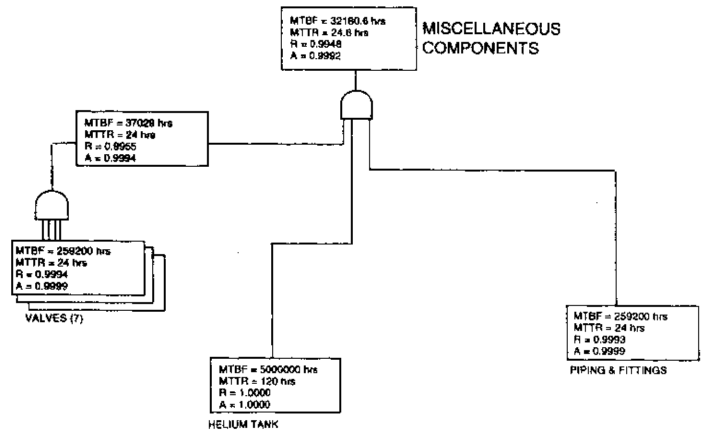


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

He Cooled Test System - Misc Comp - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

He Cooled Test System (RAM Summary Table)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

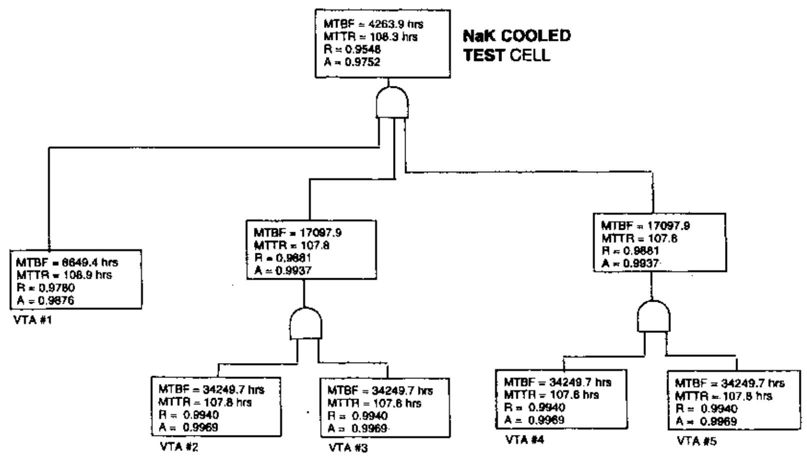
System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0= off line 1= on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
TEST SYSTEM																		
	Test Rigs			259200	24			12	0	0	0	0.0011	0.0000	0	10	0.99886956	168	0.99225239
	Comp/HX Branch																	
			Valve	259200	24			2	0	0	0	0.0002	0.0000	0	2	0.99981484	168	0.99870454
			Filter	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Compressor	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heat Exchanger	5000000	24			1	0	0	0	0.0000	0.0000	0	0	0.9999952	168	0.9999664
	Total Comp/HX Branch			63961.86	24.00	calc.						0.0004	0.0000	0	3	0.99962492	168	0.99737725
	2 Redund Comp/HX Branches			341054584.23	24.00	calc.		2	1	2	1	0.0008	0.0000	0	7	0.99999993	168	0.99999916
	Misc He Loop Components																	
			Valve	259200	24			7	0	0	0	0.0006	0.0000	0	6	0.99935209	168	0.99547324
			Helium Tank	5000000	120			1	0	0	0	0.0000	0.0000	0	0	0.999976	168	0.9999664
			Piping & Fittings	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
	Tot Misc He Loop Comp			32180.55	24.62	calc.						0.0008	0.0000	0	7	0.99923559	168	0.99479481
TOTAL TEST SYSTEM				12876.44	24.18	calc.						0.0026	0.0001	1	23	0.998126		0.987087
TEST SYSTEM AVAILABILITY GOAL (MINIMUM)																0.975		

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

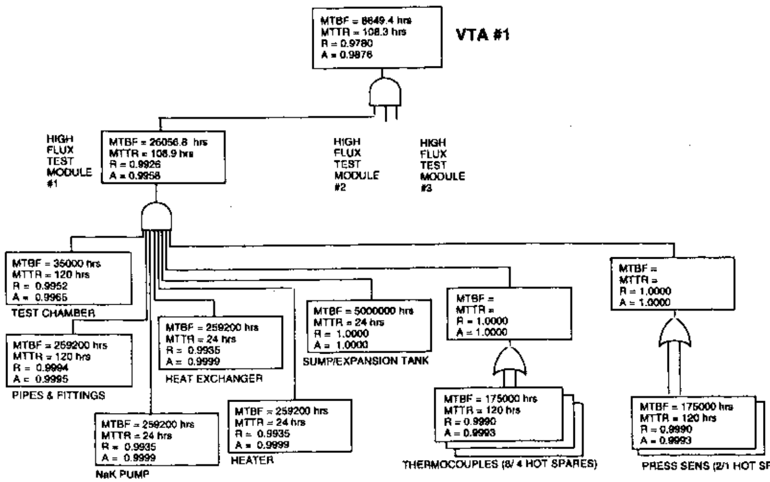


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System - VTA#1 - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

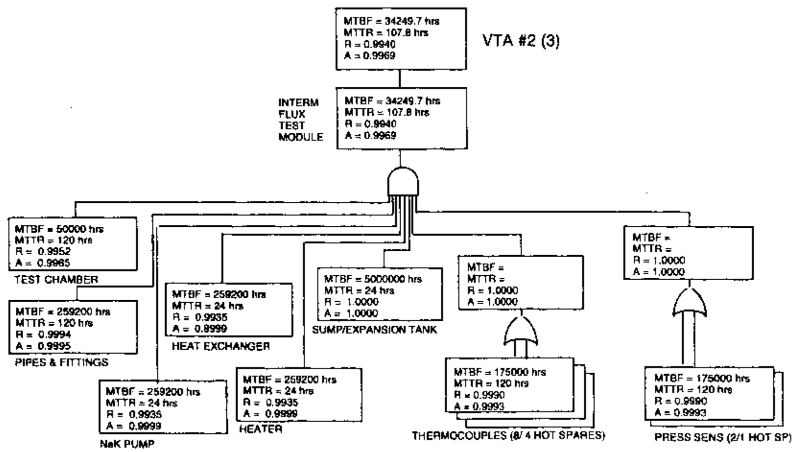


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System - VTA#2 (3) - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

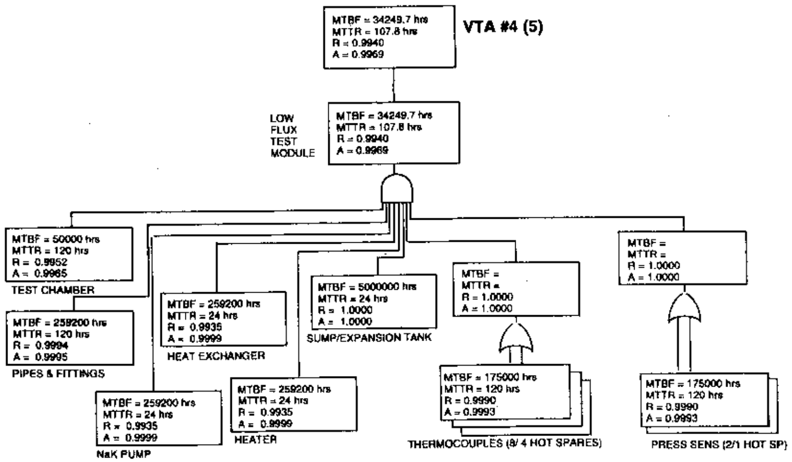


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System - VTA#4 (5) - RAM Model

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System (RAM Summary Table - I of III)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
TEST SYSTEM																		
	Vertical Test Assembly #1																	
		High Flux Test Module																
			Test Chamber	75000	120			1	0	0	0	0.0016	0.0000	0	14	0.99840256	168	0.99776251
			NaK Pump	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heat Exchanger	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heater	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Sump/Expansion Tank	5000000	24			1	0	0	0	0.0000	0.0000	0	0	0.9999952	168	0.9999664
			Thermocouples	175000	120			8	4	1	0	0.0055	0.0000	0	46	0.99922536	168	1
			Pressure Sensors	175000	120			2	1	1	0	0.0014	0.0000	0	12	0.99954307	168	0.99999908
			Pipes & Fittings	259200	120			1	0	0	0	0.0005	0.0000	0	4	0.99953725	168	0.99935206
		Total High Flux Module		29831.92	106.87	calc.						0.0092	0.0001	1	81	0.99643027	168	0.99514471
		All High Flux Modules		9908.43	106.87	calc.		3				0.0276	0.0003	2	242	0.989329		0.98550474
	Total Vertical Assembly #1			9908.43	106.87	calc.						0.0276	0.0003	2	242	0.989329		0.98550474

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System (RAM Summary Table - II of III)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
	Vertical Test Assembly #2																	
		Intermediate Flux Test Module																
			Test Chamber	100000	120			1	0	0	0	0.0012	0.0000	0	11	0.99880144	168	0.99832141
			NaK Pump	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heat Exchanger	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heater	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Sump/Expansion Tank	5000000	24			1	0	0	0	0.0000	0.0000	0	0	0.9999952	168	0.9999664
			Thermocouples	175000	120			8	4	1	0	0.0055	0.0000	0	48	0.99922536	168	1
			Pressure Sensors	175000	120			2	1	1	0	0.0014	0.0000	0	12	0.99954307	168	0.99999908
			Pipes & Fittings	259200	120			1	0	0	0	0.0005	0.0000	0	4	0.99953725	168	0.99935206
		Total Interim Flux Module		33423.61	106.34	calc.						0.0088	0.0001	1	77	0.99682837	168	0.99570215
	Total Vertical Assembly #2			33423.61	106.34	calc.		1				0.0088	0.0001	1	77	0.99682837		0.99570215
	Total Vertical Assemblies #2 #3			16685.28	106.34	calc.		2				0.0176	0.0002	1	154	0.99366679		0.99142277

Bechtel - Northrop Grumman - Westinghouse

NaK Cooled Test System (RAM Summary Table - III of III)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

System	Subsystem	Assembly	Equipment	MTBF (h)	MTTR (h)	Source of Reliability Information	No. of Acc. Legs	No. of Eq. per Leg	No. of Spares Included	Redundancy Type	Repair (0=off line 1=on line)	MTTR / MTBF	Failure Rate (1/h)	Annual Replacements	Annual Repair Time (h)	Steady State Availability	Mission Time (h)	Reliability for mission time
	Vertical Test Assembly #4																	
		Low Flux Test Module																
			Test Chamber	100000	120			1	0	0	0	0.0012	0.0000	0	11	0.99880144	168	0.99832141
			NaK Pump	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heat Exchanger	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Heater	259200	24			1	0	0	0	0.0001	0.0000	0	1	0.99990742	168	0.99935206
			Sump/Expansion Tank	5000000	24			1	0	0	0	0.0000	0.0000	0	0	0.9999952	168	0.9999664
			Thermocouples	175000	120			8	4	1	0	0.0055	0.0000	0	48	0.99922536	168	1
			Pressure Sensors	175000	120			2	1	1	0	0.0014	0.0000	0	12	0.99954307	168	0.99999908
			Pipes & Fittings	259200	120			1	0	0	0	0.0005	0.0000	0	4	0.99953725	168	0.99935206
		Total Low Flux Module		33423.61	106.34	calc.						0.0088	0.0001	1	77	0.99682837	168	0.99570215
	Total Vertical Assembly #4			33423.61	106.34	calc.		1				0.0088	0.0001	1	77	0.99682837		0.99570215
	Total Vertical Assemblies #4 &5			16685.26	106.34	calc.		2				0.0176	0.0002	1	154	0.99366679		0.99142277
TOTAL TEST SYSTEM				4494.66	106.58	calc.						0.0628	0.0006	5	550	0.978837		0.968671
TEST SYSTEM AVAILABILITY GOAL (MINIMUM)																0.975		

Bechtel - Northrop Grumman - Westinghouse

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Maintainability

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Elements of Maintainability

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Design to minimize and facilitate required maintenance:
  - components interchangeable and standardized commercial grade where possible
- Design to minimize maintenance manpower and skill requirements
  - remote maintenance to be minimized
  - color coding systems, quick disconnects, etc.
  - maintenance procedures documented
- Maintainability is traded against performance, safety, & reliability
  - adequate space and work clearances for personnel wearing protective garments
  - minimize personnel exposure to radiation
  - routine maintenance not to rely on life support systems
  - control and disposal of radioactive waste incorporated in the design
  - fail-safe features and redundancies to maximize on-line maintenance
- Maintenance equipment to be engineered as part of the design
  - Cranes, viewing access, ports and hatches, shops
  - sensors replaceable without disassembly of major components
- Anticipated lifetime and replacement schedule for each component
  - spare parts inventory including expected usage rates
- Administrative tasks
  - reporting, contingency planning, historical database

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Message

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

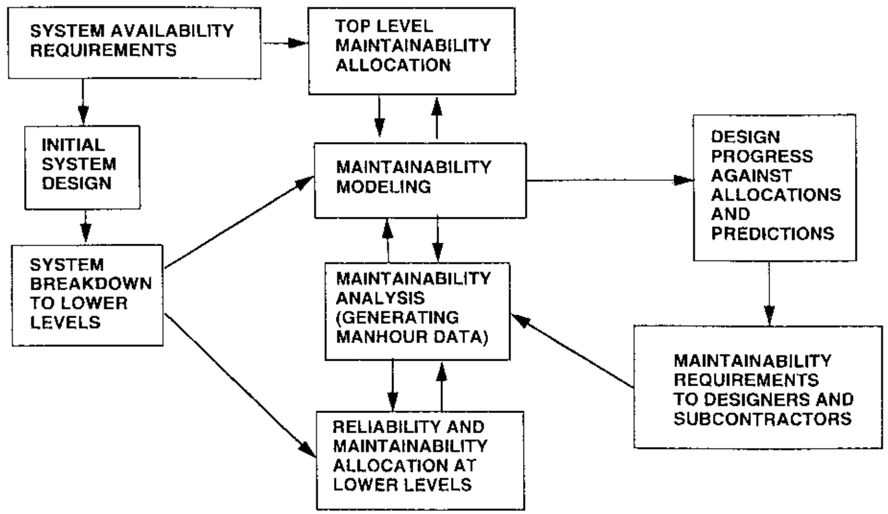
"You can spend more money designing for maintenance or spend more money for maintenance"

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Maintainability Design Process

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Maintainability Evaluation Checklist

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- General accessibility, work space, and work clearance for parts, test points, and adjustments.
- Interchangeability of parts (use of standard parts)
- Design for fault detection and identification
- Limitation of numbers and varieties of necessary tools, accessories and support
- Number of personnel, skill levels and special training requirements
- Testability of parts, adjustments, and connections
- Ease of handling and mobility
- Human factors and maintenance environment (radiation, lighting, etc)
- Inherent maintainability of components (modular plug-in design)

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Types of Maintenance Operations

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

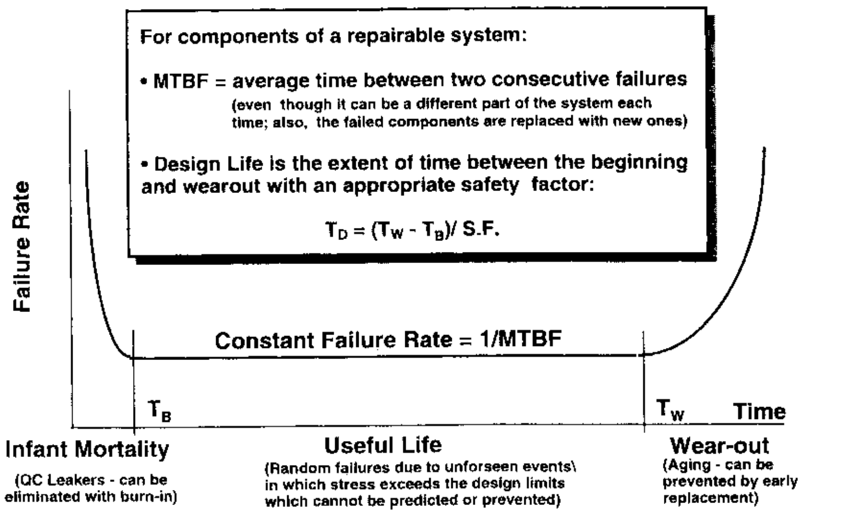
- **Preventive Maintenance**
  - Replacement of components before the wear-out part of bathtub curve is reached
  - Replacement of consumables before depletion
  - Cleaning and lubrication to prevent mechanical and electrical degradation
  - Inspection and checkout
  - Follows preventive maintenance schedule and plan
  - Performed during scheduled maintenance periods
- **Corrective Maintenance**
  - Replacement of failed components in the constant failure region of bathtub curve
  - May include components with incipient failure identified via health monitoring
  - Usually requires identification of failed items (i.e. extra time)
  - May require procurement of spare part if unavailable (e.g. expensive items)
  - May require failure specific equipment and training of personnel
  - Performed during unscheduled repair periods

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Bathtub Curve (Heuristic Arguments)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Preventive Maintenance Planning

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- List components requiring preventive maintenance actions
- Estimate required frequency of replacement
- Estimate maintenance time
- Preventive maintenance schedule is the sum total of the individual component requirements

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Corrective Maintenance Operations Planning

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **List facility components and their most significant and probable failure modes**
- **Include the pertinent maintenance steps in the repair timeline:**
  - » shutdown,
  - » cool-down,
  - » access time,
  - » disassembly,
  - » replacement or repair,
  - » reassembly,
  - » start-up

Bechtel - Northrop Grumman - Westinghouse

Factors Contributing to Reliability Degradation During Operations

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Operators stressing the system beyond design limits either to meet current operational need or inadvertently through neglect, unfamiliarity with equipment, or carelessness
- Operational abuses: rough handling, extended duty cycles, or neglected maintenance
- Excessive handling brought about by poor practice preventive or corrective maintenance:
  - Mechanical stresses imposed on components during removal, repair, and reinsertion that exceed design values
  - Foreign objects or debris left in an assembly during maintenance
  - Bolts not tightened sufficiently or overtightened
  - Dirt injection
  - Parts replaced improperly
  - Improper lubricant used
  - Erroneous replacement of good parts (counted as bad in reliability record)

Bechtel - Northrop Grumman - Westinghouse

IFMIF Accelerator Maintenance Ground Rules & Assumptions

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Vault accessible within 1 hour from shutdown (see detailed timeline for injector RF antenna replacement).
- Credible maintenance operations can be performed inside the vault by moving RFQ and DTL tanks laterally. The need to remove tank outside the vault will be extremely rare.
- If necessary, the tanks will be wheeled in and out on special trolley type cars. Only a light crane (2-5 ton) will be provided.
- Injector maintenance will use movable pallets containing the source, HV rack, extraction electrodes, vacuum vessel, and first solenoid.
- Accelerator components will represent mild-moderate radiation hazard => Accelerator maintenance area separate from test cell components maintenance area can be used.
- RF power transmission coax will run in a central pipe alley common to both accelerators accessible for limited work during the operation of accelerators.

Based on data provided by John Rathke on 5/10/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Preventive Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	15 min
• Review long term data for trends	1/shift	15 min
• Replace/clean air filters in rf & power supplies	monthly	15 min
• Service pumps & blowers	quarterly	1 hr
• Perform general housecleaning & inspection	quarterly	2 hrs
• Change RF antenna or filament	weekly	2 hrs
• Inspect interior (ECR source)	quarterly	2 hrs

Based on data provided by Joe Sredniawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

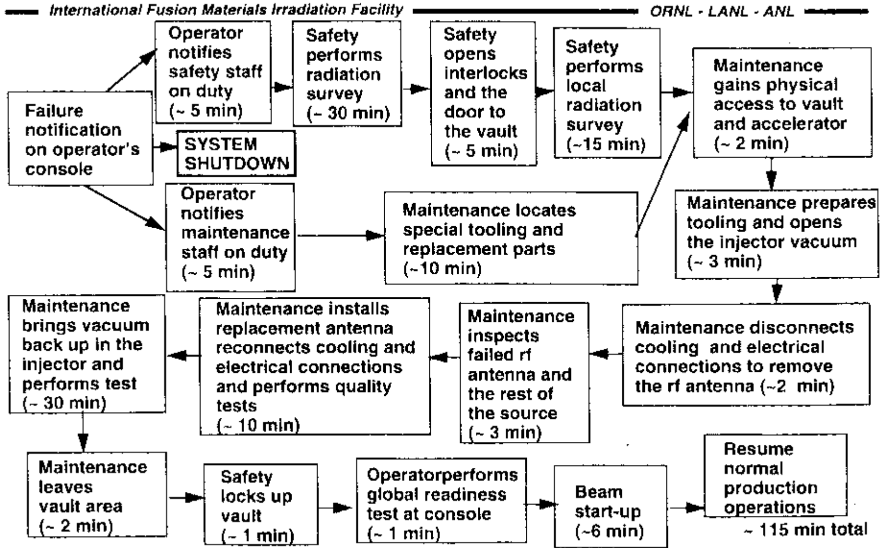
Compo-nent	Failure Mode	Assumptions	Maintenance Action
Ion source: RF antenna	Burn-through	RF antenna will be replaced during weekly preventive maintenance to minimize the possibility of it failing randomly. However, such random failure between scheduled maintenance which will require this corrective maintenance action cannot be ruled out.	1) Access vault (1 hr) 2) Replace (15 min) 3) Bring source vacuum back up (30 min - assuming continuing N2 venting during the repairs) 4) Warm start-up of injector and accelerator (10 min) Total: 1 hr 55 min
Ion source: RF generator	No RF signal	Solid state RF amplifier with plug-in modular boards.	1) Fault isolation (5 min if BIT designed, otherwise ?) 2) Replace & test (30 min) 3) Warm start-up of injector (10 min) Total: 45 min

Based on data provided by Joe Sredniawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Detailed Timeline for RF Antenna Replacement

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

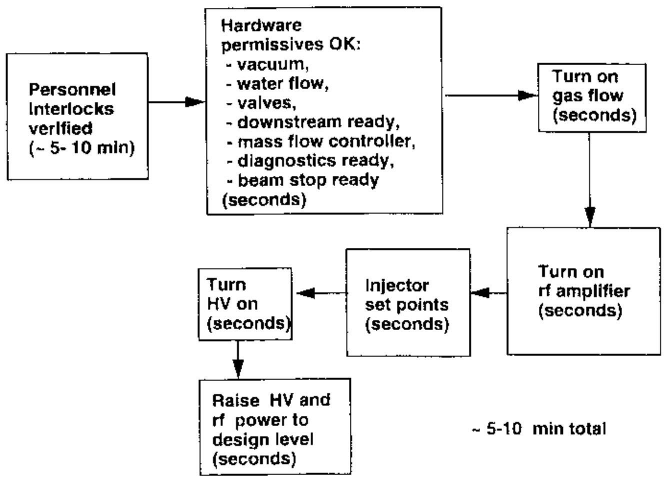


Based on data provided by Joe Sredniawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



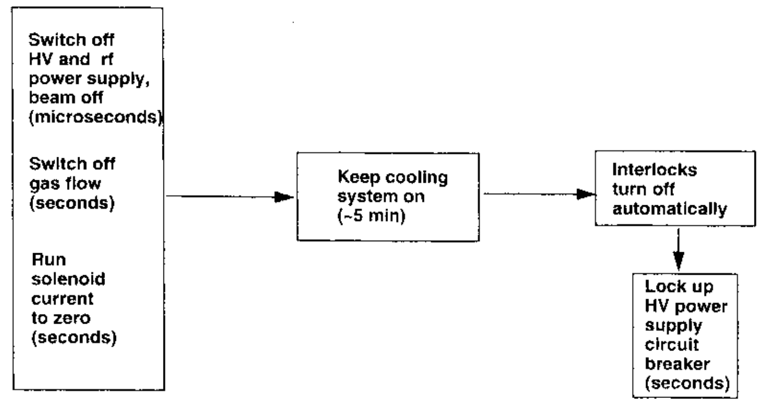
~ 5-10 min total

Based on data provided by Joe Sredniawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



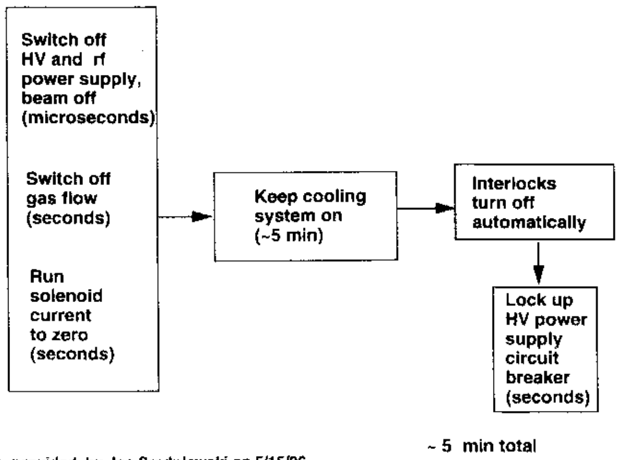
~ 5 min total

Based on data provided by Joe Sredniawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Injector - Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Based on data provided by Joe Srednlawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Preventive Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	15 min
• Review long term data for trends	1/shift	15 min
• Service pumps and blowers	annually	30 min
• Perform general housecleaning & inspection	weekly	2 hrs
• Replace plastic tubes and cables (rad damage)	annually	2 wks

Based on data provided by Joe Srednlawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Corrective Maintenance (Sample)

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

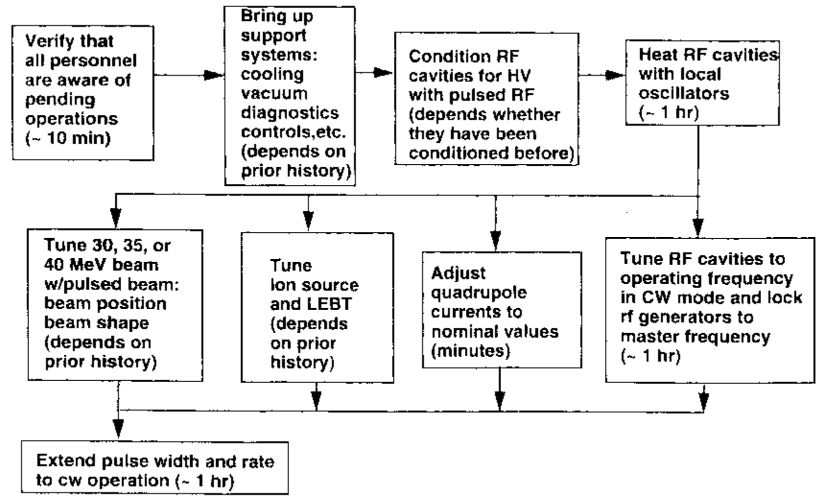
Component	Failure Mode	Assumptions	Maintenance Action
RFQ: Drive Loop	Excessive sparking	No associated vacuum window failure.	1) Shut down system 2) Access vault (~ 1hr) 3) Replace drive loop and test (~ 8 hrs) 4) Evacuate RFQ (~ 2 hrs) 5) Condition RFQ and test (~ 1 hr) 6) Start beam up Total: 12 hrs
RFQ: Turbomechanical vacuum pumps	Pump failure	6 redundant pumps with capability to tolerate 1 failure. Repair for 2 pumps failed. No on-line repair possible.	1) Access vault (~ 1 hr) 2) Replace pumps (~ 2 hrs) 3) Test (~1 hr) Total: 4 hrs

Based on data provided by Joe Srednlawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Timeline for Initial Startup or After Long Stop

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

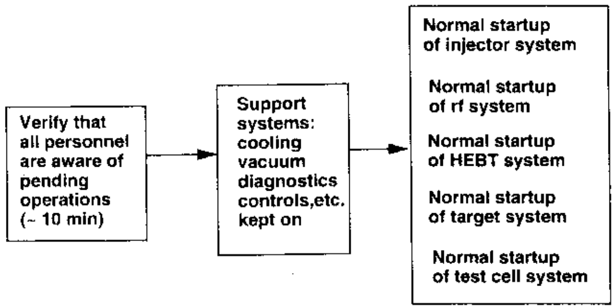


Based on data provided by Joe Srednlawski on 5/15/96

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Typical Timeline for Normal Startup (Warm Start)

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



The actual time will depend on state of readiness of each individual system.
It is expected to range from several minutes to several hours.

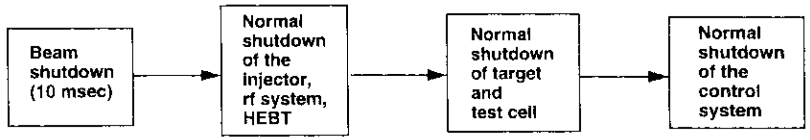
Based on data provided by Joe Sredniawski on 5/15/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator- Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



The sequence above represents the complete shutdown of the entire IFMIF facility (i.e. for the annual ~1 month scheduled maintenance period.
Depending on the specific situation, the shutdown may only include part of this sequence.

Based on data provided by Joe Sredniawski on 5/15/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Accelerator - Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

TBD

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System - Preventive Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	15 min
• Review long term data for trends	weekly	1 hr
• Replace/clean air filters in electronic cabinets	monthly	15 min
• Lubricate bearings in pumps and blowers	annualy	30 min
• Replace dess. cart. in coax press air comp	as reqd	15 min
• Test insulation oil for breakdown (laboratory)	annually	30 min
• Perform general housecleaning & inspection	quarterly	2 hrs
• Perform crowbar test	monthly	15 min
• Verify quality of RF signal samples throughout	monthly	30 min

Based on data provided by Ed Piechowiak on 4/11/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System: 9-14" Coax Parts- Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Coupler; filter; hybrid; or	1	Shutdown RF station	5
any coax element in 9" to	2	Depressurize coax	5
14" coax run	3	Remove failed part and associated coax lines	60
		to facilitate removal	
	4	Replace parts and repressurize coax line	90
	5	Perform turn on sequence for RF station	20
	6	Confirm RF system performance is adequate	10
		Total	190

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96 — NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System: Circulator - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Circulator	1	Shutdown RF station	5
	2	Depressurize coax	5
	3	Remove circulator and associated coax lines	60
		to facilitate removal (including cooling lines)	
	4	Replace parts and repressurize coax line	90
	5	Verify coolant line and control to circulator	15
	6	Perform turn on sequence for RF station	20
	7	Confirm RF system performance is adequate	10
		Total	205

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96 — NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System: 3" Coax Parts- Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Coupler; filter; hybrid; or	1	Shutdown RF station	5
any coax element in 3" or	2	Depressurize coax	5
or smaller diameter coax run	3	Remove failed part and associated coax lines	30
		to facilitate removal	
	4	Replace parts and repressurize coax line	45
	5	Perform turn on sequence for RF station	20
	6	Confirm RF system performance is adequate	10
		Total	115

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96 — NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System: Output Tube - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Output Tube	1	Shutdown RF station	5
	2	Depressurize coax	5
	3	Remove all interface connections to cavity	90
	4	Remove top half sections of cavity	40
	5	Disconnect interfaces to tube	30
	6	Extract tube & replace with new tube	60
	7	Reconnect tube interfaces	30
	8	Replace top half sections of cavity	50
	9	Replace cavity external interfaces	90
	10	Repressurize coax line	15
	11	Verify coolant line and electrical connections	10
	12	Perform turn on sequence for RF station	20
	13	Confirm RF system performance is adequate	10
		Total	455

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is 14 hrs.

Based on data provided by Ed Plechowiak on 5/13/96 — NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

RF System: Driver Tube - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Driver Tube	1	Shutdown RF station	5
	2	Depressurize coax	5
	3	Remove all interface connections to cavity	60
	4	Remove top half sections of cavity	30
	5	Disconnect interfaces to tube	30
	6	Extract tube & replace with new tube	40
	7	Reconnect tube interfaces	30
	8	Replace top half sections of cavity	50
	9	Replace cavity external interfaces	60
	10	Repressurize coax line	15
	11	Verify coolant line and electrical connections	10
	12	Perform turn on sequence for RF station	20
	13	Confirm RF system performance is adequate	10
		Total	365

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is 13 hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Tube Regulation Equipment - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Bias, Heater, Screen or Ion	1	Shutdown RF station	5
Pump Supplies, or the Control	2	Access the Final Amplifier Regulator Cabinet	5
for the Final Power Amplifier	3	Remove failed power supply subassembly	15
Regulation	4	Install replacement power supply subassembly	20
	5	Perform turn on sequence for RF station	20
	6	Confirm RF system performance is adequate	10
		Total	75

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Rectifier - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Rectifier in Transformer/	1	Shutdown RF station	5
Rectifier Assembly	2	Secure power from substation to RF station	10
	3	Access the rectifier stacks in outdoor	10
		enclosure housing the transformer/rectifier.	
		Since voltage level is low (<25kV) assume	
		that air insulation is used.	
	4	Remove failed rectifiers	15
	5	Install replacement rectifiers	20
	6	Turn on substation power	10
	7	Perform turn on sequence for RF station	20
	8	Confirm RF system performance is adequate	10
		Total	100

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Transformer - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Transformer	1	Shutdown RF station	5
	2	Secure power from substation to RF station	10
	3	Disconnect transformer	30
	4	Remove failed transformer	240
	5	Install replacement transformer	240
	6	Turn on substation power	10
	7	Perform turn on sequence for RF station	20
	8	Confirm RF system performance is adequate	10
		Total	565

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: RF Station Switchgear - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
RF Station Switchgear	1	Shutdown RF station	5
Subassemblies &	2	Secure power from substation to RF station	10
Components	3	Access the components in switchgear	10
		assembly.	
	4	Remove failed components	15
	5	Install replacement components	20
	6	Turn on substation power	10
	7	Perform turn on sequence for RF station	20
	8	Confirm RF system performance is adequate	10
		Total	100

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: RF Source - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Selected Control & Monitoring	1	Turn RF station into standby mode	3
Assemblies, RF Source, or	2	Access the appropriate enclosure	5
Phase & Amplitude Control	3	Remove failed board or subassembly	10
Asemblies	4	Install replacement board or subassembly	10
	5	Turn on RF station	1
	6	Confirm RF system performance is adequate	10
		Total	39

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Controls - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Control & Monitor Assemblies	1	Turn off the RF station	5
that impact FPA Operation	2	Access the appropriate enclosure	5
	3	Remove failed board or subassembly	10
	4	Install replacement board or subassembly	10
	5	Turn on RF station	20
	6	Confirm RF system performance is adequate	10
		Total	60

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Predriver - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Predriver	1	Turn RF station into standby mode	3
	2	Access the appropriate enclosure	5
	3	Remove failed board or subassembly	10
	4	Install replacement board or subassembly	10
	5	Turn on RF station	1
	6	Confirm RF system performance is adequate	10
		Total	39

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Crowbar - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Crowbar	1	Shutdown RF station	5
	2	Access the Crowbar Cabinet	5
	3	Remove failed component or subassembly	15
	4	Install replacement component or subassembly	20
	5	Perform turn on sequence for RF station	20
	6	Confirm RF system performance is adequate	10
		Total	75

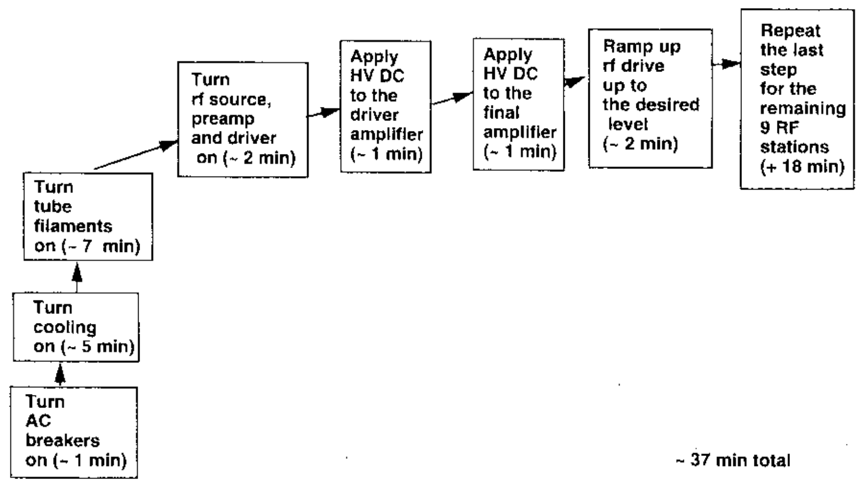
Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is TBD hrs.

Based on data provided by Ed Piechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



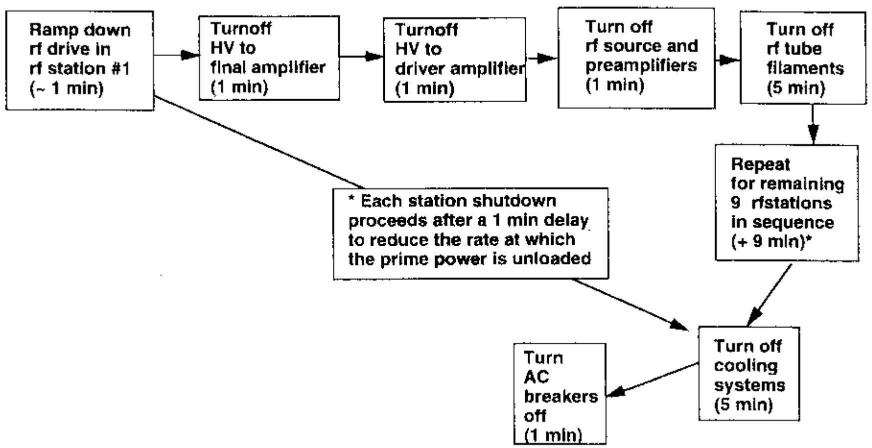
~ 37 min total

Based on data provided by Ed Piechowiak on 5/14/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



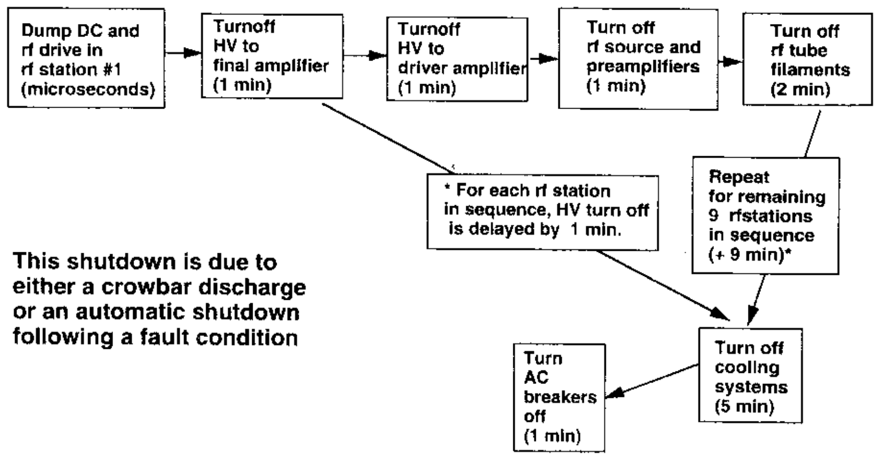
~24 min total

Based on data provided by Ed Piechowiak on 5/14/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



This shutdown is due to either a crowbar discharge or an automatic shutdown following a fault condition

~20 min total

Based on data provided by Ed Piechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

HEBT - Preventive Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	15 min
• Review long term data for trends	weekly	1 hr
• Replace/clean air filters in electronic cabinets	monthly	15 min
• Perform general housecleaning & inspection	quarterly	2 hrs
• Alignment check	annually	2 wks

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

HEBT - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Component	Failure Mode	Assumptions	Maintenance Action
Low activity room: electromagnet	Loss of field		1) Access HEBT (1 hr) 2) Replace & test (1 hr) Total: 2 hrs
High activity room: electromagnet	Loss of field		1) Cool-down (46 hrs) 2) Access HEBT (1 hr) 3) Replace & test (1 hrs) Total: 48 hrs

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

HEBT - Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

TBD

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

HEBT - Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

TBD

Bechtel - Northrop Grumman - Westinghouse

NORTHROP GRUMMAN

Target System Ground Rules and Assumptions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Repair crews are available 24 hours a day.
- The replaceable backwall requires regular maintenance/ replacement.
- Hot trap and cold trap may also require regular maintenance to limit tritium inventory on site
- At the operating temperature of 250 deg C, nozzle erosion is not expected to be a problem.
- If needed, the entire target assembly may be replaced after an extended period of operation (probably after the first 10 years - not really expected after that)

Based on data provided by Thanh Hua and Larry Green on 5/7/96

Bechtel - Northrop Grumman - Westinghouse

Target System - Preventive Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Preventive Maintenance Action	Frequency	Duration
• Backwall replacement	1/9 mo.	124 hrs
• Target assembly instrumentation* test	TBD	TBD
• Mechanical pumps maintenance**	annually	TBD
• Cold Trap Blower/Cooler mainteance**	annually	TBD
• Impurity Monitoring Loop - on line monitors	annually	TBD
• Chemistry Clean-up System - hot & cold traps	1/TBD yrs	124 hrs
• Data recording and review	1/shift	15 min
• Review long term data for trends	weekly	1 hr
• Vacuum pump replacement	annually	TBD

* Thermocouples, acoustic monitors, cameras, pressure transducers, beam wire scanner
** Monitored continuously via temperature and acoustic sensors

Based on data provided by Thanh Hua and Larry Green on 5/7/96

Bechtel - Northrop Grumman - Westinghouse

Target System: Backwall - Corrective Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Failure Mode	Assumptions	Maintenance Action
Backwall	Overheating by TBD degrees above the design limit	May occur as a result of lithium jet instability or in the event of the main loop failure. Measured with a thermocouple sensor.	1) Main (Li) loop shutdown (12 hrs) 2) Cool-down (48 hrs) 3) Test cell access (12 hrs) 4) Remote replacement of backwall (24 hrs) 5) Lithium spill cleanup, if necessary (16 hrs) 6) Main loop startup (16 hrs) 7) Evacuate test cell and target chamber (12 hrs) Total: 140 hrs
Backwall	Seal break	With an associated lithium leak	1) Shutdown (12 hrs) 2) Cool-down (48 hrs) 3) Repairs (52 hrs) 4) Startup (28 hrs) Total: 140 hrs
Backwall	Embrittlement due to radiation damage	Will be characterized more fully during the initial 3 months of system operation.	1) Shutdown (12 hrs) 2) Cool-down (48 hrs) 3) Repairs (52 hrs) 4) Startup (28 hrs) Total: 140 hrs

Based on data provided by Thanh Hua and Larry Green on 5/7/96

Bechtel - Northrop Grumman - Westinghouse

Target System: Target Chamber/EM Pump - Corrective Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Failure Mode	Assumptions	Maintenance Action
Target Chamber	Loss of Vacuum	Caused by vacuum pump failure. Redundant pumps provided. Replacement during next maintenance period. This analysis applies when both pumps fail (or as an estimate of time during the scheduled maintenance period)	1) Main loop shutdown leaving trace heaters on (7 hrs) 2) Cool-down (48 hrs) 3) Access vault (12 hrs) 4) Disconnect pump exhaust (2 hrs) 5) Replace pump (4 hrs) 6) Evacuate test cell and target chamber (12 hrs) 7) Main loop startup (11 hrs) Total: 96 hrs
EM Pump	Loss of pressure head	Only return duct EMP stator replacement considered.	1) Shutdown (12 hrs) 2) Cool-down (72 hrs) 3) Repairs (48 hrs) 4) Startup (16 hrs) Total: 148 hrs

Based on data provided by Thanh Hua and Larry Green on 5/7/96

Bechtel - Northrop Grumman - Westinghouse

Target System: Valves in Li & Organic Loops- Corrective Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Failure Mode	Assumptions	Maintenance Action
Valve	Leak	Assuming an all welded system. Valve replacement involves cutting and rewelding. Includes Li spill cleanup, etc.	1) Main loop shutdown (12 hrs) 2) Cool-down (72 hrs) 3) Repairs (144 hrs) 4) Startup (16 hrs) Total: 244 hrs
Primary HX	Leak	Leak detected by gamma-ray monitors on the organic side of the loop or buildup of carbon in the impurity monitoring system.	1) Shutdown - 4 hours extra for organic coolant drainage (16 hrs) 2) Cool-down (72 hrs) 3) Repairs (140 hrs) 4) Startup (16 hrs) Total: 244 hrs

Based on data provided by Thanh Hua and Larry Green on 5/7/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Target System: Prime Power - Corrective Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Failure Mode	Assumptions	Maintenance Action
Prime Power	Loss of power	Prime power backed-up by an emergency generator. However, if emergency power fails as well, programmed startup required to avoid trapped lithium expansion.	1) Stepwise startup (48 hrs) Total: 48 hrs

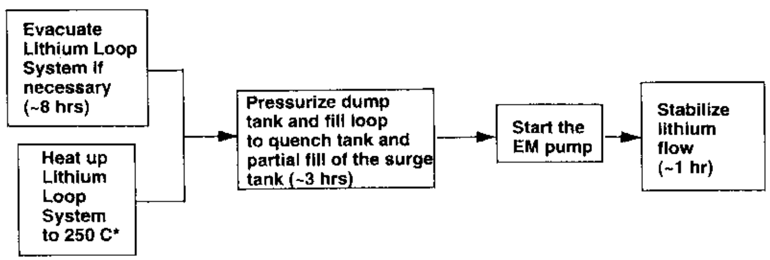
Based on data provided by Thanh Hua and Larry Green on 5/7/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Target System - Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Assumptions:
- Impurity control processes not included
- Evacuation of Test Cell Proceeds simultaneously with step 1
- *Lithium already melted in the dump tank

Total: 12 hrs

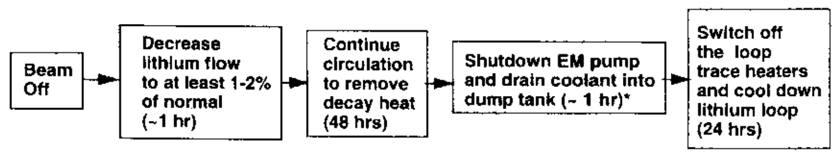
Based on data provided by Thanh Hua and Larry Green on 5/7/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Target System - Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Assumptions:
- *Not applicable if loop continues service to the second target

Total: 74 hrs

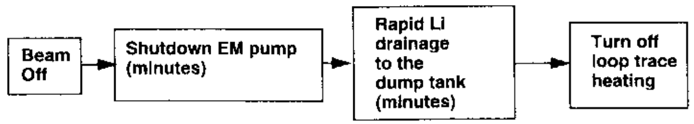
Based on data provided by Thanh Hua and Larry Green on 5/7/96

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Target System - Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



This type of shutdown would apply in case of a lithium leak, organic leak into lithium, instrumentation failure, etc.

Total: minutes

Bechtel - Northrop Grumman - Westinghouse

Test Cell System Ground Rules and Assumptions

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- Highly activated assemblies will be designed for replacement rather than repair.
- The He coolant loops have hands-on access (in the Access Cell only and when the shield plug is closed) because He does not get activated
- Utility systems (vacuum, inert gas coolant loop and instrumentation) are placed in the Technology Room with hands-on repair capability (Need to cool-down TBD)
- Components requiring remote handling will be designed to match available remote handling systems
- Special purpose cells will be used to perform repetitive tasks such as module change-out and specimen sorting
- If the VTA fails, specimens are quickly reloaded into a spare VTA
- Two VTAs will be used in normal operations to reduce specimen changeout time.
- Personnel training will be required to perform remote handling operations. Cold mock-up areas will be used for personnel training for specific rare event repair tasks (obviously, such training will be very expensive. The system should be designed so that all such high criticality events are also very unlikely - NOT EXPECTED DURING THE ENTIRE FACILITY LIFETIME).

Based on data provided by Mark Rennich and Dan Williams on 4/30/96
Reviewed by Anton Moslang on 5/20/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Preventive Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	5 min
• Review long term data for trends	weekly	1 hr
• Inspect VTAs during module changeout	1/9 mo.	TBD
• VTA refurbishment	1/9 mo.	TBD

Based on data provided by Mark Rennich and Dan Williams on 4/30/96
Reviewed by Anton Moslang on 5/20/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Normal Specimen Changeout Process

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Changeout Action	Duration (days)
• Shutdown cell operations	1
• Changeout target assembly	3 *
• Remove specimen modules from VTAs	2 **
• Remove specimens from modules	1 **
• Sort and reload VTA modules	30 **
• Install modules on VTAs	5 **
• Install VTAs in Test Cell	2
• Startup Test Cell	1

Total: 7 days

* Every 9 months, if necessary
** With 2 VTAs, this activity proceeds independently of beam operations.

Based on data provided by Mark Rennich and Dan Williams on 4/30/96
Reviewed by Anton Moslang on 5/20/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

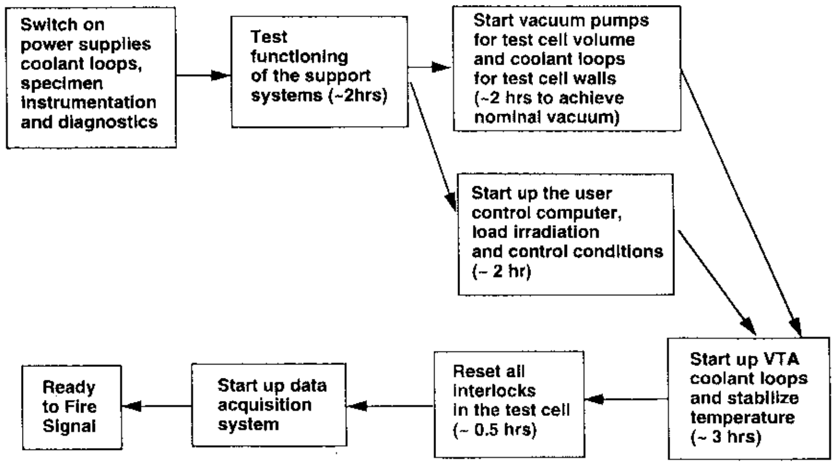
Compo-nent	Failure Mode	Assumptions	Maintenance Action
• VTA	TBD	1/2-3 years	Replace VTA - spare available (5+ days)
• Cell Liner	TBD	1/10 years	Replace Test Cell Liner (2+ wks)
• Heat Shield	TBD	Not expected	Replace Heat Shield (3-6 months)
• Nak Loss	Leak	1/10 yrs	Strip Test Cell & Cleanup (2-4 wks)
• Utility eqpt	TBD	1/4 months	Hands on maintenance (8 hrs)

Based on data provided by Mark Rennich and Dan Williams on 4/30/96
Reviewed by Anton Moslang on 5/20/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

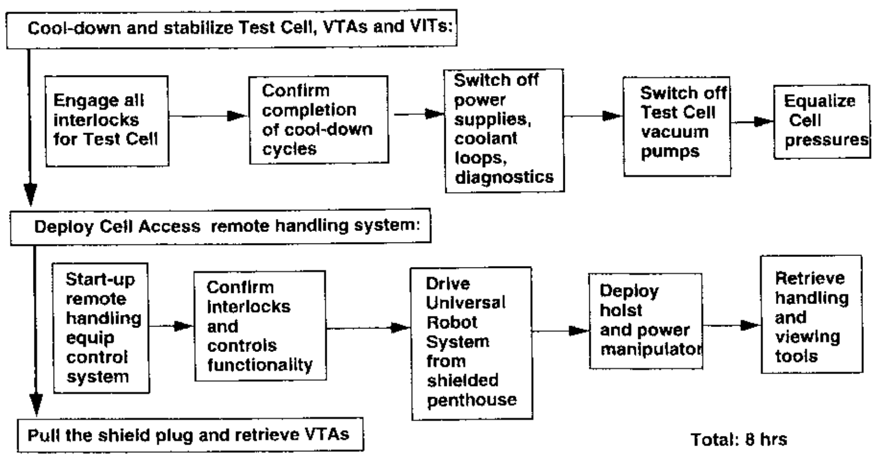


Based on data provided by Mark Rennich and Dan Williams on 4/30/96
Reviewed by Anton Moslang on 5/20/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

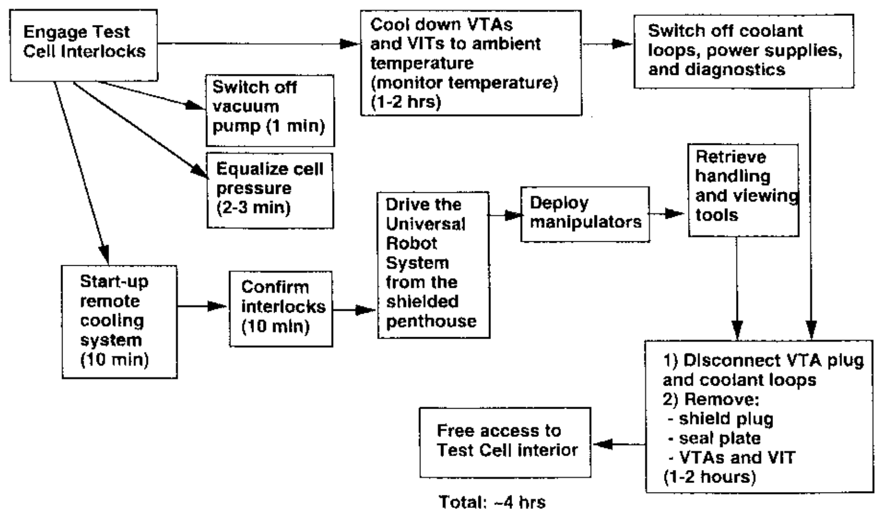


Based on data provided by Mark Rennich and Dan Williams on 4/30/96

Bechtel - Northrop Grumman - Westinghouse

Test Cell System - Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*



Bechtel - Northrop Grumman - Westinghouse

Central I&C - Ground Rules and Assumptions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Central control system will be automated to the extent that relatively few operators can operate and maintain it.
- Central controls will provide a run-permit function that shall continually monitor the state and performance of all the critical subsystems functions.
- Central control system will support maintenace and trouble-shooting using diagnostics distributed throughout the facility and archived time-tagged diagnostics data, status data, and values of plant perfomance parameters. Subsets of stored data will be available for near real-time and post-run analysis.
- Central control system will provide fault detection, shutdown, and recovery at which a predefined set of faults will initiate sequential control recovery processes.
- Central control system shall provide hardware and software features that enable the operator to run confidence tests of the control system itself.
- Central Control System's main computer system includes 4 CPUs in a redundant configuration. In addition, the support computer can take over the main computer's function for a limited time, if necessary.

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Central I&C - Preventive Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Preventive Maintenance Action	Frequency	Duration
• Data recording and review	1/shift	15 min
• Review long term data for trends	weekly	1 hr
• Replace/clean air filters in electronic cabinets	monthly	15 min
• Replace demineralizer/deionizer cartridges	quarterly	30 min
• Lubricate bearings in pumps and blowers	annually	30 min
• Perform general housecleaning & inspection	quarterly	2 hrs
• Data backup management	weekly	1 hr
• Test of uninterruptible power supplies	weekly	1 hr
• Test of the cable TV system	monthly	1 hr
• Check out of the radiation monitoring system	semiannually	1 hr
• Replacement of TV cameras in high radiation env.	TBD	TBD

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Central I&C - Corrective Maintenance

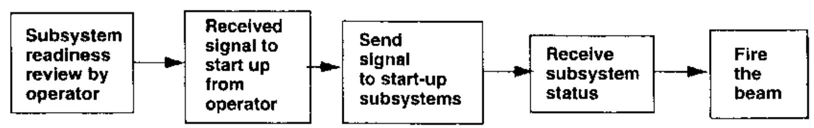
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Component	Failure Mode	Assumptions	Maintenance Action
Main Computer	TBD	Main computer has 4 CPUs in a redundant configuration. In addition, the support computer can take over the function of the main computer for a limited period.	TBD

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Central I&C - Typical Timeline for Normal Startup

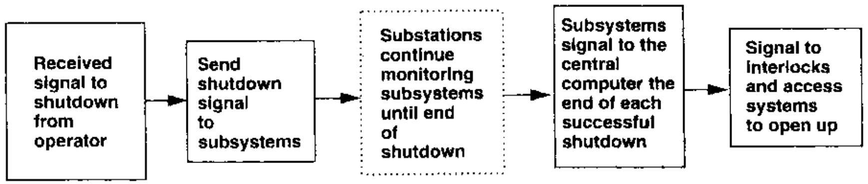
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Central I&C - Typical Timeline for Normal Shutdown

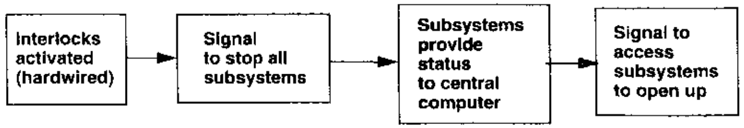
International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse

Central I&C - Typical Timeline for Off-Normal Shutdown

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



The hardwired interlock logic bypasses the main computer in this scenario

Bechtel - Northrop Grumman - Westinghouse

Conventional Facilities - Ground Rules and Assumptions

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Conventional facilities are responsible for supply of all electrical power, operational heat rejection, and plant HVAC.
- Electrical power in the form of high voltage AC is supplied by the facilities from the grid across the local substation. Redundancy at this level is very costly and will not be implemented.
- Depending on the final location of the IFMIF facility, power outages due to lightning storms could contribute significantly to unavailability.
- Emergency diesel electric generator is being considered to maintain essential loads. Uninterruptible power supplies will be provided to assure orderly shutdown of the system in the event of an unexpected power failure.
- Heat rejection system, including the cooling tower and a circulating water system with pumps, pipes, fittings and valves, water treatment system, etc., will be designed with ample margin and redundancies to permit maintenance and repairs without the need to stop the beam to the maximum extent possible.
- Plant heating and ventilation subsystems shall contain multiple redundancies. Full availability shall be assured with regular maintenance.

Bechtel - Northrop Grumman - Westinghouse

Conventional Facilities - Preventive Maintenance

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

Preventive Maintenance Action	Frequency	Duration
• Check SF6 pressure in HV equipment	weekly	TBD
• Check insulating oil level in HV equipment	weekly	TBD
• Check dessicants (color of silica gel)	weekly	TBD
• Replace light bulbs	weekly	1 hr
• Grounding checkout	monthly	TBD
• Replace/clean air filters in HVAC	monthly	1 hr
• Replace demineralizer/deionizer cartridges	quarterly	30 min
• Test overload relays alarms	semiannually	TBD
• Service pumps and blowers	annually	30 min
• Perform general housecleaning & inspection	TBD	TBD
• Test dielectric strength of insulating oil	annually	TBD
• Clean bushings & radiator contacts	annually	TBD

Bechtel - Northrop Grumman - Westinghouse

Conventional Facilities - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Component	Failure Mode	Assumptions	Maintenance Action
Electric Power	TBD	TBD	TBD
Operational Heat Rejection	TBD	TBD	TBD
HVAC	TBD	TBD	TBD

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Conventional Facilities - Typical Timeline for Normal Startup

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

NOT APPLICABLE

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Conventional Facilities - Typical Timeline for Normal Shutdown

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

NOT APPLICABLE

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Appendix-5.3 Documents Presented at Target Group Meeting

Table of Contents

IFMIF D. I. Meeting at JAERI 20, May 1996

Target System Group

Discussion Points

Y. Kato (JAERI)

1) **Reconfirmation of our Target System Flowsheet**

* Reconfirmation of our Total Target System Flowsheet

* Other cooling method for the target decay heat :
  Independent cooling lines with small scale EMP.

* Function of the Surge Tank

* Target - Accelerator Interface
  Differential pumping system with each spare.

2) **Target System cell Structure and Ventilation System**

* Two images of Target System Cell
  Concept of cell rooms: Radiation shieldings may be functioned by the room walls.
  Optimizations for installation and repair are required.
  Unit cell : Radiation shieldings for each components are required.
  Installation and repair will be simple.
  Separation wall will be required between main lithium system and water cooling system.
* Selection of gas for the ventilation in Lithium System Cell.
  The cost of Ar gas system will be very high but at the replacement of the target assembly/replaceable backwall, Ar gas should be filled and ventilated in the Test Cell at least.
* Interface with conventional facility
  Tritium safety and Li hazard

3) **Lithium System Design**

* Design base for cost estimation
  Maximum design parameters of lithium flow rate
  Is it proper to use 20 m/s ?
* Cavitation problem of EMP
  The problem may be improved by some recent progress on the EMP. The height of the lithium system depends on this progress of EMP and/or success of diffuser in the target assembly.

4) **Target Assembly Design**

* Lifetime of the nozzle
  The lifetime will be determined by erosion and by deuteron or neutron damage.
  The nozzle lifetime is just the lifetime of target assembly. Otherwise, replaceable nozzle-back plate unit should be developed.
* Lip welding technology
  In the remote handling system to replace a backwall or an assembly, the lip welding technology may be one of the key issue.

5) **Lithium Impurity Monitoring and Purification System**

* Tritium inventory in the conventional facility
  The operation time (repair time) of a cold trap and hot traps may be restricted by the licensing limit of the Tritium mass.
  The space for used cold traps and hot traps.
* Design for the remote handling system
* Design for the heat valance in purification system
  Reheater will be required to the cold trap.

6) **Cost Estimation**

* Definitions of the items
* How to treat the vacant column
  Fill out with large uncertainty or leave them vacant as pending matters.
* How to make the agreement for the final cost estimation

7) **Planning for EVP**

* Preliminary discussion for the work sharing

IFMIF Lithium Target System

Flowsheet and System Layout

Presented by

Y. Kato
JAERI Target Group

May 1996
IFMIF D. I. Meeting at JAERI

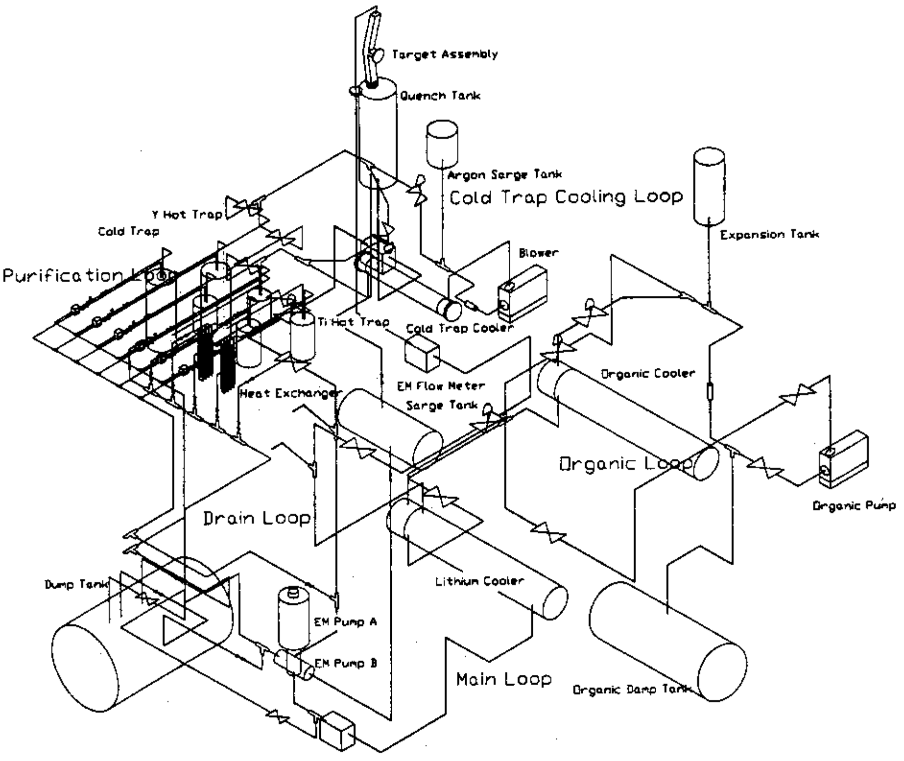


Fig. Isometric View of IFMIF Target System

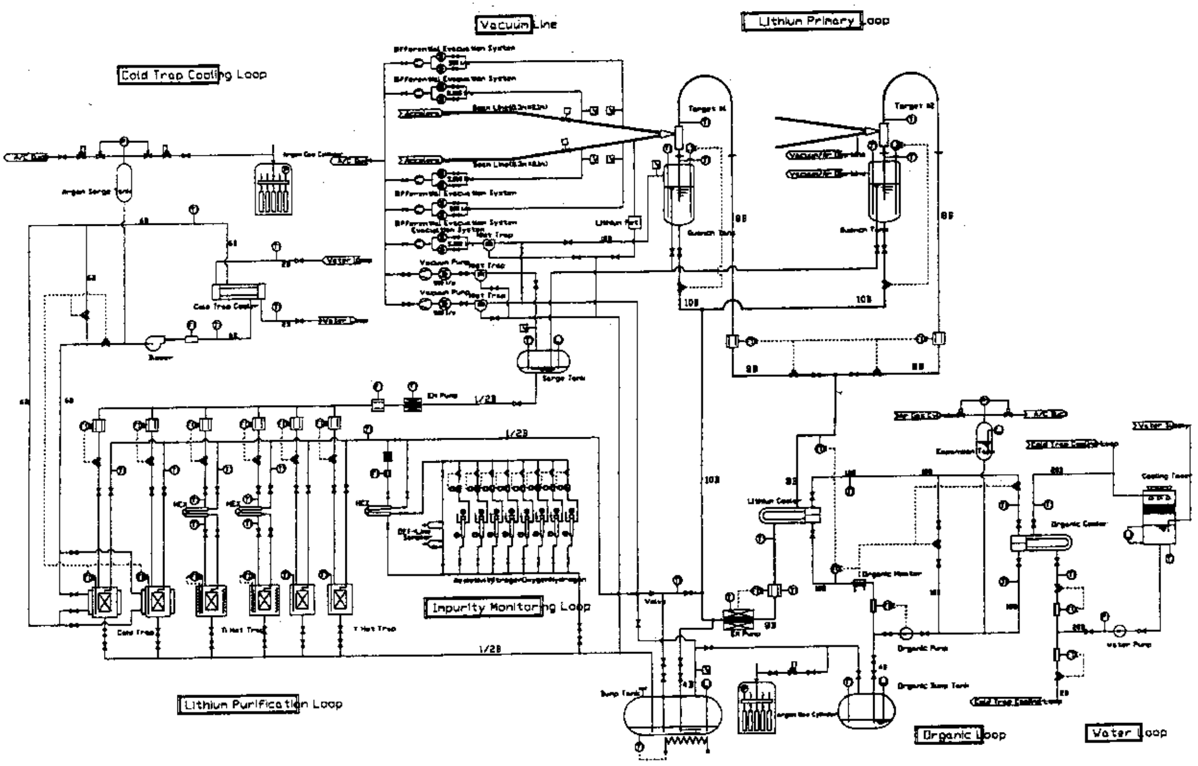


Fig.1 Flow Diagram of Lithium Loop System

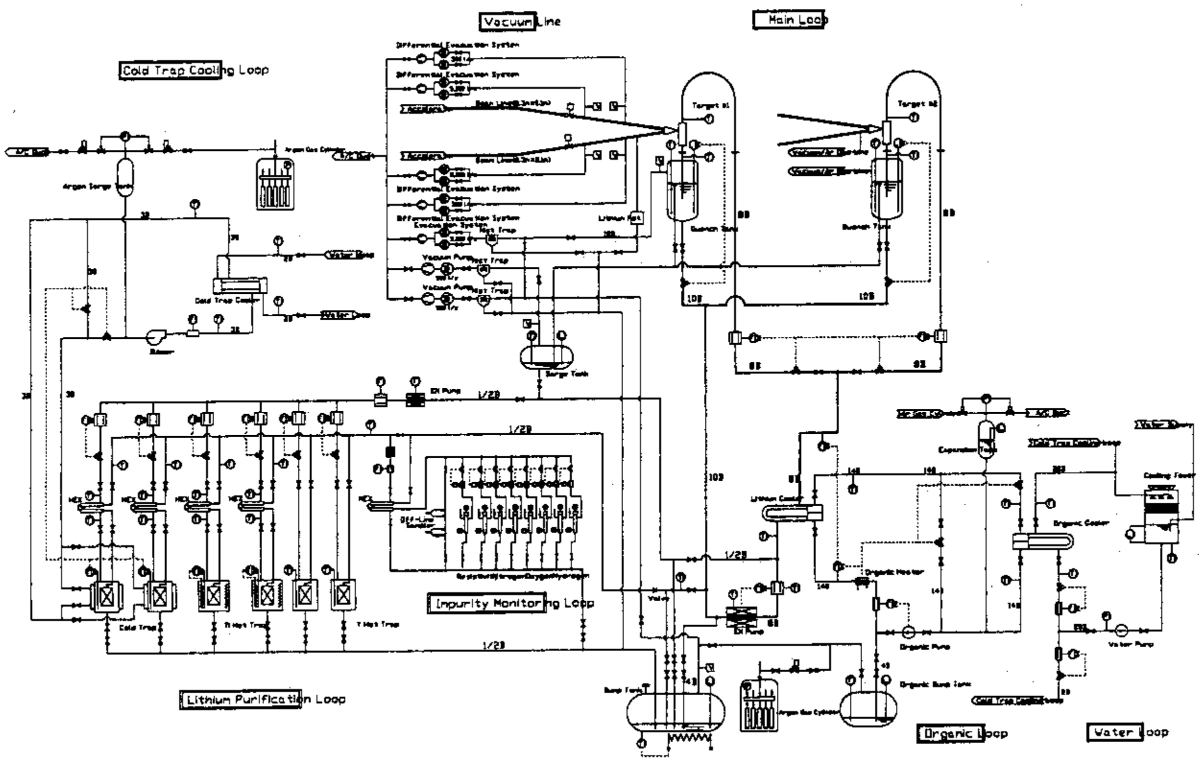


Fig.1 Flow Diagram of Lithium Loop System

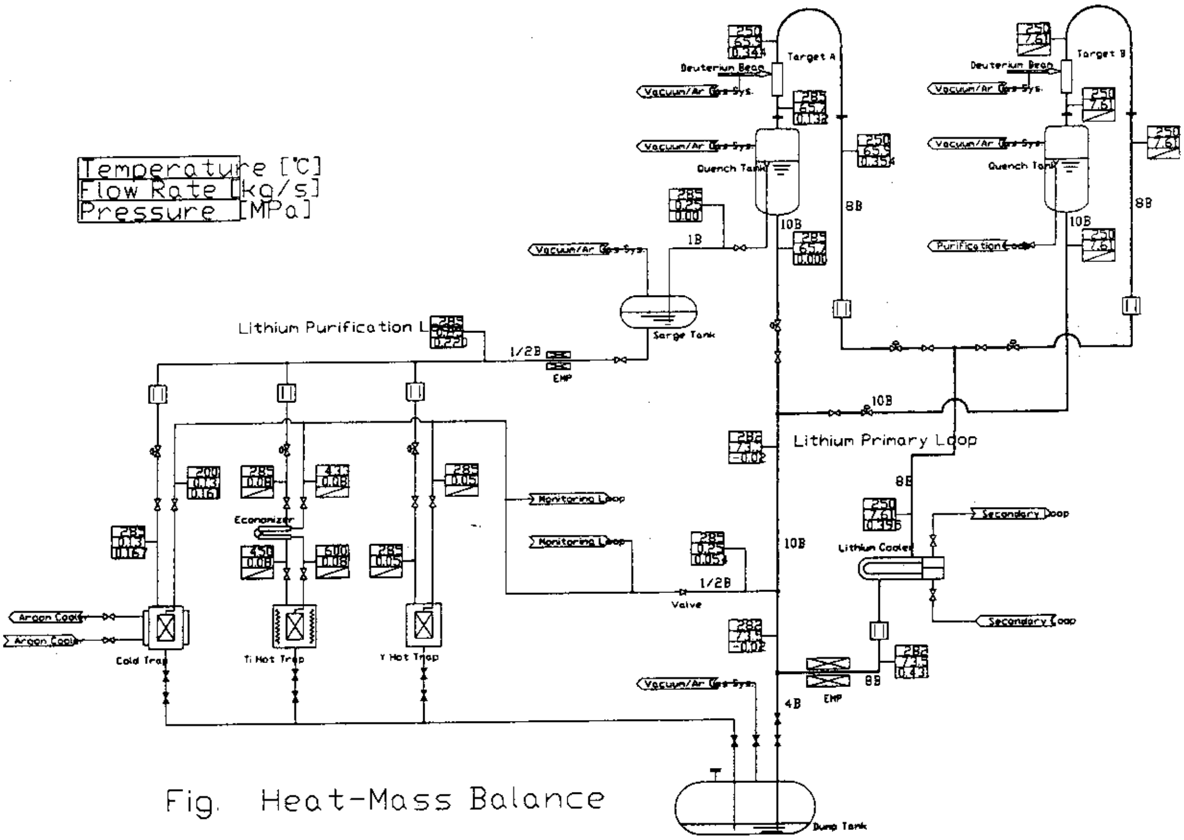


Fig. Heat-Mass Balance

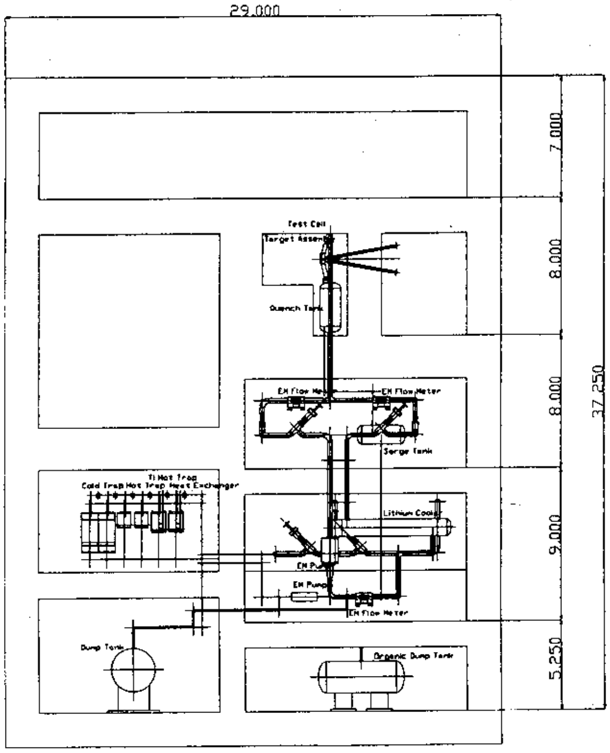


Fig. Cross Section View (A-A)

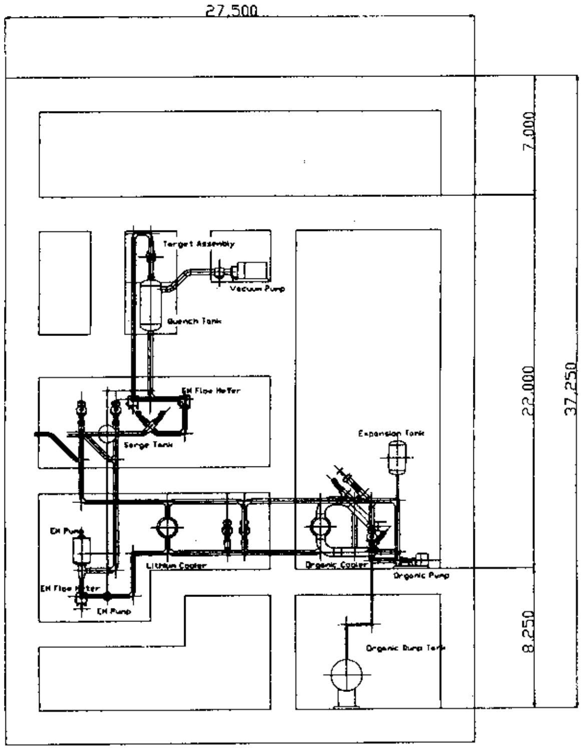


Fig. Cross Section View (B-B)

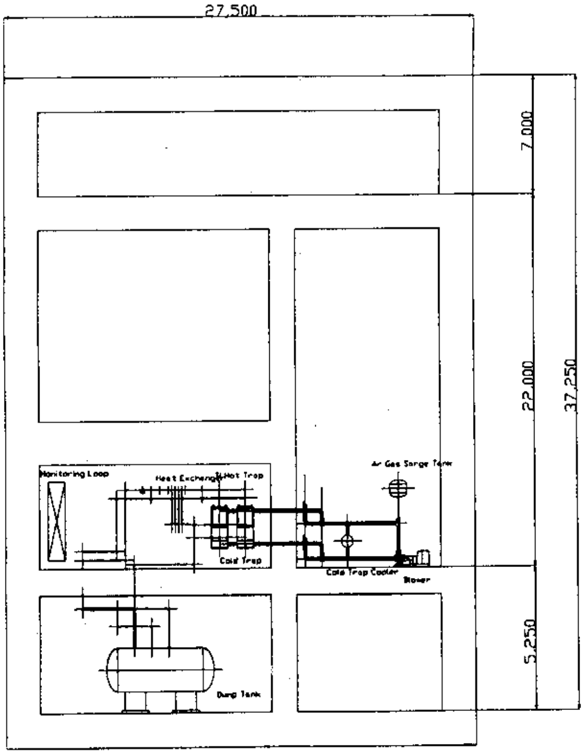


Fig. Cross Section View (C-C)

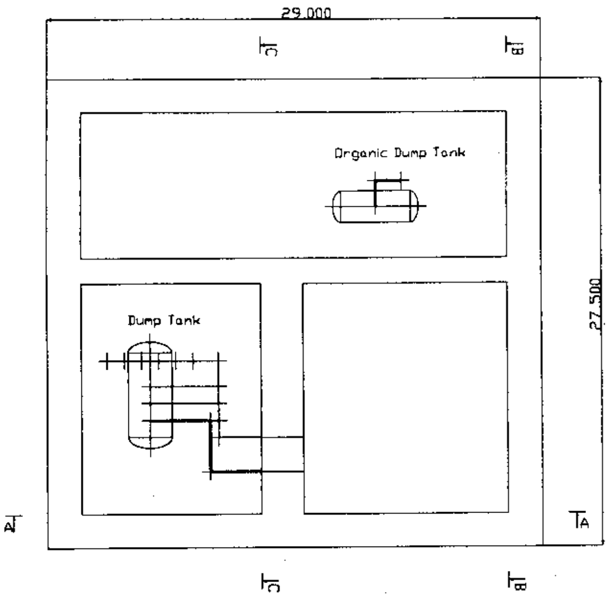


Fig. Plan View(1F)

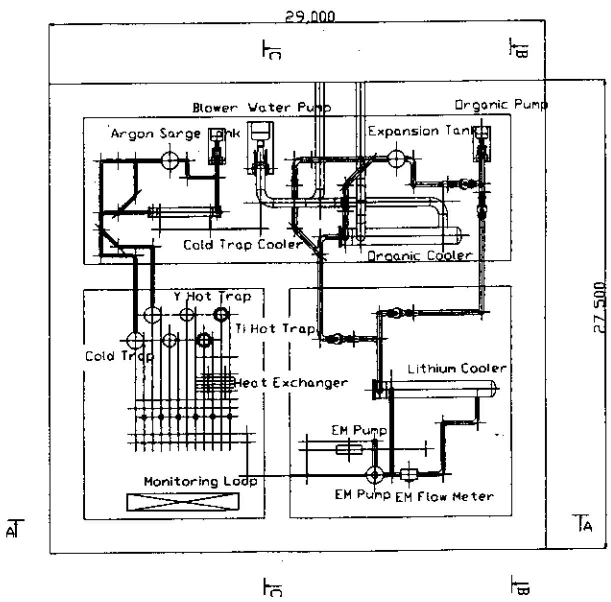


Fig. Plan View (2F)

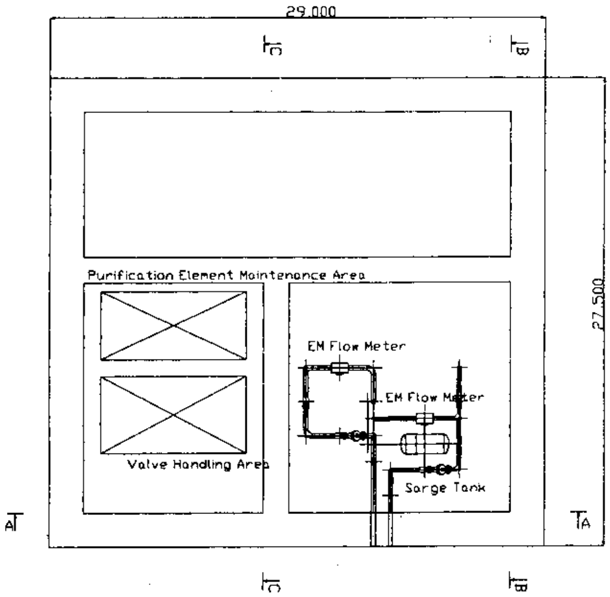


Fig. Plan View (3F)

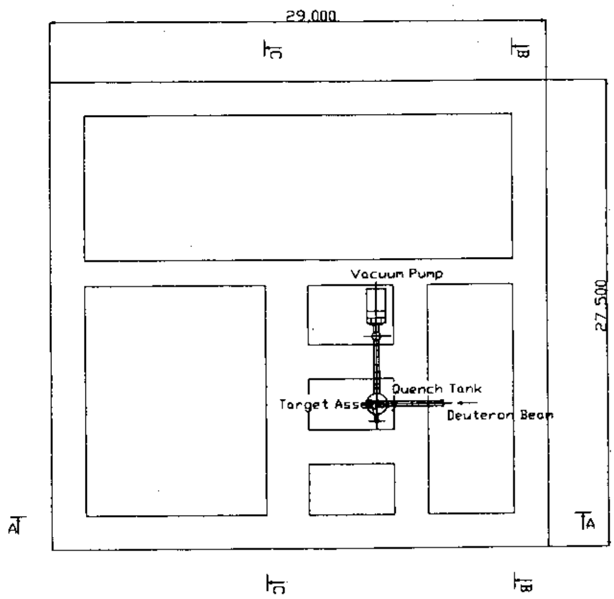


Fig. Plan View (4F)

REVIEW OF REPLACEABLE BACKWALL DESIGN

Presented by

Thanh Hua
Argonne National Laboratory

IFMIF Design Integration Meeting, May 20-26, 1996 at JAERI, Tokai, Japan

Decay Heat in Backwall

- Preliminary neutronic calculations (Gomes) Showed main contributions to decay heat in ferritic steel are Mn-52 ($t_{1/2}$=5 d), and Co-58 ($t_{1/2}$=70 d).

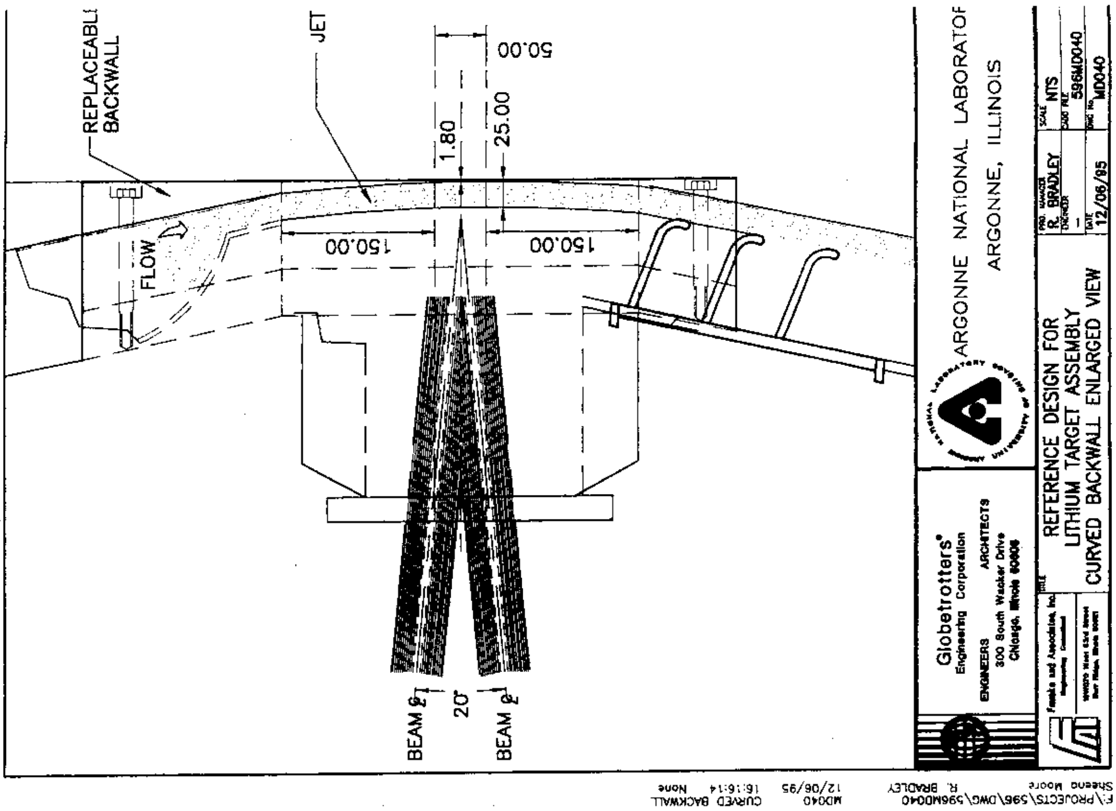
- Therefore decay heat doesn't change much in the first few days after loop shutdown. After 1 week, decay heat is reduced to about half. Decay heat is probably less serious for vanadium

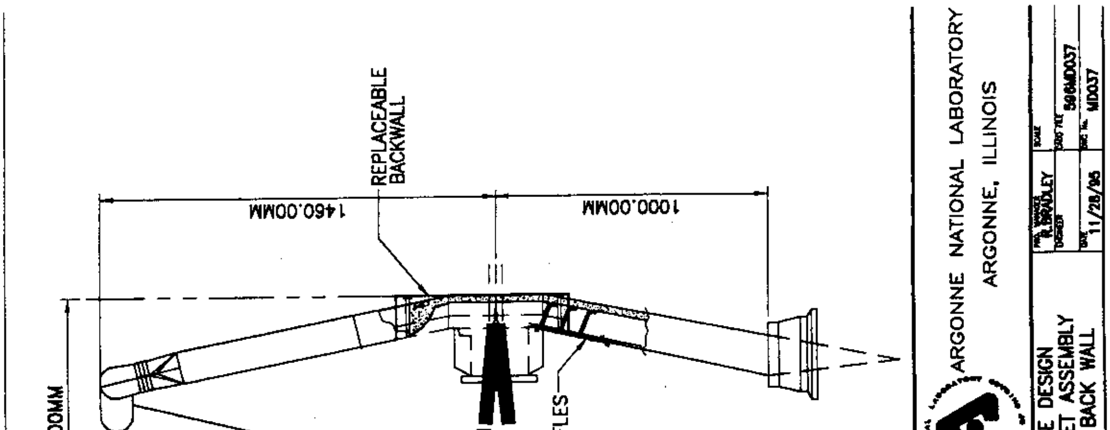
- Long cooldown time affects plant availability

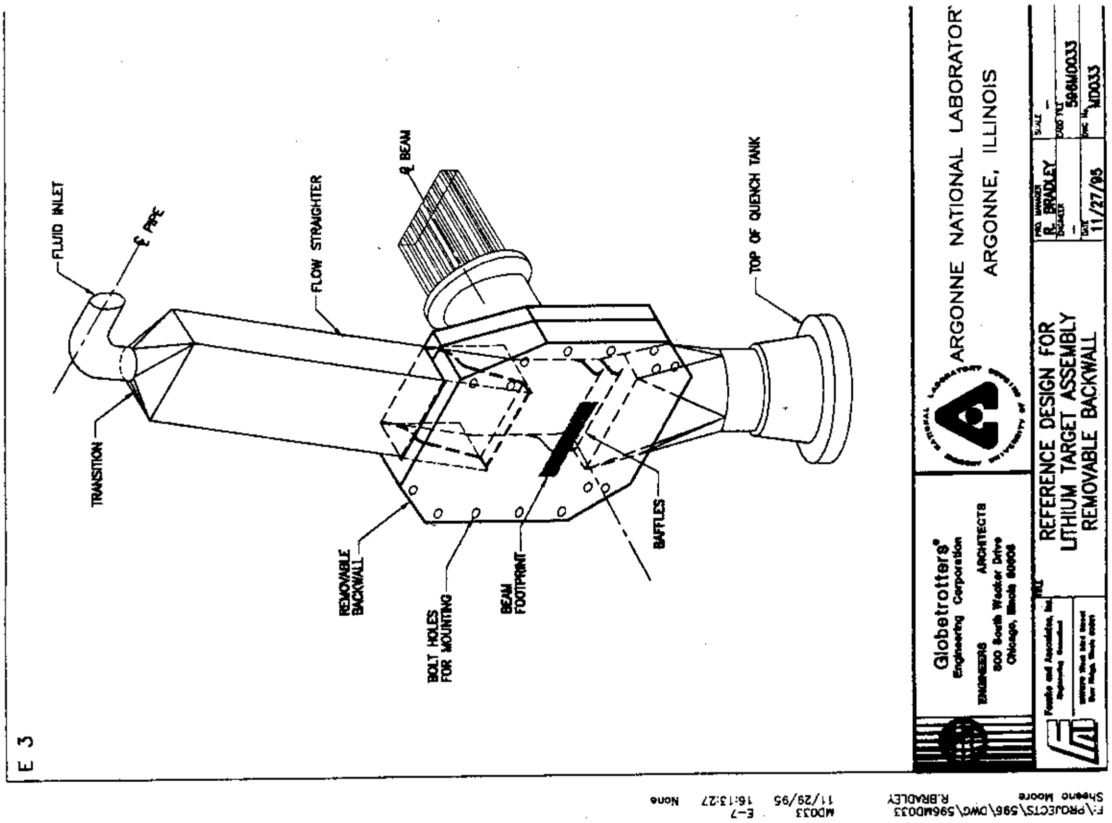
- Decay heat:
  - At beam footprint: ~1.5 w/cc
  - Outside beam footprint: <0.4 w/cc

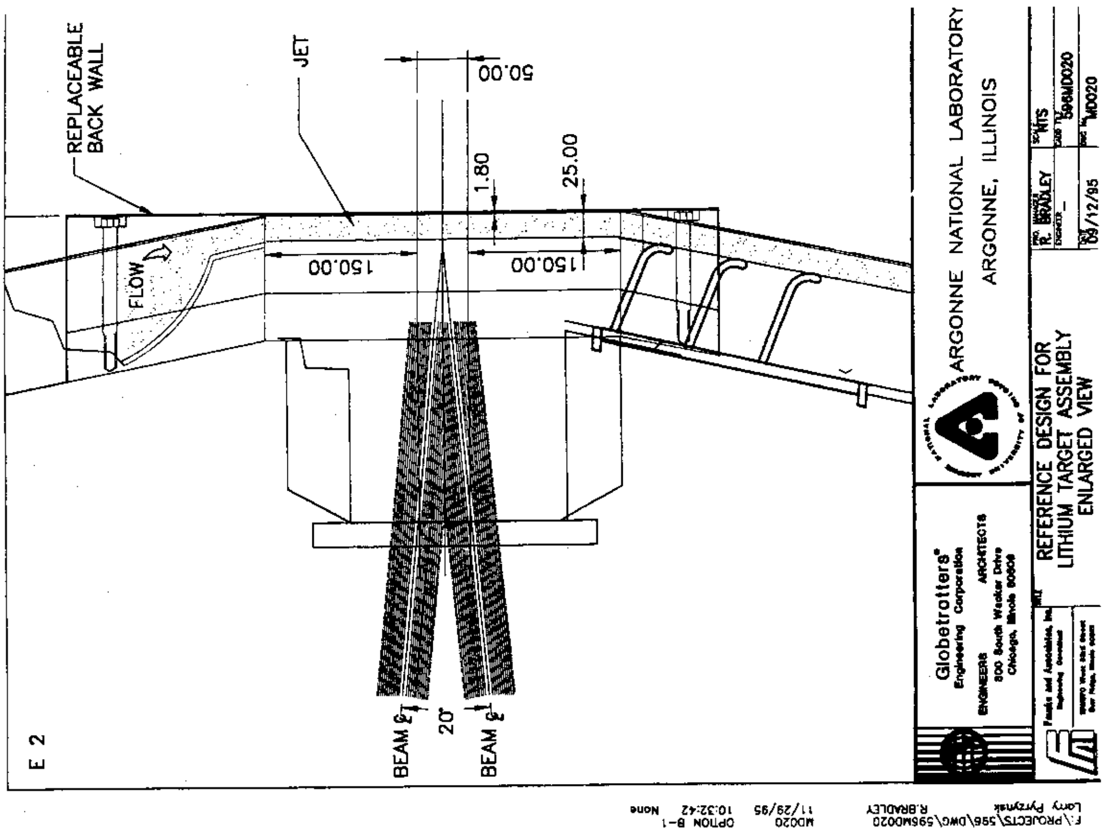
- Without active cooling(loss of flow), and if conduction or radiation is not considered, initial temperature rise at the beam footprint for steel is ~ 0.3 deg/s, at this rate the material will melt in less than 2 hours

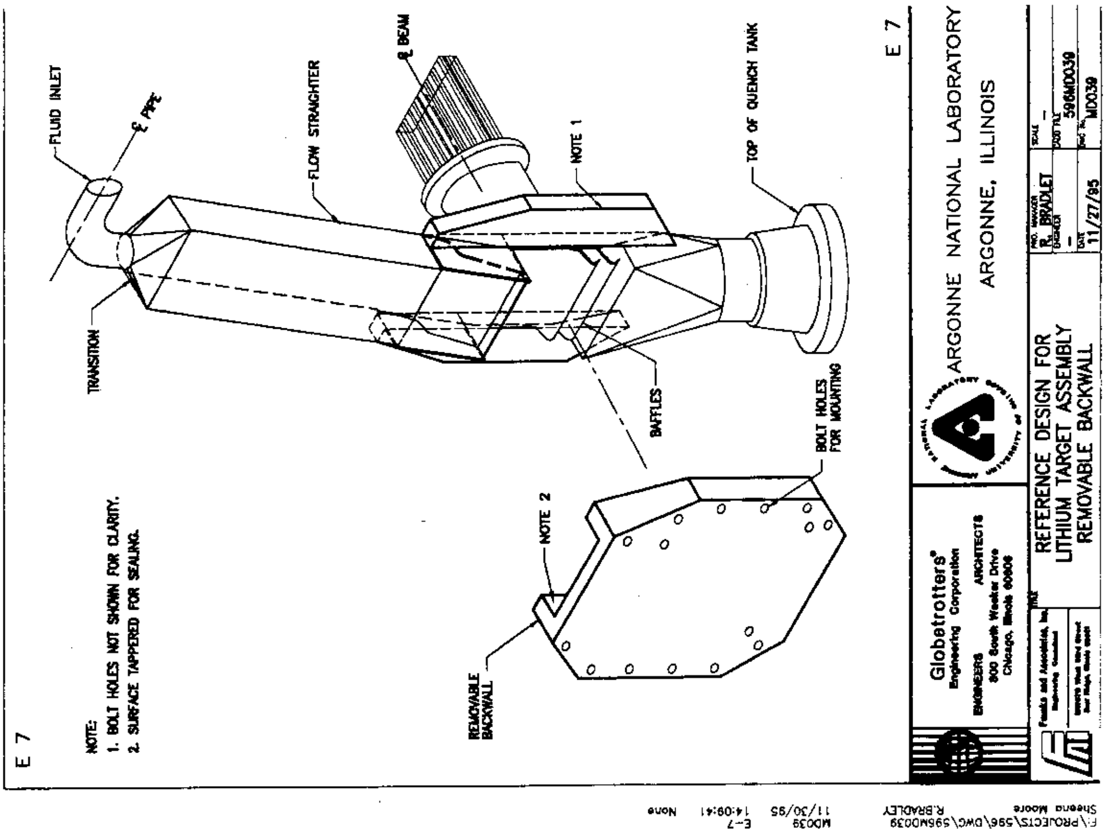
- <u>Thermal analysis will be needed to assess the impact of decay heat</u>

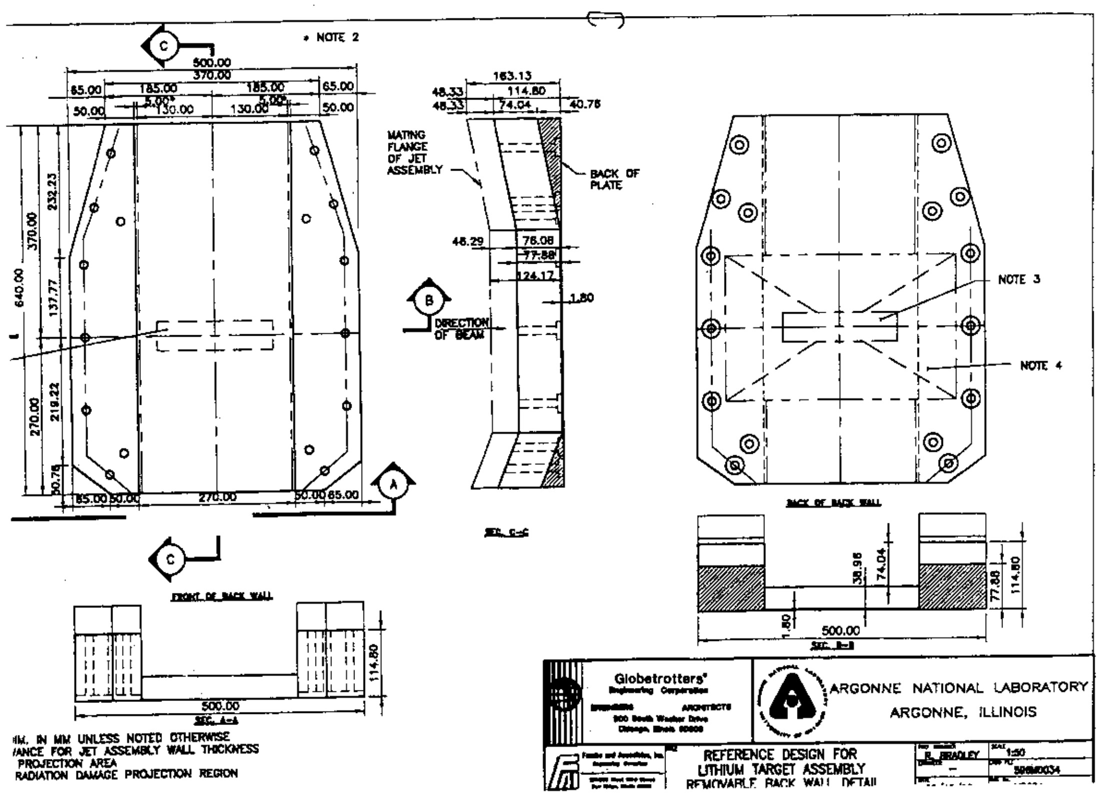

REPLACEABLE BACKWALL
JET
50.00
1.80
25.00
150.00
150.00
FLOW
BEAM
20°
BEAM
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
ENGINEERS ARCHITECTS
300 South Wacker Drive
Chicago, Illinois 60606
REFERENCE DESIGN FOR
LITHIUM TARGET ASSEMBLY
CURVED BACKWALL ENLARGED VIEW
R. BRADLEY
NTS
596MD040
12/06/95
MD040

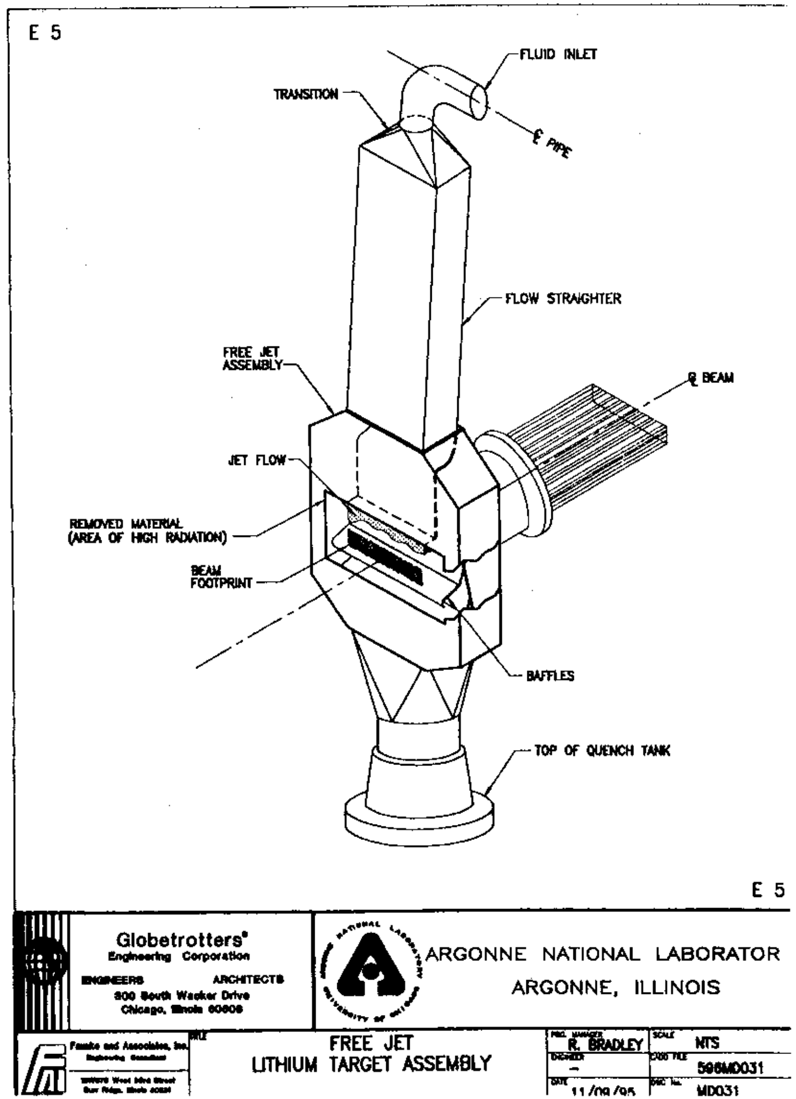

REPLACEABLE BACKWALL
1460.00MM
1000.00MM
1000.00MM
FLOW
BEAM
BEAM
BAFFLES
E 1
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
ENGINEERS ARCHITECTS
300 South Wacker Drive
Chicago, Illinois 60606
REFERENCE DESIGN
LITHIUM TARGET ASSEMBLY
REMOVABLE BACK WALL
R. BRADLEY
596MD037
11/28/95
MD037


FLUID INLET
℄ PIPE
FLOW STRAIGHTENER
℄ BEAM
TOP OF QUENCH TANK
TRANSITION
REMOVABLE BACKWALL
BOLT HOLES FOR MOUNTING
BEAM FOOTPRINT
BAFFLES
E 3
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
REFERENCE DESIGN FOR LITHIUM TARGET ASSEMBLY REMOVABLE BACKWALL
R. BRADLEY
11/27/95
596MD033
MD033


REPLACEABLE BACK WALL
JET
50.00
1.80
25.00
150.00
150.00
FLOW
BEAM ℄
20°
BEAM ℄
E 2
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
REFERENCE DESIGN FOR LITHIUM TARGET ASSEMBLY ENLARGED VIEW
R. BRADLEY
09/12/95
NTS
596MD020
MD020


E 7
FLUID INLET
℄ PIPE
FLOW STRAIGHTENER
℄ BEAM
NOTE 1
TOP OF QUENCH TANK
TRANSITION
BAFFLES
BOLT HOLES FOR MOUNTING
NOTE 2
REMOVABLE BACKWALL
NOTE:
1. BOLT HOLES NOT SHOWN FOR CLARITY.
2. SURFACE TAPPERED FOR SEALING.
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
REFERENCE DESIGN FOR LITHIUM TARGET ASSEMBLY REMOVABLE BACKWALL
R. BRADLEY
11/27/95
MD039


NOTE 2
MATING FLANGE OF JET ASSEMBLY
BACK OF PLATE
DIRECTION OF BEAM
NOTE 3
NOTE 4
FRONT OF BACK WALL
BACK OF BACK WALL
SEC. A-A
SEC. B-B
SEC. C-C
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS
Globetrotters Engineering Corporation
REFERENCE DESIGN FOR LITHIUM TARGET ASSEMBLY REMOVABLE BACK WALL DETAIL



Welding Design for Replaceable Backwall

Presented by

H. Katsuta
JAERI Target Group

IFMIF Design Integration Meeting, May 20-26, 1996
at JAERI

Welding Design for Replaceable Backwall

For the remote-handling replaceable backwall, the seal structure for confinement of lithium leakage is the most important problem. A welding connection is one of methods to realize the firm seal with no leakage. The YAG laser welding/cutting device recently developed using a high average power YAG laser can perform sealing and welding for remote-replace backwall by controlling the laser power.

Fig. 1 shows schematic of the total system primarily composed of a high-power laser oscillator, a optical fiber cable for power transmission and a compact welding head being positioned by a manipulator. A distinct advantage of this system is the capability to maximize the laser output while keeping the beam quality necessary for coupling into the optical fiber cable. The silica-glass-made optical fibers with a core diameter of 1.0 mm enables transmission of 4.8 kW laser power with high transmission efficiency (>90%) for the transmission distance of more than 120 m.

As shown in Fig. 2 and Fig. 3, this laser system confines lithium leakage by power-controlled fine "lip-seal welding" on the edge of the two thin-plate rims of the backwall and the target assembly. The pressing plate fixes the backwall onto the target assembly. By increasing the laser power, the system cuts the welded edge of the rims. For one pair of rectangular rims, more than five times of welding/cutting procedure are possible. The thin-plate rims can be placed on the test assembly side for ease of backwall maintenance. Minimization of the amount of sputter during the cut operation is one issue to limit radioactive spread around the target assembly.

This laser system is applicable to any part of the target assembly including inlet piping, nozzle, diffuser, and so on. The remote-replacing flange with "lip-seal" structure is used to join piping as shown Fig. 1, enabling the remote replacement of the whole target assembly without seal ring.

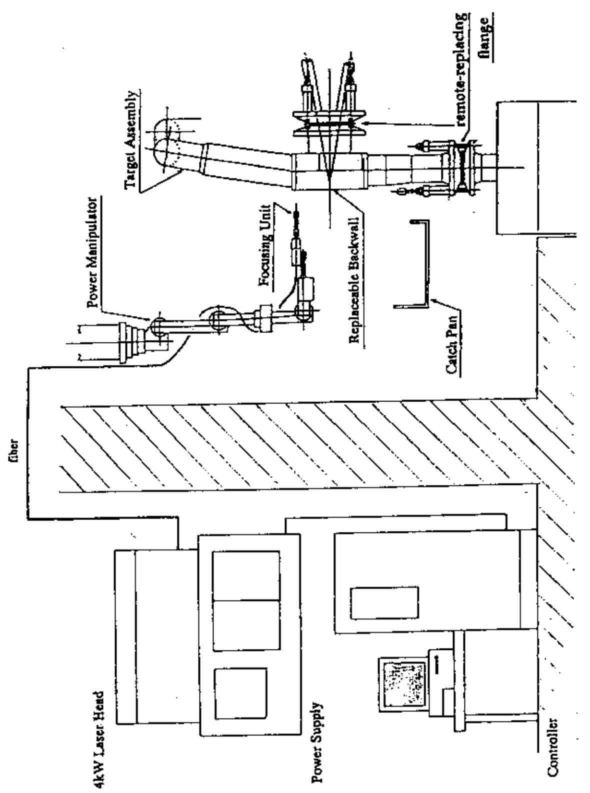


Fig. -1. Schematic of the YAG Laser Processing System

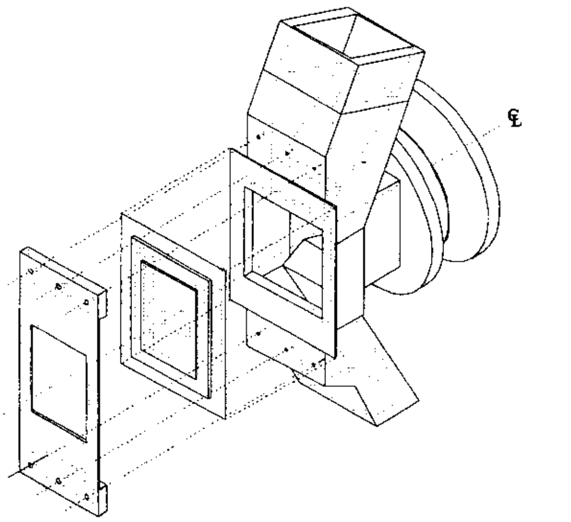


Fig. 2 Replaceable Backwall Attachment Scheme (Bolt-Fix, Welding-Seal Type)

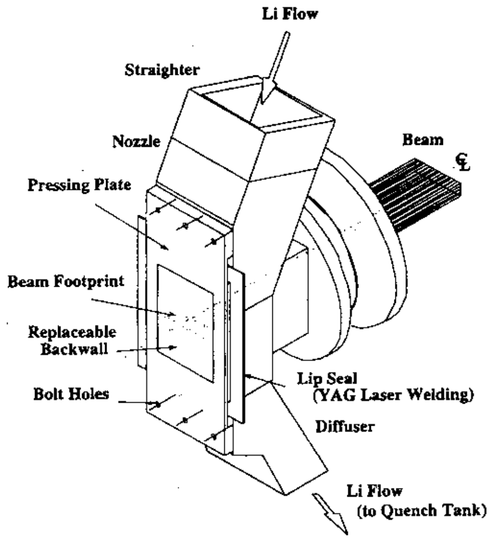


Fig. 3 Replaceable Backwall Attachment Scheme (Bolt-Fix, Welding-Seal Type)

ENEA	ERG FISS	Contribution to the IFMIF-CDA Design Integration Meeting Tokai (Japan), May 20-25, 1996 B. Baratozzi, S. Cevolani, D. Tirelli

IFMIF Replaceable Back Plate Attachment Scheme.

Preliminary Report

by

B. Baratozzi, S. Cevolani, D. Tirelli

ENEA-ERG-FISS
Bologna (Italy)

Presented by
G. Benamati

cevolani, arap2\ifmif\relazioni\Tokai96 - 09/05/96

Replaceable back wall concept:

- proposed by ANL during the *IFMIF-CDA Technical Workshop on Lithium Target System*, held in Tokai in July 1995. Adopted as back-up solution.

- adopted as reference solution for the IFMIF design, during the *IFMIF Design Integration Workshop*, held in Oak Ridge in October 1995.

ENEA | ERG FISS | Contribution to the IFMIF-CDA Design Integration Meeting
Tokai (Japan), May 20-25, 1996
B. Baratozzi, S. Cevolani, D. Tirelli

Main Features of the Attachment Scheme proposed by ENEA:

- No bolts: the back plate is held in place by means of a bayonet connection.
- No necessity to move the Test Assembly for changing the back plate.
- Good possibility of recovering the differential expansions.
- Good sealing with respect to the Test & Target Cell.
- Small (and modifiable) gap at the transition between back plate and nozzle.

cevolani, arap2\ifmif\relazion\Tokai96 - 09/05/96

ENEA | ERG FISS | Contribution to the IFMIF-CDA Design Integration Meeting
Tokai (Japan), May 20-25, 1996
B. Baratozzi, S. Cevolani, D. Tirelli

Design Constraints

(form the ***IFMIF-CDA Interim Report ORNL/M-4908***)

Geometry:

• Jet width		260 mm
• Beam width		200 mm
• Beam height		50 mm
• Back Plate thickness in the beam area	≈	2 mm
• Test & Target Cell height	>	2.5 m
• Distance from the beam centerline to the Test & Target Cell ceiling	>	1.5 m
• Distance between Target Assembly and Test Assembly	≈	2 mm

Pressures:

• Target Assembly internal pressure		10^{-3} Pa
• Test & Target Cell pressure		10^{-1} Pa

Temperature:

• Operating temperature	≈	250 °C

Various:

- in order to minimise the effect of the neutron damage, the permanent Target Assembly structure has to be at least 100 mm away from the edges of the beam footprint.
- the flow perturbation at the junction between back plate and nozzle has to be minimised

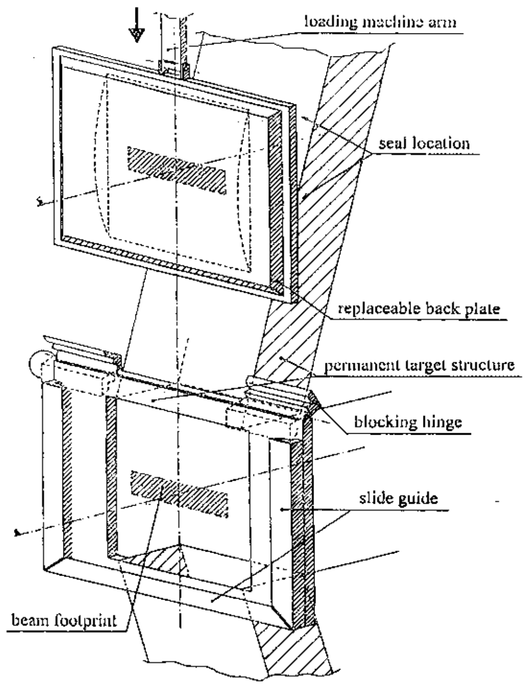
cevolani, arap2\ifmif\relazion\Tokai96 - 09/05/96

ENEA | ERG FISS | Contribution to the IFMIF-CDA Design Integration Meeting
Tokai (Japan), May 20-25, 1996
B. Baratozzi, S. Cevolani, D. Tirelli

Replacement scheme

1. The replaceable back plate is inserted/removed from the top.
   The replacement is performed by means of a simple loading machine.
   Any displacement of the Test Assembly during the back plate replacement operation is not necessary.
2. The permanent Target Assembly structure is equipped with slide guides for the correct insertion/extraction of the back plate.
3. The back plate is held in place by means of two devices acting as hinges.
4. The seal is inserted inside a cavity worked in the back plate and it is lying on a single plane.

cevolani, arap2\ifmif\relazion\Tokai96 - 09/05/96



ENEA ERG - FISS Bologna

REPLACEABLE BACK PLATE ATTACHMENT SCHEME

2-5-96

Dis.: Rev.: BOZZA

ENEA	ERG FISS	Contribution to the IFMIF-CDA Design Integration Meeting Tokai (Japan), May 20-25, 1996 B. Barstozzi, S. Cevolani, D. Tirelli

Open Issues

(concerned with any replaceable back plate design)

- Jet stability analysis at the transition between back plate and nozzle:
  - theoretical determination of a convenient gap dimension.
  - experimental verification of the acceptability of this gap size.
  - experimental identification of the maximum acceptable gap, in order to simplify the fabrication with consequent cost reduction.
- Optimisation of the duct geometry upstream the jet, with following purposes:
  - to increase the flow straightening effect
  - to increase the flow stability at the transition point
  - to increase the jet stability
- Definition of the interaction with the cooling system of the permanent Target Assembly structure.

All these issues, having some influence on the developed scheme, will not be covered in the frame of the present activity.

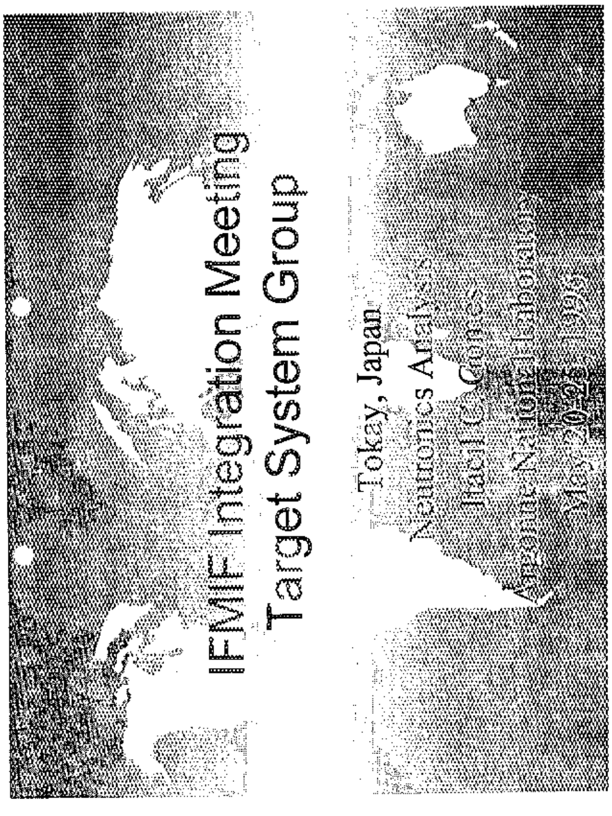
cevolani, arap2\ifmif\relazioni\Tokai96 - 13/05/96

ENEA	ERG FISS	Contribution to the IFMIF-CDA Design Integration Meeting Tokai (Japan), May 20-25, 1996 B. Barstozzi, S. Cevolani, D. Tirelli

CONCLUSIONS

- An attachment scheme of the replaceable back plate to the permanent Target Assembly structure is proposed.
- the proposed scheme is based on a simple bayonet connection. No bolts are needed. As a consequence, there is no necessity for moving the Test Assembly for changing the back plate.
- this scheme allows for a good sealing with respect to the Test & Target Cell and has a good capability of recovering the differential expansions.
- Some open issues concerned with the replaceable back plate concept have to be solved during the next Engineering Validation Phase.

cevolani, arap2\ifmif\relazioni\Tokai96 - 10/05/96



Preliminary Nuclear Heat Deposition Analysis for the Target System

- An analysis of the in-test-cell components of the Target system was performed to assess the nuclear heating deposition during operation and after shut-down.
- A full MCNP model of the in-test-cell components of the target system was built and nuclear heating deposition was calculated at several locations.

I.C.Gomes - ANL - 05/16/96

Preliminary Nuclear Heat Deposition Analysis for the Target System

- The total heat deposition in the beam-guide tube, during operation, was calculated to be ~1.55 kW.
- The total heat deposited in the back-plate structural piece was calculated to be 3.5 kW and in the matching piece 2.3 kW.
- Decay heat in the back-plate produces a total of 64 Watts over the back-plate.

I.C.Gomes - ANL - 05/16/96

Future Work

- Identify activation levels of the target components for different replacement scenarios.
- Introduce the photon transport from other regions to the amount of nuclear heat deposited in the target structure.
- Analyze other back-plate materials in terms of decay heating.

I.C.Gomes - ANL - 05/16/96

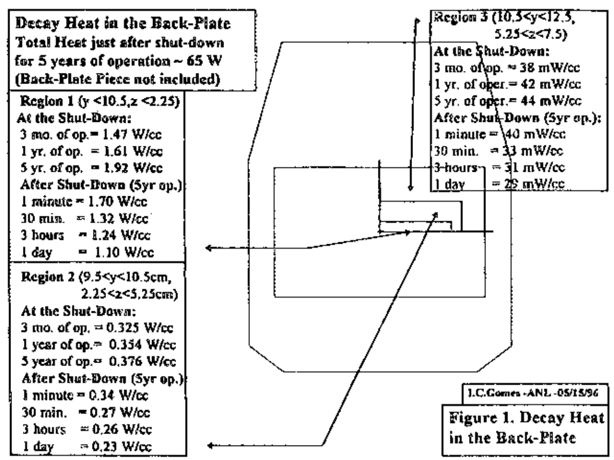


Figure 1. Decay Heat in the Back-Plate

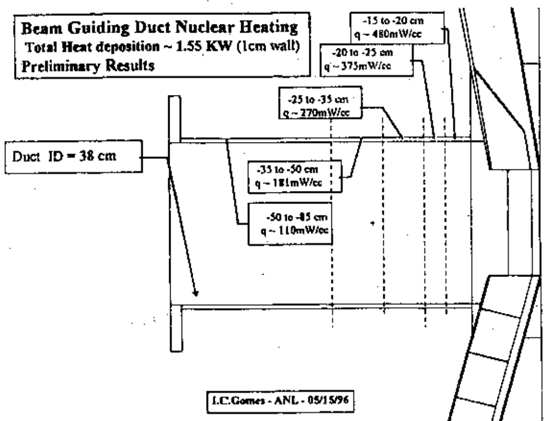


Figure 2. Nuclear Heating in the Beam-Tube

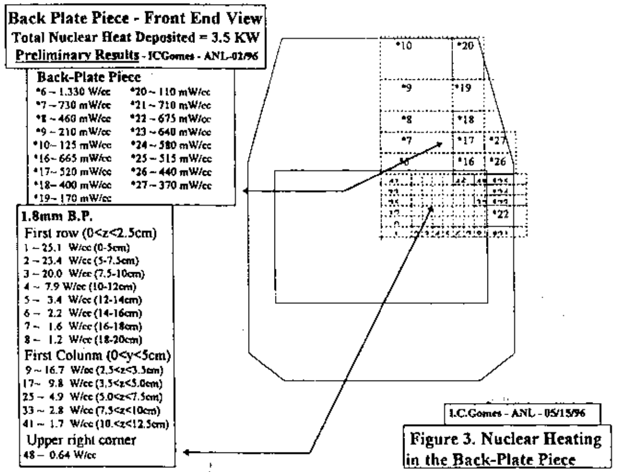


Figure 3. Nuclear Heating in the Back-Plate Piece

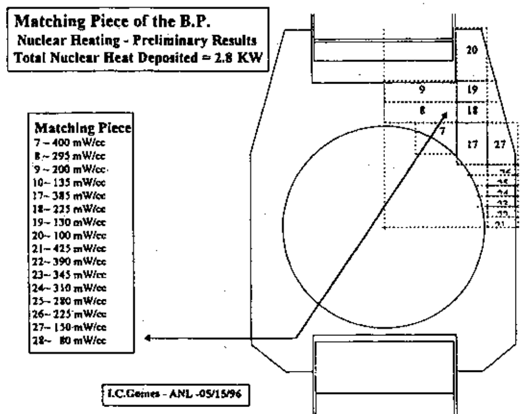


Figure 4. Nuclear Heating in the Back-Plate Matching Piece

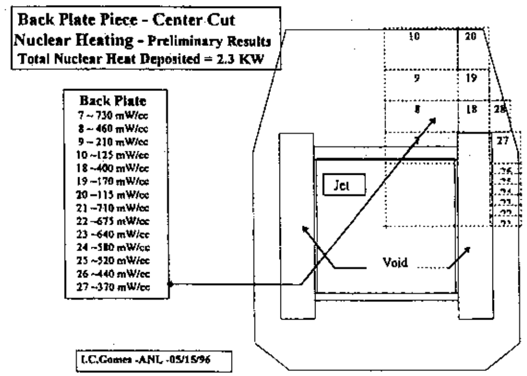


Figure 5. Nuclear Heating in the Back-Plate Piece -- Center Cut

Current Status of Water-Loop Test for Optimized Target Design

Hideo NAKAMURA, K. Ito* and Y. KATO

IFMIF Target System Group of JAERI
* Nagoya University

IFMIF-CDA Design Integral Workshop
May 20-24, JAERI, Tokai, JAPAN

IFMIF-CDA D.I.WS, May 20-24 at JAERI

Background

1) Requirements for controlled & stable n-irradiation with maximum sample volume
   - Well-defined, stable & long free-surface Li jet with minimum surface disturbance
   - Minimum Li vaporization and no flashing

2) Base (proposed) Target Designs
   - **FMIT** Good experimental results,
     but 'design' empirical, variation in Jet thickness & small irradiation volume
     Difficult to access results as well as experimental conditions
     Room for improvement
   - **ANL** Free-Jet type, No firm design with experimental validation
   - **JAERI** Backwall-type (FMIT-alike), Original symmetric nozzle

3) Design and Prediction Tools
   - No theory for development of surface disturbance along jet, free-jet instability,
     2-D reducer design & flow straightner performance etc...

Validation by experiments aided by numerical analyses is indispensable.

IFMIF-CDA D.I.WS, May 20-24 at JAERI

JAERI Approach for IFMIF Jet Flow

- Fully-respect FMIT design & results (open document)
  - Design: Concaved jet guided by backwall, Asymmetric 2D reducer nozzle
  - Result: Concaved backwall necessary for jet stability,
    Jet velocity & thickness profile defined by upstream channel structure
- Design Concept: Hi-speed (Re) jet, but laminar-like at nozzle exit
  - ⇨ Straightener: Flat velocity profile with low-turbulence
  - ⇨ Reducer nozzle: Symmetrical 2D (design based on theory & exp.s by Dr. Shima)
    Large contraction ratio by double reducer
    Without flow separation
  - ⇨ Downflow diffuser: Pressure recovery for low-height plant (option for Li loop)
- System design tentative but can be **final** ⇨ Validate performance of target as a total system
- Try to find relation between jet initial velocity profile and interface ripple development

IFMIF-CDA D.I.WS, May 20-24 at JAERI

JAERI Water-Loop Experiments

- Simulate Li target flow by full-size water jet

  Test Parameter = Velocity (~1 to 20 m/s)

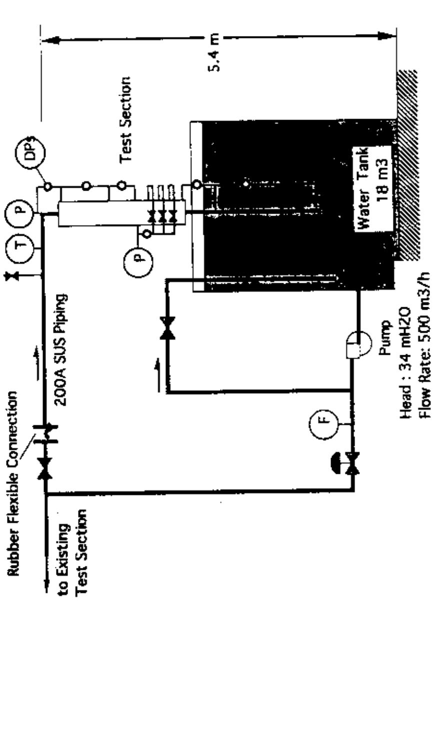
Interfacial ripple:	We number	~6.2 m/s
Flow condition:	Re, Fr numbers	Full velocity

  Note:
  Not necessary to fully simulate Li flow condition at once
  Seek relation between ripple development and upstream flow structure

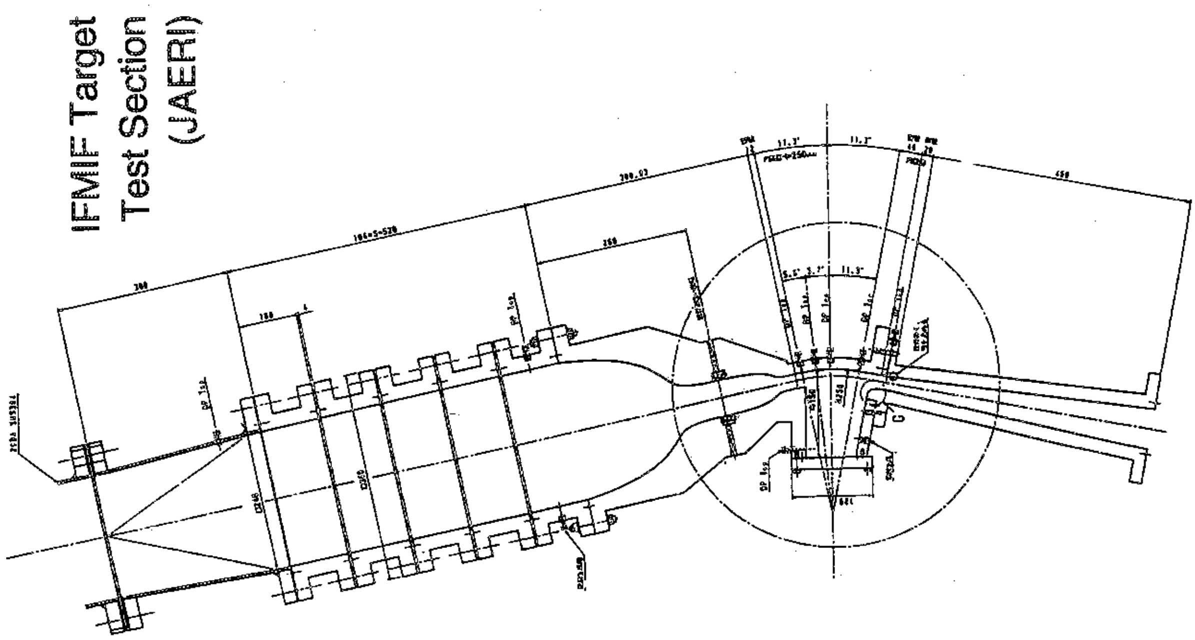
- Measure detailed flow structure as much as possible for wide range of velocity
  ⇨ Data base for Analyses

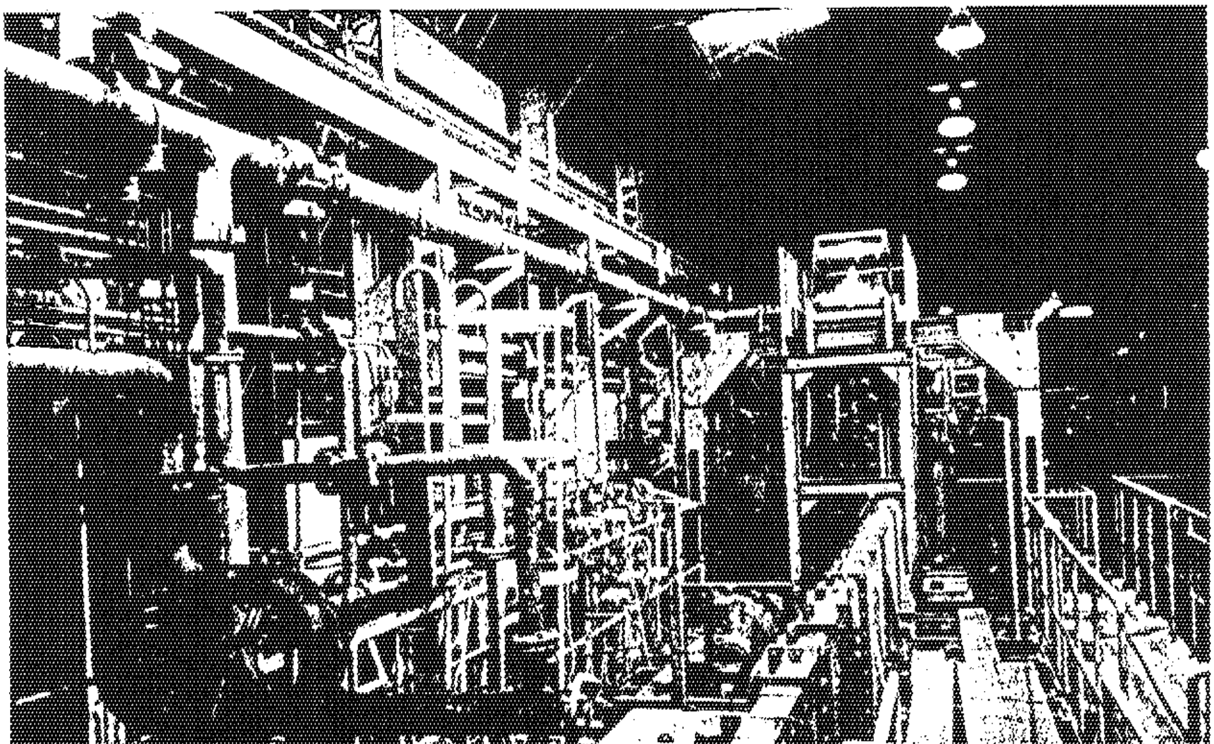
IFMIF-CDA D.I.WS, May 20-24 at JAERI

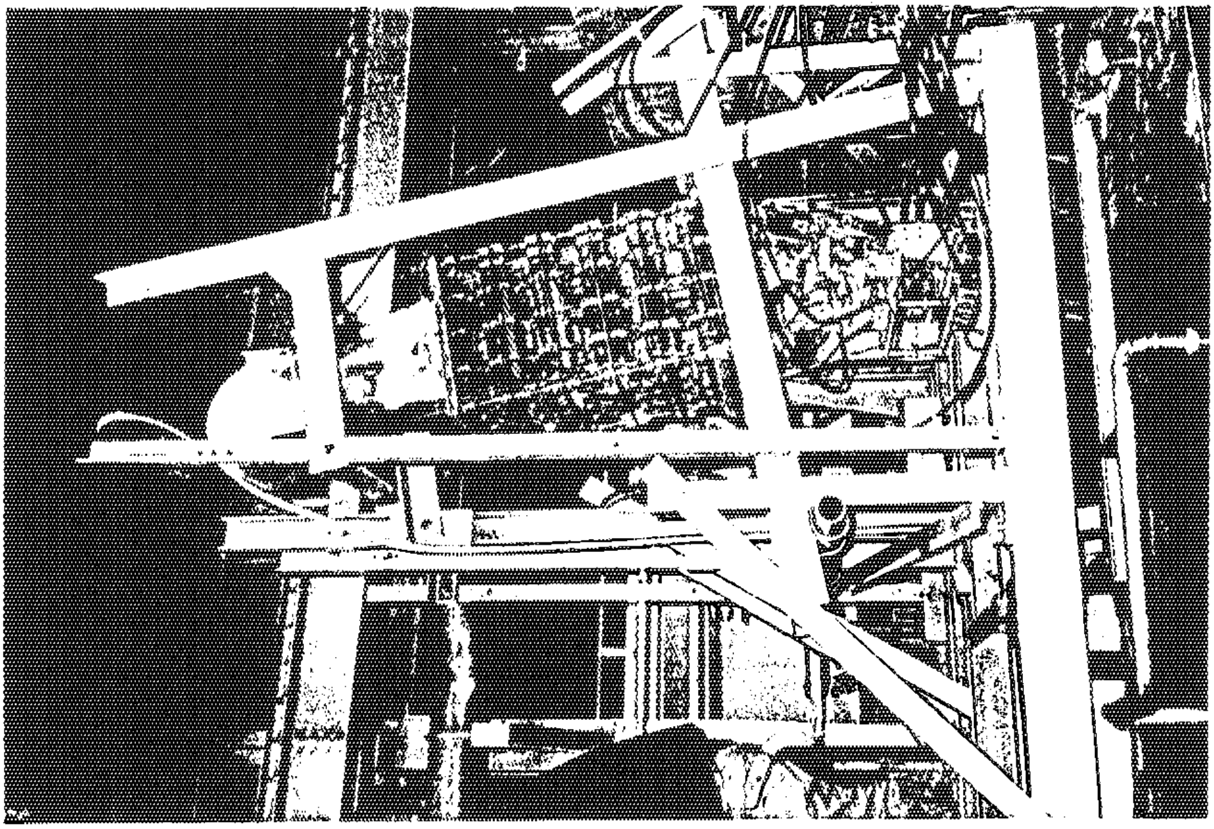
Schematic of JAERI Water Loop

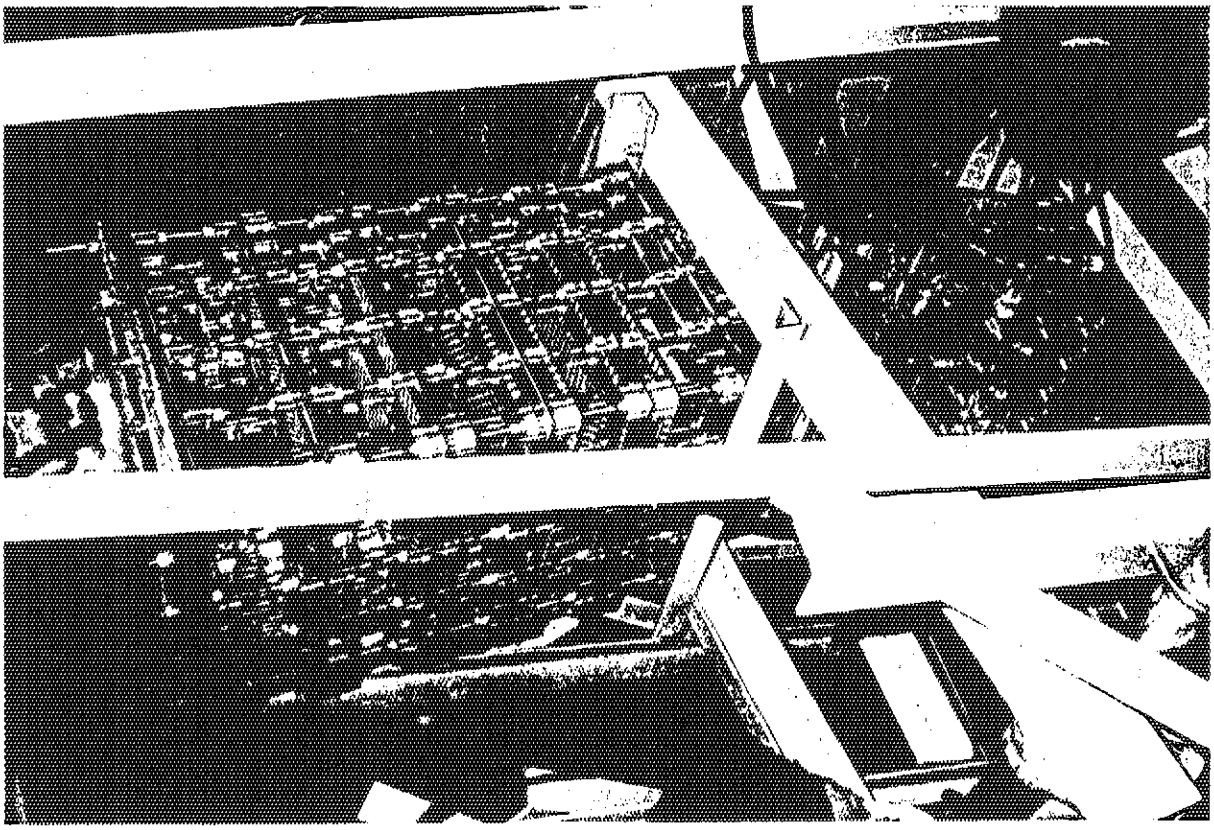


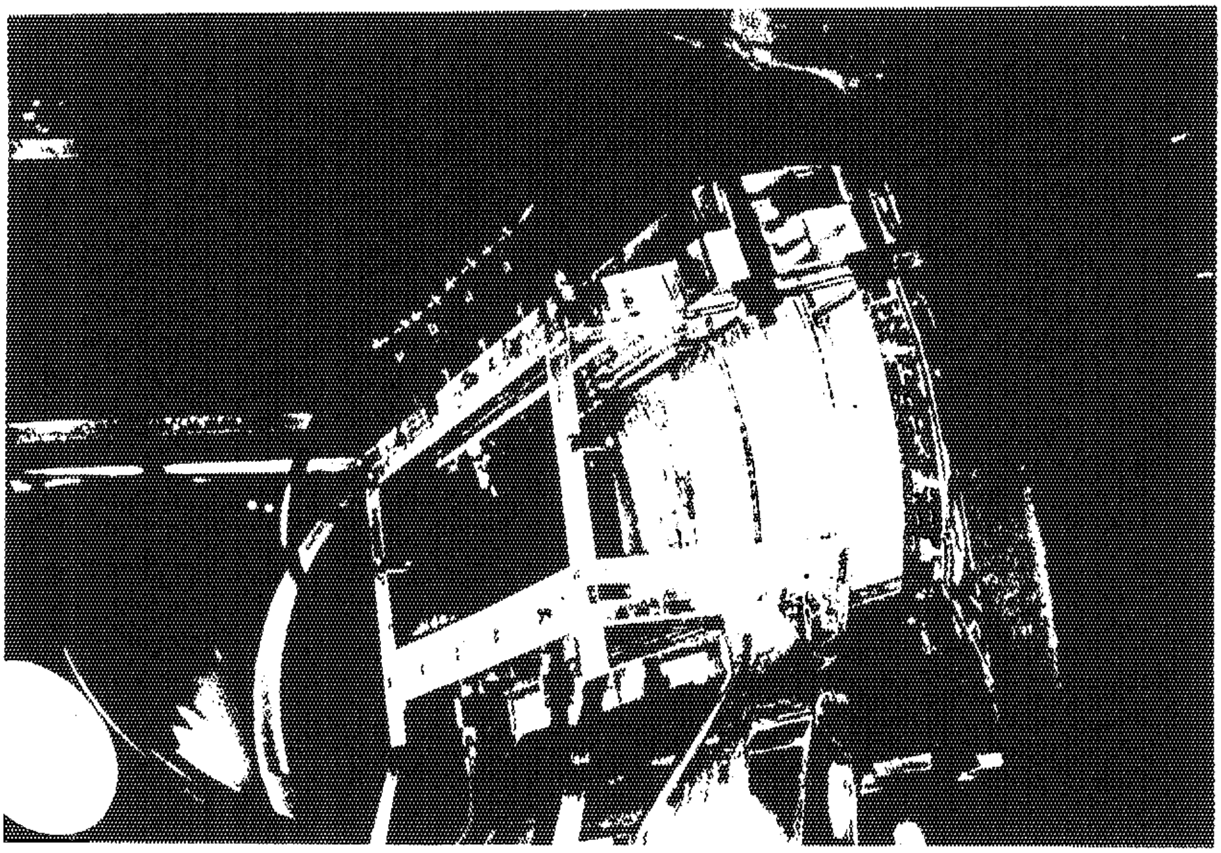
IFMIF-CDA D.I.WS, May 20-24 at JAERI


IFMIF Target
Test Section
(JAERI)









Current Status of Water Target Experiments

Facility End of modification for IFMIF experiments — March 1, 1996
Phase separator in water tank — May 15, 1996

Experiment

Quick-look Results

Observe ripples under 1 bar air by High-speed Video (1 k fps, 10 μs exposure)

FMIT Li-like observation for ~5 m/s (We number preserve),

Not much increase in ripple size along jet (~10 cm) even in air.

No splash, No liquid entrainment (Kelvin-Helmholts instability ??)

Under Testing

Measure velocity profile in reducer nozzle and jet by Flow Visualization

Measure ripple amplitude using Laser Displacement Meter
(Difficult to trace the wave profile ! Any good idea ?)

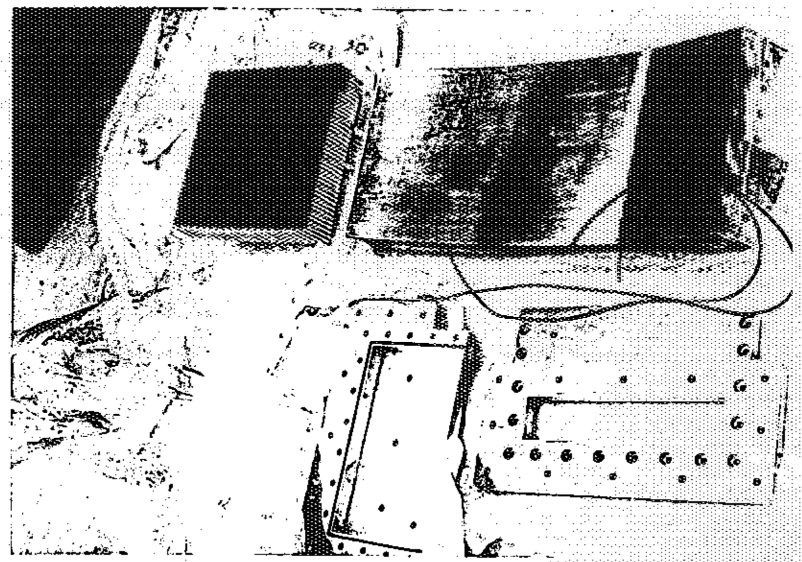
Measure facility vibration condition using Acceleration Sensors

Problems

Diffuser not work well (vacuum condition not realized) ⇨ improve soon

Vibration probably because of violent two-phase flow in water tank

IFMIF-CDA D.I.WS, May 20-24 at JAERI



Future Plan of Experimental Program

Facility

New Nozzle: (mamufacture almost completed)

FMIT-type for bench mark but double-reducer (10 to 1)

FMIT-type with large-radius long backwall

Diffuser: Improve for vacuum experiment

Test Section Location:

Move to other place in case that vibration affects measurement
("Phase separator" was successful to decrease vibration.)

Experiment

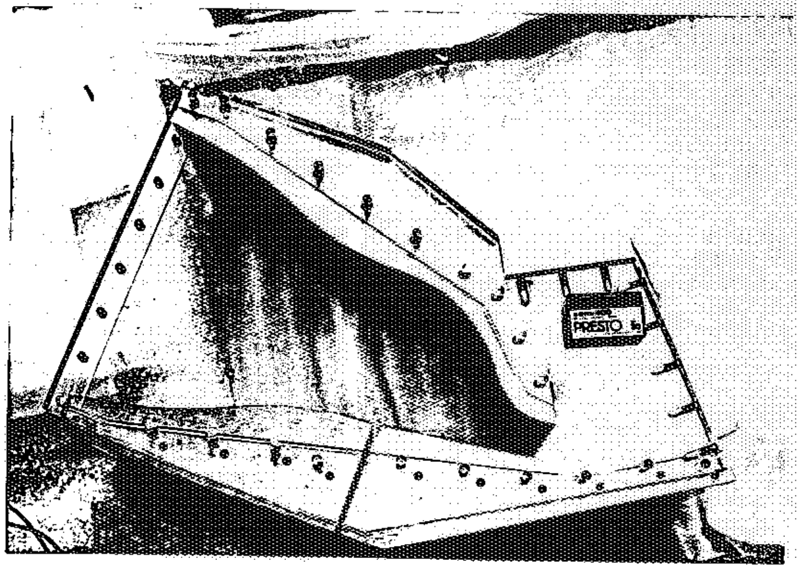
Persuit "Under Testing" items

Measure velocity profile in reducer and jet using LDV

Analyses

Predict detailed flow structure in reducer and jet

IFMIF-CDA D.I.WS, May 20-24 at JAERI



IFMIF-CDA
Li-Target System

Some Comments on the Target Jet Analysis

M. Ida, Y. Kato, H. Nakamura
IFMIF Target System Group of JAERI

May 1996
IFMIF D. I. Meeting at JAERI

Japan Atomic Energy Research Institute

We should make sure which nozzle is better . . .

Backwall / Free Jet

Symmetric / Asymmetric

Single / Double Reducer

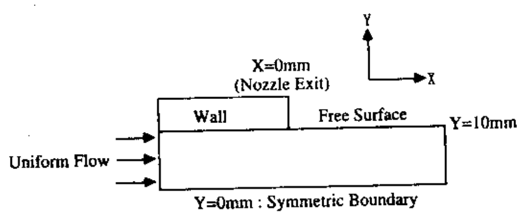
We are planning to investigate the relations between

Turbulence, Boundary Layer in Nozzle (Numerical Analysis)

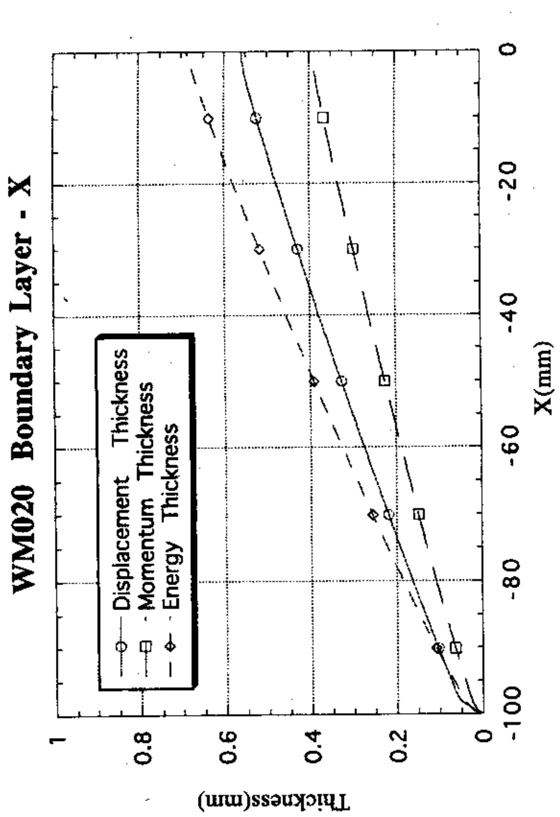
and

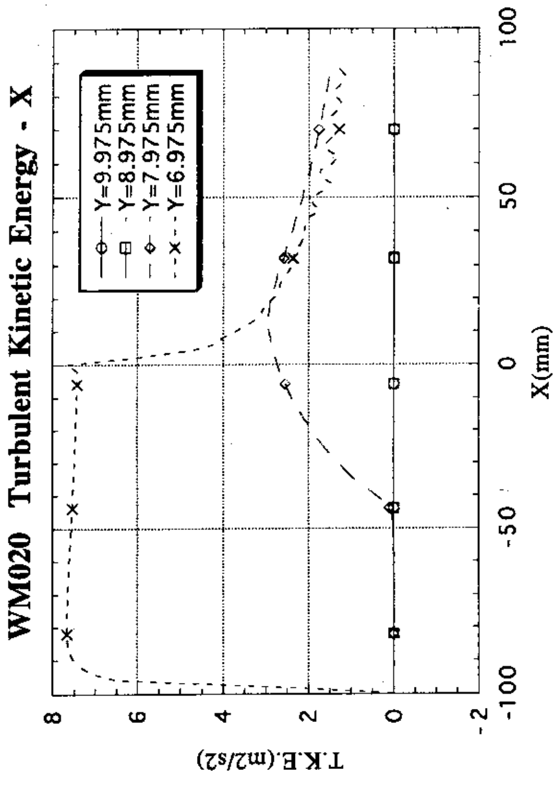
Instabilities on Jet (Water Experiment)

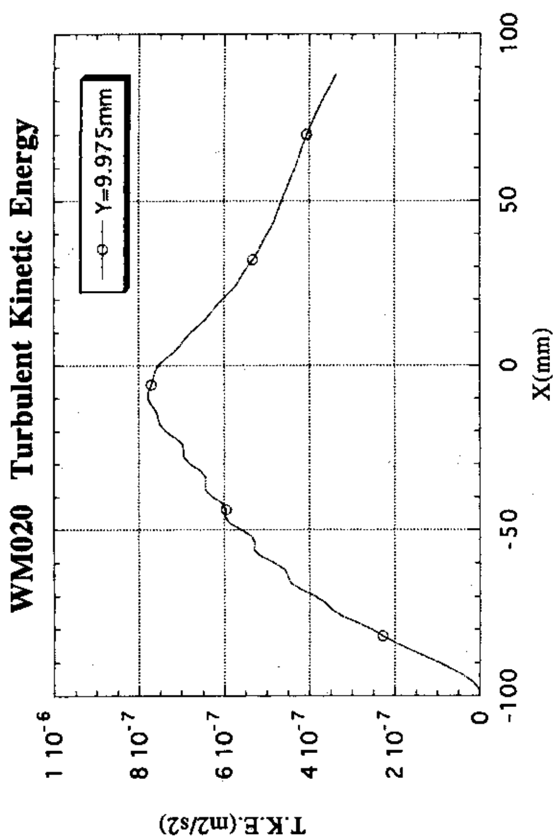
We are trying to calculate Turbulence and Boundary Layer with the simplified model as follows . . .

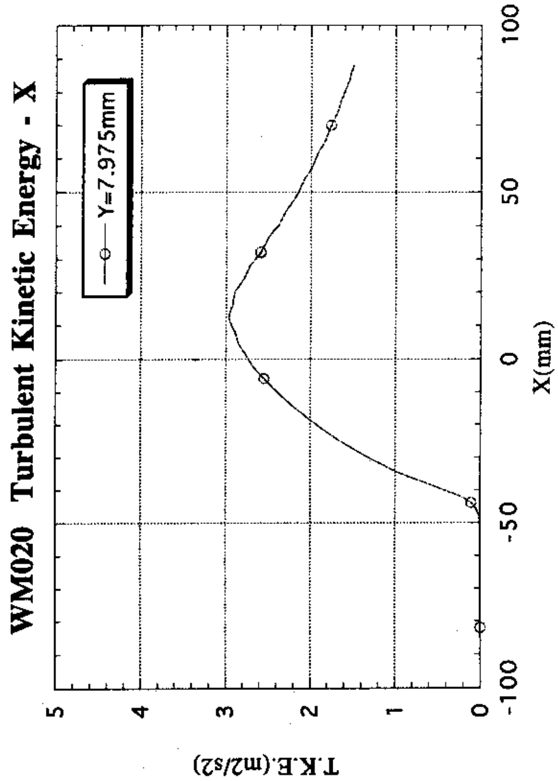


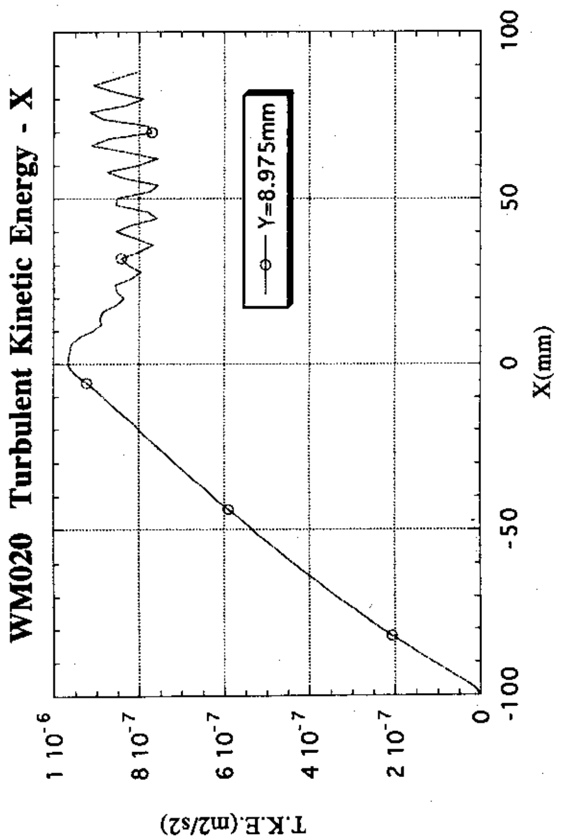
Schematic of Calculation Model

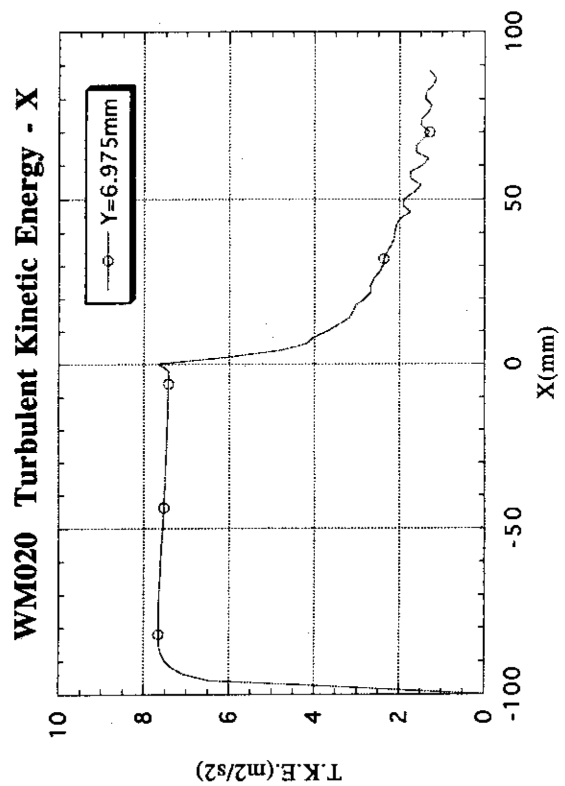

WM020 Boundary Layer - X
Displacement Thickness
Momentum Thickness
Energy Thickness
Thickness(mm)
X(mm)


WM020 Turbulent Kinetic Energy - X
Y=9.975mm
Y=8.975mm
Y=7.975mm
Y=6.975mm
T.K.E.(m2/s2)
X(mm)


WM020 Turbulent Kinetic Energy
Y=9.975mm
T.K.E.(m2/s2)
X(mm)


WM020 Turbulent Kinetic Energy - X
Y=7.975mm
T.K.E.(m2/s2)
X(mm)





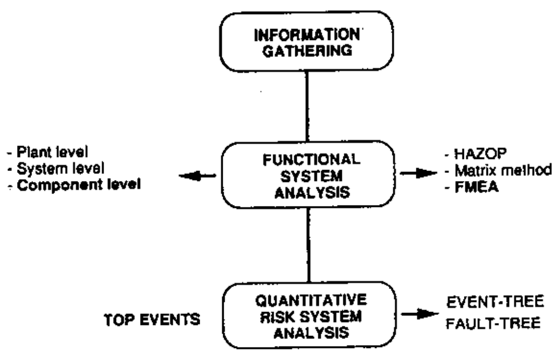
SAFETY ANALYSIS METHODOLOGY

THE SAFETY ANALISYS METODOLOGY HAS BEEN SELECTED TAKING INTO ACCOUNT:

- **PLANT CONSIDERED**
- **PLANT LIFE PHASE**
- **RESULTS EXPECTED**
- **AVAILABLE DATA**

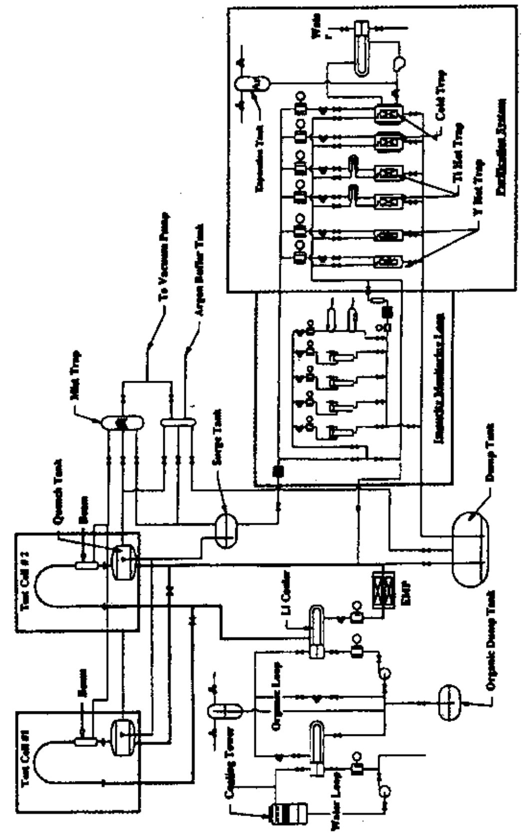
Presented by
G. Benamati
ENEA

ENEA METHODOLOGY



DATA BASE :

- **INTERIM REPORT OF THE IFMIF-CDA (12/95)**
- **SIMPLIFIED FLOW DIAGRAM**
- **PERSONNAL COMUNICATIONs**
- **ISOMETRIC VIEW OF IFMIF TARGET (1ST WORKSHOP In JAERI);**



ENEA Settore Energia Nucleare da Fissione	CT-FBB-00004	0	R	13	83

FREQUENCY OF OCCURRENCE		
A	Operational Events	More than one per year
B	Likely Events	$1 \div 10^{-2}$/y
C	Unlikely Events	$10^{-2} \div 10^{-4}$/y
D	Extremely Unlikely Events	Less than 10^{-4}/y
RISK POTENTIAL		
I		Operational caution required
II	Danger	Limited operation
III	Minor Hazard	Plant stop and repair
IV	Major Hazard	Accident, damage of facility
V	Extreme	Possible environmental effect

Table 1 - FMEA Factors

MOD. 02/94 bis FISS

ASSUMPTIONS

- LITHIUM CONTAINMENT: ONE WALL PIPE
- THE TRACE HEATING SYSTEM MAINTAINS THE LITIUM COOLING SYSTEM IN TEMPERATURE AS LONG AS THE METAL IS PRESENT IN THE LOOP. ONLY THE FAILURES UP TO JUNCTION CABINET OR BOX ARE CONSIDERED
- THE AUTOMATIC ACTIONS ARE NOT FORESEEN OWING TO A SPURIOS SIGNAL. THE CONTROL MEASURES ARE EQUIPPED WITH THE RESERVES

PRIMARY COOLING SYSTEM

- FLOW METER : NO REDUNDANCY
- EMP WITH ONE OR DOUBLE STATOR

PRYMARY PURIFICATION SYSTEM

- DRAINING IS POSSIBLE ONLY IF IT IS CONFIRMED BY THE OPERATOR AFTER HIS ACTION OF VALVE OPENING
- FLOW METER : NO REDUNDANCY

IMPURITY MONITORING LOOP

- ON-LINE METERS : COMPONENT REDUNDANCY
- HEATER : ELECTRIC HEATING
- FLOW METER : NO REDUNDANCY

COOLING GAS SYSTEM:

- ONLY ONE LOOP FOR THE TWO COLD TRAPS COOLING
- GAS CIRCULATOR : REDUNDANT
  ELECTRIC DRIVEN
- NO REDUNDANCY FOR HEAT EXCHANGER

SECONDARY COOLING SYSTEM

- ORGANIC PUMP: TWO PUMPS (ONE IN STAND-BY)
  ELECTRIC DRIVEN
- ORGANIC COOLER: NO REDUNDANCY

TARGET SYSTEM BUILDING

- LITHIUM CELL MAINTAINED IN THE AIR AT LOW PRESSURE
- TEST CELL/TARGET CELL MAINTAINED AT VACUUM CONDITION OF 10^{-1} Pa

LEAKED LITHIUM DETECTION SYSTEM:

- TWO COMPLEMENTARY TYPES:

- DETECTION AND LOCATION OF LEAK BY ELECTRIC DEVICES (e.g. Spark plugs, Bead wire detectors)
- LEAK DETECTION BY LITHIUM FUMES (Smoke Detectors)

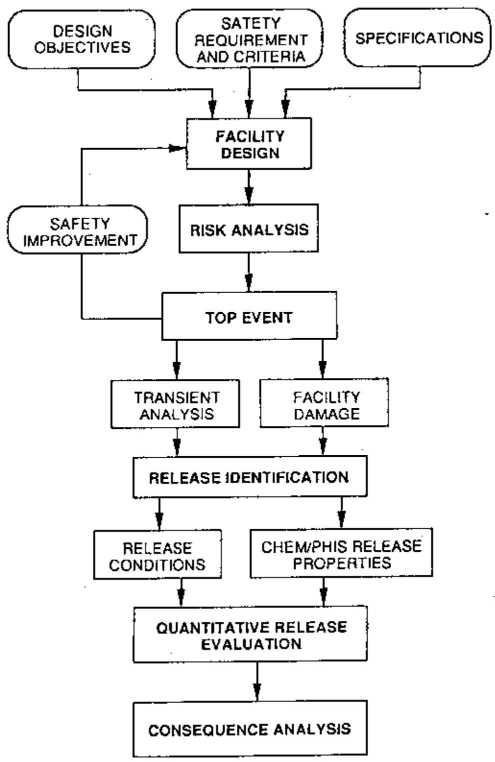
- ONLY THE FAILURE UP TO JUNCTION BOXES ARE CONSIDERED.

RADIOACTIVE GAS EVACUATION SYSTEM - OTHER RADIOISOTOPE TREATMENT FACILITY:

- HEPA FILTER TO REMOVE THE HAIRBONE ACTIVITY.

MAIN ADVANTAGES

- **ASSESS THE FOLLOWING POINTS:**
  - **THE BEHAVIOUR IN RESPONSE TO TRANSIENTS AND ACCIDENTS EVENTS,**
  - **THE VULNERABILITY AND SENSITIVITY OF THE DESIGN TO HUMAN INTERACTION;**
  - **THE CAPABILITY TO MEET THE SAFETY GOALS WITH SUFFICIENT MARGIN;**
- **IDENTIFY DESIGN AND ANALYSIS AREAS WHERE MAJOR INVESTIGATIONS AND/OR IMPROVEMENT ARE NEEDED**
- **PROVIDE AN INTEGRATED AND SYSTEMATIC VIEW OF THE REALISTIC BEHAVIOUR OF THE PLANT DESIGN IN RESPONSE TO ACCIDENTS EVENTS;**
- **PROVIDE TOOLS TO INVESTIGATE ALTERNATIVE DESIGN SOLUTIONS.**



PRESENT ACTIVITIES

- UPDATING OF FMEA
- INTERNAL AND EXTERNAL EVENTS ANALYSIS
- DEPENDENT FAILURE ANALYSIS
- CONSEQUENCES ANALYSIS

CONCLUSION

THE MOST RELEVANT EVENTSS EVIDENCED DURING THE FMEA ANALYSIS ARE :

- LITHIUM LEAKAGE IN TEST CELL
- LITHIUM LEAKAGE IN LITHIUM CELL
- RADIATION RELEASE
- VACUUM LOSS
- CONTROL LOSS
- SAFETY FUNCTION LOSS

FOR EACH OF THESE HAZARDS THE ORIGINS ARE IDENTIFIED.

CONCLUSION

THE EVENT OF LITHIUM LEAKAGE AND THE RESULTING LITHIUM FIRS CANNOT BE EXCLUDED.

AT THE SAME TIME RADIATION RELEASE IS POSSIBLE AS CONSEQUENCE OF :

- LITHIUM FIRE IN TEST CELL
- RUPTURE OR CRACKING OF THE EVACUATION TUBE AND/OR IN BEAM LINE.

THE FMEA PERFORMED COMPONENT BY COMPONENTS IS NOW AVAILABLE; THE RELEVANCE OF SINGLE COMPONENT (EM PUMP, HEAT EXANGER, DRAINNING VALVE, FLOW METER) IS EVIDENCED AND SOME PREVENTION OR MITIGATION MEASURES ARE INDICATED.

THE PRESENT ANALYSIS SHOULD BE COMPLETED BY THE FMEA UP-GRADING (TAKING INTO ACCOUNT THE DESIGN EVOLUTION) AND BY QUANTITATIVE RISKS EVALUATION.

IFMIF-CDA

Design Integration Meeting

IFMIF Tritium System Proposal

presented at the 2nd IFMIF-CDA
Design Integration Meeting
May 20-25, JAERI, Tokai, Japan

S. Konishi, Y. Kato, K. Noda
JAERI IFMIF Target / Test Cell Group

TRITIUM CONFINEMENT AND VENTILATION

OBJECTIVE

Confinement of radioactivity and
Processing radwaste
are identified as outstanding design issues.
Tritium is not a major radioactivity in IFMIF, but
Regarded as a major radiological hazard of IFMIF.
Possible significant impact on cost estimation

The objectives of this preliminary study are:
- To identify possible source of contaminated gas
- To identify possible hazards and waste
- To consider inter-subsystem flow of hazardous material,
- To propose possible solution, and
- To estimate the impact on the entire facility.

Sources

TRITIUM EFFLUENT
- Tritium removal system from lithium
- Lithium waste
- Irradiated breeder materials
- In-pile / in situ breeder irradiation

VACUUM EXHAUST
- Evacuation from target chamber
- Lithium cover gas
- Test cell evacuation
- Accelerator beam line
  - low level tritium contamination
  - possible high level in off-normal
  - some mixed hazard
  - mixed nuclides

GENERAL FACILITY / HOUSE VACUUM
- Various vacuum services
- Maintenance exhaust

Hazards

Workers / in facility / Environmental
- negligible in normal operation
- significant potential hazard
- accompanied with other chemical/radiologicals
  - lithium
  - activated air
  - neutron, gamma
  - active solid particles

Vacuum Pumping

1. Requirements for tritium pumping
   - Oil-free
   - Li-compatible for target system
   - No organics
   - Good Vacuum
   - Maintenance-free
   - Moderate capacity needs
2. Specific problems
   - Vacuum system design: shielding, sealing
   - Existing chemicals, nuclides
   - Activation and maintenance

Exhaust Processing

1. Tritiated effluent
   - Evacuation from target chamber
   - Any other Li loop components
   - Beam transport
   - Test cell / PIE facility
2. Processing
   - Removal of Li aerosol, radioactive particle
   - Removal of tritium
   - Release to environment in non-toxic form
   - Normal exhaust processing requires small throughput

Zoning and multiple confinement

1. Tritium Facility
   - Tertially confined,
   - Each with dedicated detritiation
   - 3rd confinement costs most.
2. IFMIF classification

(1).PRIMARY
- Lithium loop
- Lithium facing vacuum
  - beam line, test cell behind back wall
- Vacuum exhaust processing
- Breeder materials handling

(2) SECONDARY
- Lithium containing inert atmosphere
  - vulnerable boundary
- Gloveboxes and Hot cells in the PIE
- Test cell surroundings ??
- Accelerator beam transport?

(3) ROOMS
- Neutron area needs independent control
- No major tritium spill anticipated
  -> no costly emergency cleanup
- Local temporary ventilation for maintenance

SUGGESTIONS

1. SECONDARY CONTAINMENT OF LITHIUM
   Inert atmosphere reduces potential hazard
   Less expensive gas processing and containment fabrication
   Possible optimization with glovebox atmosphere control

2. GENERAL TRITIATED EFFLUENT PROCESSING
   To design multi-purpose detritiation system for primary exhaust is efficient
   High once-thorough DF required for negative pressure in the facility .

3. DEDICATED SECONDARY CONTAINMENT. CONTROL
   For flexible operation needs
   Possible substitution

4. TRITIUM COMPATIBLE WASTE SYSTEMS
   Solid and liquid wastes are anticipated to be tritium-contaminated.
   Waste treatment systems must be adequately designed to process tritium as contaminant.

CONCLUSION

◇ Movable (airborne) radioactive nuclides, particularly tritium is a major hazard

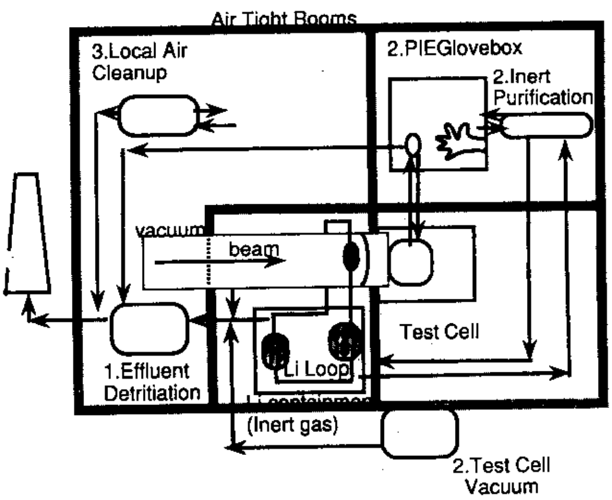
◇ Multiple confinement of tritium and other movable nuclides should be considered.

◇ Isolation of primary subsystems of beam, target and test cell is not reliably achieved.

◇ Secondary, and if needed, tertially confinement for isolated subsystems are possible and effective.

◇ Exhaust control can be designed with current technology to meet current regulations.

◇ Integrated waste management program needed

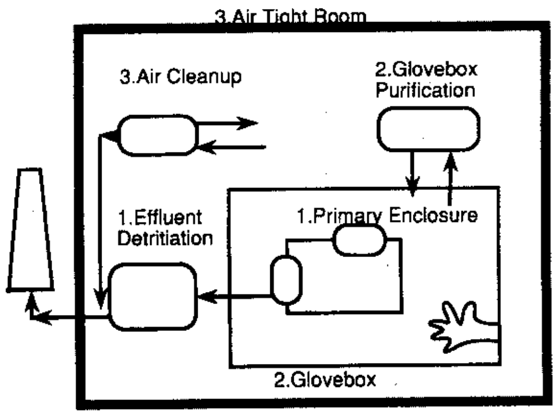


Example of IFMIF Confinement

Li loop, beam line and test sample exhaust is primary confinement for airborne activity

Li loop, test cell and PIE is 2ndary contained

Room does not expect major tritium release



For large amount of tritium inventory
3rd containment costs

Typical Tritium Confinement System

IFMIF TARGET TESTING IN EVP - CONSIDERATIONS FOR USING ALEX FACILITY

Presented by

Thanh Hua
Fusion Power Program
Argonne National Laboratory

IFMIF Design Integration Meeting, May 20-26, 1996 at JAERI, Tokai, Japan

OUTLINE

- Test objectives and requirements
- History of ALEX facility and current status
- Advantages of ALEX for IFMIF target testing
- Resource requirements for facility construction and operation
- Conclusions
  - Time and cost savings
  - Collaboration is very important

Test Objectives

- Determine jet dynamic characteristics and compare with analysis (stability, surface smoothness, thickness uniformity)
- Test target assembly prototypes (more than one design) for selecting optimal design

Test Requirements

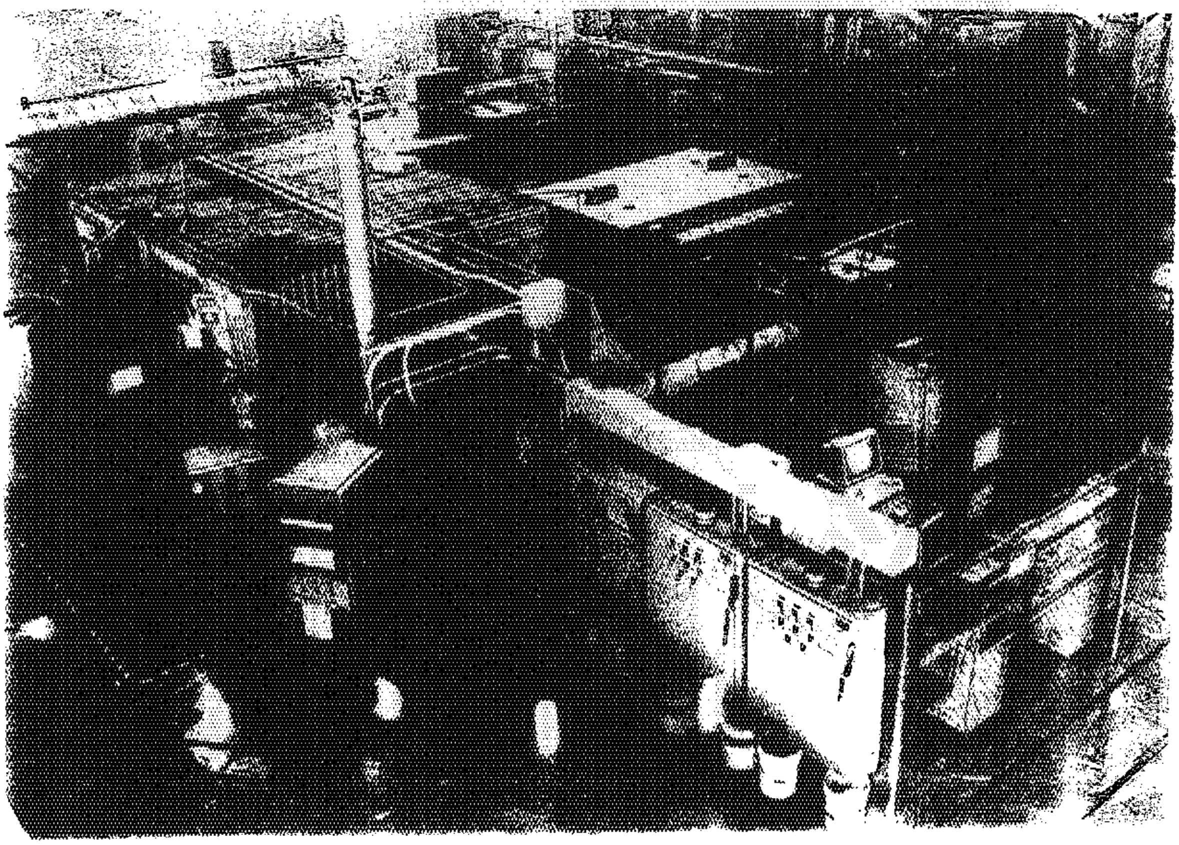
- Li working fluid in low ambient pressure (many times lower than atmospheric pressure)
- Jet velocity up to 15 m/s
- Full size nozzle ? half size?
- Vibration free support of test article, particularly the nozzle
- Measurements/data include jet thickness, surface roughness, wave amplitude, wavelength and wave frequency as functions of position, distance and velocity

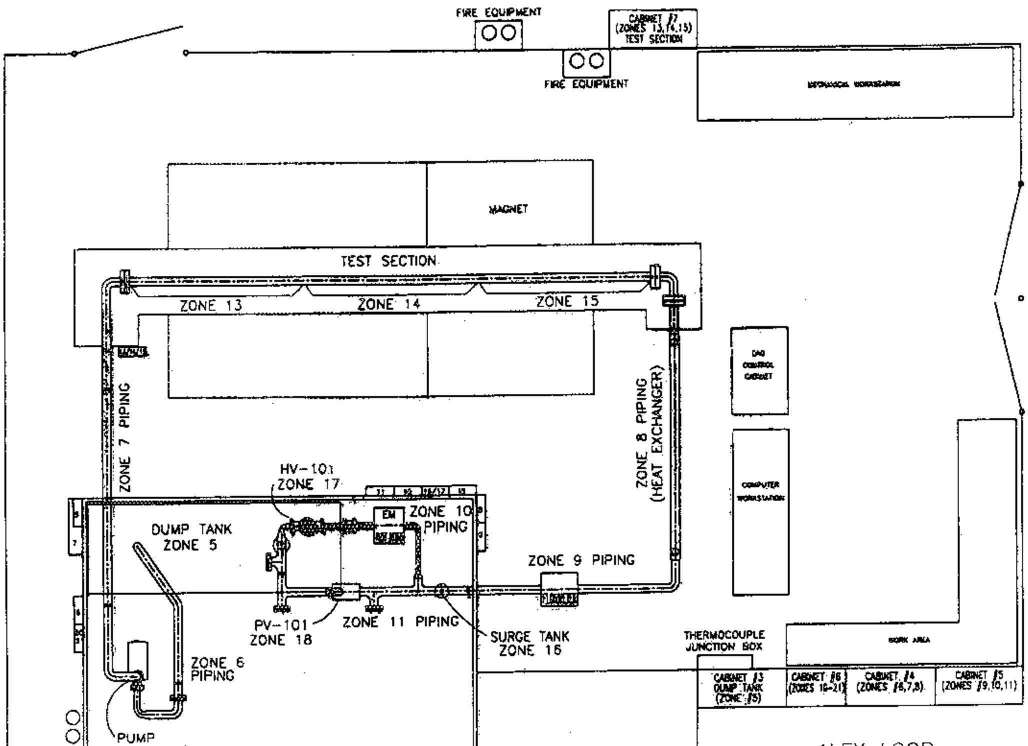
Brief Summary of ALEX Facility - History

- The facility was constructed in 1984 for the study of liquid metal MHD for fusion LM self-cooled blankets
- NaK was the working fluid from 1984 - 1994. The facility was converted to Li in 1995. Tests were run at 230°C
- Facility cost ~ $ 5 M
- A clean safety record has been maintained, the facility conforms with all environmental safety and health (ES&H) requirements
- International collaborative projects, in the form of joint design and experiments at ALEX, were conducted with great success and benefits including with
    - FzK, Germany
    - Efremov Institute, Russia
- Principal investigator, Claude Reed, has been with the project from the beginning

Brief Summary of ALEX Facility - Status

- Ongoing MHD experiment with vanadium test section and CaO coating material to demonstrate MHD pressure drop reduction
- Experiments are expected to be completed by September 1996
- ALEX is proposed by ANL as an option for IFMIF target testing
- DOE/OFE and ANL/FPP management strongly support using ALEX for IFMIF target testing
- The original FMIT-ELS electromagnetic pump was transferred to ALEX facility and could be used for IFMIF target experiments
- ALEX personnel will be available if a decision is made to modify the facility for IFMIF
- ALEX facility can be shared between MHD/coating work and IFMIF target work, if necessary




FIRE EQUIPMENT
CABINET /7 (ZONES 13,14,15) TEST SECTION
FIRE EQUIPMENT
MAGNET
TEST SECTION
ZONE 13
ZONE 14
ZONE 15
ZONE 7 PIPING
ZONE 8 PIPING (HEAT EXCHANGER)
HV-101 ZONE 17
ZONE 10 PIPING
DUMP TANK ZONE 5
ZONE 9 PIPING
PV-101 ZONE 18
ZONE 11 PIPING
SURGE TANK ZONE 16
ZONE 6 PIPING
PUMP ZONES 20/21
COMPUTER WORKSTATION
THERMOCOUPLE JUNCTION BOX
WORK AREA
CABINET /3 DUMP TANK (ZONE /5)
CABINET /6 (ZONES 16-21)
CABINET /4 (ZONES /6,7,8)
CABINET /5 (ZONES /9,10,11)
LOOP CONTROL CABINET
FIRE EQUIPMENT
ALEX LOOP
LITHIUM UPGRADE

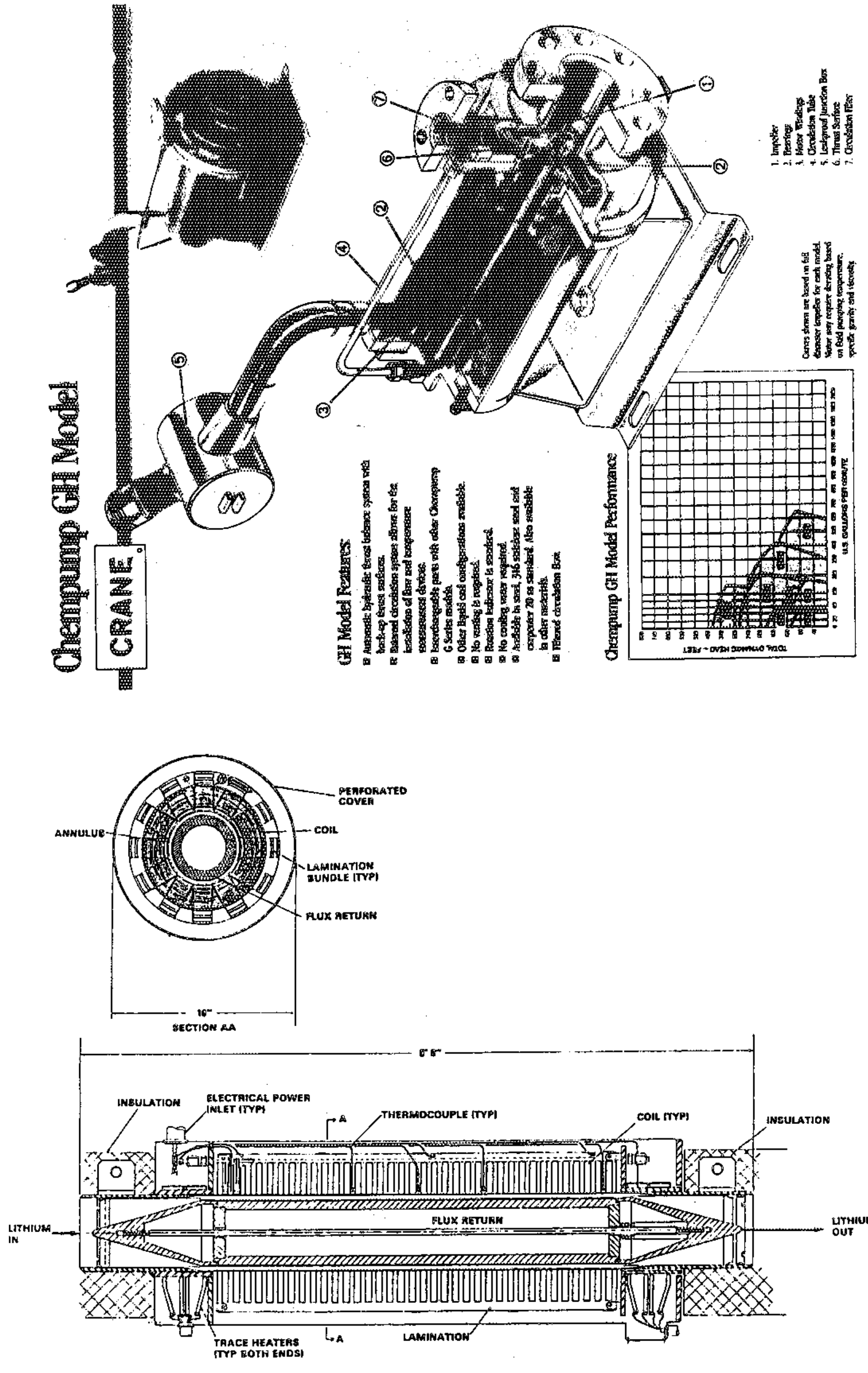


FIGURE 13. Main Loop Pump. Neg 7913221-2

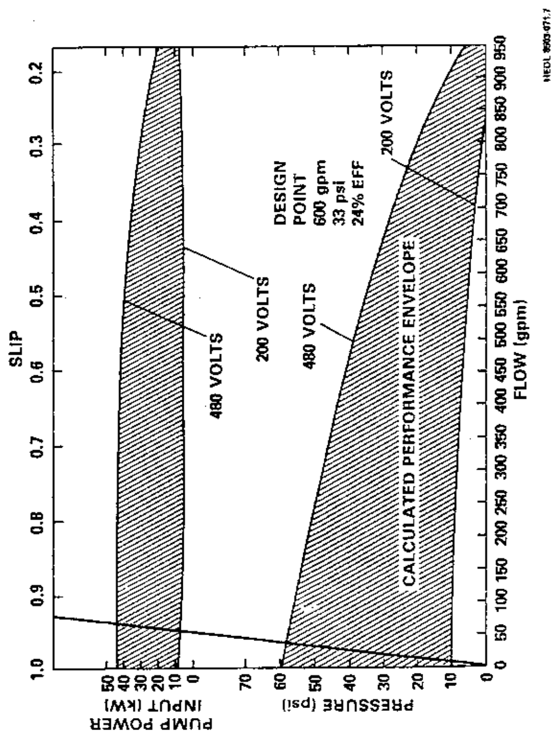


FIGURE 15. Calculated Performance Envelope for ELS Annular Linear Induction Pump.

Considerations of ALEX for Target Testing

- Availability of existing facility including:
  - Loop
  - Dump tank
  - Pumps, including the large EM pump
  - Lithium
  - Heaters and insulation
  - Impurity traps
  - Instrumentation: flow meters, pressure measurement system, thermocouples
- Long history of safe, productive liquid metal experience

Flow Rate Comparison

	Velocity, m/s	Flow rates, l/s
ALEX mech. pump		0 - 20
ELS EM pump		0 - 40
Target nozzle:		
- 2.5cm x 25cm	10	63
- 2.5cm x 25cm	15	94
- 1.2cm x 25cm	15	45
- 2.5cm x 12cm	15	45
- 1.2cm x 12cm	15	22

- Existing pumps at ALEX can accommodate half or quarter size nozzle

Resource Requirements For Facility Modification

I. Hardware (excluding test article)

Component	Est. Cost ($K)
Collector tank	5
Vacuum chamber	10
Vacuum system	30
Piping/Connectors	20
Additional heaters	25
Additional Insulation	10
Instrumentation	15
Data Acquisition Upgrade	20
Miscellaneous	15
Total	150
AFI	30
Grand total	180

II. Personnel

Staff*	Technician*	Phase
1.5	0.5#	Design
1.5	2.0	Construction
1.0	1.0	Operation

* Full time equivalent, in man-year
\# Drafting

III. Schedule and Estimated Cost

Activity	Est. Time (months)	Est. cost* ($K)
Design	9 - 12	500
Construction	9 - 12	1000
Target testing	12 - 24	850 - 1700
Total	32 - 48	2350 - 3200

* Staff man-yr: $240 K, technician: $180K

Cost of test section and modeling efforts have not been included

Conclusions

- Target testing in a modified ALEX facility could save a lot of time and money
- We can benefit from the long history of liquid metal experience at ALEX
- Total estimated time required for design, construction and testing is 3 to 4 years
- Commitment or projection for funding has not been defined. The U.S. can not carry out the program alone
- Collaboration is an important element to optimize resources and expertise (for example, JAERI's experience with the water experiments and test article design & fabrication will be very beneficial)

ENEA proposal for some activities to be performed during the IFMIF Engineering Validation Phase (1997-99)

by

S. Cevolani, D. Tirelli
ENEA-ERG-FISS

presented by

The activities proposed by ENEA-ERG-FISS for the IFMIF Engineering Validation Phase (1997-99) are concerned with two main lines:

1. DESIGN: development of the design of the back plate and permanent target structure

2. EXPERIMENT: supporting experiments, devoted to the analysis of the phenomena influencing the jet stability particularly at the transition between nozzle and replaceable back wall

Development of the design of the back plate and permanent target structure

Objective: *Development of the present design and integration with the design of other Target Assembly components.*

Stages:

1. *Review of IFMIF Conceptual Design*
2. *Design of Prototype Components; definition of some still open items: allowable gap dimension between back plate and permanent structure, curvature radius, etc.*
3. *Optimization of the duct geometry upstream the jet. The objectives are:*
   - *to increase the flow straightening effect*
   - *to increase the flow stability at the transition point*
   - *to increase the jet stability.*
4. *Homogeneization of the back plate design with the design of the permanent target structure cooling system.*
5. *Homogeneization of the back plate design with the design of the loading machine.*
6. *Definition of some devices connecting the replaceable back plate to the permanent target structure.*

cevolani, arap2/ifmif/relazion/possi5

Experimental analysis of the jet stability at the transition between nozzle and replaceable back wall

Objective: *Verification and optimization of the instability due to the geometrical transition between nozzle and replaceable back wall.*

Stages:

1. *Theoretical analysis of the jet behaviour in order to determine the operating conditions.*
2. *Theoretical analysis of the gap geometry effect and identification of a convenient gap dimension.*
3. *Experimental verification of the performances of this gap size.*
4. *Experimental identification of the maximum acceptable gap, in order to simplify the fabrication with consequent cost reduction.*
5. *Experimental determination of the effect of the duct geometry upstream the jet on the flow stability.*

cevolani, arap2/ifmif/relazion/possi5

Development of the design of the back plate and permanent target structure

Cost estimate: *80,000 US$/y*

Experimental analysis of the jet stability at the transition between nozzle and replaceable back wall

Cost estimate:

- *Test Section Buid Up and Loop Improvement:* *50,000 - 100,000 US$*
- *Experiment conduction:* *100,000 US$/y*

cevolani, arap2/ifmif/relazion/possi5

Some ENEA proposals for the IFMIF Engineering Validation Phase

by

G. Benamati, F. Bianchi

presented by

G. Benamati

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

THE CONTROL OF THE IMPURITIES (MAINLY H, O, N AND C) IS FUNDAMENTAL FOR THE OPERATION OF LITHIUM LOOP.

TWO KIND OF CONTROL COULD BE ENVISAGED :

- **OFF-LINE MONITORING BY SAMPLING**
- **ON-LINE MONITORING BY SENSORS.**

THE OFF-LINE MONITORING PROVIDE ACCURATE RESULTS BUT A DELAY IN THE AVAILABILITY OF THEM IS AN IMPORTANT DISADVANTAGES.
ON THE CONTRARY ON-LINE MONITORING (I.E. SENSORS) PROVIDES RESULTS IN REAL TIME AND CAN BE USED ALSO FOR SAFETY FUNCTION.

THE DEVELOPMENT OF RELIABLE AND ACCURATE LITHIUM IMPURITY SENSORS IS AN IMPORTANT TARGET OF THE R&D ACTIVITY OF IFMIF FACILITY (SEE SECTIONS: 2.5.1.8, 2.5.2.8, 2.5.2.9 AND MAINLY 2.5.7.2 2.5.7. 2.2 OF THE IFMIF REPORT).

ENEA PROPOSAL, TAKING INTO ACCOUNT THE AVAILABILITY OF AN EXPERIMENTAL LOOP IN BRASIMONE CENTRE AND THE COMPETENCIES PRESENT IN EUROPE IN THIS FIELD, AIMS AT DEVELOPING AND VALIDATING MONITOR SYSTEMS FOR LI IMPURITIES.

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

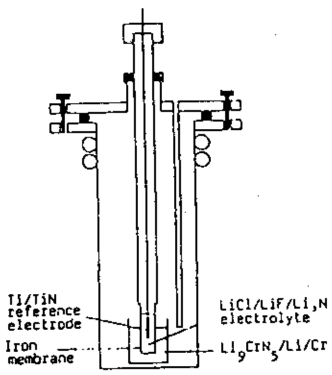
- **DEVELOPMENT OF A N-SENSOR FOR LITHIUM;**
- **VALIDATION, BY MEANS OF ENDURANCE TESTS (1000-3000 H), OF SENSORS DEVELOPED IN EUROPEAN LABORATORIES OR IN OTHER LABORATORIES INVOLVED IN THE IFMIF PROJECT.**
- **ASSESSMENT OF THE POSSIBLE USE OF ON-LINE SENSORS FOR H AND C (INDICATION ABOUT THE MOST PROMISING SOLUTION).**

THE ACTIVITY WILL BE PERFORMED IN COLLABORATION WITH OTHER EUROPEAN PARTNERS (I.E. NOTTINGHAM UNIVERSITY AND FZK).

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

ELECTROCHEMICAL NITROGEN METER :

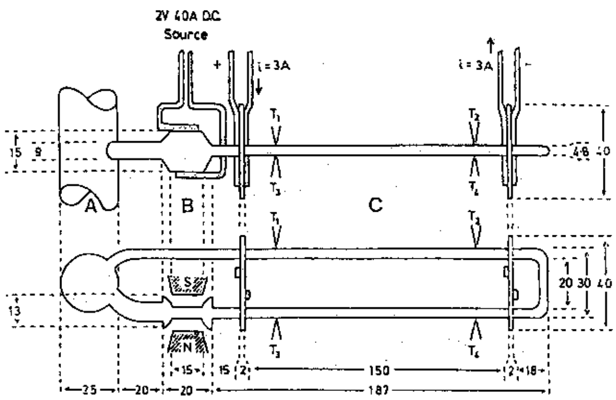


Li_9CrN_5, Li, Cr II Fe, LiCl,LiF,Li_3N, Fe II Ti, TiN

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

RESISTIVITY NITROGEN METER:



ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

ELECTROCHEMICAL NITROGEN METER:

* PRINCIPLE IDENTIFIED AND TESTED
* TESTED IN THE RANGE OF 300-400 WPPM

* COMPATIBILITY PROBLEMS
* SIGNIFICANT DEVELOPMENT EFFORT IS REQUIRED.

RESISTIVITY NITROGEN METER:

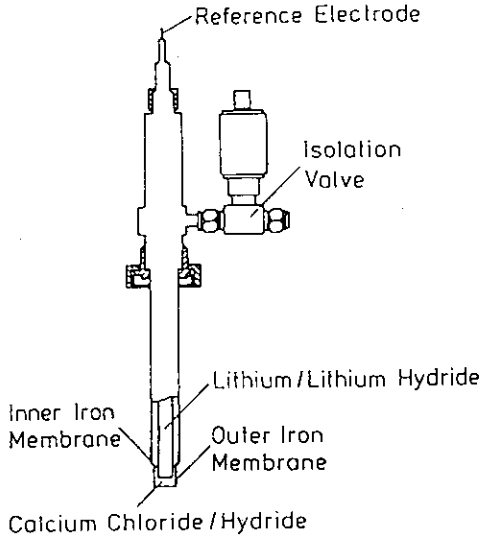
* EASY AND RELIABLE METHOD
* HIGH SENSITIVITY TO NITROGEN (GOOD FOR AIR-LEAKAGE)
* SENSITIVITY IN THE RANGE OF 100 WPPM

* INFLUENCE OF OTHER NONMETALLIC IMPURITIES (MAINLY H)
* DEVELOPMENT EFFORT IS REQUIRED (IMPROVE SENSITIVITY)
* COMPATIBILITY PROBLEMS

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

ELECTROCHEMICAL HYDROGEN METER:



DEVELOPED FOR SODIUM:

Na, NaH II Fe, $CaCl_2$, 15 % mol CaH_2, Fe II Li, LiH

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

DEVELOPMENT OF IMPURITY METERS

ACTIONS :

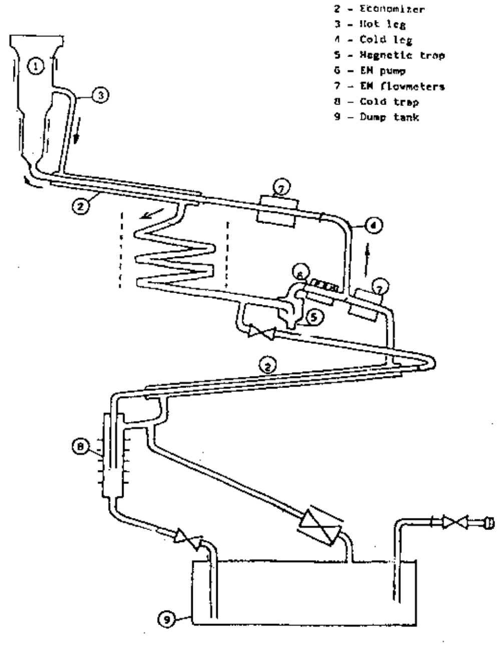
- N-Li SENSORS SELECTION
- VERIFY THE BASIC PERFORMANCE IN LABORATORY SCALE (I.E. GLOVE BOX);
- RELIABILITY AND ENDURANCE TESTS IN A FLOWING Li LOOP (THE SENSORS MUST BE CHECKED DURING OPERATION BY LABORATORY ANALYSIS);
- ASSESSMENT OF THE POSSIBLE USE OF ON-LINE SENSORS FOR H AND C (INDICATION ABOUT THE MOST PROMISING SOLUTION).

IN THE FRAME OF THE PRESENT TASK PARTICULAR ATTENTION WILL BE GIVEN TO ELECTROCHEMICAL AND RESISTIVITY METERS.

PRELIMINARY TIME TABLE

	START	END
ASSESSMENT ON H,C SENSOR S	1/97	10/97
N-Li SENSOR SELECTION	1/97	4/97
LABORATORY TESTS	4/97	6/98
LOOP TESTS	12/97	6/99
FINAL CONCLUSION	6/99	12/99

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali



Hot leg temperature	550°C
Cold leg temperature	385°C
Pressure	2 BAR
Flow rate in the test	0,016 dm^3/s.
Lithium inventory	10,5 dm^3
Test tank volume	1,5 dm^3
Material	AISI 316L

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

HYDROGEN PROBLEMS IN BACKWALL

BACKWALL WILL BE SUBJECTED TO HIGH NEUTRONS FLUX DURING OPERATION AND HIGH H/DPA AND He/DPA RATIOS IN THE BACKWALL ARE EXPECTED TO BE ONE OF THE MOST CRITICAL POINT IN THE DESIGN AND OPERATION OF TARGET SYSTEM IS THE .

SEVERAL MATERIALS MAY BE CONSIDERED AS POSSIBLE CANDUDATE FOR BACKWALL :

- FERRITIC/MARTENSITIC STEELS
- AUSTENITIC STEELS
- VANADIUM ALLOYS.

HOWEVER SEVERE EFFECTS OF:

- SWELLING
- IRRADIATION CREEP
- H AND HE EMBRITTLEMENT
- RIS (RADIATION INDUCED SEGREGATION)
- IRRADIATION ASSISTED CORROSION CRACKING

MY BE ENVISAGED FOR BACKWALL MATERIAL.

ENEA PROPOSAL AIMS AT CONTRIBUTING TO THE PRODUCTION OF A VALUABLE DATA BASE FOR BACKWALL MATERIAL ASSESSMENT.

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

HYDROGEN PROBLEMS IN BACKWALL

DUCTILITY LIMITS FOR STEELS IN PRESENCE OF HYDROGEN DEPENDING ON:

HYDROGEN LEVEL
DEFORMATION RATE
MULTI-AXIAL STRESS STATE
TEMPERATURE AND IRRADIATION PARAMETERS.

RADIATION INDUCED HARDENING GIVE A RISK OF HYDROGEN EMBRITTLEMENT.

AS CONCERNS THE USE OF FERRITIC/MARTENSITIC STEELS, SOME OF THE MORE IMPORTANT OPEN POINTS ARE:

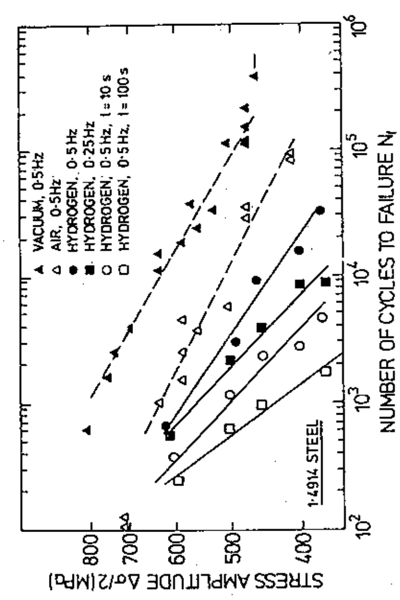
1) EVALUATION OF THE SYNERGETIC EFFECT OF H AND HE ON MECHANICAL PROPERTIES.

2) EFFECTS OF H ON DUCTILITY AT TEMPERATURE IN THE RANGE BETWEEN 373 AND 573 K BEFORE AND AFTER IRRADIATION.

3) EFFECTS OF H ON DUCTILITYAT LOW TEMPERATURE BEFORE AND AFTER IRRADIATION.

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

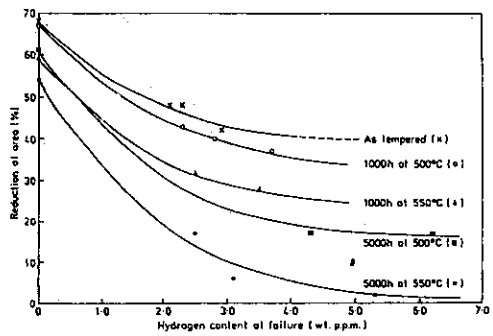
P. Jung et al. J. of Nucl. Mat. 212-215 (1994) 579



Number of cycles to failure as a function of stress amplitude for specimens of 1.4914 martensitic steel fatigue tested at room temperature in vacuum, air and hydrogen; at frequency and hold times are indicated.

FIG 2

C.A Hippsley Mat. Sci. and Tech. vol 4 1988 731



Reduction of area v. hydrogen content at failure for each aging condition

FIG 1

BEGHINI, G. BENAMATI, L. BERTINI J. of ENG. MAT. AND TECH. Vol 118 APR 1996

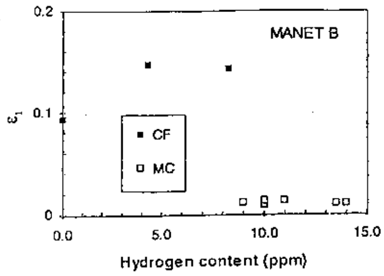
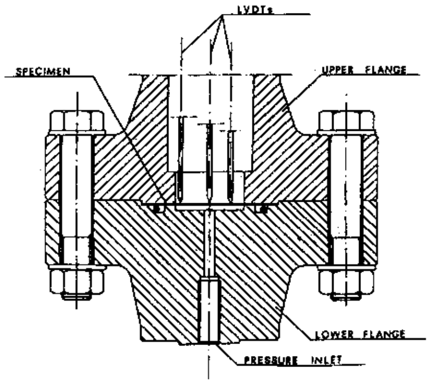
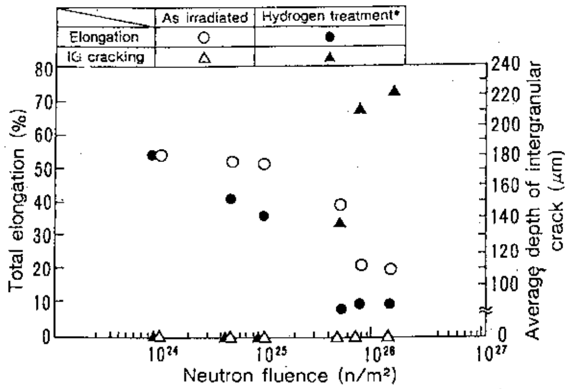


Fig. 11 - Maximum principal strain at failure vs. hydrogen content for MANET B stee



J MORISAWA et alt J. of NUC. MAT. 212-215 (1994) 1396



* : (24h Hydrogen charging+24 Hydrogen discharging) ×2

Fig. 4 Effect of neutron fluence and hydrogen treatment on ductility

HYDROGEN PROBLEMS IN BACKWALL

IN THIS FRAME THE FOLLOWING ACTIVITIES ARE PROPOSED:

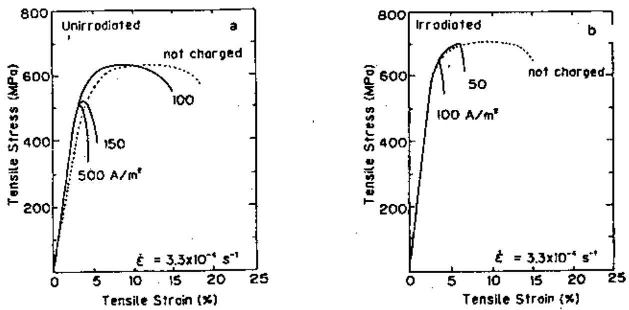
1) A CRITICAL REVIEW ON THE HYDROGEN AND HELIUM EMBRITTLEMENT ON AUSTENITIC AND FERRITIC-MARTENSITIC STEELS UNDER IRRADIATION;

2) TESTS AIMED AT EVALUATING THE CRITICAL HYDROGEN CONCENTRATION FOR VOID FORMATION (CCV) AND/OR THE CRITICAL HYDROGEN CONTENT FOR MECHANICAL PROPERTIES (CCM). THESE EVALUATIONS WILL BE PERFORMED FOLLOWING THE ASTM STP 962 METHOD FOR THE MEASURE OF CCV BY ASTM STP 543 "DISK PRESSURE TESTS " FOR CCM;

(THESE ACTIVITIES REFERS TO THE SECTIONS 2.5.7.1 AND 2.5.7.2 OF THE IFMIF REPORT).

ENEA IS ALREADY ENGAGED IN THE FRAME OF EUROPEAN FUSION TECHNOLOGY PROGRAMME IN TASKS AIMED AT EVALUATING HYDROGEN PERMEATION AND EMBRITTLEMENT OF SEVERAL REDUCED ACTIVATION MARTENSITIC STEELS.

A. KIMURA J. of Nucl MAT. 175-181 (1991) 737



Effects of hydrogen charging on the stress-strain curve of (a) unirradiated and (b) irradiated specimens.

FIG 3

LITHIUM AIR REACTION

TAKING INTO ACCOUNT THE RESULTS OF ENEA ACTIVITY IN THE FIELD OF SAFETY ANALYSIS, AND HAVING IN MIND THE GENERAL REQUIREMENTS FOR LITHIUM SYSTEM IN IFMIF FACILITY (SEE SECTION 2.5.1.8 OF IFMIF REPORT), THE FOLLOWING ACTIVITIES COULD BE ENVISAGED:

1) EXPERIMENTAL STUDIES ON THE EFFECT OF MASS/SURFACE RATIO ON THE EVOLUTION OF A LITHIUM POOL FIRE;

2) EVALUATION, BY MEANS OF SPECIFIC TESTS, OF THE POSSIBLE USE OF DEVICES LIKE "HEAT SINK" IN ORDER TO HAVE PASSIVE SYSTEMS ABLE TO REDUCES LITHIUM FIRE VIOLENCE;

3) EVALUATION OF THE MOST PROMISING FIRE SUPPRESSION MATERIALS.

AT PRESENT NO EXPERIMENTAL ACTIVITY MAY BE PERFORMED BEFORE 1998.

ENEA Sezione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Cost Estimations for Developmental Lithium Loop, IFMIF Main EMP and Review of Heat Exchanger Design

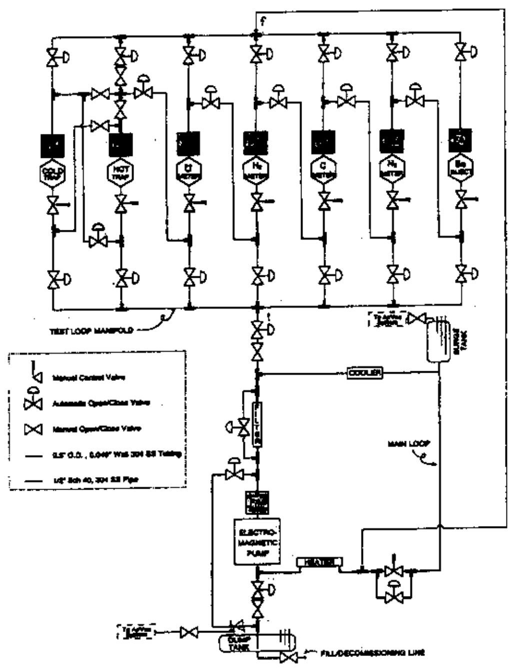
Presented by

L. Green

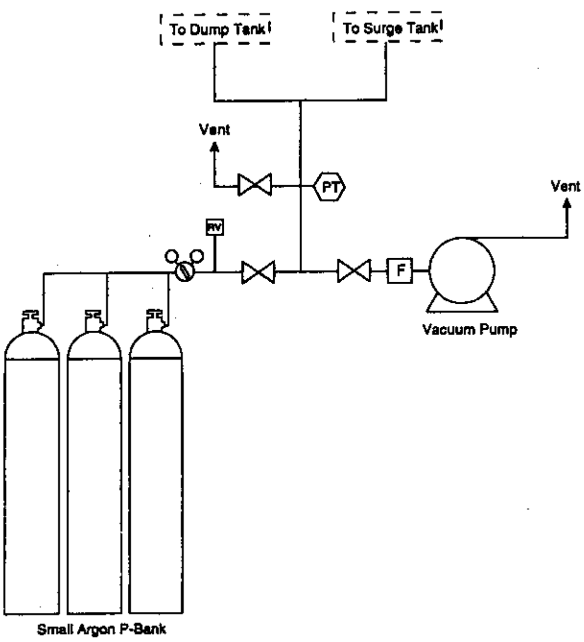
Westinghouse Science and Technology Center

IFMIF Design Integration Meeting,
May 20-26 at JAERI, Tokai, JAPAN

Preliminary Cost Estimation
---Developmental Lithium Loop---



Argon/Vacuum System



Preliminary Cost Estimation, Developmental Lithium Loop

		Professional Hours	Professional Cost ($)	Technician Hours	Technician Cost ($)	Total Cost
Capital						$592,314
Engineering	Final Design	200	$30,000			$30,000
	Drafting			80	$8,000	$8,000
Assembly	Machining	4	$600	80	$8,000	$8,600
	Pipe Fitting/Welding	8	$1,200	160	$16,000	$17,200
	Cleaning	2	$300	20	$2,000	$2,300
	Leak Testing/Inspection	2	$300	20	$2,000	$2,300
	Electrical	20	$3,000	100	$10,000	$13,000
	Data Acquisition System	16	$2,400	120	$12,000	$14,400
	Facility Renovations	120	$18,000	320	$32,000	$50,000
Shake Down /Start Up	Hazard Operability Study	80	$12,000			$12,000
	Procedures	40	$6,000			$6,000
	Conduct Start Up Test	20	$3,000	40	$4,000	$7,000
Testing	Test Plan Development	160	$24,000	160	$16,000	$40,000
	Conduct Tests	3000	$450,000	3000	$300,000	$750,000
	Health Physics	40	$6,000	120	$12,000	$18,000
	Data Reduction and Reporting	480	$72,000	160	$16,000	$88,000
Decomissioning	Loop Shut Down	40	$6,000	40	$4,000	$10,000
	Lithium Removal	16	$2,400	16	$1,600	$4,000
	Dismantle and Dispose	40	$6,000	80	$8,000	$14,000
	Totals	4288	$643,200	4516	$451,600	*$1,687,114*

Prelimina.y Material and Equipn t, Developmental Lithium Loop

Subassembly	Component	Size/Model	Vendor	Vendor Contact	Vendor Phone	Quote Date	Quantity	Price Each	Total Cost
Main Loop	Dump Tank	6" Sch 40, 304 SS Stainless Pipe, 20" long	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	3/29/96	1	$232	$232
		6" Sch 40, 304 SS Pipe Cap	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	3/29/96	2	$68	$135
	Dump Tank Liquid Level Probes	Spark Plug Type	Eng. Est.	R. Beleski	412-256-2154		3	$20	$60
	Dump Tank Heater	1700 W Tubular, Omega P/N TRI-8212/120	Omega			Catalog No. 28	2	$111	$222
	Dump Tank Fill/Drain Valve	Nupro SS-12UW-PW-HT	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	1	$1,034	$1,034
	Fill/Drain Connection	12 VCR Gland, Male Nut and Gasket P/N's SS-12-VCR-3-12MTW, SS-12-VCR-4, SS-8-VCR-12-GR	Pittsburgh Valve & Fitting	Tracy Maggiorini	412-761-3212	3/25/96	1	$42	$42
	Blanket Pressure Transducer	Precise or Sensotec (0-45 Psia) SRS Tritium Facility Equivalent	Eng. Est.	R. Beleski	412-256-2154	4/25/96	2	$1,600	$3,200
	Pressure Digital Readout	Vielpak/Doric, SRS Tritium Facility Equivalent	Eng. Est.	R. Beleski	412-256-2154	4/25/96	2	$2,300	$4,600
	Electromagnetic Pump	Style III Liquid Metal Conduction Pump, 8 - 12 liters/min	Mine Safety Appliances	Stan Hoover	412-967-4180	4/24/96	1	$29,075	$29,075
	Pump Controller	Voltage Controller	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$2,500	$2,500
	Electromagnetic Flowmeter	Liquid metal flowmeter, type FM-2	Mine Safety Appliances	Stan Hoover	412-967-4180	4/24/96	1	$11,250	$11,250
	Flow Indicator	Voltmeter with Readout	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$350	$350
	Filter	Custom	Westinghouse STC	R. Beleski, Eng. Est	412-256-2154	4/25/96	1	$500	$500
	Filter Bypass Valve	Nupro SS-12UW-PW-HT-SO, Normally Open Valve	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	3	$1,638	$4,913
	Surge Tank	4" Sch 40, 304 SS Stainless Pipe, 12" long	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/29/96	1	$89	$89
		4" Sch 40, 304 SS Pipe Cap	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/29/96	1	$28	$28
		1/4" 304 SS Plate	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$15	$15
	Surge Tank Liquid Level Probes	Spark Plug Type	Eng. Est.	R. Beleski	412-256-2154	4/29/96	3	$20	$60
	Surge Tank Heater	850W, 120V Clamshell Heater with 4" Vestibule. Omega Part NumberCRWS-66/120-C	Omega			Catalog No. 28	1	$187	$187
	Flow Control Valve	Nupro SS-12UW-PW-HT (Special Stem Tip)	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	1	$1,551	$1,551
	Automatic Dump Valves	Nupro SS-12UW-PW-HT-SO, Normally Open Valve	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	3	$1,638	$4,913
	Manual Isolation Valves	Nupro SS-12UW-PW-HT	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	2	$1,034	$2,068
	Cooler Chamber	2" Sch 10 Pipe, 20" Long 304 SS	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$50	$50
	Cooler Blower	5 CFM Variable Speed	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$200	$200
	Process Thermocouples	Type K, Grounded, .040" 304 SS Sheath, P/N KMTSS-040G-12	Omega	Dave	800-826-6342	4/26/96	8	$29	$229
	Tank Thermocouples	Spring loaded, Type K, Grounded, 1/16" dia 304 SS sheath, P/N NB2-CASS-116G-12-TBSL	Omega	Dave	800-826-6342	4/26/96	2	$57	$114
	1/2" Sch 40 304 SS Pipe,ft	Seamless, standard ID finish	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/23/96	20	$5	$90
	1/2" Sch 40 304 SS Pipe,ft	Seamless, 600 grit polished ID finish	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/23/96	20	$8	$153
	1/2" Sch 40 pipe to 3/8" tube (.049" wall) reducer	Cajon P/N SS-8-MPW-A-4TSW (will be modified)	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	4	$9	$34

Prelimin.., Material and Equipn t, Developmental Lithium Loop

	1/2" Sch 40 pipe to 1/2" tube (.049" wall) reducer	Cajon P/N SS-8-MPW-A-6TSW (will be modified)	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	5	$9	$43
	Flow Splitter	Custom	Westinghouse STC	R. Beleski, Eng. Est	412-256-2154	4/25/96	2	$100	$200
	1/2" Sch 40, 45° Elbows	Butt Weld Prepared	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/23/96	2	$14	$28
	1/2" Sch 40, 90° Elbows	Butt Weld Prepared	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/23/96	5	$11	$56
	1/2" Sch 40, Tees	Butt Weld Prepared	American Alloys, Inc.	Bernie Fingerhut	201-864-5900	4/23/96	12	$34	$412
	Tubular Heaters	1835 W, Omega P/N TRI-8812/120	Omega			Catalog No. 28	2	$117	$234
	Heater Controllers	Athena Model XT16 Temperature Controller, with 4-20 output to PLC	L. H. Bolelty Co.	Scott Carter	412-761-8994	4/29/96	3	$300	$900
						Main Loop Subtotal =			$89,767
Test Loops	Flow Control/Backup Isolation Valves	Nupro SS-8UW-PW-HT (Special Stem Tip)	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	14	$740	$10,364
	Automatic Loop Valves	Nupro SS-8UW-PW-HT-4O	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/25/96	23	$727	$16,710
	Electromagnetic Flowmeter	Liquid metal flowmeter, type FM-2	Mine Safety Appliances	Stan Hoover	412-967-4180	4/24/96	7	$11,250	$78,750
	Flow Indicator	Voltmeter with Readout	Eng. Est.	R. Beleski	412-256-2154	4/29/96	7	$350	$2,450
	Cold Trap	Custom	Westinghouse STC	R. Beleski, Eng. Est	412-256-2154	4/25/96	1	$5,000	$5,000
	Hot Trap	Custom	Westinghouse STC	R. Beleski, Eng. Est	412-256-2154	4/25/96	1	$5,000	$5,000
	Conductivity Meter	Custom	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$15,000	$15,000
	Hydrogen Meter	Custom	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$10,000	$10,000
	Carbon Meter	Design and Build Prototypes	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$100,000	$100,000
	Nitrogen Meter	Design and Build Prototypes	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$100,000	$100,000
	Beryllium Trap	Custom	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$7,500	$7,500
	Beryllium Detector	Quote No. EC-046-0319-1PA	EG&G Instruments, Inc.	Harold B. Winslett	800-251-9750	4/23/96	1	$53,289	$53,289
	Beryllium-7	3 mCi	Brookhaven National Lab	Susan Cataldo	516-344-4461	4/25/96	1	$500	$500
	Residual Gas Analyzer	Moderate off-the Shelf Model	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$20,000	$20,000
	Process Thermocouples	Type K, Grounded, .040" 304 SS Sheath, P/N KMTSS-040G-12	Omega	Dave	800-826-6342	4/26/96	20	$29	$573
	Process Tubing	1/2" O.D. Tube, .049" wall, ft	American Alloys, Inc.	Bernie Fingerhut	201-864-5500	4/29/96	180	$2	$376
	Process Tees	1/2" tube butt weld, Cajon P/N 6LV-6MW-3	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/26/96	22	$35	$763
	Process Crosses	1/2" tube butt weld, Cajon P/N 6LV-6MW-4	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/26/96	3	$41	$123
	Process Reducing Union	1/2" to 3/8" tube, Cajon P/N 316L-6TB7-6-6	Pittsburgh Valve & Fitting	Michelle	412-761-3212	4/26/96	14	$50	$700
	Tubular Heaters	1835 W, Omega P/N TRI-8812/120	Omega			Catalog No. 28	18	$117	$2,106
	Heater Controllers	Athena Model XT16 Temperature Controller, with 4-20 output to PLC	L. H. Bolelty Co.	Scott Carter	412-761-8994	4/29/96	18	$300	$5,400

Prelimina.y Material and Equipr. t, Developmental Lithium Loop

								Test Loops Subtotal =	$434,603
Cover Gas System	Argon P-Bank	3 Cylinder	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$500	$500
	Vacuum Pump	Varian SD-200, Mechanical Vacuum Pump	Varian			95/96 Catalog	1	$1,680	$1,680
	Oil Backstreaming Trap	Varian No. 345	Varian			95/96 Catalog	1	$560	$560
	Flow Control/Backup Isolation Valves	Nupro SS-8UW-PW-HT	Pittsburgh Valve & Fitting	Michelle	412-781-3212	4/25/96	6	$494	$2,961
								Covergas System Subtotal =	$5,701
Enclosure	Lithium Ionization Detector	Custom	Westinghouse STC	Bob Witkowski, Eng Est.	412-256-1969	4/25/96	1	$10,000	$10,000
	Smoke Detector	Photoelectric, with thermostat. P/N 6634T32	McMaster			Catalog No 98	1	$66	$66
	Drain Pan	Custom	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$1,000	$1,000
	Enclosure	Custom	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$5,000	$5,000
								Enclosure Subtotal =	$16,066
Data Acquisition	Hardware	Molytek RTU, 32 Channel A/D Converter, P/N RTURN10000201	Glatte & Company	Mike Luck	216-333-1380	5/15/96	3	$1,836	$5,514
		Molytek DACQ Switch P/N DACQ01	Glatte & Company	Mike Luck	216-333-1380	5/15/96	1	$670	$670
	Software	Communications Protocols, etc. AFE P/N IC2000-SR	Glatte & Company	Mike Luck	216-333-1380	5/15/96	1	$995	$995
		Data Archiving and Trending, etc. AFE P/N IC2000-HAE/DGR	Glatte & Company	Mike Luck	216-333-1380	5/15/96	1	$875.	$875
		Data Exchange Blocks, etc. AFE P/N IC2000-DEB	Glatte & Company	Mike Luck	216-333-1380	5/15/96	1	$875	$875
	Computer	IBM Pentium or 486 clone with color monitor, keyboard, mouse, and printer	Eng. Est	R. J. Beleski	412-256-2154	4/30/96	1	$5,000	$5,000
								Data Acquisition Subtotal =	$13,929
Safety	Heat Protective Clothing	Full Complement, Aluminized PBI	McMaster			Catalog No 98	2	$1,072	$2,144
	Liquid Metal Fire Extinguisher	Met-L-X	Eng. Est.	R. Beleski	412-256-2154	4/29/96	2	$500	$1,000
	Bulk Fire Extinguishing Media	Met-L-X	Eng. Est.	R. Beleski	412-256-2154	4/29/96	1	$500	$500
	Shower/Eye and Face Wash Station	Stainless, P/N 5582ST3	McMaster			Catalog No. 98	1	$1,596	$1,596
	Self-Contained Breathing Apparatus	Dual Purpose, P/N TC-13F-154	McMaster			Catalog No. 98	2	$1,897	$3,795
	Safety Control System	Alarms, Interlocks, Ventilation Monitoring and Control	Eng Est	P. Clarelli	412-256-1982		1	$15,000	$15,000
	Fire Supression System	For Loop Enclosure	Eng Est	P. Clarelli	412-256-1982		1	$20,000	$20,000
	Portable Gamma Monitor	BiCron Surveyor 2000 with side wall G/M	Eng Est.	Jack Lenhardt	412-256-1942		2	$1,000	$2,000

Preliminary Material and Equipr t, Developmental Lithium Loop

	Radiation Shielding	None Required if Be-7 as point source is kept a minimum of 12" from enclosure wall	Eng Est.	Tom Congedo	412-256-1084		0	$0	$0
	Dosimetry		Eng Est.	Jack Lenhardt	412-256-1942		1	$500	$500
	Thermal Insulation		Eng. Est.	R. Beleski	412-256-2154		1	$1,000	$1,000
	Combustible Gas Alarm		Eng. Est.	R. Beleski	412-256-2154		1	$500	$500
								Safety Equipment Subtotal =	$46,035
Auto Valve Operation	Solenoid Valves	3-way Multipurpose, Schrader Bellows P/N 74514-0115	Grainger			Catalog No. 361	25	$36	$893
	Position Indicating Limit Switches	Dual Switch for Independent Open/Close Indication	Eng Est.	R. Beleski	412-256-2154		50	$50	$2,500
	Air Compressor	Tank Mounted, 3/4 HP, P/N 5Z674	Grainger			Catalog No. 361	1	$622	$622
	Air Tubing/Fittings	Poly-Flo with fittings	Eng Est.	R. Beleski	412-256-2154		1	$200	$200
								Auto Valve Operation Subtotal =	$4,214
								Grand Total =	$592,314

Cost Estimates of IFMIF Main Electromagnetic Pump System

Summary of IFMIF Main Electromagnetic Pump Requirements

Basis of Estimate	One Pump & Set of Accessories	One Pump & Set of Accessories
Configuration	Annular Linear Induction Straight Thru Duct	Annular Linear Induction Return Duct
Design Flow	2300 Gallons/Minute	2300 Gallons/Minute
System Pressure	80 Pounds/Inch^2	80 Pounds/Inch^2
Input Power	3 Phase 60 Hertz 0 to 660 Volts Line-Line 90% Power Factor (Approx) Corrected <200 Kilowatts (Approx)	3 Phase 60 Hertz 0 to 660 Volts Line-Line 90% Power Factor (Approx) Corrected 200 Kilowatts (Approx)
Cooling	Natural Convection	Natural Convection
Pumped Lithium Temperature	300 ^{o}C (Approx)	300 ^{o}C (Approx)
Accessories	Motor Driven Variac Power Factor Correction Capacitors Pump Overtemperature Protection Phase Loss Protection	Motor Driven Variac Power Factor Correction Capacitors Pump Overtemperature Protection Phase Loss Protection

Summary of Basis for Cost Estimating of IFMIF Main Electromagnetic Pump System

1. Electromagnetic Pump

The Pump Assembly constitutes a complete package from the weld prep ends of the flow duct to the input power terminals of the Pump winding and includes six internally mounted thermocouples for thermal monitoring.

Note that the Pump Assembly is not based on a detailed pump design but is rather approximated from machinery of comparable power rating. Similarly, no comprehesive thermal analysis was made. Consideration of the specified lithium temperature leads to the qualified conclusion that conventional electrical steels and Class H insulation may be employed successfully.

In the event that detailed pump design demonstrates that high cobalt alloy steels and/or non-conventional winding insulation such as ceramics are required, the Pump Assembly cost could increase on the order of 200%.

Testing of the Pump Assembly is limited to dimensional checks and piecewise electrical checks of winding and thermocouples (e.g. room temperature resistance checks, surge test, hipot test, phase sequence test, polarity test), duct pressure test, etc.

Flow tests with lithium are assumed to be part of the IFMIF facility commissioning and outside the scope of this estimating effort.

2. Power Supply

2.1 Power Factor Correction Capacitor Bank

A power factor correction bank connected at the terminals of the Pump Assembly and sufficient to correct the input power factor to approximately 95% (lagging) is included. The bank consists of sheet metal cabinets, capacitors, contactors, and all internal wiring and assembly. Routine factory test of the bank for opens, shorts, grounds, capacitance value, etc is included.

Summary of Basis for Cost Estimating of IFMIF Main Electromagnetic Pump System (Continued)

2.2 Motor Driven Variac Assembly

A variable transformer assembly is included capable of adjustment of output voltage from 0 to 660 volts, 3 phase AC, 60 Hertz (with 575 volts, 3 phase AC, 60 Hertz input). The transformer output voltage is adjusted by a sprocket and chain system driven by a DC motor operated from an AC-to-DC speed controller. The system, as costed, is open loop. (i.e. Voltage adjustment is manual based on operator command to the AC-to-DC speed controller as warranted in response to visual observation of IFMIF facility lithium loop flow monitors.)

Conversion to closed loop flow control (i.e. set it and forget it) is possible by addition of appropriate monitoring/control/feedback components between the lithium loop flow monitors and the AC-to-DC speed controller ***but is assumed to be part of the IFMIF facility design and outside the scope of this estimating effort.***

2.3 Control & Protection

The Power Supply includes appropriate input controls to disconnect the Supply from the IFMIF facility power system if an overtemperature condition is sensed in the Main Electromagnetic Pump or loss of phase is detected at the Pump.

This hardware, as estimated, is a relatively small fraction of the overall Power Supply cost and is included more to reflect the requirement for some control and protection capability in the Pump System than to represent a definitive control and protection package.

It is assumed the ultimate Pump System control and protection package is an activity of the overall IFMIF facility design and outside the scope of this estimating effort.

3. Shipping, Installation, & Interconnections

3.1 Shipping

Estimated Main Electromagnetic Pump System component costs are FOB points of manufacture and do not include shipping, preservation packing, custom duties and clearance fees, or similar presently undefined incidental costs.

Summary of Basis for Cost Estimating of IFMIF Main Electromagnetic Pump System (Continued)

3.2 Installation & Interconnection

Estmated Main Electromagnetic Pump System component costs do NOT include as follows :

3.2.1 Cost of local labor for installation at the IFMIF facility site
3.2.2 Cost of cable, conduit, junction boxes, expendables, and similar components and materials required for interconnection of Pump Systems components at the IFMIF facility site.
3.2.3 Cost of IFMIF facility lithium loop infrastructure, power system, and monitoring/controls/protection engineering, hardware, and installation labor.

3.3 IFMIF Facility Lithium Flow Testing

Estmated Main Electromagnetic Pump System component costs do NOT include as follows :

3.3.1 Receiving inspections or tests at the IFMIF facility site.
3.3.2 Flow tests with lithium in the IFMIF facility for verification of Pump System component performance/installation/operation and/or lithium loop performance/installation/operation.

4. Documentation, Certification, Administrative Requirements

Estmated Main Electromagnetic Pump System component costs do NOT include as follows :

4.1 Documentation other than drawings, specifications, quality control records, and operator manuals consistent with USA domestic good commercial practice.
4.2 Certifications, material traceability records, maintenance of sample materials or assemblies, and similar procedures in excess of USA domestic good commercial practice.
4.3 Design reviews, presentations, travel, reports, witness tests, adherence to domestic or international hiring, procurement, safety, and other requirements in excess of USA domestic good commercial practice.

Summary of Basis for Cost Estimating of IFMIF Main Electromagnetic Pump System (Continued)

5. Tooling

It is expected, at the present level of Pump System detail and the limitations detailed in preceeding Paragraphs, that components other than the Pump will be vendor catalog items or near derivatives of same.

Nominal values of tooling are listed for the two pump configurations subject to the following limitations:

5.1 Tooling is of a "one shot" nature suitable for production of one or two Pump assemblies only.
5.2 Typical commercial materials and processes are used.
5.3 Tooling estimats are representative but is highly dependent on the specific fabricator(s) selected to produce the Pump components and assembly.

6. Non-recurring Design, Documentation, Administration & Follow

The estimates for Non-Recurring Design, Documentation, Administration & Follow are considered representative of the level of effort anticipated subject to the limitations detailed in preceeding Paragraphs.

For Westinghouse internal reference, note that the estimates are based on the following rates derived from recent STC proposals :

Professional - $160/Hour
Support - $ 55/Hour

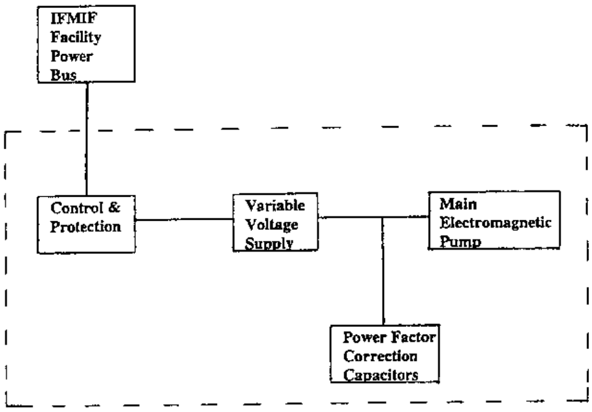
The non-recurring estimates should therefore be considered representative but not necessarily conclusive depending on what organization performs the effort (i.e. Westinghouse STC, and who within STC, or others) or the time period during which it is performed.

Cost Estimates of IFMIF Main Electromagnetic Pump System

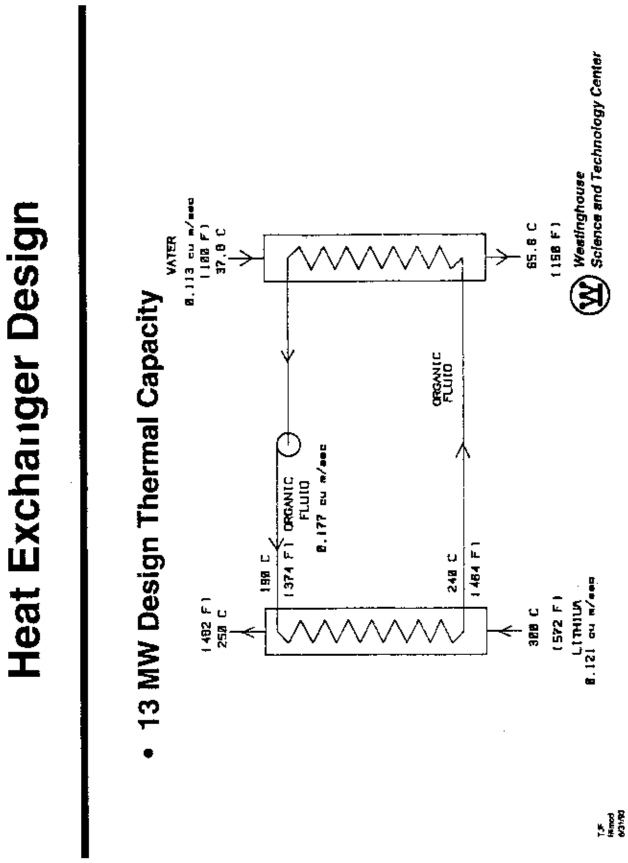
	Straight Duct Design	Return Duct Design
1. Non-Recurring Costs		
1.1 Pump		
1.1.1 Design	$ 76.8 K	$ 102.4 K
1.1.2 Documentation	$ 68.8 K	$ 86.0 K
1.1.3 Administration & Follow	$ 41.0 K	$ 47.4 K
1.1.4 Pump Tooling	$ 71.0 K	$ 81.0 K
1.2 Pump Power Supply		
1.2.1 Design	$ 25.6 K	$ 25.6 K
1.2.2 Documentation	$ 34.4 K	$ 34.4 K
1.2.3 Administration & Follow	$ 15.4 K	$ 15.4 K
2. Hardware Costs		
2.1 Pump	$ 81.0 K	$ 113.0 K
2.2 Pump Power Supply		
2.2.1 Power Factor Correction Sub-System	$ 63.8 K	$ 78.6 K
2.2.2 Variable Voltage Power Supply Sub-System	$ 38.5 K	$ 49.7 K
2.2.3 Protection & Control Sub-System	$ 7.5 K	$ 18.9 K

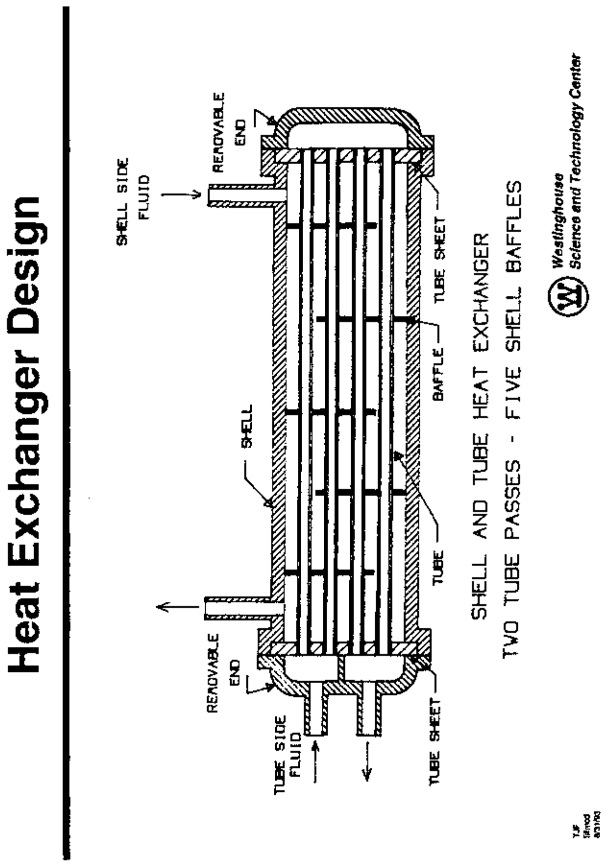
NOTE : See Notes in Attachment II for assumptions used in generating estimates.

IFMIF Main Electromagnetic Pump System Block Diagram



NOTE : Dotted lines indicate limit of estimated hardware.





Heat Exchanger Design

- LITHIUM-ORGANIC HEAT EXCHANGER
- SHELL SIDE
- Lithium - 0.122 m^3/sec
- 1.49 m diameter - 4.24 m long
- 19 baffles
- TUBE SIDE
- Organic fluid - 0.180 m^3/sec
- 1008 tubes - 304 stainless steel
- 31.75 mm O.D. - 1.651 mm wall thickness
- 12 passes

Westinghouse Science and Technology Center

Heat Exchanger Design

- WATER - ORGANIC HEAT EXCHANGER

  SHELL SIDE

  Water - 0.113 m^3/sec

  0.641 m diameter - 8.38 m long

  11 baffles

  TUBE SIDE

  Organic fluid - 0.180 m^3/sec

  204 tubes - 304 stainless steel

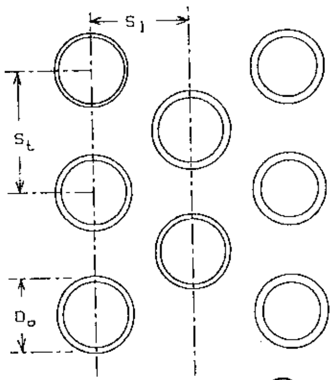
  31.75 mm O.D. - 1.651 mm wall thickness

  2 passes

Westinghouse Science and Technology Center

Heat Exchanger Design

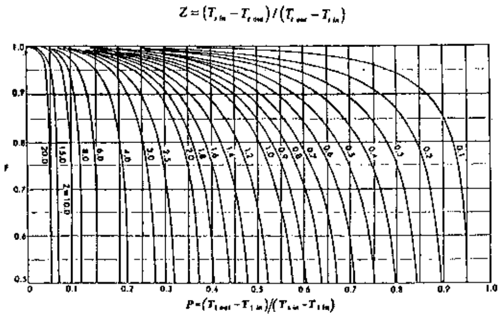
- Heat exchanger tube geometry

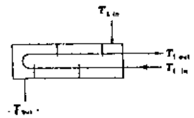


Westinghouse Science and Technology Center

Heat Exchanger Design

- Correction factor to LMTD for two or a multiple of two tube passes, and one shell pass.





Westinghouse Science and Technology Center

Heat Exchanger Design

- Reynolds Number Based on Maximum Velocity

$$\mathrm{Re}_{max} = \left(\frac{\rho V_{max} D_o}{\mu}\right)$$

$$V_{max} = \frac{S_t - D_o}{S_t} V_{free}$$

$$\text{If } \sqrt{S_l^2 + S_t^2} < S_t + D_o/2$$

$$V_{max} = \left(\frac{S_t}{\sqrt{S_l^2 + S_t^2}} - D_o\right) V_{free}$$

Westinghouse Science and Technology Center

Heat Exchanger Design

- Lithium in shell side of heat exchanger

Convection coefficient by Brookhaven Labs correlation for liquid metals over tube banks:

$$h = (k/D)\{4.03 + 0.228(\mathrm{Re}_{max}\mathrm{Pr})_f^{0.67}\}$$

Westinghouse Science and Technology Center

Heat Exchanger Design

- Organic fluid in tube side of heat exchanger

Convection coefficient by Dittius-Boelter correlation for turbulent flow in tubes:

$$h = 0.023(k/D)(\mathrm{Re}_d^{0.8})(\mathrm{Pr}^{0.333})$$

Westinghouse Science and Technology Center

Heat Exchanger Design

- Water in shell side of heat exchanger

Convection coefficient by Kays correlation for flow over tube banks:

$$h = 0.33(k/D)(\mathrm{Re}_{max}^{0.6})(\mathrm{Pr}_f^{0.3})$$

Westinghouse Science and Technology Center

Appendix-5.4 Documents Presented at Plenary/General Meeting

Table of Contents

Thomas E. Shannon
The University of Tennessee

Outline of the 2nd IFMIF Design Integration Meeting

JAERI
Tokai Research Establishment
May 20, 1996

OBJECTIVES OF THIS MEETING

1. **Review and Update the Baseline Design Concept**
   - **Provide a written summary (addendum) of changes from Interim Report.**
2. **Establish the R&D Needs for the Engineering Validation Phase**
   - **Provide a written description of the need and scope of the required activity.**
3. **Review the Preliminary Cost and Schedule Estimates**
   - **Construction Project**
   - **Operation**
   - **Research and Development for Engineering Validation**

OBJECTIVES OF THIS MEETING (CONTINUED)

4. **Identify Areas of Major Uncertainty in the Estimates**
   - **Determine range of cost or contingency**
5. **Write the First Draft of the Cost and Schedule Sections for the Interim Report.**
6. **Review Detailed Results of RAM, Safety and Maintenance**
   - **Document results (addendum) for Interim Report**
7. **Continue to Prepare for a Project, Work Hard, Learn, Produce Good Results, Build Relationships, Have Fun.**

IFMIF Design Integration Workshop

May, 1996

JAERI, Japan

- Test Cell Design - Progress
- Work Breakdown Structure
- Cost Estimate - Summary

Anton Möslang

Meeting Format

- General Meetings
  - Discuss status, conclusions and unresolved problems
- Group Meetings
  - Plan Work
  - Discuss Technical Issues
  - Compare Results
  - Resolve Problems
- Individual Work
  - Write Reports
  - Integrate Results (DI Group)
- Group Leaders
  - Write Reports
  - Discuss Issues
  - Prepare Presentation for Subcommittee
  - Meet with Subcommittee

Meeting Outline

	Monday May 20	Tuesday May 21	Wed. May 22	Thurs. May 23	Friday May 24	Saturday May 25	Sunday May 26	Monday May 27	Tuesday May 28
General Meeting	x	x	x	x	x x	x			
Group Meeting	x	x	x	x					
Group Leaders								x x	x x

Summary

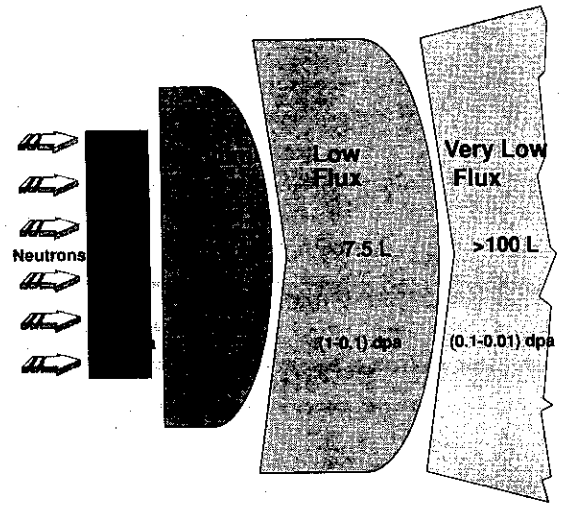
Complements to Design Team for Completing Work on Time

Thanks to Japanese Colleagues for Excellent Job of Preparation and Planning

Introduce Team Members (See List)

International Fusion Materials Irradiation Facility IFMIF

Test Cell Zones



IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Removable Cover (ORNL)

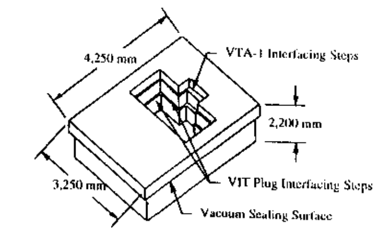


Figure of Test Cell Removable Cover

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Liner and Heat Shield (ORNL)

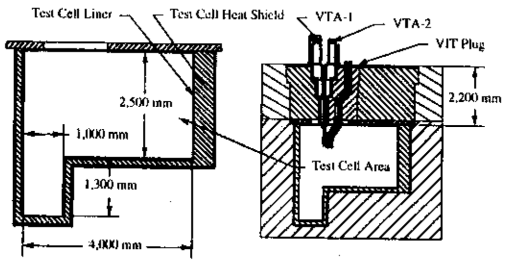


Figure Of Test Cell Liner And Heat Shield

IFMIF Design Integration Meeting May 1996, JAERI, Japan

NaK Controlled Vertical Test Assemblies VTA-1 and VTA-2 (ORNL)

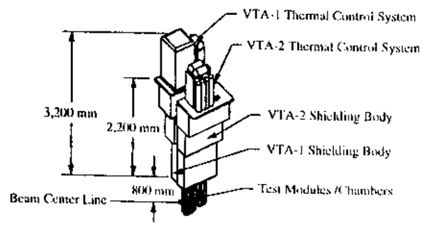


Figure Of NaK Thermally Controled Vertical Test Assemblies VTA-1 and VTA-2

Vertical Irradiation Tube Plug VIT (ORNL)

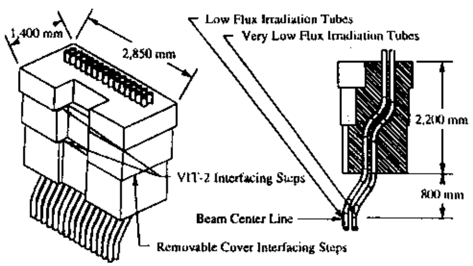


Figure Of The Vertical Irradiation Tube Plug

Test Cell Shielding Plug Arrangement (ORNL)

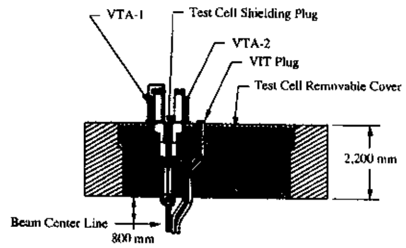
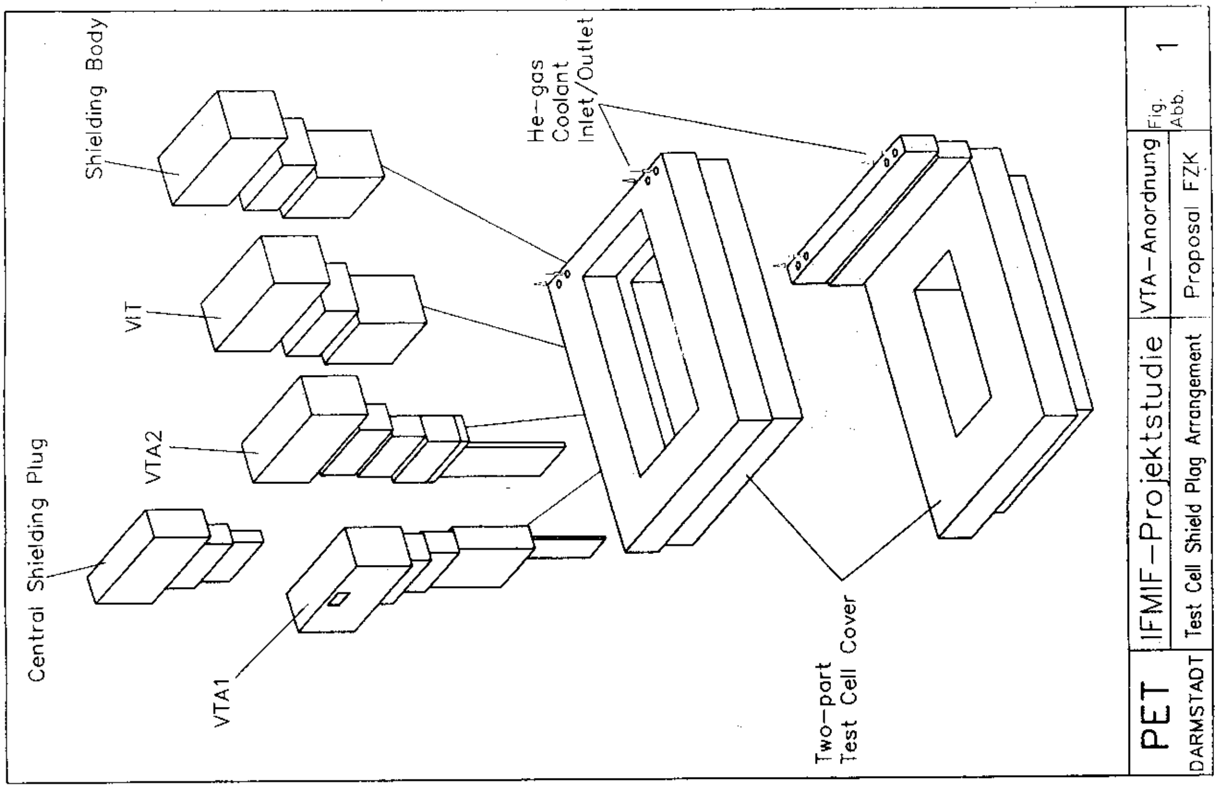
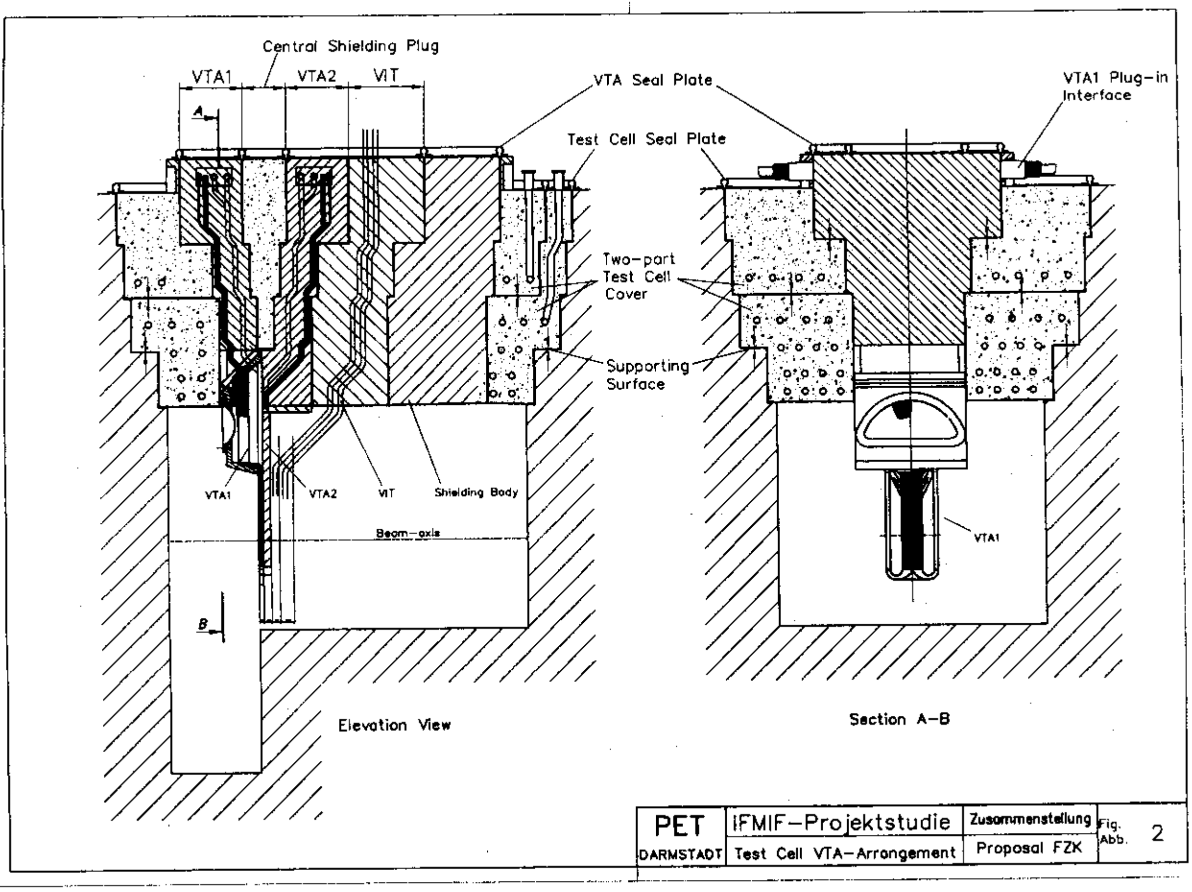
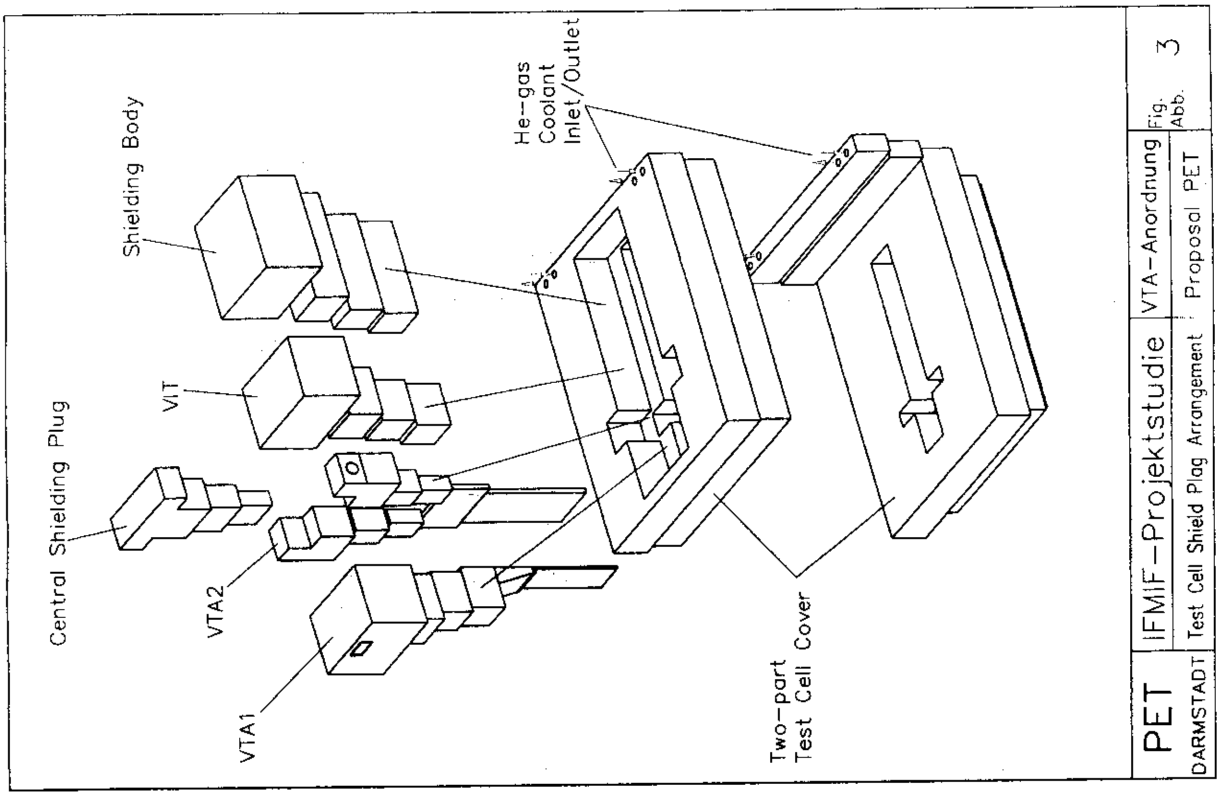
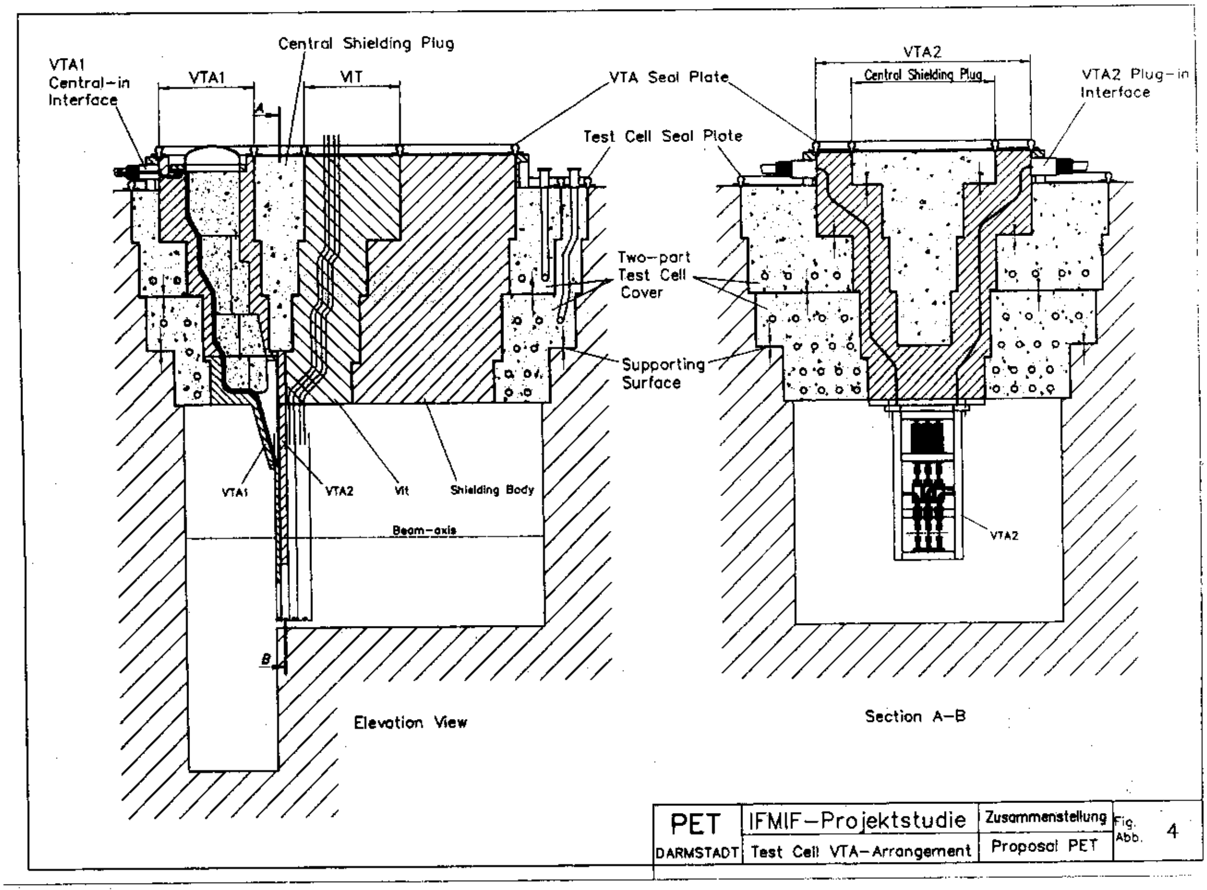


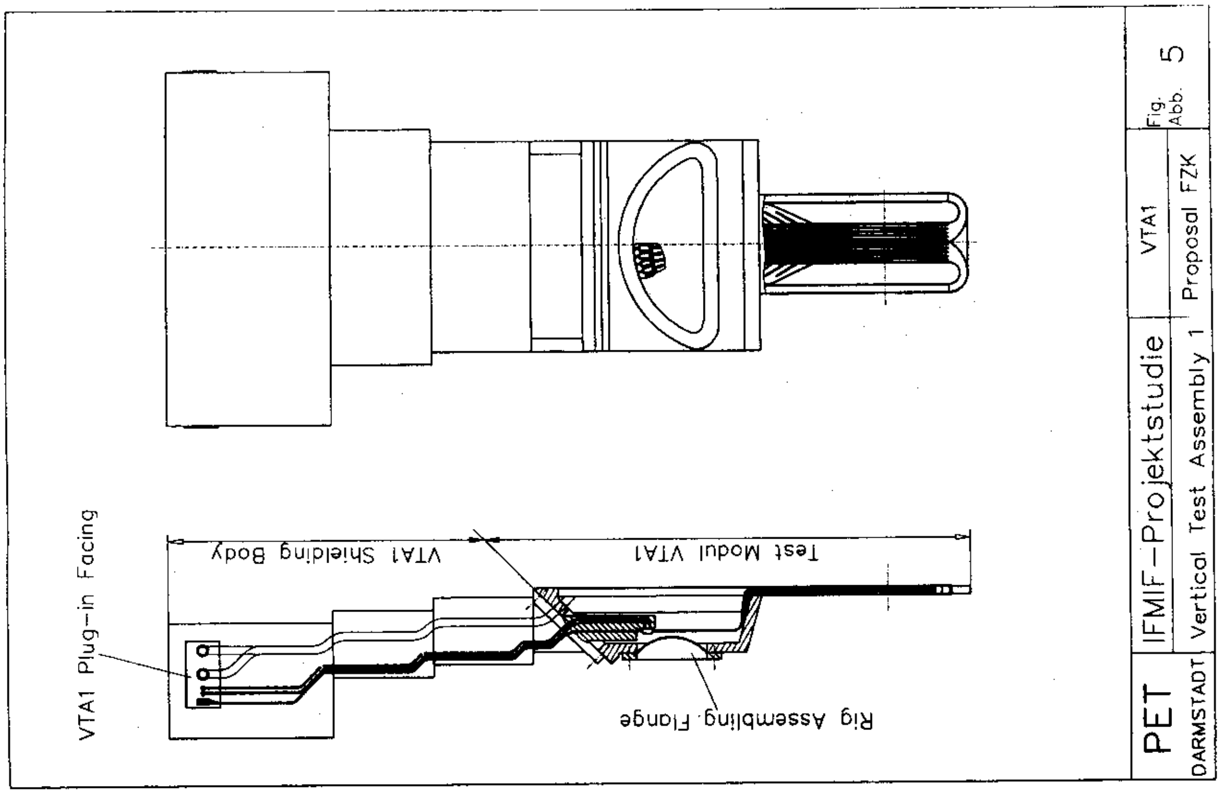
Figure OF Test Cell Shielding Plug Arrangement

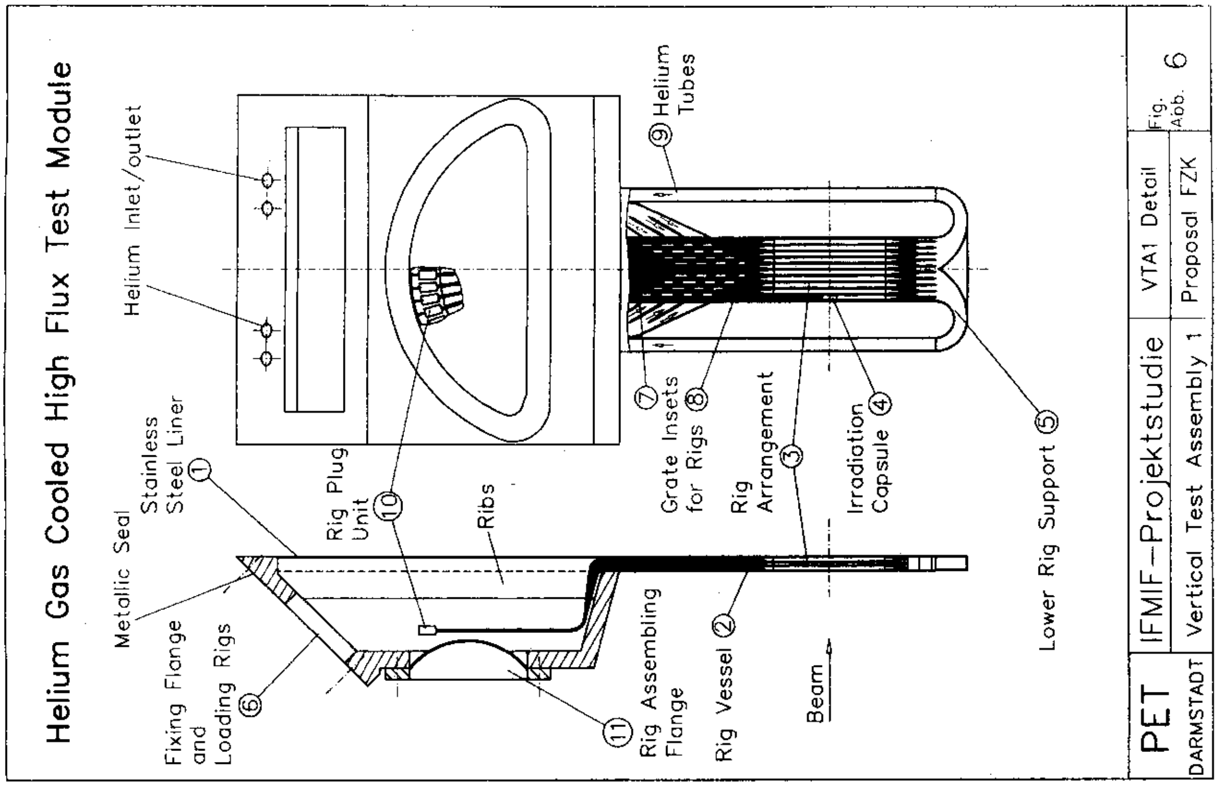

Shielding Body
He-gas
Coolant
Inlet/Outlet
ViT
VTA2
Central Shielding Plug
VTA1
Two-part
Test Cell Cover
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell Shield Plag Arrangement
VTA-Anordnung
Proposal FZK
Fig.
Abb.
1

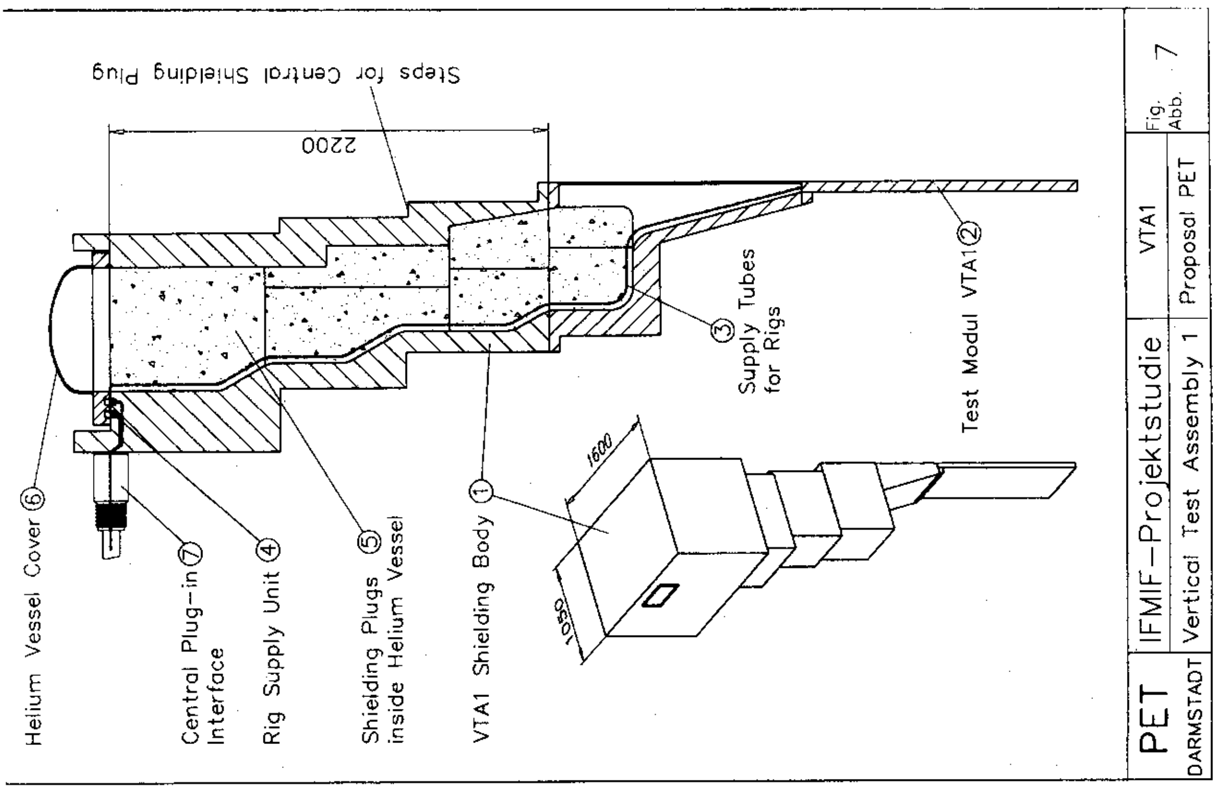

Central Shielding Plug
VTA1
VTA2
ViT
A
B
VTA Seal Plate
VTA1 Plug-in
Interface
Test Cell Seal Plate
Two-part
Test Cell
Cover
Supporting
Surface
VTA1
VTA2
ViT
Shielding Body
Beam-axis
VTA1
Elevation View
Section A-B
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell VTA-Arrangement
Zusammenstellung
Proposal FZK
Fig.
Abb.
2

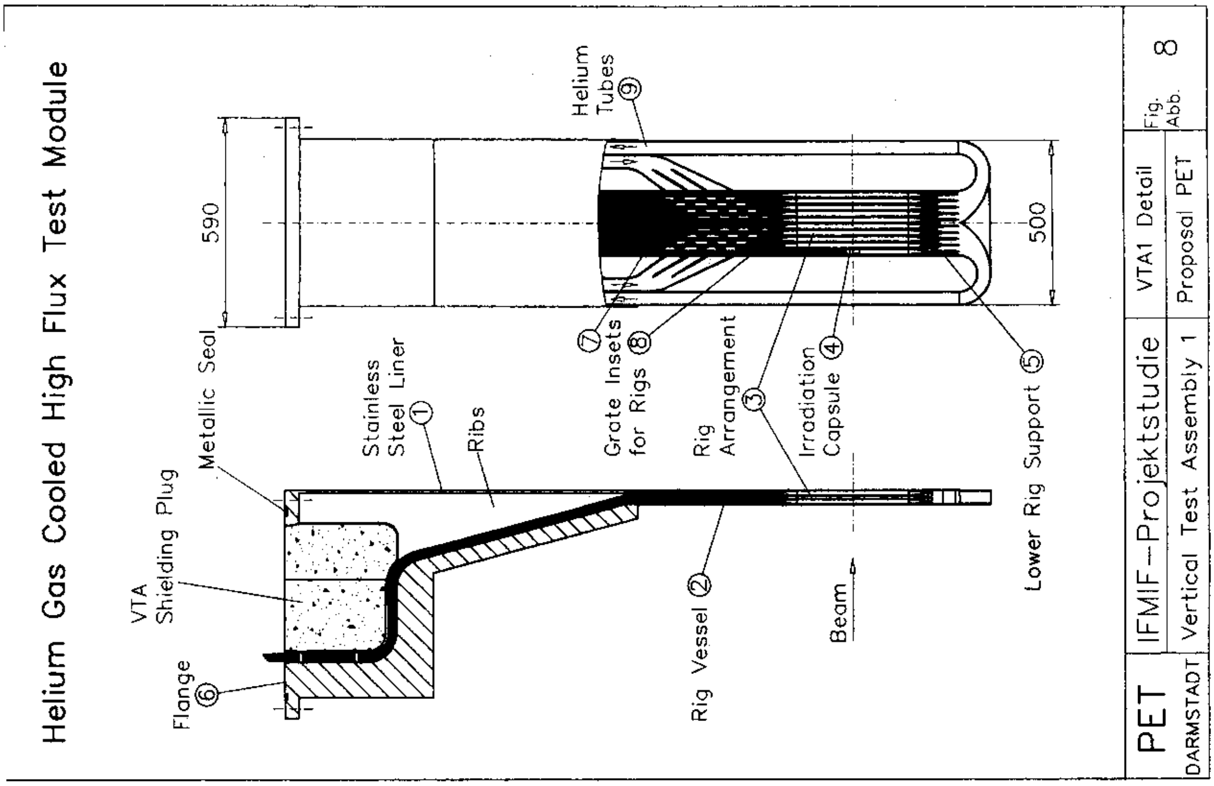

Shielding Body
He-gas
Coolant
Inlet/Outlet
VIT
Central Shielding Plug
VTA2
VTA1
Two-part
Test Cell Cover
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell Shield Plug Arrangement
VTA-Anordnung
Proposal PET
Fig.
Abb.
3


VTA1
Central-in
Interface
Central Shielding Plug
VTA1
VIT
VTA Seal Plate
Test Cell Seal Plate
Two-part
Test Cell
Cover
Supporting
Surface
VTA1
VTA2
Vit
Shielding Body
Beam-axis
Elevation View
VTA2
Central Shielding Plug
VTA2 Plug-in
Interface
VTA2
Section A-B
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell VTA-Arrangement
Zusammenstellung
Proposal PET
Fig.
Abb.
4


VTA1 Plug-in Facing
VTA1 Shielding Body
Test Modul VTA1
Rig Assembling Flange
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1
Proposal FZK
Fig.
Abb.
5


Helium Gas Cooled High Flux Test Module
Fixing Flange and Loading Rigs ⑥
Metallic Seal
Stainless Steel Liner ①
Helium Inlet/outlet
Rig Plug Unit ⑩
Ribs
⑨ Helium Tubes
⑦
Grate Insets for Rigs ⑧
Rig Arrangement ③
Irradiation Capsule ④
Lower Rig Support ⑤
⑪ Rig Assembling Flange
Rig Vessel ②
Beam
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1 Detail
Proposal FZK
Fig.
Abb.
6

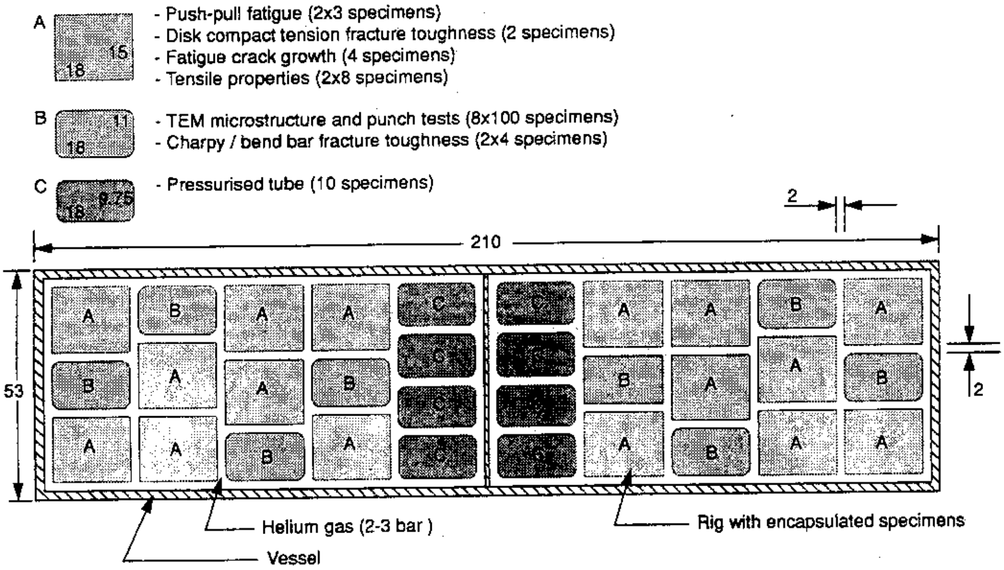

Helium Vessel Cover ⑥
Central Plug-in Interface ⑦
Rig Supply Unit ④
Shielding Plugs inside Helium Vessel ⑤
VTA1 Shielding Body ①
1600
1050
Test Modul VTA1 ②
Supply Tubes for Rigs ③
2200
Steps for Central Shielding Plug
PET
DARMSTADT
IFMIF–Projektstudie
Vertical Test Assembly 1
VTA1
Proposal PET
Fig.
Abb.
7


Helium Gas Cooled High Flux Test Module
Flange ⑥
VTA Shielding Plug
Metallic Seal
590
Stainless Steel Liner ①
Ribs
Rig Vessel ②
Beam
⑦
Grate Insets for Rigs ⑧
Rig Arrangement ③
Irradiation Capsule ④
Lower Rig Support ⑤
500
Helium Tubes ⑨
PET
DARMSTADT
IFMIF–Projektstudie
Vertical Test Assembly 1
VTA1 Detail
Proposal PET
Fig.
Abb.
8

Forschungszentrum Karlsruhe
Technik und Umwelt

A.M. 04. 1996

Cross section of helium gas cooled high flux test module - DRAFT -



Volume considerations

Typical volume fractions within the rigs:

	A	B	C
Helium for gas gaps	23%	26%	36%
rig and capsule	35%	37%	38%
specimens	42%	37%	26%

Because both the rigs and capsules will likely consist of materials very similar to the specimens itself, the following volume fractions for the neutron scattering can beused:

A: 77% structural material 23% void
B: 74% structural material 26% void
C: 64% structural material 36% void

Volume fractions within the high flux volume:

8 rigs for A : 39% of total vessel volume
8 rigs for B: 14% of total vessel volume
8 rigs for C: 12% of total vessel volume
Vessel structure: 10% of total vessel volume
He gas coolant: 25% of total vessel volume

Therefore, the following averaged volume fractions can be considered as typical for the high flux test module:

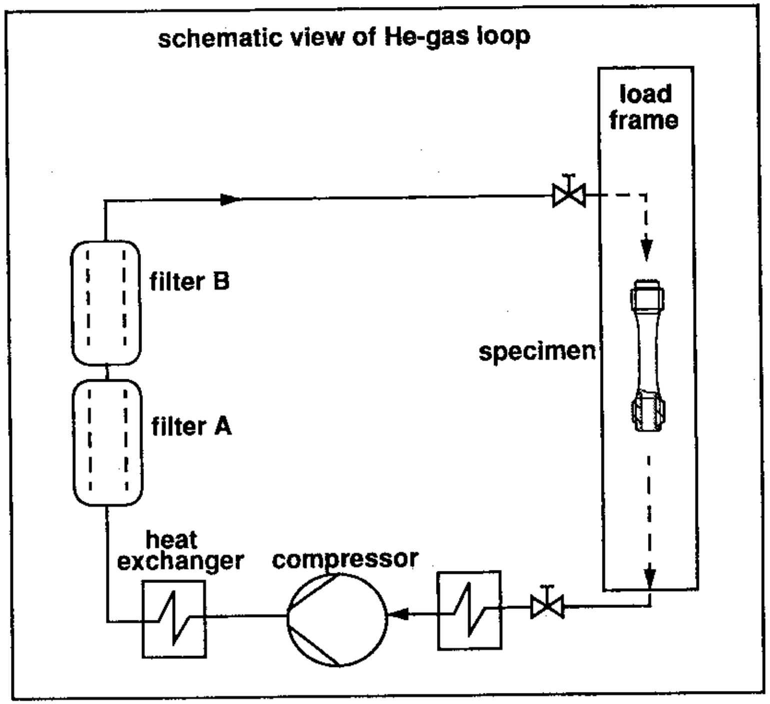
	Volume fraction
He-gas (coolant and gas gaps)	42 %
Material (specimens, rigs, capsules, vessel)	58 %

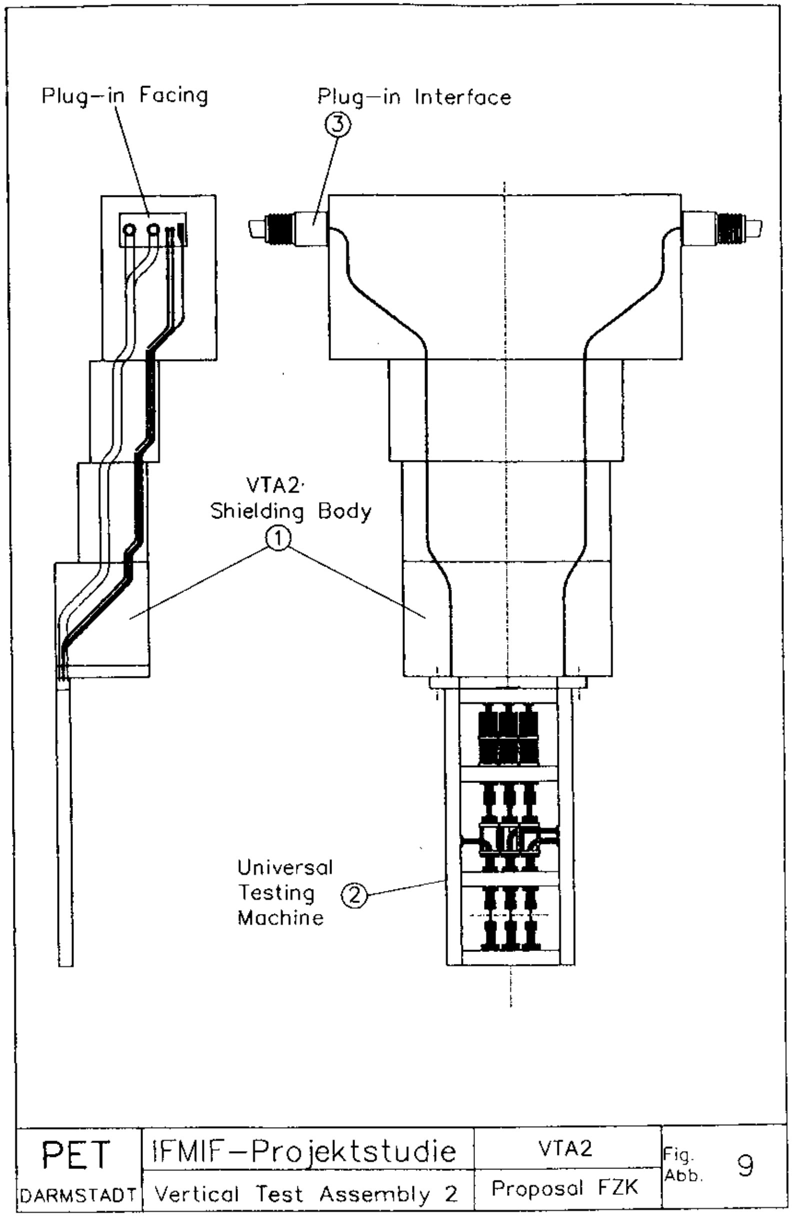
Helium gas coolant loop

Long-term experience for He-loops operating in neutron and light ion irradiation facilities is available.

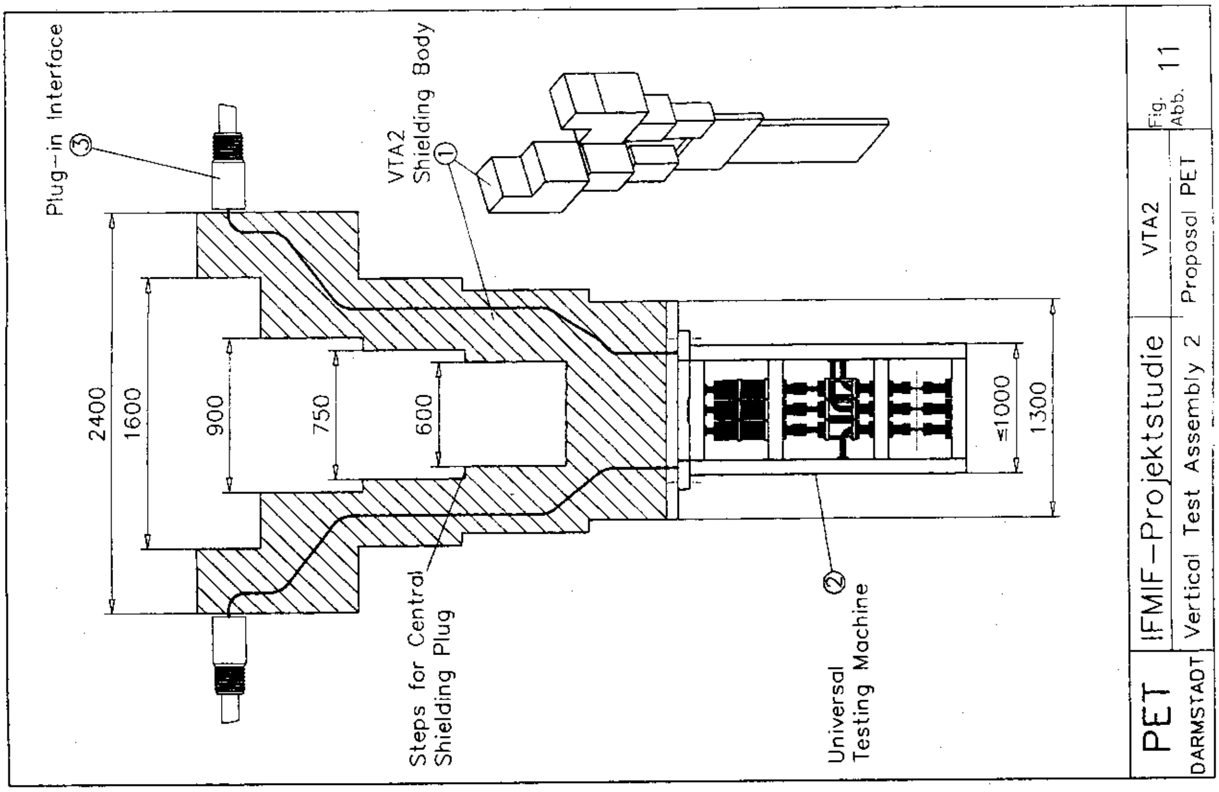
According to the proposed in-situ fatigue design, the following lay-out of a He-gas loop was found to be sufficient ($T_{specimen} \geq 250$ °C) for the med-flux region (≤8 dpa/year) of IFMIF downstream the P.I.E. module:

○ He inlet (pressure pipe)	$\leq 2.5\ bar_{abs}$	25 °C
○ He outlet (suction pipe)	$\geq 1.5\ bar_{abs}$	≤35 °C*
○ He pressure drop (specimen & rods)	≤0.9 bar	
○ He-gas throughput	12×10^{-3} kg/s	
○ Compressor size	240 m^3/h	25 kW
○ He-gas purity (C, N, O)	≤ 0.1 appm	



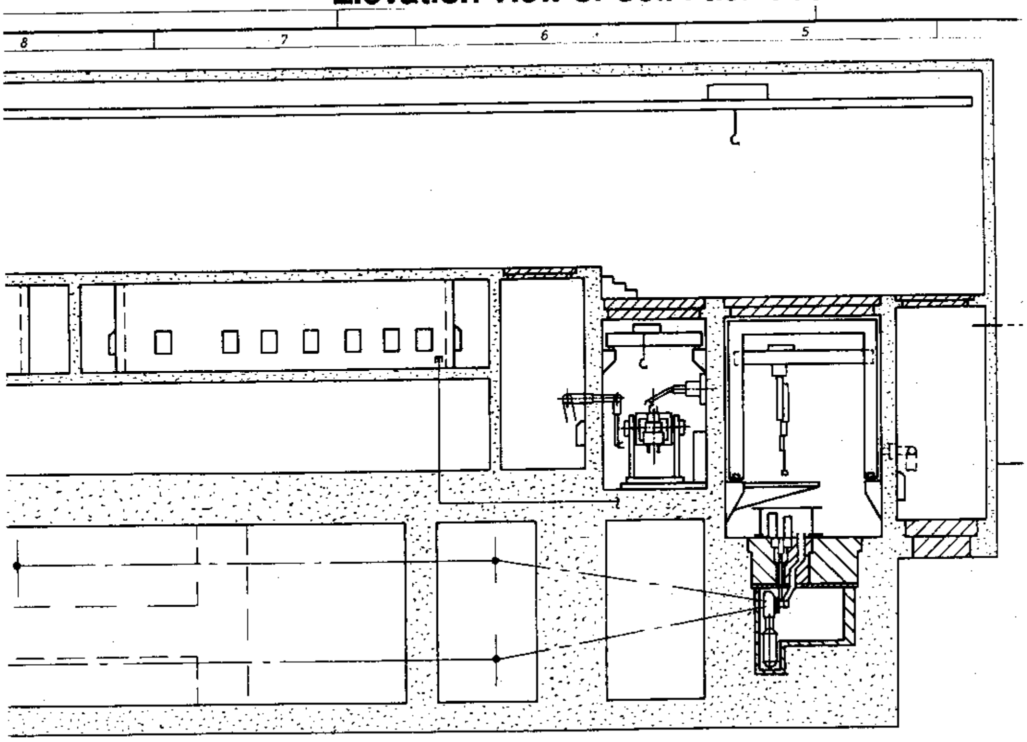


* at specimen outlet



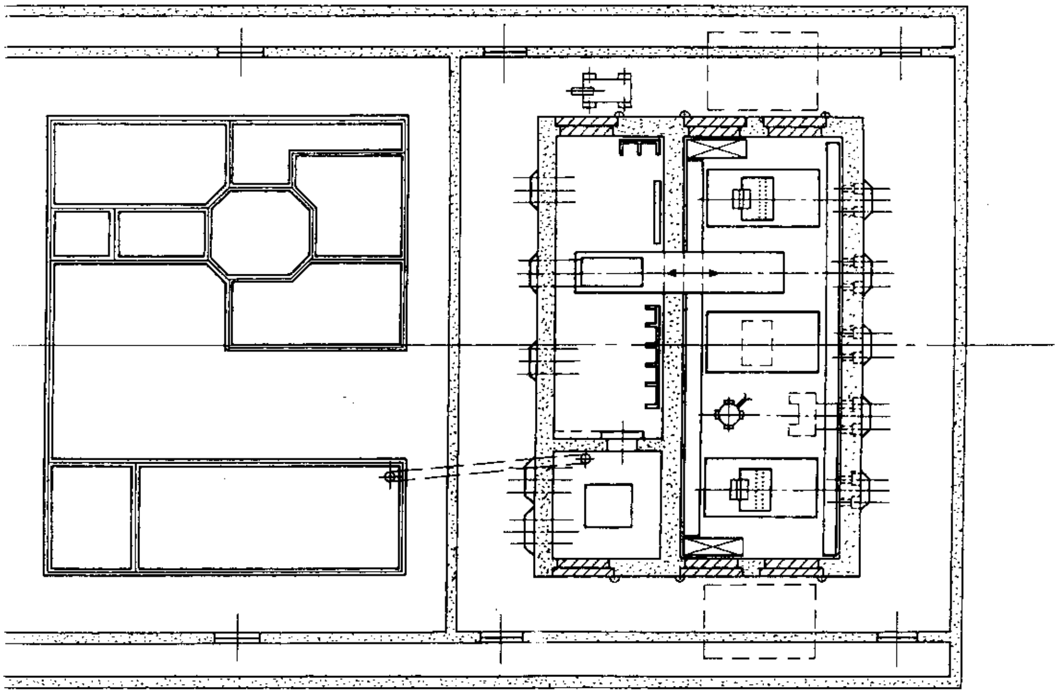
IFMIF Design Integration Meeting May 1996, JAERI, Japan

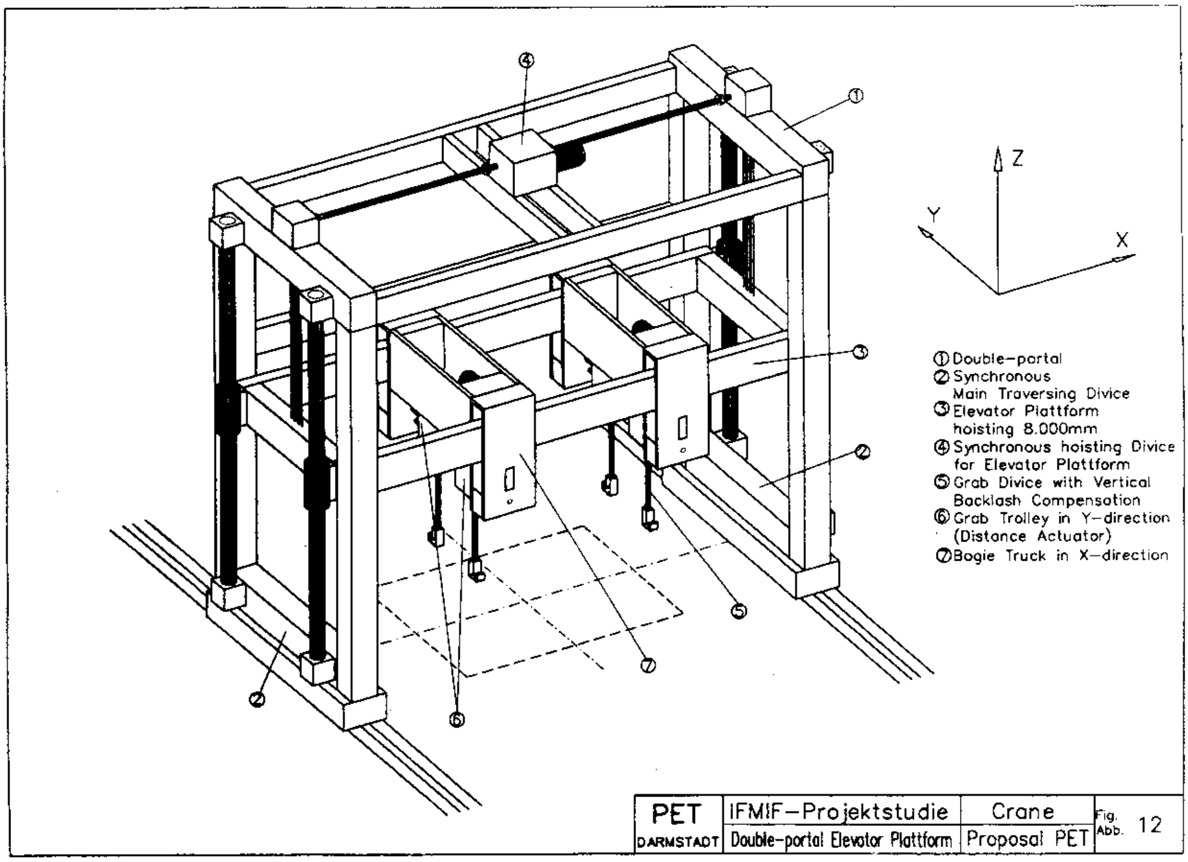
Elevation View of Cell Facilities



IFMIF Design Integration Meeting May 1996, JAERI, Japan

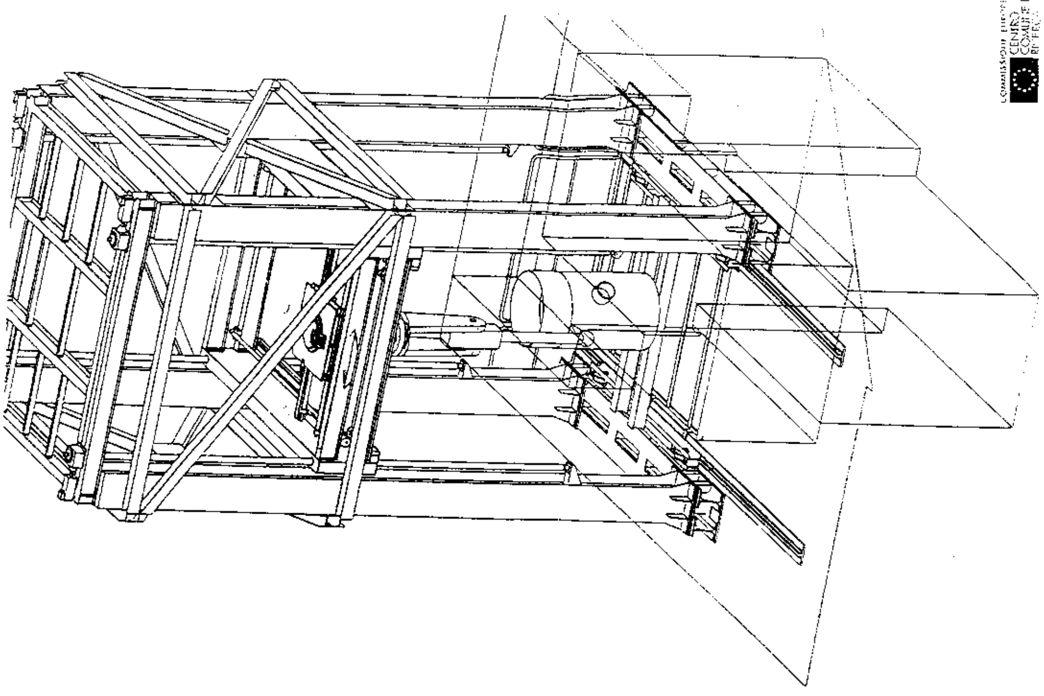
Plan View of Cell Facilities





IFMIF Design Integration Workshop May 1996 JAERI

Universal Robot System (ENEA)



Forschungszentrum Karlsruhe
Technik und Umwelt

Test Facilities Ventilation System - DRAFT-

L. Dörr, A. Möslang, W. Nägele

Design Integration Workshop, May 1996, JAERI, Japan

5 Zones Ventilation System:

A Ventilation System with five different zones is proposed. It supplies besides all Test Facility cells and rooms also various Li-Target rooms. The present proposal suggests the following zones:

□	White:	Office rooms, cold labs, workshops
▒	Yellow:	Manipulation rooms, shipping bay area, machine rooms
▬	Yellow-red:	High bay area
■	Red:	Cells (Access Cell, Service Cell, Test Module Handling Cell, PIE Hot Cell, Tritium Laboratory)
■	Green:	Protective gas for Lithium-zones (Test Cell, Lithium Processing Cells

Proposed IFMIF Ventilation System

Zone	Reduced Pressure	Risk	Air Exchange
White	~ 0 - 2 mbar	No handling with open radioactivity	4
Yellow	~ 3 - 6 mbar	Handling with radioactivity in exceptional cases	4
Yellow-red	~ 6 - 8 mbar	Frequent handling with radioactivity	4
Red	~ 20-50 mbar	Permanent handling with radioactivity	40 AE/h
Green	~ 3 - 5 mbar	Handling with Li-contaminated matter	Test Cell: Vacuum Li-Processing Cells: TBD *

- The reduced pressure increases from white to red
- The red zone is sucked in through a filter system from the yellow-red zone
- The exhaust air of the zones white, yellow and red is filtered separately before it goes to the Vent stack. Each group consists of various mechanical filters with 98.98% extraction (HEPA-filters).
- The ventilation system is pressure controlled by the exhaust air fan.
- Air Exchange: Red (40 AE/h) : ~ 100 000 m^3/h
  white/yellow: ~ 400 000 m^3/h

* Proposal: Inert gas (Argon), 3-4 AE/h : ~ 30 000 m^3/h Ar-gas closed loop

Preliminary Concept for Tritium Retention at IFMIF

1. Test Cell

To maintain a vacuum in the 30 m^3 large test cell the gas throughput rate of the pumps is low. The tritium concentration in the offgas is also low. Therefore for tritium retention a small molecular sieve / catalyst combination is suggested. Hydrogen that becomes eventually present in the offgas will be oxidised and trapped as tritiated water.

2. Medium Flux VTA

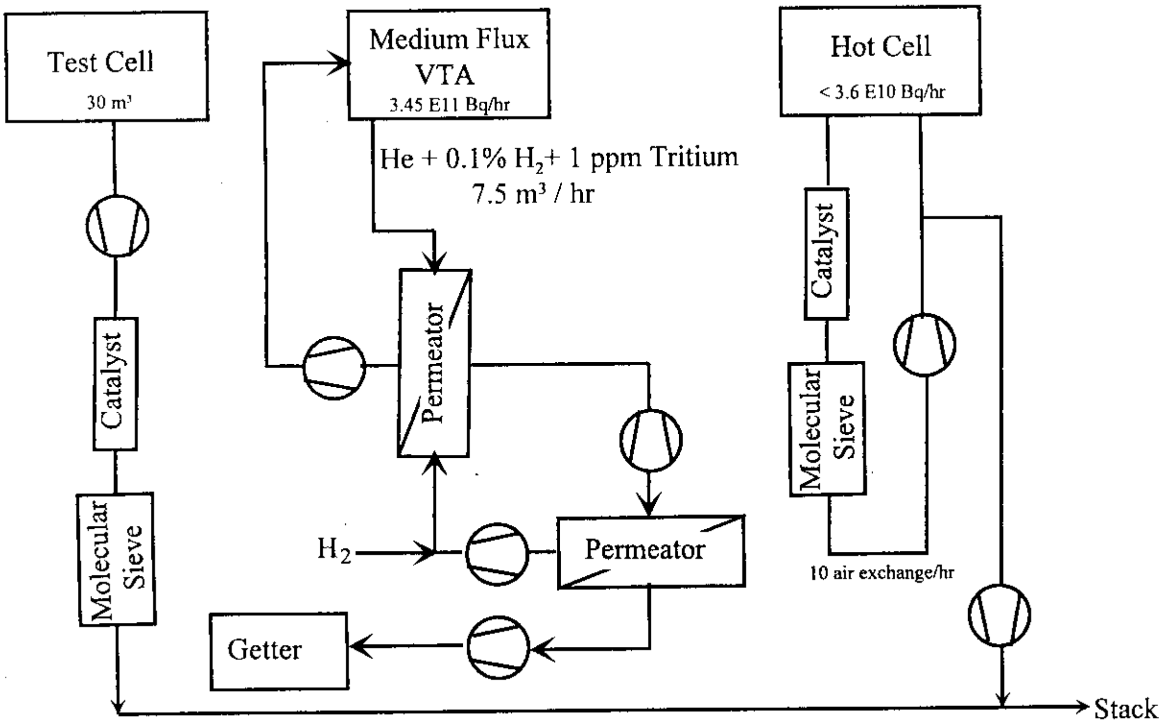
In the VTA the tritium production rate is high. To separate the tritium from the purge gas we propose to use two permeators. In these permeators the hydrogen is separated from helium. The helium can be led back to the process. The tritium will be stored in a matal-getter bed. The combination of two permeators as represented in the flow sheet is a process optimization for high decontamination factors at low tritium concentrations.

3. Hot Cell

The tritium release into the hot cell is less than 3.6E10 Bq/h. To remove hydrogen from the cell atmosphere a molecular sieve / catalyst combination is suggested. It will be operated in a loop with a gas stream of 10 air exchanges / hr.

4. Costs

The total amount of costs for the described tritium retention systems will be in the range of DM 7.5 M.


Test Cell
30 m³
Catalyst
Molecular Sieve
Medium Flux VTA
3.45 E11 Bq/hr
He + 0.1% H₂+ 1 ppm Tritium
7.5 m³ / hr
Permeator
H₂
Permeator
Getter
Hot Cell
< 3.6 E10 Bq/hr
Catalyst
Molecular Sieve
10 air exchange/hr
Stack

Proposed IFMIF Work Breakdown Structure

DICM0801.XLS

1 2 3 4 5 6 *Level*

1, 0, 0, 0, 0, 0, Project Management

1, 0, 0, 0, 0, Project Management and Administration
1, 0, 0, 0, Administration
2, 0, 0, 0, Cost Control
3, 0, 0, 0, Schedule
4, 0, 0, 0, Development Oversight
5, 0, 0, 0, Construction Management
6, 0, 0, 0, Documentation
2, 0, 0, 0, 0, Systems Engineering
1, 0, 0, 0, Design Integration
2, 0, 0, 0, Systems Analysis
3, 0, 0, 0, Requirements/Specs
4, 0, 0, 0, RAM Analysis
3, 0, 0, 0, 0, Environmental, Safety & Health Documentation
4, 0, 0, 0, 0, Quality Assurance

2, 0, 0, 0, 0, 0, Test Facilities
1, 0, 0, 0, 0, Test Facility Management
1, 0, 0, 0, Project Management and Administration
1, 0, 0, Administration
2, 0, 0, Cost Control
3, 0, 0, Schedule
4, 0, 0, Documentation
2, 0, 0, 0, Systems Engineering
1, 0, 0, Design Integration
2, 0, 0, Systems Analysis
3, 0, 0, Requirements/Specs
4, 0, 0, RAM Analysis
3, 0, 0, 0, Environmental, Safety & Health Documentation
4, 0, 0, 0, Quality Assurance
2, 0, 0, 0, 0, Test Facility Subsystems
1, 0, 0, 0, Vertical Test Assemblies
1, 0, 0, Factory Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, High Flux VTA (VTA1- NaK)
3, 0, 0, High Flux VTA (VTA1-Helium)
1, 0, Test module with specimens
2, 0, VTA shielding body
3, 0, Helium coolant loop
4, 0, 0, Medium Flux VTA (VTA2-NaK)-Breeders
5, 0, 0, Medium Flux VTA (VTA2-He)-Fatigue
1, 0, In-situ test module
2, 0, VTA shielding body
3, 0, Helium coolant loop
6, 0, 0, Vertical Irradiation Tube (VIT) System
7, 0, 0, Shielding plugs
2, 0, 0, 0, Test Cell
1, 0, 0, Test Cell Removable Cover
2, 0, 0, Test Cell liner
3, 0, 0, Test Cell heat shield
4, 0, 0, Test Cell seal plate
5, 0, 0, Test Cell camera system
6, 0, 0, Test Arrey/Target interface assembly
7, 0, 0, Beam and Test Cell diagnostic sensors
8, 0, 0, Emergency shutdown system
3, 0, 0, 0, Test Cell Technology Room
1, 0, 0, Assembly and Testing
2, 0, 0, Test Cell cooling system
3, 0, 0, Test Cell pumping system

15.05.1996 Page 1

Proposed IFMIF Work Breakdown Structure

DICM0801.XLS

1 2 3 4 5 6 *Level*

4, 0, 0, Argon backfill system
5, 0, 0, Test Cell diagnostic control system
6, 0, 0, Subsystem Power
4, 0, 0, 0, Test Facility Control Room
1, 0, 0, Assembly and Testing
2, 0, 0, Data Acquisition for VTA1-NaK
3, 0, 0, Data Acquisition for VTA1-Helium
4, 0, 0, Data Acquisition for VTA2-Fatigue
5, 0, 0, Data acquisition for VTA2-Tritium Release
6, 0, 0, Data Acquisition for VIT System
7, 0, 0, Supervising Computer
8, 0, 0, Subsystem power
5, 0, 0, 0, Access Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Access Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, 0, Universal Robot System
4, 0, 0, Manipulator Systems
5, 0, 0, Maintenance and Support Devices
1, 0, Telescopic Master/Slave Manipulators
2, 0, Service Robots
6, 0, 0, Infrastructure Installation
6, 0, 0, 0, Service Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Service Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, 0, Component Transfer Systems
1, 0, Transfer Rail System
2, 0, Transfer Chart
4, 0, 0, Manipulator Systems
1, 0, Telescopic Master7Slave Manipulators
2, 0, Service Robot
3, 0, Special Purpose Manipulator
5, 0, 0, Bridge Crane
6, 0, 0, Maintenance and Support Devices
7, 0, 0, Infrastructure Installation
7, 0, 0, 0, Test Module Handling Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Cell Structure
1, 0, Cell Liner
2, 0, Through wall windows
3, 0, Tube Mailing System
3, 0, 0, Manipulator System
1, 0, Telescopic Master7Slave Manipulators
2, 0, Modular Robot Systems
4, 0, 0, Bridge Crane
5, 0, 0, Maintenance and Support Devices
6, 0, 0, Infrastructure Installatiton
8, 0, 0, 0, PIE Hot Cell
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Cell Structure

15.05.1996 Page 2

Proposed IFMIF Work Breakdown Structure **DICM0801.XLS**

1 2 3 4 5 6 Level
1. 0, Cell Liner
2. 0, Lead shield
3. 0, Removable Cell Ceiling
3, 0, 0, Manipulator Systems
1. 0, Working Stations
2. 0, Power Manipulator Systems
4, 0, 0, Bridbe Crane
5, 0, 0, Infrastructure Installation
1, 0, Electric Power and Gases
2, 0, Mechanical Infrastructure
6, 0, 0, Examination Equipment
1, 0, Universial testing machines
2, 0, Vacuum furnaces
3, 0, Thermal fatigue test devices
4, 0, Corrosion test devices
5, 0, Fracture toughness test devices
6, 0, Fatigue crack growth
7, 0, Pressurized tube test devices
8, 0, Optical microscope
9, 0, Specimen preparation tools
9, 0, 0, 0, Shielded Glove Box Laboratory
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Structure and Support Systems
1, 0, Structure
2, 0, Support systems
3, 0, 0, Examination Equipment
1, 0, SEM
2, 0, TEM
3, 0, TEM preparation
4, 0, Specimen storage
5, 0, Optical Microscope
6, 0, Microhardness tester
7, 0, Activation analysis system
10, 0, 0, 0, Tritium Laboratory
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Laboratory installation
1, 0, Laboratory Structure
2, 0, Infrastructure
3, 0, Personal entry
3, 0, 0, Manipulator Systems
4, 0, 0, Examination Equipment
11, 0, 0, 0, Test Facility Ventilation Systems
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, 5 Zones Ventilation System
1, 0, Controls
2, 0, Component Systems
3, 0, 0, Tritium Retention System
1, 0, Controls
2, 0, Component Systems
12, 0, 0, 0, Maintenance Systems
1, 0, 0, Maintenance Procedure Development
2, 0, 0, Special Purpose Tooling
3, 0, 0, Remote Handling Equipment
4, 0, 0, Mockup Facilities and Testing

3, 0, 0, 0, 0, Subsystem Development

15.05.1996 Page 3

Proposed IFMIF Work Breakdown Structure **DICM0801.XLS**

1 2 3 4 5 6 Level
4, 0, 0, 0, 0, System Installation and Startup
1, 0, 0, 0, Installation
2, 0, 0, 0, Verification Testing
3, 0, 0, 0, Startup

5, 0, 0, 0, 0, Maintenance Systems
1, 0, 0, 0, Maintenance Procedure Development
2, 0, 0, 0, Special purpose tooling
3, 0, 0, 0, Remote handling equipment
4, 0, 0, 0, Mockup Facilities and Testing

3, 0, 0, 0, 0, 0, Target Facility

1, 0, 0, 0, 0, Target Facility Management
1, 0, 0, 0, Project Management and Administration
1, 0, 0, Administration
2, 0, 0, Cost Control
3, 0, 0, Schedule
4, 0, 0, Documentation
2, 0, 0, 0, Systems Engineering
1, 0, 0, Design Integration
2, 0, 0, Systems Analysis
3, 0, 0, Requirements/Specs
4, 0, 0, RAM Analysis
3, 0, 0, 0, Environmental, Safety & Health Documentation
4, 0, 0, 0, Quality Assurance

2, 0, 0, 0, 0, Subsystems
1, 0, 0, 0, Lithium Target System
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Components
1, 0, Target Assembly
1, Li Flow Rectifier
2, Nozzel
3, Backwall
4, Down Stream Guide
5, Measuring System
6, Li System/Target Interface
2, 0, Beam-Target Interface
1, Beam/Target Interface Structure
2, Evacuation System
3, Emergency Shutdown System
4, Test Cell/Target Interface Structure
2, 0, 0, 0, Lithium Cooling System
1, 0, 0, Assembly and Testing
1, 0, Assembly
2, 0, Testing
2, 0, 0, Components
1, 0, Primary Cooling System
1, EM pump
2, Heat Exchanger
3, Valve
4, Piping
5, Quench Tank
6, Dump Tank
7, Control System
8, Measuring Devices
9, Radiation Shielding
10, Inert Gas System
2, 0, Primary Purification System
1, Cold Trap

15.05.1996 Page 4

IFMIF TEST FACILITIES

Cost Estimate

Anton Möslang
May 1996

- Practically all Elements of the present WBS are included
- Cost estimates are available down to level 4 of the WBS (only 2 exceptions)
- Input came from
  - ORNL ~ 30 pages
  - FZK
    - Institute of Materials Research, ~ 80 pages
    - Hot Cell Facility 11 pages
    - Tritium Laboratory 2 pages
    - Financial System Department 14 pages
  - German Industry ~ 35 pages
- Quality of the estimate: Because of the various sources the work sheets could not always be structured in the same way. However, the overall estimate should be credible because
  - practically all completely individual devices and modules (e.g. VTAs, Test Cell Structure and Removable Cover) are estimated in detail,
  - other expensive components (remote handling systems, cranes, hot cells, technical and scientific equipment) could be estimated from existing facilities.

1 11

IFMIF Cost Format Test Facility

WBS 2.1, 2.2.

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
		nc	3% (i)	TBE	TBE	TBE	TBE	c,d,e,f	TBE	TBE	TBE	TBE	h,i,j,k	b,g,l		
2.1.	Managem´t	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
2.2.1.2.	VTA1-NaK	nc	nc	134	143	59	nc	336	nc	nc	nc	nc	336	336	nc	nc
2.2.1.3	VTA1-He	nc	nc	1,230	218	60	nc	1,508	nc	nc	nc	nc	1,508	1,508		
2.2.1.4	VTA2-NaK	nc	nc	504	nc	258	nc	762	nc	nc	nc	nc	nc	762	nc	nc
2.2.1.5	VTA2-He	nc	nc	695	104	25	nc	824	nc	nc	nc	nc	nc	824	nc	nc
2.2.1.6	VIT-System	nc	nc	393	49	429	nc	871	nc	nc	nc	nc	nc	871	nc	nc
2.2.1.7	Shield Plug	nc	nc	9	nc	20	nc	29	nc		nc	nc	nc	29	nc	nc
2.2.2.1	TC Cover	nc	nc	1,049	nc	184	nc	1,233	nc	nc	nc	nc	nc	1,233	nc	nc
2.2.2.2.	TC Liner	nc	nc	681	nc	79	nc	760	nc	nc	nc	nc	nc	760	nc	nc
2.2.2.3	Heat shield	nc	nc	211	nc	138	nc	349	nc	nc	nc	nc	nc	349	nc	nc
2.2.2.4	Seal Plate	nc	nc	309	nc	94	nc	403	nc	nc	nc	nc	nc	403	nc	nc
2.2.2.5	Camera Sys.	nc	nc	162	nc	236	nc	398	nc	nc	nc	nc	nc	398	nc	nc
2.2.2.6	Test Array	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
2.2.2.7	Diagnostics	nc	nc	53	nc	nc	nc	53	nc	nc	nc	nc	nc	53	nc	nc
2.2.2.8	Emergency	nc	nc	40	nc	72	nc	112	nc	nc	nc	nc	nc	112	nc	nc
														7,638		

Abreviations:
- nc Nocost in this element
- TBE To be estimated
- AFI Allowance for Indeterminates

2 22

IFMIF Cost Format Test Facility

WBS 2.2.3, 2.2.4

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.3.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	77,9	nc	77,9	78	nc	nc
2.2.3.2	Cooling	nc	nc	124	nc	99	nc	223	107	nc	79		186	409	nc	nc
2.2.3.3	Vac. Pumps	nc	nc	89,3	nc	8,2	nc	97,5	nc	18,2	6,2	nc	24,4	122	nc	nc
2.2.3.4	Ar backfill	nc	nc	36	nc	19	nc	55	13	nc	6	nc	19	74	nc	nc
2.2.3.5	Diagn,Contr	nc	nc	62,5	nc	nc	nc	62,5	31,1	nc	62,3	nc	93,4	156	nc	nc
2.2.3.6	Syst. Power	nc	nc	nc	nc	0.5	nc	0.5	3,5	nc	nc	nc	3,5	4	nc	nc
2.2.4.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	62,3	nc	62,3	62	nc	nc
2.2.4.2	Data Acq	nc	nc	43,4	nc	nc	nc	43,4	nc	nc	36,3	nc	36,3	80	nc	nc
2.2.4.3	Data Acq	nc	nc	105,3	nc	nc	nc	105,3	nc	nc	36,3	nc	36,3	142	nc	nc
2.2.4.4	Data Acq.	nc	nc	262,9	nc	31,2	nc	294,1	nc	nc	62,3	nc	62,3	356	nc	nc
2.2.4.5	Data Acq	nc	nc											300	nc	nc
2.2.4.6	Data Acq	nc	nc	144,7	nc	41,2	nc	175,9	nc	nc	31,2	nc	31,2	207	nc	nc
2.2.4.7	Sperv Comp	nc	nc	46	nc	nc	nc	46	nc	nc	62,3	nc	62,3	108	nc	nc
2.2.4.8	Syst. Power	nc	nc	nc	nc	0,5	nc	0,5	3,5	nc	nc	nc	3,5	4	nc	nc
														2,102		

Abreviations:

nc	Nocost in this element
TBE	To be estimated
AFI	Allowance for Indeterminates

3 33

IFMIF Cost Format Test Facility

WBS 2.2.5, 2.2.6

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.5.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	125	nc	125	125	nc	nc
2.2.5.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	164	nc	13	nc	177	177	nc	nc
2.2.5.3	Univ. Robot	nc	nc	3,434	nc	nc	nc	3,434	nc	nc	395	nc	395	3,829	nc	nc
2.2.5.4	Manip. Syst	nc	nc	1,546	nc	nc	nc	1,546	nc	nc	165	nc	165	1,711	nc	nc
2.2.5.5	Maint, Supt	nc	nc	660	nc	nc	nc	660	nc	nc	132	nc	132	792	nc	nc
2.2.5.6	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	526	nc	79	nc	605	605	nc	nc
2.2.6.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	125	nc	125	125	nc	nc
2.2.6.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	573	nc	13	nc	586	586	nc	nc
2.2.6.3	Transf. Syst	nc	nc	nc	nc	nc	nc	nc	198	nc	26	nc	224	224	nc	nc
2.2.6.4	Manip. Syst	nc	nc	1,546	nc	nc	nc	1,546	nc	nc	224	nc	224	1,770	nc	nc
2.2.6.5	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	460	nc	6,2	nc	466	466	nc	nc
2.2.6.6	Maint, Supt	nc	nc	nc	nc	nc	nc	nc	660	nc	132	nc	792	792	nc	nc
2.2.6.7	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	658	nc	98,7	nc	757	757	nc	nc
														11,959		

Abreviations:

nc	Nocost in this element
TBE	To be estimated
AFI	Allowance for Indeterminates

4 44

IFMIF Cost Format Test Facility

WBS 2.2.7, 2.2.8

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.7.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	78	nc	78	78	nc	nc
2.2.7.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	280	nc	13	nc	293	293	nc	nc
2.2.7.3	Manip. Syst	nc	nc	1,414	nc	nc	nc	1,414	nc	nc	145	nc	145	1,559	nc	nc
2.2.7.4	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	197	nc	6,2	nc	203	203	nc	nc
2.2.7.5	Maint, Supt	nc	nc	nc	nc	nc	nc	nc	197	nc	79	nc	276	276	nc	nc
2.2.7.6	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	164,5	nc	24,7	nc	189	189	nc	nc
2.2.8.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	103	nc	103	103	nc	nc
2.2.8.2	Cell Structr	nc	nc	nc	nc	nc	nc	nc	1,868	nc	164	nc	2,032	2,032	nc	nc
2.2.8.3	Manip. Syst	nc	nc	2,214	nc	nc	nc	2,214	nc	nc	112	nc	112	2,326	nc	nc
2.2.8.4	Bridge Crne	nc	nc	nc	nc	nc	nc	nc	197	nc	6,2	nc	203	203	nc	nc
2.2.8.5	Infstr, Instal	nc	nc	nc	nc	nc	nc	nc	1,317	nc	132	nc	1,449	1,449	nc	nc
2.2.8.6	Exam.Equip	nc	nc	1,074	nc	nc	nc	1,074	nc	nc	nc	nc	nc	1,074	nc	nc
														9,785		

Abreviations:
nc Nocost in this element
TBE To be estimated
AFI Allowance for Indeterminates

5 55

IFMIF Cost Format Test Facility

WBS 2.2.9, 2.2.10, 2.2.11, 2.2.12

		Total Projekt Cost														
		Total Estimated Capital Cost (TEC)														
		Off-IFMIF Site							On-Site at IFMIF							
				Industry		Inst			Const. Contr		Inst					
		Proj.Man	Facl. Man	Mat	Engin´g	Eng	AFI	Total	Mat	Enging	Eng	AFI	Total		Devlt	St&C
WBS	Element	(a)	(b)	©	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
2.2.9.1	Assby, Test	nc	nc	nc	nc	nc	nc	nc	nc	nc	103	nc	103	103	nc	nc
2.2.9.2	Strct, Suppt	nc	nc	7,896	nc	nc	nc	7,896	nc	nc	nc	nc	nc	7,896	nc	nc
2.2.9.3	Exam.Equpt	nc	nc	1,945	nc	nc	nc	1,945	nc	nc	nc	nc	bc	1,945	nc	nc
2.2.10	Tritium Lab	nc	nc	nc	nc	nc	nc	nc	26,000	nc	nc	nc	26,000	<26,000	nc	nc
2.2.11.1	Ventilation	nc	nc	nc	nc	nc	nc	nc	6,578	nc	nc	nc	6,578	6,578	nc	nc
2.2.11.2	Trit. Retent	nc	nc	nc	nc	nc	nc	nc	4,934	nc	nc	nc	4,934	4,934	nc	nc
2.2.12	Maint. Syst	nc	nc	nc	nc	nc	nc	nc	1,970	nc	nc	nc	1,970	1,970	nc	nc
														~~9,785~~ < 49,426		

Abreviations:
nc Nocost in this element
TBE To be estimated
AFI Allowance for Indeterminates
2.2.10 Tritium Laboratory: Global estimate (<26,000kICF)
2.2.11 Maintenance Systems:Global estimate (1,970kICF)

TARGET GROUP ACTIVITIES SINCE ORNL DI WORKSHOP(10/950)

Presented by

H. Katsuta
JAERI Target Group

IFMIF Design Integration Meeting, May 20-26, 1996
at JAERI

TARGET GROUP ACTIVITIES SINCE ORNL DI WORKSHOP(10/950)

I. FACILITY DESIGN AND ANALYSIS

II. COST ESTIMATION

III. PLANNING FOR POST IFMIF-CDA AND EVP

US TARGET GROUP ACTIVITIES SINCE ORNL DI WORKSHOP (10/95)

I. TARGET ASSEMBLY DESIGN AND ANALYSIS

- Conceptual design of replaceable backwall
- Analysis of nuclear heating in backwall and structure surrounding beam footprint (normal operation)
- Decay heat analysis in backwall and target assembly

II. LITHIUM, CHEMISTRY AND IMPURITY MONITORING LOOPS

- Cost estimate for lithium cooling system, including the main lithium loop, primary heat removal system, and secondary heat removal system
- Cost estimate for impurity monitoring system

III. Work BreakDown Structure

- Revise WBS for target facility

IV SCHEDULE

- Review and improve schedule for target facility within the overall IFMIF project schedule

V. RELIABILITY AND MAINTENANCE

- Review RAM data for target system
- Analyze target system components failure modes and effects
- Develop scheduled and unscheduled maintenance operation procedures

VI. PLANNING FOR EVP

- Develop preliminary cost and schedule for construction of an experimental test facility for the lithium target (without charged particle beam)
- Design and cost estimate for a lithium test loop for impurity monitoring and trap development and performance validation

EU/ENEA TARGET GROUP ACTIVITIES SINCE ORNL DI WORKSHOP (10/95)

I. REPLACEABLE BACK PLATE ATTACHMENT SCHEME

- Replaceable back wall concept based on a bayonet connection, avoiding use of bolts

- Ensure the sealing between the Test assembly and the Test Cell

- The jet stability at the transition point has to be analysed

II. PRELIMINARY HAZARDS ANALYSIS AT COMPONENT LEVEL OF TARGET SYSTEM

- All possible failure modes and identifying their effects on the Lithium Targetst System(on a component-by-component basis)

- Effects of the surrounding systems malfunctions on the Target System

- Integrated safety analysis methodology

III. ENEA PROPOSALS FOR THE IFMIF EVP

-Off-line monitoring by sampling

-On-line monitorring by sensors

JAPAN TARGET GROUP ACTIVITIES SINCE ORNL DI WORKSHOP(10/95)

I. CONCEPTUAL DESIGN FOR MODIFIED IFMIF TARGET SYSTEM

- Revision of target system layout

- Design of remote handling device for the exchange of target assembly and of back plate

II. COST ESTIMATION FOR THE IFMIF TARGET SYSTEM

- Cost estimation for the IFMIF target system has been performed

III. WATER SIMULATION EXPERIMENT

- Stability of the jet flow seems to be promising for beam foot print of 5 cm x20 cm, and velocity of 20 m/s

IV. HYDROGEN(D,T) ON-LINE MONITORING EQUIPMENT

- Proton conductive ceramic tube for hydrogen monitoring has been arranged for a Li-loop

V. PLANNING FOR EVP

- Develop preliminary cost and schedule for perform the engineering varidation of the IFMIF target system design

Summaries of EU/ENEA Presentations at the IFMIF-DI Meeting (Tokai 20-25,1996), for the Target Group

IFMIF Replaceable Back Plate Attachment Scheme - Preliminary Report

B. Baratozzi, S. Cevolani, D. Tirelli (ENEA-ERG-FISS)

Presented by G. Benamati

The presentation deals with the development of a replacement and attachment scheme of the IFMIF replaceable back wall. The scheme proposed by ENEA is based on a bayonet connection concept, avoiding the use of bolts for taking in place the back plate during operation.

As requested by the design constraints, this scheme ensures the sealing between the Test Assembly and the Test Cell and the limitation of the neutron damage on the permanent Test Assembly structure.

As first advantage of the proposed scheme, the removal of the Test Assembly for substituting the replaceable back plate becomes no more necessary, with consequent reduction of the substitution time. A further advantage is concerned with the fact that such a scheme allows for a simpler loading machine. Finally, this scheme ensures a good recovering of the differential dilatation between the back wall and the permanent Test Assembly structure.

The proposed design should give an acceptable effect on the jet stability at the transition between nozzle and replaceable back wall. Anyway, as for any other replaceable back wall design, the jet stability at the transition point has to be analysed.

Preliminary hazards analysis at component level of target system

G. Benamati (ENEA-ERG-FUS), F. Bianchi (ENEA-ERG-FISS)

Presented by G. Benamati

The evaluation of the risk associated with the IFMIF Facility operation requires the identification and description of the possible system failure modes and the evaluation of their consequences.

The aim of this analysis is to plan at a conceptual design level the systems and engineering improvement to mitigate the environmental consequences and to reduce the risk for the foreseen investment.

In this optics the activity performed in ENEA is a preliminary hazard analysis oriented towards detailing, on a component-by-component basis, all possible failure modes and identifying their effects on the Lithium Target System. Also the effects of the surrounding systems malfunctions on the Lithium Target System are analysed.

In the next meeting of Jaeri the following points will be discussed:

¥ the "integrated" safety analysis methodology, developed in ENEA, which should be used during the different design phases (conceptual design, executive design, etc.) of the TARGET IFMIF design in order to periodically monitor and improve plant safety;

¥ the preliminary hazard analysis at component level;

¥ the improvement necessary to meet the safety goals, to increase the availability and to reduce the costs

¥ the ENEA activity during 1996.

ENEA proposals for the IFMIF Engineering Validation Phase

G. Benamati (ENEA-ERG-FUS)

Presented by G. Benamati

The ENEA proposals for the Engineering Validation Phase are illustrated and discussed in the present talk.

The ENEA proposed activities will be focused on two mains items: the first one concerns safety improvements and the second one the impurity meter development. As regards this second point, the control of the impurities (mainly H, O, N and C) is fundamental issue for the operation of lithium loop. Two kind of control could be envisaged :

- Off-line monitoring by sampling
- On-line monitoring by sensors.

The off-line monitoring provide accurate results but a delay in the availability of them is an important disadvantages. On the contrary on-line monitoring (i.e. sensors) provides results in real time and can be used also for safety function. ENEA proposal, taking into account the availability of an experimental loop in Brasimone Centre and the competencies present in Europe in this field, aims at develop and validate monitor systems for Li impurities (mainly N, H, C).

As regard the first point experimental studies on the effect of mass/surface ratio on the evolution of a lithium pool fire as well as the evaluation of possible countermeasure in order to have reduces lithium fire violence will be presented and discussed.

Activity of IFMIF Target System Group in Japan

Since the Design Integration Meeting at ORNL in Oct.. 1995, following works have been done in Japan.

(1) **Conceptual design for modified IFMIF target system.**
The conceptual design for the lithium target system and its layout have been modified to adapt the maximum design parameters which was agreed at the ORNL Meeting. The flow sheet of the system has also been revised. The design of remote handling device for the exchange of target assembly and of its back plate is now under planning.

(2) **Cost estimation for the IFMIF target system.**
Cost estimation for the overall target system has been made on the base of above design studies. However some items which needs R&D or the items concerning interface issues with the other facilities could not be made with the same level of cost estimation as the other target components. We made three ranks on the results of these cost estimations.

(3) **Water simulation experiment .**
The water simulation experiment using the target assembly of practical model was started since last December. The test assembly was set up in the existing water loop facility of Department of Reactor Safety Engineering of JAERI. The main parts of the target assembly was made of transparent plastic so that the water jet condition during the loop operation can be observed from any direction. Though the experiment is in the initial stage, the stability of the jet flow seems to be promising for the conditions of the beam foot print of 5 cm x 20 cm and the lithium velocity of max. 20 m/s.

(4) **Hydrogen (D,T) on-line monitoring equipment.**
As the impurity on-line monitoring equipment in the lithium system, we have designed and made a trial product to apply the electrochemical method by using proton conductive ceramic tube for Hydrogen (/Deuteron / Tritium) monitoring. After some basic test in JAERI such as the material compatibility with lithium, it will be tested in the forced convection lithium loop of Tokyo Institute of Technology within this fiscal year.

IFMIF 2nd Design Integration Meeting

General Meeting

Wednesday, May 22, 1996
9:00 -10:30 AM

T. E. Shannon

Agenda

9:00 - 9:30	**Technical Status of Major Systems**	
	- Test Facilities	A. Moeslang
	- Target	H. Katsuta
	- Accelerator	R. Jameson
9:30 - 9:45	**Status of Integrated Cost and Schedule Estimate**	M. Rennich
9:45 - 10:25	**Design Integration Issues**	
	- RAM	C. Piaszczyk
	- Maintenance	T. Shannon
	- Central I&C	H. Maekawa
10:25 - 10:30	**Workshop Schedule and Report**	

- Continue mostly Small Group Meetings
- Deputy Meetings each day at 12:45
- Two Reports for this meeting:
  1. Minutes
  2. Supplement for Interim Report (Input provided by Deputies)
- Next General Meeting, Thursday 15:30

IFMIF 2nd Design Integration Meeting

General Meeting

Thursday, May 23, 1996
3:30 - 5:30 PM

T. E. Shannon

Agenda

3:30 - 4:15	**Status of Integrated Cost and Schedule Estimate**	
	- Review of Cost Estimate	M. Rennich
4:15 - 4:45	**Design Integration Issues**	
	- Safety	S. Konishi
	- Conventional Facilities	M. Martone
	- Operations	H. Maekawa
4:45 - 5:30	**Future Planning**	T. Shannon
	- Reports for this Meeting	
	- Proposed Timeline for Final Report	
	- Technical work to complete CDA	
	- Guidelines and Scope of EVP	
	- Remaining Work/Schedule for this Meeting	

IFMIF 2nd Design Integration Meeting

Final General Meeting

Friday, May 24, 1996
18:00 - 19:00

T. E. Shannon

Remaining Work/Schedule for this Meeting

May 24 (Friday)

1. Complete Plan for EVP
   - 3 years, 1997 through 1999
   - Use 10% of Total System Base Cost for Planning
   - Write-up as proposed by Haines
2. Plan Tasks to Complete CDA
   - Very Limited New Technical Tasks
   - Revise Baseline Design and Drawings
   - Complete Cost Spread Sheets
   - Write Final Report

Remaining Work/Schedule for this Meeting (Continued)

May 25 (Saturday) or Work Late Friday

- Small Group Meetings
  - Complete Task write-ups for EVP
  - Agree on remaining Technical work for CDA
  - Discuss Plan for Final Report
  - Discuss/Agree on Presentation to Subcommittee
- Final General Meeting

  Report by Group Leaders
  - Review EVP
  - Review CDA Completion Plans
  - Review Final Report Plans

May 27 (Monday)

- Group Leaders Prepare Presentation for Subcommittee

Reports for this Meeting

- Prepare Minutes of Meeting — JAERI Staff
  - Compile all Presentation Material and Outline of Meeting
  - Brief summary of Meeting Objectives, Schedule and Results
- Write Sections for Addendum to Interim Report
  - All input to JAERI by June 14, 1996
  - Use Interim Report Format and Sections

1.	Project Management	Shannon
2.	Test Facilities	Moeslang
3.	Target Facility	Katsuta
4.	Accelerator Facility	Jameson
5.	Conventional Facilities	Martone
6.	Central I&C	Maekawa
7.	Operational Startup and Commissioning	Maekawa
8.	Schedule	Rennich

- Summary of Cost Estimate (Limited Distribution)
  - Copies available by June 14, 1996

1.	Introduction	Shannon
2.	Cost Estimate	Rennich

Remaining Action Items

1.	Complete Task Sheets for EVP	Deputies	May 27
2.	Draft of Minutes and Addendum Reports	Maekawa	June 14
3.	Issue Guidance for Final Report	Shannon	June 14
4.	Draft of Cost Report - List key assumptions such as site support	Rennich	June 14
5.	Organize Rad Gas/Lithium/Safety Group	Konishi	June 28
6.	Complete Design Work and Drawings	Deputies	Sept. 15
7.	Complete First Draft of Report	Deputies	Sept. 15

Agenda

18:00 - 18:15	Update Status of Cost Estimate	Rennich
18:15 - 18:45	Group Leaders Summary - Review EVP Tasks - Review CDA Completion Plans - Review Final Report Plans	Group Leaders
18:45 - 18:50	Plans for Frascati Meeting	Shannon/Martone
18:50 - 19:00	Action Items	Shannon

Advanced Plans for Frascati Meeting

1. **Meetings Dates:** October 14-25, 1996
2. **Deadlines:** Participants List — June 15; Reservation Forms to Frascati — July 10
3. **Action:** Deputies E-mail List if Names to Professor Martone With copy to Shannon by: Friday June 14.

IFMIF-CDA Design Integration

Safety related tasks

S. Konishi

1. General Consideration

Detailed safety design is not a scope of CDA.
However, design will be expected to include
<u>SOME SAFETY ISSUES</u>.

◇ Environmental impact
◇ Possible hazard to public
◇ Site requirements / limitation

Safety consideration, if any needed, will be an OUTSTANDING TECHNICAL ISSUE .

2. Objective

To show IFMIF is a <u>SAFE</u>, and <u>ATTRACTIVE</u> facility to construct.
for Local Community, public and authority.

- no technical detail needed
- design should show obvious safety
(eliminate all inherent hazard, if possible)
- reflect safety consideration to the design .

3. Task
  - We have good FMEA to identify hazards.-
  - ◇ Review FMEA
  - ◇ Identify a few important hazards
    - regular, or frequent
      (including regular radiation and release)
    - unlikely, but extreme
  - ◇ Assess and describe the hazards
  - ◇ Prevention and operation (HAZOP?)
  - ◇ Identify site requirement, if any.
  - ◇ Reflect result to design (cost?)

4. Related subjects
  - Some are outstanding issues-
  - ◇ Building ventilation
  - ◇ Zoning and facility design
  - ◇ Radioactive gas treatment
  - ◇ Beam halo
  - ◇ Skyshine and activation of air
  - ◇ Solid and liquid waste
  - ◇ Lithium hazards

5. Schedule

◇ Issue questionnaire to deputies	5/E
◇ Issue subtasks work request	6/M
◇ Subtask reports sent	8/E
◇ Incorporate results to subsystems	9/E
◇ Write a section for final report	next meeting

May 22, 1996

EVP - Test Facility Tasks

Neutronics tasks

- Nuclear data evaluation and data library preparation (20-50 MeV)
- Re-evaluate relevant irradiation parameters to support needs of the Users Group
  - Neutron spectra, dpa- and gas production rates
- Evaluation of overall tritium production rate in the Test Cell
  - Supports safety analyses and design of tritium processing and ventilation systems
  - Tritium production rates for breeding material experiments
- Shielding and activation analyses
  - Thickness of walls for Access Cell, Hot Cell, etc.
  - Gamma generation and total heat generation in Test Modules
  - Decay heat evaluation for Test Cell components (He and NaK coolant)

May 22, 1996

EVP - Test Facility Tasks

Hardware Fabrication and Testing

- He cooled High Flux module full-scale prototype development and testing
  - Fabricability
  - Remote handling and encapsulation
  - Thermal-hydraulics
  - In-situ instrumentation and data acquisition
- Medium flux prototype development (breeding tests, creep-fatigue tests)
  - SMA sealing under irradiation/thermal environments
  - Demonstration of feasibility of one full-scale tritium release sub-test module
    - Fabrication (several different specimen types. e.g. pebble bed, discs, ...)
    - Thermal-hydraulics/Temperature control
- VTA Prototype Development
  - Fabricate (less than full-scale VTA)
  - Remote handling - demonstrate precise positioning
  - Vacuum sealing

May 22, 1996

Remaining Test Facility Tasks

Design and Evaluation Tasks

Review/harmonize/establish feasibility of existing design options	May 96-Oct 96	1997-1998
VTA's	x	x
Removeable shield plug	x	
Test Cell design	x	
Access Cell Size and Equipment	x	
Tritium in-situ release - glovebox location	x	x
Wall thickness - shielding	x	x
Evaluation/selection of remote handling approaches	x	
Heat shield thickness	x	

May 22, 1996

IFMIF
Engineering Validation Phase

Development Task

Task Title: Helium Cooled High Flux Module prototype development and testing

Facility: Test Facility

Need /Motivation:

Providing a test module for specimen temperatures up to 1000 °C is one of the most challenging design requirements for the IFMIF Test Facilities. Under such conditions it is necessary to demonstrate (1) fabricability of specimen encapsulation, helium gas pipes, active ohmic heating elements, and rigs, (2) remote handling of all assembly and disassembly procedures, (3) thermal hydraulics under different loading conditions and beam-on and beam-off scenarios, (4) structural integrity, as well as (5) proper function of the instrumentation equipment. All these requirements have to be demonstrated under relevant conditions on a full scale high flux test module assembled with an adequate number of completely instrumented rigs.

Brief Task Description:

A representative collection of miniaturized specimens made of reduced activation materials will be fabricated, instrumented and encapsulated. Active ohmic heating elements integrated in the encapsulation and well defined narrow gas gaps require sophisticated fabrication and alignment methods. Remote handling, assembly and disassembly tests will be performed followed by extended thermohydraulic experiments using an already existing helium gas coolant loop equipped with a modified test chamber. The instrumentation equipment will also be tested under IFMIF relevant conditions.

Schedule: January 1997 - December 1999

Sub task	Duration
- FE assisted engineering design of specimen capsules, rigs and test module elements	12 months
- Fabrication	9 months
- Perform tests	6 months
- Data evaluation and documentation	3 months

Estimated Costs:

750 kICF

May 22, 1996

IFMIF
Engineering Validation Phase

Development Task

Task Title: Development of one full-scale tritium release sub-test module

Facility: Test Facility

Need/Motivation:

Tritium release experiments using several different types of breeding material candidates are planned for the medium flux region of the Test Cell. To function properly, the temperature of the tritium-release test specimens must be controlled at a prescribed temperature, while the temperature of the structural material should be maintained as low as possible (ambient temperature) to avoid tritium permeation. To enable this and for the tritium gas release experiment, pipes, five or more in number, with a diameter of about 1 to 2 mm will be attached to a specimen packet. These specimens are further complicated by the need to easily connect and disconnect these pipes for re-encapsulation. Because of the complicated design and rather severe requirement for temperature control, verification of the performance, including the ability to fabricate the test specimens, needs to be examined together with the irradiation performance of some parts.

Brief Task Description:

One full scale sub-test module will be designed and fabricated. The sub-test module will include four kinds of specimen packets - disk, pellet, and pebble shaped specimens and a compatibility test specimen. Pipes for sweep gas and He cooling gas will be attached to the specimen packets. The pipes will be joined with re-usable couplers designed to enable replacement in a short time. A shape memory alloy (SMA) may be used for the couplers. Tests on temperature controllability will be performed. The feasibility of fabrication of the sub-test module including SMA coupling together with irradiation performance of the coupler will be examined.

Schedule: January 1997 - December 1999

Sub task	Duration
Design tritium release sub-test module	8 months
Fabrication	6 months
Perform tests	8 months
Data evaluation and documentation	2 month

Estimated Costs:

600 kICF

May 22, 1996

IFMIF
Engineering Validation Phase

Development Task

Task Title: Prototypic in situ creep-fatigue testing device development

Facility: Test Facility

Need/Motivation:

Simultaneous in-situ push-pull creep fatigue tests on three individual specimens are foreseen in the medium flux region. To demonstrate the feasibility and overall integrity of the novel concept, several activities need to be done. These include (1) engineering development and fabrication of the prototypic universal testing device, miniaturized actuators and grips, (2) thermo hydraulic tests under various conditions, (3) tests of various sensors under irradiation, and (4) extended creep-fatigue tests on miniaturized specimens under IFMIF specific loading conditions.

Brief Task Description:

One sub-scale (single specimen) test machine will be fabricated and mechanical tests at elevated temperatures with ohmic heating will be performed. Demonstration of specimen replacement will be also accomplished. Resistance to irradiation (gamma ray and neutron) of sensors will be examined in a separate set of tests.

Schedule: January 1997 - December 1999

Sub task	Duration
Design of the creep-fatigue testing machine	12 months
Fabrication	6 months
Perform tests	15 months
Data evaluation and documentation	3 months

Estimated Cost:

700 kICF

May 22, 1996

IFMIF
Engineering Validation Phase

Development Task

Task Title: Vertical Test Assembly (VTA) Prototype Development

Facility: Test Facility

Need/Motivation:

To function properly the Vertical Test Assemblies (VTAs) must (1) be positioned to ensure that the test modules are accurately aligned (~ ± 1 mm) relative to the neutron source, (2) be adequately sealed to ensure that a pressure of 0.1 Pa can be maintained in the Test Cell, (3) be easily removed and replaced with the remote handling equipment available in the Access Cell, and (4) provide adequate shielding for the Access Cell. Satisfying the fourth requirement leads to a VTA configuration that includes about xx tonnes of concrete shielding arranged in a stair-step fashion. Satisfying the other three requirements with this heavy and awkward configuration requires that a VTA handling and development effort be undertaken to demonstrate the feasibility of the concept and to develop handling approaches.

Brief Task Description:

A less than full-scale mock-up of the High Flux VTA (VTA-1) will be fabricated and tested. The mock-up will include a small vacuum chamber and vacuum pumping system. The connection between the VTA and the small vacuum chamber will be configured to simulate the Test Cell/VTA vacuum seal interface. Handling and alignment tests will be performed to demonstrate and develop VTA removal, replacement, and alignment operations and to identify improvements in the VTA design that facilitate these operations. Vacuum leak tests will also be performed to demonstrate that the sealing concept performs adequately.

Schedule: January 1997 - August 1998

Subtask	Duration
Design VTA and seal configuration mock-up	6 months
Fabricate mock-up	6 months
Perform tests	5 months
Data evaluation and documentation	3 month

Estimated Cost:

650 kICF

May 22, 1996

IFMIF Engineering Validation Phase

Development Task

Task Title: Vertical Irradiation Tube (VIT) System Prototype Development

Facility: Test Facility

Need/Motivation:

The Vertical Irradiation Tube (VIT) system, which consists of an array of tubes, pneumatic pumps, valves and heat exchangers, is designed for rapid insertion and removal of test specimens in the low and very low flux regions of the Test Cell. The array of tubes contains pneumatic capsules that remain in the irradiation region until the specimens are irradiated to the desired dose. The pneumatic capsules are then transported back to the Loading/Unloading Station where they are removed and placed into a shielded container and transported to the PIE Hot Cells or Lead Boxes. The major challenges in the VIT system are (1) development of a thermal control system that can accurately maintain and control test specimen temperatures within individual tubes, while allowing capsules to be rapidly removed and replaced, and (2) integration of the array of tubes, each operating at a different temperature ranging from 4 K to 800 K, into the overall VIT configuration

Brief Task Description:

This task includes development of a more detailed design concept for the VIT system, including its thermal control and capsule transport systems, followed by fabrication and demonstration testing of a protoypical array of a few tubes. These tests will demonstrate: (1) temperature control over the full range of environments (4 K - 800 K), and (2) removal and replacement of capsules.

Schedule:

Subtask	Duration
Design VIT system including thermal control approach	6 months
Fabricate prototype array	6 months
Perform tests	6 months
Data evaluation and documentation	2 months

Estimated Cost:

500 kICF

May 22, 1996

IFMIF Engineering Validation Phase

Development Task

Task Title: Test Cell Design Concept Development

Facility: Test Facility

Need/Motivation:

The Test Cell consists of the Vertical Test Assemblies, Vertical Irradiation Tube system, Test Cell Liner, Test Cell Heat Shield, Shield Plug between Vertical Test Assemblies, Test Cell Removable Cover, Vacuum Seal Plate, and Test Cell Camera/Viewing System. Because of the importance of optimizing the utilization of the irradiation environment, progress in further developing the details of the designs for these components and integrating them into a single unit is judged to be of critical importance for focusing the other Test Facility development efforts. These efforts are also important for ensuring that the implications of the results of the other development efforts are factored into the overall Test Facility.

Brief Task Description:

This task includes development of more detailed design concepts and integration of the results of other development efforts for all Test Cell components including the Vertical Test Assemblies, Vertical Irradiation Tube system, Test Cell Liner, Test Cell Heat Shield, Shield Plug between Vertical Test Assemblies, Test Cell Removable Cover, Vacuum Seal Plate, and Test Cell Camera/Viewing System. Thermal-hydraulic and stress analyses and further development of remote handling approaches and equipment are also included in this task.

Schedule: January, 1997 - December, 1999

Subtask

Develop mechanical design concepts for Test Cell components
Perform thermal hydraulic and stress analyses
Develop remote handling concepts and define equipment requirements

Estimated Cost:

450 kICF

May 22, 1996

IFMIF
Engineering Validation Phase

Development Task

Task Title: Engineering Design for Tritium Laboratory and Tritium Processing

Facility: Test Facility

Need/Motivation:

The Tritium Laboratory has two major independent sections - one for sample disassembly and another for sample preparation and tests. All tritium systems are assumed to be self contained and stand-alone. All the exhaust gas and effluent are processed within this subsystem. In order to demonstrate the feasibility of the overall concept, various engineering efforts are necessary.

Brief Task Description:

Due to the nature of that subject, various engineering efforts have to be undertaken in the fields (i) process analysis, (ii) design of tritium hot cell, tritium glove boxes, and tritium laboratory equipment, (iii) gas processing and Tritium retention systems, as well as (iv) laboratory equipment systems.

Schedule: January 1997 - July 1999

Subtask	Duration
Process analysis	12 months
Design development of cells and subsystems	12 months
Design development for Tritium retention and processing	6 months

Estimated Cost:

900 KICF

IFMIF

Engineering Validation Phase

Development Task

Task Title: Nuclear Data Evaluation

Facility: All Facilities

Need/Motivation:

Neutron nuclear data files for energies above 20 MeV need to be developed and processed for the calculational tools available for the IFMIF design. Such a task is very time consuming and it is an on going activity. In the IFMIF Test Cell there will be a considerable amount of neutrons produced above 20 MeV and a realistic assessment of the influence of this part of the neutron spectrum on nuclear responses, such as dpa, nuclear heating, gas production, and others is crucial.

Brief Task Description:

There are a considerable number of activities worldwide to extent the upper energy of the nuclear data files to energies of 50 MeV and up. Particularly there is a preliminary nuclear data file of JENDL, for a few elements to be released at the end of 1996.
A continuous activity is proposed with the aim at producing an IFMIF nuclear data file. This activity is foreseen as an in-parallel activity to the design and probably even to the operation of the machine.

Schedule:

To be performed continuously during the EVP period (1997-1999)

Estimated Cost:

250 kICF per year

IFMIF

Engineering Validation Phase

Development Task

Task Title: Nuclear Safety Analysis including Shielding and Activation Calculations

Facility: Conventional and Test Facilities

Need/Motivation:

To support the IFMIF design activities wall thicknesses of the different parts of the buildings have to be defined. Dose levels (absorbed and biological) in the accessible areas of the facility must be within the acceptable limits and shielding has to be provided as required. Also hot cells and PIE laboratories shielding requirements should be addressed.

Post shut-down nuclear responses such as decay heat and biological doses due to activated material are also to be assessed.

Brief Task Description:

Throughout the facility the assessment of the radioactive sources and biological doses due to those sources is to be performed. Calculations are going to be carried out to define shielding requirements and personnel accessibility, during operation and after shut-down. Total activity of specific components and of the overall facility are to be estimated.
Decay heat of the irradiated materials is also to be calculated to define cooling requirements.

Schedule:

To be performed continuously during the EVP period (1997-1999)

Estimated Cost:

500 kICF per year

IFMIF

Engineering Validation Phase

Development Task

Task Title: Re-evaluate relevant irradiation parameters

Facility: Test Cell

Need/Motivation:

As a more accurate nuclear data comes available, a re-evaluation of the preliminary assessment of nuclear responses for the irradiation modules will be necessary. This task is also needed as the design develops and more detailed description of the test modules and the whole facility are available. Also an assessment of the tritium production and inventory in the facility is to be performed.

Brief Task Description:

The main purpose concerns the calculation of nuclear heat deposition, gas production, gamma production, damage rate and other relevant responses to support the design activities of the test facility and the users' group. The assessment of tritium production into the facility is also a relevant requirement related to safety problems.

Schedule:

To be performed continuously during the EVP period (1997-1999)

Estimated Cost:

500 kICF per year

-1-

Remaining Test Facility Tasks

Design and Evaluation Tasks	May 96-Oct 96	1997-1998
Review/harmonize/establish feasibility of existing design options		
VTA's	x	x
Removeable shield plug	x	
Test Cell design	x	
Access Cell Size and Equipment	x	
Tritium in-situ release - glovebox location	x	x
Wall thickness - shielding	x	x
Evaluation/selection of remote handling approaches	x	
Heat shield thickness	x	

May 1996

-2-

EVP - Test Facility Tasks

Neutronics Tasks

- Nuclear data evaluation and data library preparation (20-50 MeV)
- Source Term of the D-Li reaction
  Re-evaluate relevant irradiation parameters to support needs of the Users Group
  - Neutron spectra, dpa- and gas production rates
- Evaluation of overall tritium production rate in the Test Cell
  - Supports safety analyses and design of tritium processing and ventilation systems
  - Tritium production rates for breeding material experiments
- Shielding and activation analyses
  - Thickness of walls for Access Cell, Hot Cell, etc.
  - Gamma generation and total heat generation in Test Modules
  - Decay heat evaluation for Test Cell components (He and NaK coolant)
- Experimental data base (E_n < 50 MeV) for Dosimetry

May 1996

EVP - Test Facility Tasks

Hardware Fabrication and Testing

- **He cooled High Flux module full-scale prototype development and testing**
  - Fabricability
  - Remote handling and encapsulation
  - Thermal-hydraulics
  - In-situ instrumentation and data acquisition
- **Medium flux prototype development (breeding tests, creep-fatigue tests)**
  - SMA sealing under irradiation/thermal environments
  - Demonstration of feasibility of one full-scale tritium release sub-test module
    - Fabrication (several different specimen types. e.g. pebble bed, discs, ...)
    - Thermal-hydraulics/Temperature control
- **VTA Prototype Development**
  - Fabricate (less than full-scale VTA)
  - Remote handling - demonstrate precise positioning
  - Vacuum sealing

EVP - Test Facility Tasks
Cost Estimate

Activity	<Cost>/yr (KICF)	No. of yrs	Tot. Cost (KICF)
Components			
He cooled high flux test module	320	3	950
Tritium release test module	235	3	700
Creep-fatigue test module	235	3	700
VTA mock-up	300	2	600
VIT mock-up	350	2	700
Universal Robot mock-up	285	3	850
Design			
Integral Test Cell design	315	2	630
Tritium Laboratory	315	2	630
Neutronics			
Re-evaluation of irrad. param.	210	3	630
Nuclear savety & shielding	210	3	630
Nucl. data evaltn. (<50 MeV)	160	3	460
d-Li source term	320	1	460
Total			**7940**

Thomas E. Shannon
IFMIF/CDA Leader

Overview of IFMIF 2nd Design Integration Workshop

Tokai Research Establishment
JAERI
May 28, 1996

Overview Topics

1. Objectives of the 2nd Design Integration Meeting
2. Attendees
3. Meeting Format
4. Summary of Conclusions
5. Outstanding Issues
5. Reporting on the Results of the Meeting
6. Plan for Report and Completion of the CDA
7. Next Meeting(s)
8. Action Items

OBJECTIVES OF THIS MEETING

1. Review and Update the Baseline Design Concept
   - Provide a written summary (addendum) of changes from Interim Report.
2. Establish the R&D Needs for the Engineering Validation Phase
   - Provide a written description of the need and scope of the required activity.
3. Review the Preliminary Cost and Schedule Estimates
   - Construction Project
   - Operation
   - Research and Development for Engineering Validation

Meeting Format

- General Meetings
  Discuss status, conclusions and unresolved problems
- Group Meetings
  Plan Work
  Discuss Technical Issues
  Compare Results
  Resolve Problems
- Individual Work
  Write Reports
  Integrate Results (DI Group)
- Group Leaders (Each Day at 12:45)
  Plan Work
  Write Reports
  Discuss Issues
  Prepare Presentation for Subcommittee
  Meet with Subcommittee

OBJECTIVES OF THIS MEETING (CONTINUED)

4. Identify Areas of Major Uncertainty in the Estimates
   - Determine range of cost or contingency
5. Write the First Draft of the Cost and Schedule Sections for the Interim Report.
6. Review Detailed Results of RAM, Safety and Maintenance
   - Document results (addendum) for Interim Report
7. Continue to Prepare for a Project, Work Hard, Learn, Produce Good Results, Build Relationships, Have Fun.

Summary of Conclusions of the 2nd Design Integration Meeting

1. The User Requirements (FZK, Sept. '94) can be met by the CDA Concept.
2. The Basic Design Requirements Established at the Design Meetings in 1995 are Confirmed.
3. Several Design Changes were Agreed Upon with Modest Impact on the Baseline Design.
4. The Detailed Construction and R&D Schedule Required only Minor Modifications to FPCC Proposal by Professor Kondo.
5. There is Good Agreement on the Preliminary Cost Estimate.
   - Several Areas Require Checking and Possible Site-Specific Adjustments for National Differences.
6. A Detailed Plan and Cost Estimate for the EVP has been Prepared.

Outstanding Issues

- CDA Reporting on Safety and Environmental Issues.
- Design Integration and Cost of Radioactive Gas Handling Systems.
  - These activity will be led by Dr. Konishi with participation by TBD specialists in the USA and EU.
- Activation and Maintenance Requirements for Test Cell, Target and Accelerator Systems.
  - Approach will be discussed by Deputy Leaders
- Detailed Plan, Schedule and Agreement for Completion of the Report by December 31

Next Meeting(s)

September 16-18	Possible Pre-meeting	FZK, Germany
October 14-25	Frascati	Frascati, Italy

- October 14-18 Design Workshop
- October 21-23 Formal Presentation of Results
- October 24-26 Final Report Changes

Planning for the Frascati Meeting

1. Deadlines: **Participants List June 15**
Reservation Forms to Frascati July 10

2. Action: **Deputies E-mail List if Names to Professor Martone With copy to Shannon by: Friday June 14.**

Reporting on the Results of the Meeting

Five Reports

- Minutes	JAERI
- Addendum to Interim Report	JAERI
- Engineering Validation Phase Plan	JAERI
- Preliminary Cost Estimate and Schedule (Limited Distribution)	ORNL
- Presentation to the Subcommittee	JAERI

Action Items from Meeting

1.	**Complete Task Sheets for EVP**	**Deputies**	**May 27**
2.	**Draft of Minutes and Addendum Reports**	**Maekawa**	**June 14**
3.	**Issue Guidance for Final Report**	**Shannon**	**June 14**
4.	**Draft of Cost Report** **- List key assumptions such as site support**	**Rennich**	**June 14**
5.	**Organize Rad Gas/Lithium/Safety Group**	**Konishi**	**June 28**
6.	**Complete Design Work and Drawings**	**Deputies**	**Sept. 15**
7.	**Complete First Draft of Report**	**Deputies**	**Sept. 15**

Appendix-5.5 Documents Prepared for the Subcommittee Meeting

Table of Contents

Group Leader Reports

- Brief Review of System Concept
- Changes resulting from this Meeting
- Plan for the EVP
- Cost Estimate Issues

IFMIF ACCELERATOR SYSTEM REPORT

2nd Design Integration Workshop

Tokai, 20-25 May 1996

R.A. Jameson

R.A. Jameson
May 27, 1996

IFMIF 2nd Design Integration Workshop

Tokai May 20-25 1996

Minutes of Accelerator Group Meeting

Participants:

Japan	Sugimoto, Miyahara, Odera, Kinsho, Tanabe, Sawada, Maekawa, Chernogubovsky
EC	Klein, Lagniel, Ferdinand
US	Jameson, Berwald, Bruhwiler, Myers, Piaszczyk, Rathke

Group Meetings: Monday through Friday, except for general meeting attendance.

Presentations:

- ECR source and injector studies, Lagniel
- Injector work in Japan, Kinsho
- Injector work at IAP, Klein
- Modeling of ion source/LEBT/RFQ transmission, beam loss, and neutron generation vs. source emittance, Bruhwiler
- Perspective on deuterium performance scaling for various positive ion sources at Northrup Grumman, Berwald
- Halo formation, Lagniel
- RF amplifiers for IFMIF, Lagniel
- Japan study of superconducting linac option, Tanabe
- Review/Update of accelerator interfaces, Berwald
- Comments on RFQ beam dynamics, Sawada and Chernogubovsky
- Japan RF system work (solid state, etc.), Maekawa
- Neutron activation of ion source/LEBT/RFQ, Gomes
- Design and RAM considerations for rapid replacement of ion injector, Rathke and Piaszczyk
- Accelerator access and maintainability, Rathke
- Accelerator I&C System, Berwald
- Cost, WBS and manufacturing schedule, Myers
- Reference Linac, Matching and HEBT, Jameson

1.) Significant progress has been made on all aspects of the 2nd year CDA tasks on the Accelerator System, as indicated in the list of presentations above. The material from these presentations will be included in the Tokai Design Integration Meeting Report. The CDA activities are proceeding on schedule.

2.) A deuteron current of 80 mA has been extracted at 35 keV from the IAP source. This is an important step toward reaching the full IFMIF specification of 140 mA at 100 keV. Injector development continues to be of high priority; the EVP plan shows injector development as the second highest priority task (after the RF amplifier, discussed below).

3.) Many changes were made to the facility layout, in coordination with the facilities group. The configuration of the accelerator halls, RF halls, and beam-turning room were all changed to minimize space and improve efficiency. One area where these changes are still under evaluation is the high-energy-beam-transport (HEBT) turning room, where the combination of space discussions and more detailed target specifications results in a difficult beam transport design problem.

4.) A detailed cost estimate has been prepared by the US, and was presented at this meeting for discussion. Japan has agreed to provide formal comment on the Cost Estimate, and EU comment will also be gathered.

5.) Considerably more detail has been added to the RAM model, maintainability and operability procedures, and control system definition.

6.) New work (beyond earlier FMIT studies) was done on the modeling of beam losses in the ion source/LEBT/RFQ. The beam loss model was used to develop radiation source-term models and estimation of radioactivity levels during planned operation and maintenance periods. This work was instrumental in helping decide that radiation would make it very difficult to do maintenance on a second injector while one was operating, so the two-injector concept has been replaced with an in-line injector concept.

7.) Concern about develop of the main rf amplifiers to full cw performance for IFMIF led to a major decision to reduce the specification from 1.3 MW to 1 MW per amplifier. This decision also has advantages in that more than one vendor can be involved. The major task of the EVP has been determined to be the successful test of a full-scale rf system for 100 hours cw.

8.) Evaluation of the superconducting linac as the primary alternative for the accelerator was reported by the Japanese group, with the conclusion that this approach is feasible from the technical view. Issues are cost, including the need for full development, and the type of rf amplifier that could be used. Japan is working on the development of 100-kW solid-state rf amplifiers, and will provide some budgetary cost estimates for projected near- and long-term prices. A second rf approach is to use the 1 MW tetrode amplifiers, but further study of power-splitting to the SC tanks is required.

9.) Discussion and planning for the Engineering Development Phase occupied a major portion of the meeting. A budget is 25M ICF is target to rf amplifier development to a 100 hour test (15M ICF), injector development to a 100 hour test (5M ICF) and all other tasks (5M ICF). This latter item can be summarized as minimization of beam loss and activation such that remote handling will not be necessary. It includes beam dynamics, linac structure mechanical aspects (but no prototype hardware), continued development of cost and RAM, and so on, and is considered marginal in terms of full preparation for a construction phase.

GENERAL ACCELERATOR PARAMETERS

Output Energy - 40 MeV

Two lower energy steps, nominally 35 MeV, 30 MeV

Output Beam Current - 125 mA / accelerator

Two Accelerator Modules -> 250 mA total

Operational redundancy at 125 mA is a significant availability advantage.

Frequency - 175 MHz

Cautiously at higher end of allowable range (~150~175 MHz) to give improved beam dynamics, smaller size.

ACCELERATOR GROUP MEETINGS

Karlsruhe
Dallas
Santa Fe
ORNL (partial)
Tokai

Tokai Presentations:

- ECR source and injector studies, Lagniel
- Injector work in Japan, Kinsho
- Injector work at IAP, Klein
- Modeling of ion source/LEBT/RFQ transmission, beam loss, and neutron generation vs. source emittance, Bruhwiler
- Perspective on deuterium performance scaling for various positive ion sources at Northrup Grumman, Berwald
- Halo formation, Lagniel
- RF amplifiers for IFMIF, Lagniel
- Japan study of superconducting linac option, Tanabe
- Review/Update of accelerator interfaces, Berwald
- Comments on RFQ beam dynamics, Sawada and Chernogubovsky
- Japan RF system work (solid state, etc.), Maekawa
- Neutron activation of ion source/LEBT/RFQ, Gomes
- Design and RAM considerations for rapid replacement of ion injector, Rathke and Piaszczyk
- Accelerator access and maintainability, Rathke
- Accelerator I&C System, Berwald
- Cost, WBS and manufacturing schedule, Myers
- Reference Linac, Matching and HEBT, Jameson

INJECTOR

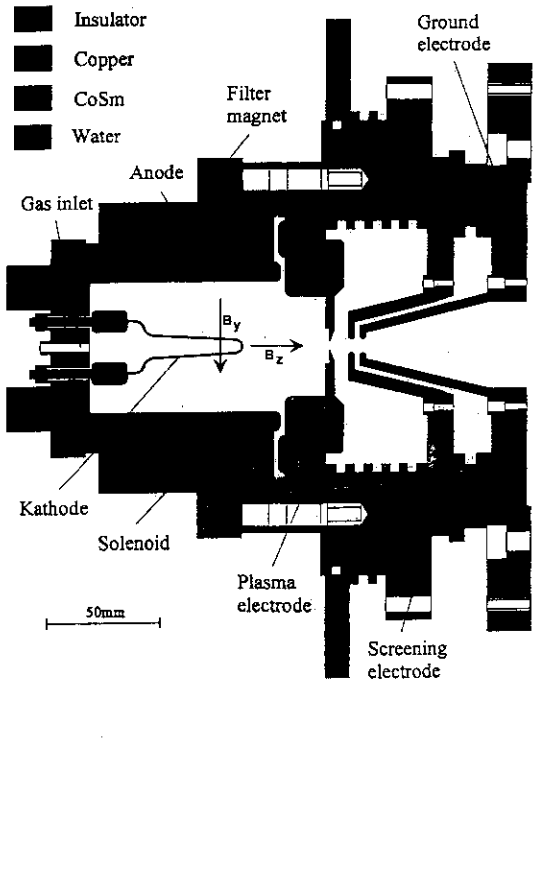
- 80 mA deuterons extracted at 35 keV from IAP Volume Source (Klein)

- Significant new work on
  - Beam dynamics modeling of ion source/LEBT/RFQ (Bruhwiler)
  - Neutronics, shielding (Gomes)

- Decisions:
  - Radiation background too strong for maintenance of 2nd source while another source is running. Use single on-line injector; engineer for quick replacement.
  - H2+ tuneup mode limited to ~50 mA unless separate injector development is funded.
  - Parallel development of ECR and Volume source approaches reconfirmed. Strong development leverage from other programs.

Institut für Angewandte Physik, Universität Frankfurt *H. Klein*

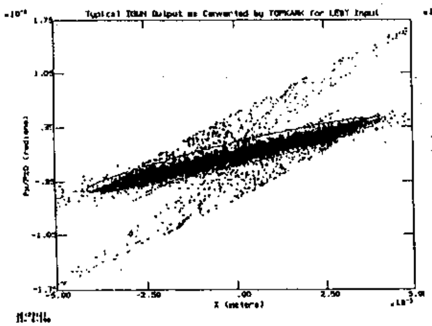
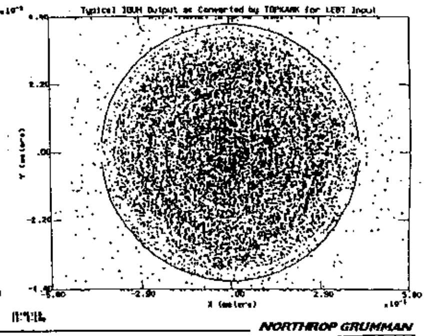
Schematic drawing of the deuterium source



IGUN Output Trajectories Converted to TOPKARK Particles

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Northrop Grumman code TOPKARK was used to model the LEBT
  - IGUN assumes cylindrical symmetry; uses radially-weighted "rays"
  - TOPKARK uses unweighted macroparticles & Cartesian coord.'s
- A small-radius Gaussian distribution was added to plug "hole" in beam
- Circles show envelope of beam with "total" emittance equal to 6 times the RMS emittance (such as a waterbag distribution)

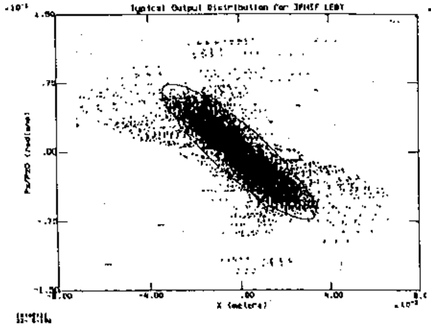
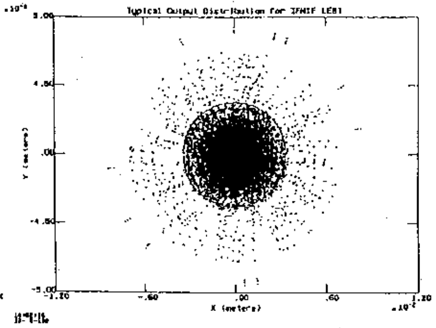



Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Typical LEBT Output as Simulated with TOPKARK Code

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- Typical beam as injected into PARMTEQ
- Shows three overlapping beams due to differing neutralization
- Circles show envelope of idealized waterbag distribution for the nominal RFQ input emittance of 0.02 cm-mR (RMS, normalized)
- Roughly 10% of beam lies outside of the circles (the halo)
- TOPKARK output was converted directly to PARMTEQ input

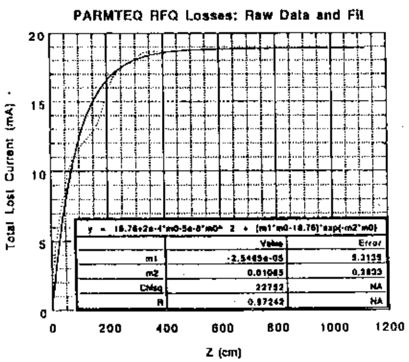



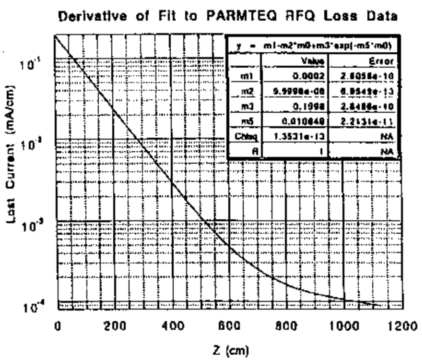
Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

Beam Loss in the RFQ

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL

- The aggregate beam loss data was fit with a function
  - The fit was required to be very close at high-energy end of RFQ
- This function was differentiated to obtain lost current in mA/cm

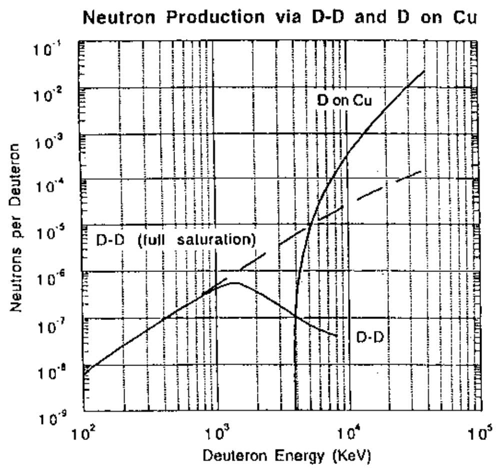




Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN

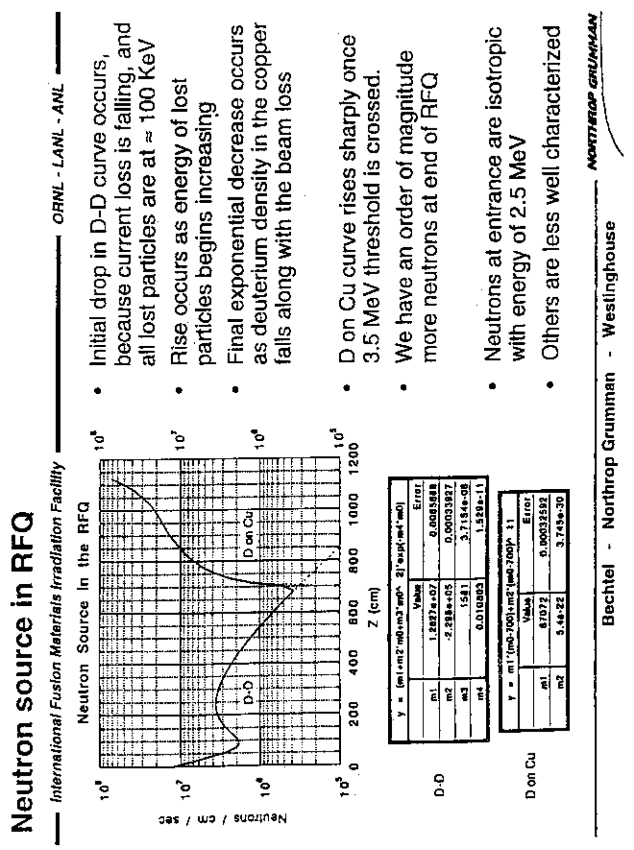
Neutrons per Deuteron: both D-D and D on Cu

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



- Dashed curve shows D-D neutrons per deuteron, assuming full saturation of deuterium in copper
- Lower solid line gives D-D neutrons per deuteron, using estimated densities
- Upper solid line gives neutrons per deuteron arising from D / Cu reaction
- Cross-over for solid lines occurs at 4 MeV
- 6 orders of magnitude more neutrons per deuteron at 40 MeV than at 100 KeV

Bechtel - Northrop Grumman - Westinghouse — NORTHROP GRUMMAN



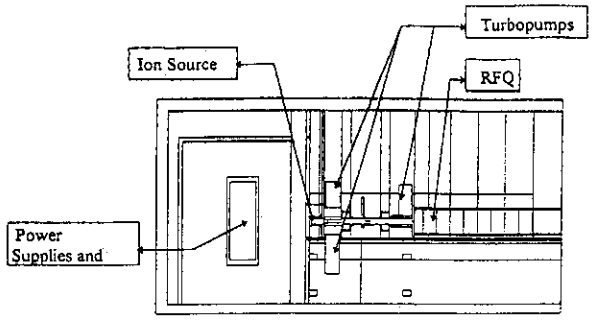


Figure 1. MCNP model of the accelerator room at low deuteron energies

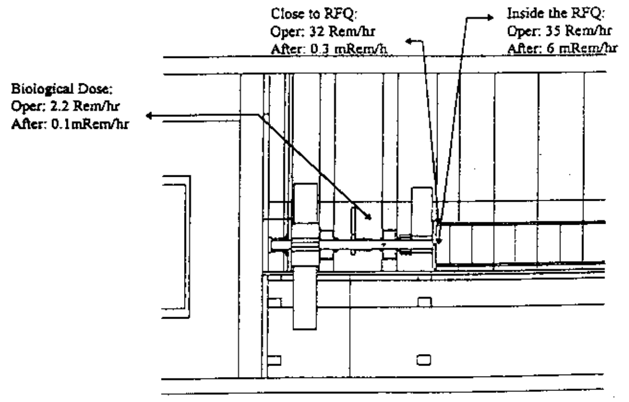


Figure 2.- Vertical view of the LEBT and RFQ model with selected position's radiation levels before and after shut-down.

RF POWER SYSTEM

• Existing tube performance discussed again -
  - Only burst of a few seconds to one minute, generally at lower frequencies.

• Consensus that performance limit of 1.3 MW anticipated by one vendor is too risky.

• Decision to reduce tube performance goal to 1 MW cw.

• Effect of 1 MW tube on design
  Main interface is that lower energy steps may be ~36 MeV and ~32 MeV; considered acceptable by test cell group.

• 1st priority EVP task

• RF Group Discussion Summary attached

RF Group

Summary Of Discussions

21 May 1996

1) The test experience with the Eimac 4CM2500KG tube was reviewed and discussed, including JT-60 test results and more recent Japanese experience. It was agreed that a more conservative design point of 1000 kW at 175 MHz would be adopted. This lower power level will provide increased assurance of obtaining the required design lifetime and reliability. It will also allow for increased competition between two and possibly three vendors. [Thomson plans a test of their ~1000 kW Diacrode design in the August timeframe.]

2) It was agreed that although the expected tube power would be higher at lower frequency (e.g., 150 MHz), such a change would not be recommended at this time. [Power scaling ~$F^{-2.5}$ has been suggested.]

3) It was agreed that for the time being we will continue to use tube parameters for the Eimac 4CM2500KG so that we will have a definitive basis for the baseline design and system layout. [We recognize that the parameters for the Diacrode are not expected to be different in areas that will have a substantial effect on the design performance or its cost.]

4) It was agreed that a test program to establish the actual CW (preferred) or long pulse operational capabilities of the Eimac 4CM2500KG at 175 MHz should be established as soon as possible during the technology validation phase. [This may or may not be required also for the Diacrode.] The Japanese participants may have an existing capability to perform these tests at Naka. There are other possibilities as well (e.g., at Princeton). The results will be considered in subsequent design activities.

5) Northrop Grumman/ORNL plans to develop and test a coaxial rf window with specification of 600 kW at 175 MHz were reviewed. It was agreed that window testing should also be a program priority.

6) The cost of 4 MW (total) of solid state cw rf power for ~40, 100 kW superconducting cavities was discussed. The Japanese team agreed to develop a preliminary estimate based upon 50 kW commercial broadcast stations manufactured by Toshiba.

ACCELERATOR FACILITY COST, SCHEDULE, MANUFACTURING FLOW

- Detailed material developed by US; presented for discussion at this meeting
- Formal comment to be supplied by Japan
- Comment to be supplied by EU

US Costing Approach - "Grass Roots"

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

- **Develop lower level accelerator component activities from program master schedule**
  - » engineering design
  - » procurement/fabrication/manufacturing
  - » installation, assembly and checkout
- **Define each activity in terms of labor and material**
- **Compare results with similar programs/estimates**
  - » Contraband Detection System
  - » Continuous Wave Deuterium Demonstrator
  - » Accelerator Transmutation of Waste (ATW) and other high power accelerator programs

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Contributors

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Name	Area of Responsibility
John Rathke	Overall engineering labor estimate (preliminary and final design, and manufacturing support)
David Bruhwiler/Alan Todd	Physic support labor estimate
Al Burger/Ed Peterson	Accelerator/HEBT manufacturing labor and material estimates
Ed Piechowiak/Eric Ulanowicz	RF power system engineering/manufacturing labor and material estimates
Mike Cole	Accelerator cavity tuning/installation labor and material estimates
Joe Sredniawski	Injector design and manufacturing labor and material estimates
Stephen Melnychuk	Injector startup labor and material estimates
Stan Mendelsohn	Accelerator Segment Instrumentation and control design and installation labor and material estimates
Ted Debiak	Accelerator/HEBT diagnostic labor and material estimate

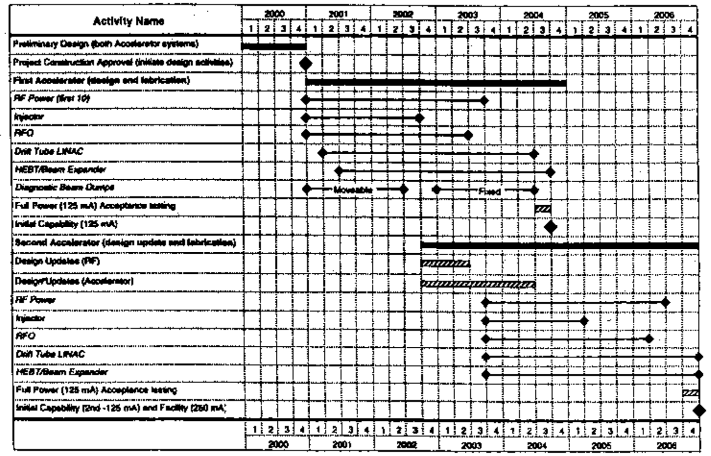
- **Coupled to over 90 component or service vendors supplying quotation in ~ 20 different technical areas**

NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Program Master Schedule - Accelerator

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

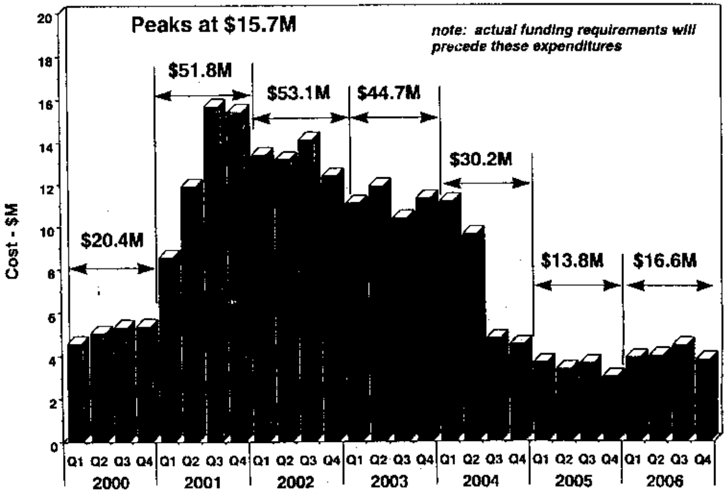


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Spending Profile

International Fusion Materials Irradiation Facility — ORNL - LANL - ANL



Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

FACILITY LAYOUT REVISIONS

- Important interactions with facility team to
  - minimize floor space
  - improve efficiency of operations and maintenance
- New layout drawings

May 1996 Configuration

International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- Single Injector Designed for Rapid Maintenance
  - Beam Loss Study Indicates No Access Allowed During Operation
  - Allows Much Narrower Vault
- Simple, Short Dual Solenoid LEBT
  - Lessens Concern Over Space Charge Neutralization
- Accelerator Vaults Below Grade, RF Above
  - Common Central Pipe Chase Between Vaults For RF Coax and Services
  - Reduces Shielding Requirements for Vault Walls
- Accelerators Moved on Trolleys Over the Floor
  - Used For Initial Installation and Rare Case When Tank Must Be Removed
  - Saves Overhead Clearance and Reduces Crane Capacity to 5 Tons
  - Technique used at SLAC, Fermilab, and Others
- Accelerator Maintenance Area At RF Floor Level
  - 25 Ton Crane on RF Floor Lifts Accelerator Tanks When Necessary
  - Normal Accelerator Maintenacne Performed In-Place

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

May 1996 Configuration II

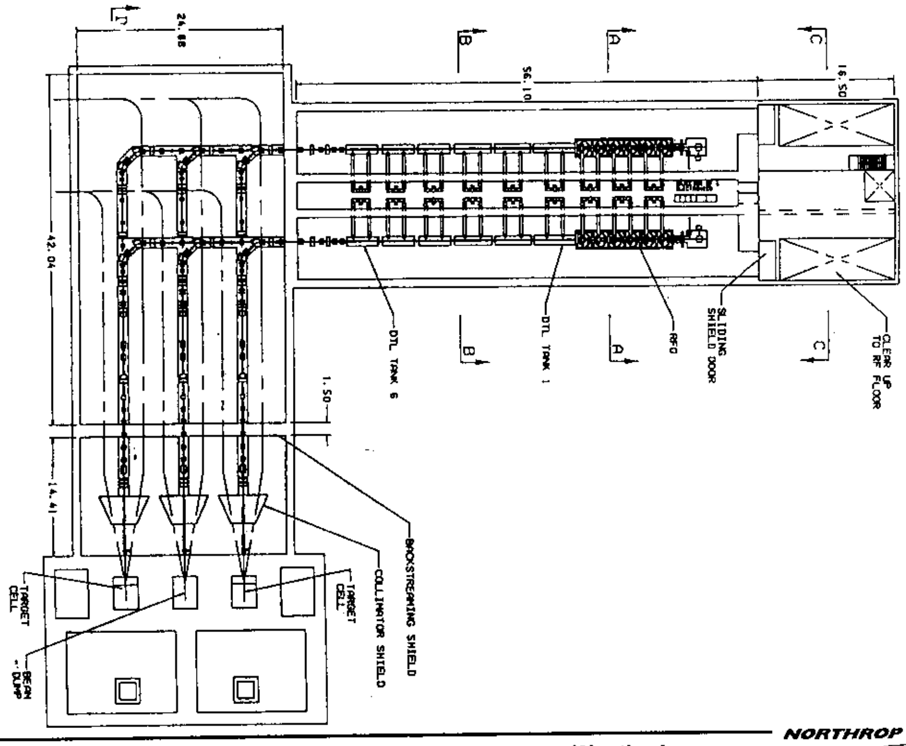
International Fusion Materials Irradiation Facility — ORNL - ANL - LANL

- High Energy Beam Transport System Design Has Been Performed by Los Alamos
  - Not Optimized But Works End to End
  - Closely Conforms to the Overall Geometry Used Previously
  - Consists of:
    - > Four Quad DTL to HEBT Matching Section
    - > 2.4 Meter FDo Lattice With Bunchers Every 2nd or 3rd Cell (Before Bend)
    - > Achromatic Bend With Dual Bunchers
    - > 2.75 Meter FDo Lattice With Bunchers Every Other Cell (After Bend)
    - > Four Quad Plus Buncher Telescope Matching Section
    - > Nonlinear Expander (Oct-Quad-Quad-Oct)
    - > Six Quad Imager
    - > 10 Degree Dipole
    - > Two Energy Dispersion Cavities
- Bend to Target 2 Meters Greater Than Previously Shown

Bechtel - Northrop Grumman - Westinghouse   NORTHROP GRUMMAN

Accelerator Plan View - 1996

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*

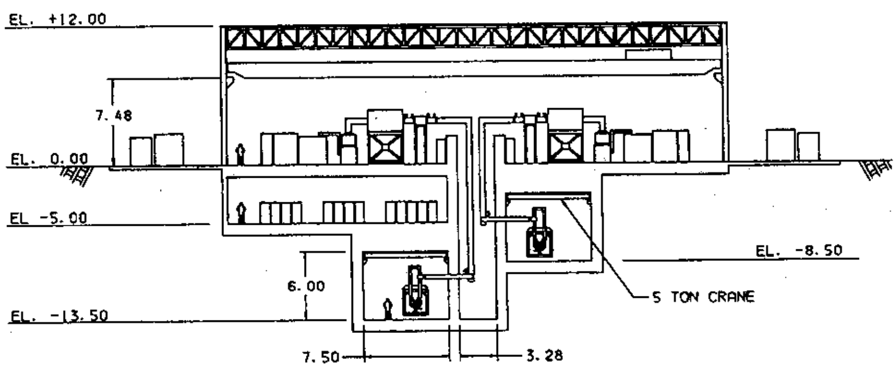


NORTHROP GRUMMAN

Bechtel - Northrop Grumman - Westinghouse

Section Through Accelerators - 1996

International Fusion Materials Irradiation Facility — *ORNL - ANL - LANL*



SECTION A-A

NORTHROP GRUMMAN

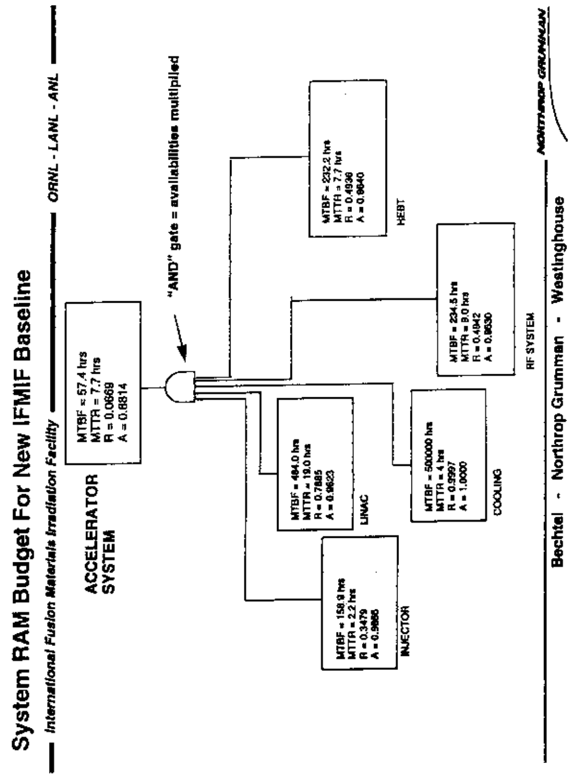
Bechtel - Northrop Grumman - Westinghouse

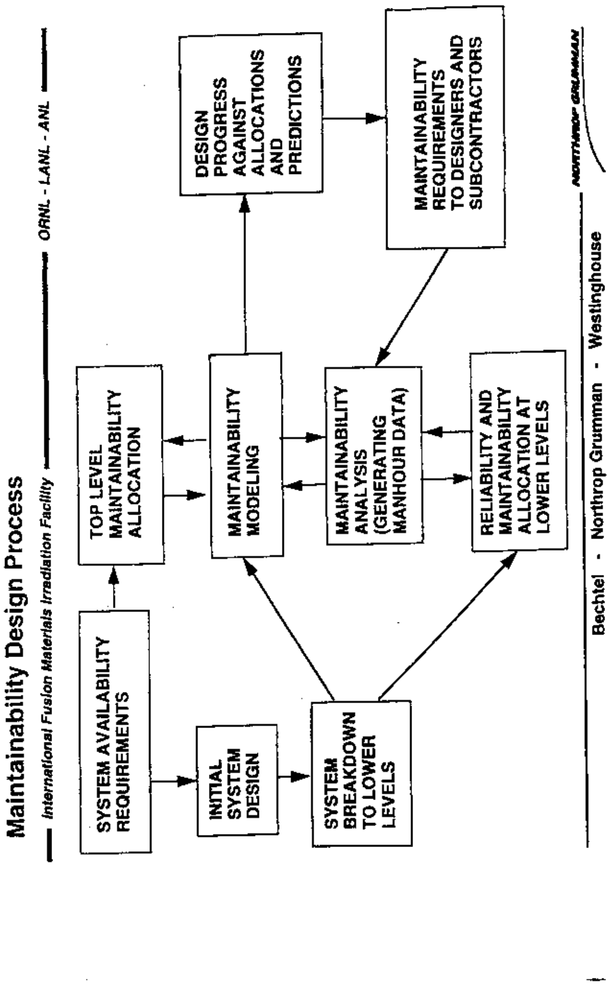
ACCELERATOR RAM

- Detailed RAM modeling has been accomplished:
  - Definitions
  - Detailed subsystem models

- Overall integration shows accelerator RAM budget of 0.88 is feasible

- Similar model for maintainability





RF System: Output Tube - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Output Tube	1	Shutdown RF station	5
	2	Depressurize coax	5
	3	Remove all interface connections to cavity	90
	4	Remove top half sections of cavity	40
	5	Disconnect interfaces to tube	30
	6	Extract tube & replace with new tube	60
	7	Reconnect tube interfaces	30
	8	Replace top half sections of cavity	50
	9	Replace cavity external interfaces	90
	10	Repressurize coax line	15
	11	Verify coolant line and electrical connections	10
	12	Perform turn on sequence for RF station	20
	13	Confirm RF system performance is adequate	10
		Total	455

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is 14 hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

RF System: Driver Tube - Corrective Maintenance

International Fusion Materials Irradiation Facility — *ORNL - LANL - ANL*

Failed Item	Seq. #	Action	Time (min)
Driver Tube	1	Shutdown RF station	5
	2	Depressurize coax	5
	3	Remove all interface connections to cavity	60
	4	Remove top half sections of cavity	30
	5	Disconnect interfaces to tube	30
	6	Extract tube & replace with new tube	40
	7	Reconnect tube interfaces	30
	8	Replace top half sections of cavity	50
	9	Replace cavity external interfaces	60
	10	Repressurize coax line	15
	11	Verify coolant line and electrical connections	10
	12	Perform turn on sequence for RF station	20
	13	Confirm RF system performance is adequate	10
		Total	365

Additional time will be required for fault identification, location of tools and spare parts, and access time for the maintenance personnel. The estimated total MTTR for the entire process is 13 hrs.

Based on data provided by Ed Plechowiak on 5/13/96

Bechtel - Northrop Grumman - Westinghouse

PRIMARY LINAC OPTIONS

Superconducting Linac

New studies presented by Japanese group

- indicate technical feasibility

- Cost issues:
  - -- full development program (similar to room-temperature) would be required
  - -- rf power costs

RF Power

- Small 100 kW solid-state amplifiers under development in Japan, but costs high at present. Budget estimates to be provided.

- Large 1 MW tetrode amplifiers would make SC linac cost approximately equal to room-temperature linac cost, but technical aspects must be evaluated.

Advantages of SC Linac

- Lower beam loss
- Good dimensional stability
- Possible upgrade advantages
- Strongly emerging technology

CCDTL Option - set aside

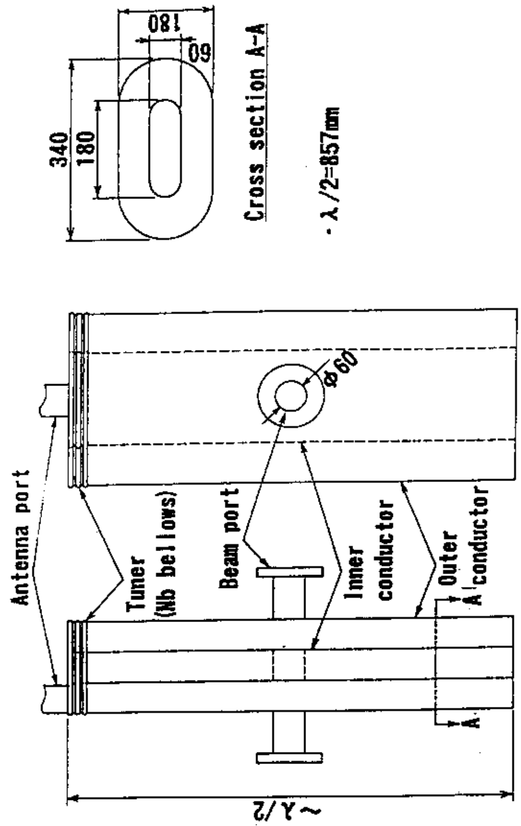


Fig. 2.1.3 Optimized s/c cavity

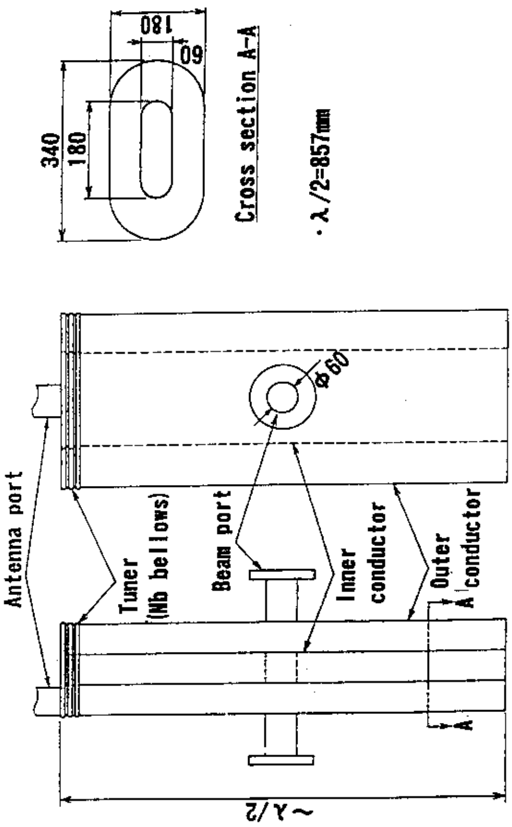


Fig. 2.1.3 Optimized s/c cavity

ACCELERATOR EVP PLAN

Total Budget ~25M ICF

Accelerator is largest cost system
highest technology system

Much can be accomplished in 3 years at this budget, but inadequate for full preparation.

Task One - RF System 100-hour Demonstration (~15M ICF)

- Competitive bid - 2 manufacturers
- Intention that remainder of procurement could be fixed price
- Test facility does not exist in US, Japan, or EU; possibly in Russia?

Task Two - Injector 100-hour Demonstrations
- Concentrate in EU
  - ECR Injector at Saclay
  - Volume source Injector at IAP
- Support by US, Japan
- --All have some budget share

Task Three - Minimization of Beam Loss Such That Remote Maintenance Is Not Needed
- All other aspects of design
  - beam dynamics
  - mechanical engineering support
  - no hardware (probably not even cold models)
- Not sufficient to fully prepare for construction phase

ENGINEERING VALIDATION PHASE
Accelerator

Total - $25M ICF

An Engineering Validation Phase is proposed for 1997-1999. A budget allocation of ~25M ICF is presently allocated for the IFMIF accelerator system, on the basis of a pro-rated 10% of the project cost. The accelerator system is the largest cost system, but also the highest technology system. Based on our assessment of the IFMIF task and knowledge of comparable projects, 25M ICF is quite marginal, but a great deal could be accomplished in these three years with this amount.

Task One - RF System Development and Test - 15M ICF

Development and testing of a 1 MW rf system is identified as the highest impact development item. Existing operating experience is with pulses of a few seconds to order a minute of cw operation, at frequencies generally lower (easier) than the IFMIF frequency. No test stand capable of 1 MW cw tests to 100-1000 hours is available in the world, with the possible exception of Russia. Detailed costs to design, construct, and test the first rf station are available in the extensive costing information developed for the Tokai meeting, so a reliable estimate of ~15M ICF for this task is in hand. As the EVP proceeds, efforts would be made to economize on this number, including exploration of the possibilities in Russia.

The rf amplifier power level baseline of 1 MW and the defined EVP program have important advantages. The 1 MW power level insures that a competitive bid could be obtained from two manufacturers. Accomplishing a full-scale test of the first system would allow the remaining large procurement to be on a fixed-price basis. The involvement of two manufacturers would help insure a tube supply over the facility lifetime.

Task Two - Injector System Development and Test - 5M ICF

The injector system has the second highest impact in terms of reaching the required performance and RAM goals for IFMIF. Two technical approaches (the ECR and volume type ion sources) are to be developed to the full test stage. The primary effort will be located at EU facilities with strong support from Japanese and US teams. A budget of ~5M ICF is presently assigned to this task. It is anticipated that source test stands can be brought to fully operational level at the end of 1998 within this budget. Operational test to demonstrate an initial goal of 100-hour lifetime would be conducted in 1999; further budget discussion will probably be required to complete these tests.

Task Three - All Other Conceptual Design Activity - 5M ICF

These are many other tasks necessary to reach a stage where productive preliminary design activity could start in the year 2000. The remaining ~5M ICF is allotted to these tasks. An overall category for these detailed design tasks is maintaining beam loss and activation low enough that remote handling is not necessary. The tasks involve detailed design of the accelerator beam transport from ion source to target, fundamental investigations to gain understanding of the loss mechanisms, coordination with neutronics calculations and shielding design, coordination with engineering aspects of the accelerator design, and so on. The allocation for this area is insufficient for full preparation for the construction phase; however much can be accomplished and plans can be made to merge with the final design and construction phase.

TARGET GROUP REPORT

Second Design & Integration Workshop

Presented By

Hiroji Katsuta
IFMIF Deputy Leader For Target Facility

OUTLINE

- **Review and Update of Technical Issues**
- **Cost Estimation**
- **Proposal For Engineering Validation Phase Activities**
- **Proposal For Collaboration Among Parties**

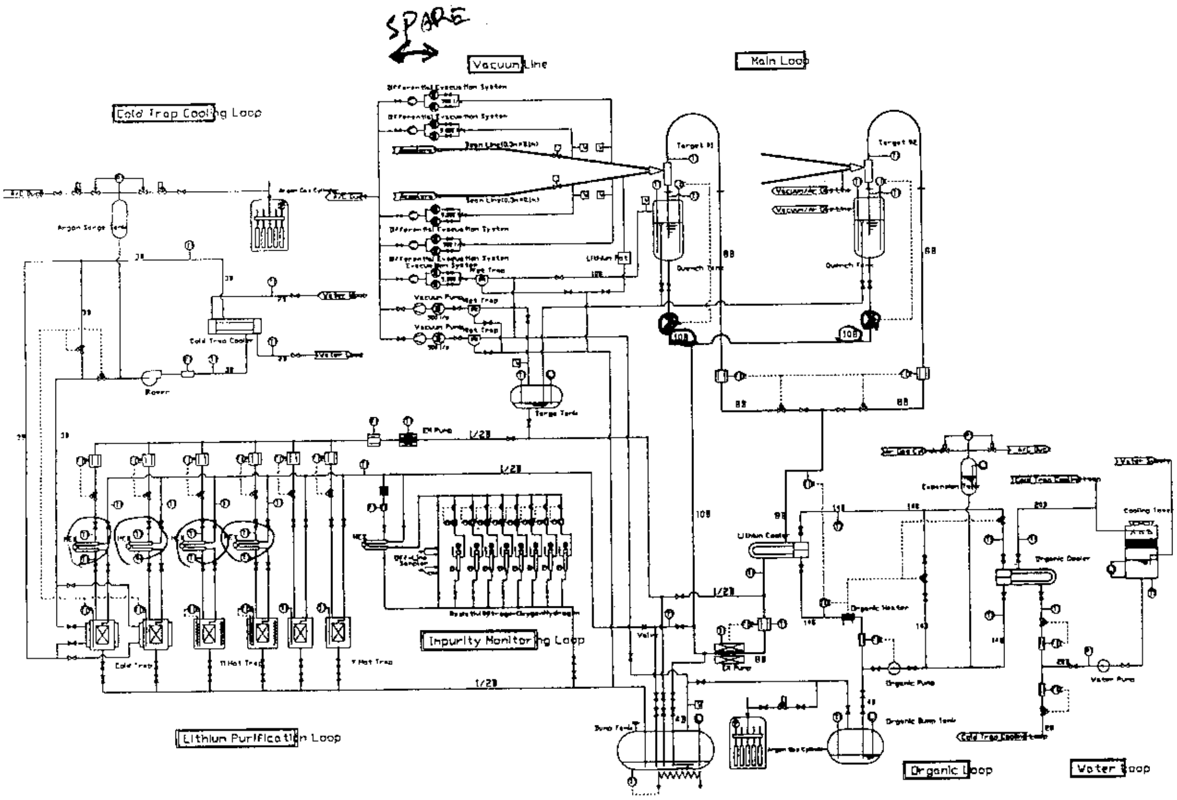
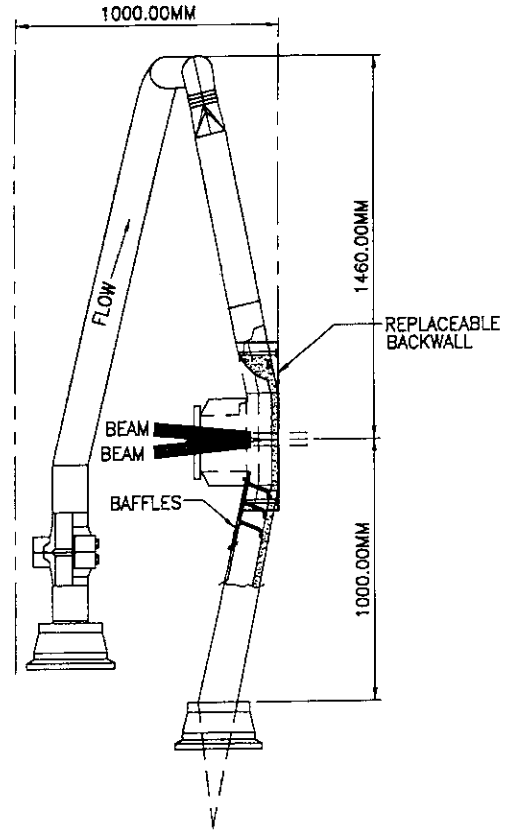
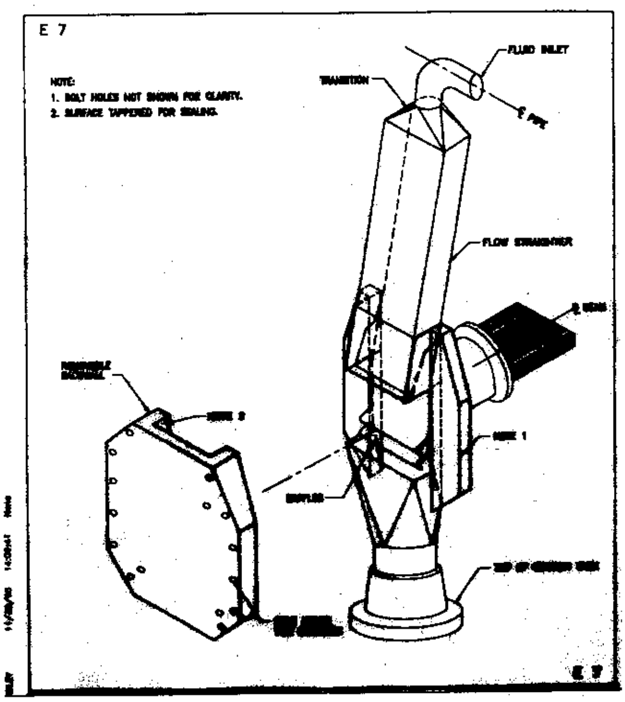


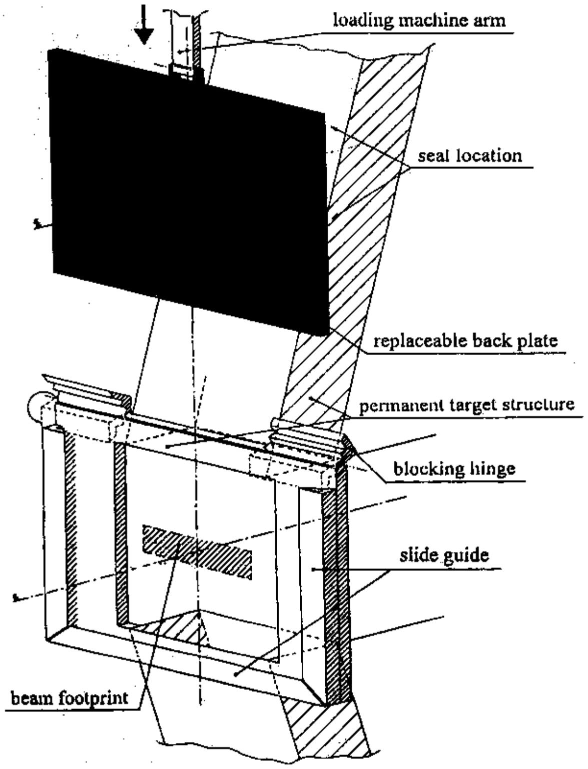
Fig.1 Flow Diagram of Lithium Loop System

Target Assembly

- **Replaceable Backwall Design**
  - **- Reference bolted design**
  - **- Bayonet connection design option (no bolts)**
  - **- Welding and cutting for sealing of backwall**
- **Nuclear Heating**
  - **- Heat generation in target chamber HEBT is about 1.5 kW. Requires active cooling by a small Li stream (15 cc/s)**
  - **- Peak decay heat at backwall ~ 1.5 w/cc, total decay heat in backwall ~ 65 watts, long decay time. Thermal analysis for backwall is needed**







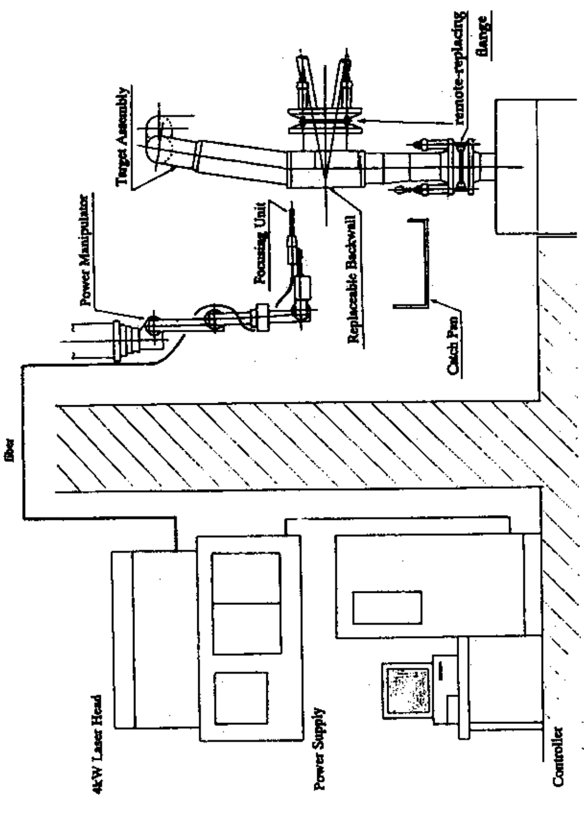


Fig. -1. Schematic of the YAG Laser Processing System

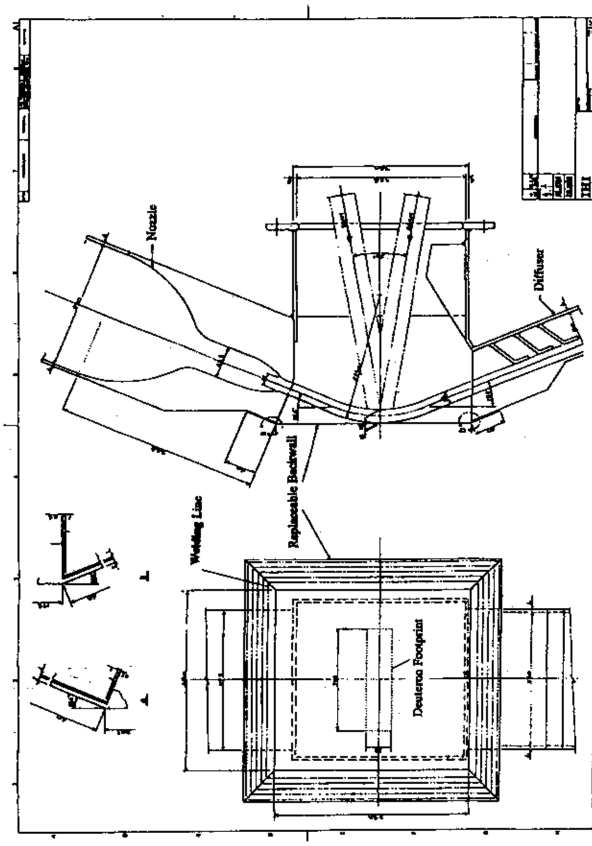
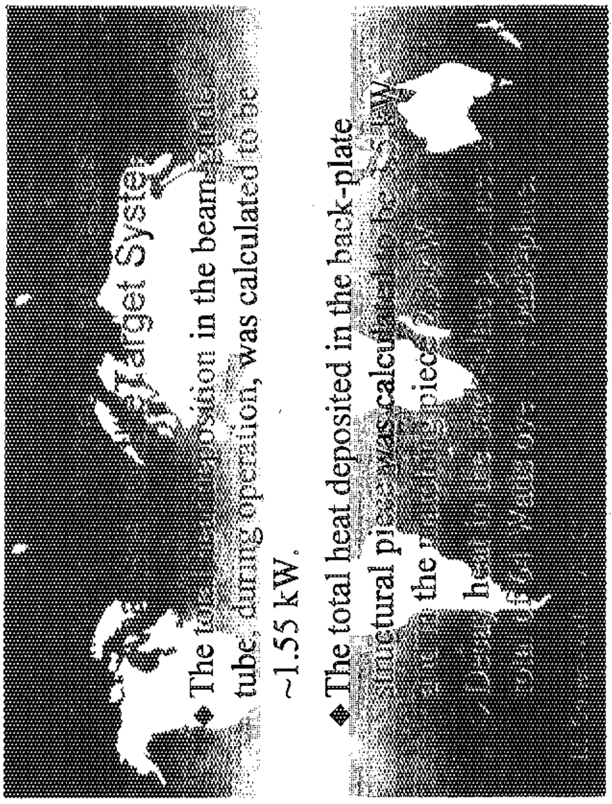


Fig. -2. Replaceable Backwall fixed by Welding



Safety Considerations for Li Cell Environment

Options for cell environment include:

- Dry air
  - Low cost
  - Li fire concern which would result in release of Li aerosol containing tritium
- Nitrogen
  - Higher cost
  - Limited personnel access
- Dry air/Argon gas
  - Box major tritium containing components such as dump tank and fill box with Ar
  - Dry air in rest of lithium cell

Summary of Cost Estimate Issues for the Target Facility

. US costed the main loop, primary and secondary heat removal loops, and impurity monitoring system

. Japan costed almost all items in the WBS, including the target assembly, lithium loops, remote handling, ventillation, project management, control systems, etc.

. Differences in the US and Japanese costs were identified and resolved:

- Nuclear vs non-nuclear grade components
- Materials costs higher in Japan
- Construction practices in Japan

. Nuclear grade components are considered necessary because of Japanese regulatory requirements for all lithium containing parts of the loop, which has a significant cost impact

. EU costs will be produced in the near future for comparison

Engineering Validation Activities for Target Facility

- Three Major Activities Have Been Identified:

(1) Target Assembly
  - Review and selection of replaceable backwall design options, nozzle, and diffuser
  - Screening tests with water
  - Performance validation tests of prototype with Li in vacuum

(2) Lithium Impurity Monitoring and Control
  - On-line meters development
  - Hot and cold traps

(3) Lithium Safety
  - Research existing data and assess their applicability to IFMIF conditions
  - Conduct additional experiments as needed

- Potential Test Facilities For Each Activity Are Identified. Preliminary Estimated Cost and Schedule Have Been Discussed

Potential Test Facilities and Loops for Target System

Facility	Location/ Country	Purpose	Availability for EVP	Remarks
ALEX	ANL/ U.S.	Li tests of target prototype, instru. development	Oct. 96	Being used for LM MHD study. Requires modifications of facility
JWLT	JAERI/ Japan	Water screening tests	Immed.	Concept selection, benchmark codes
WSTC	Westingh/ U.S.	Impurity monitor-ing, traps devlp	Oct. 96	Small loop, requires modifications
LIFUS4	ENEA/ Italy	Impurity monitor-ing, traps devlp	Immed.	Small loop, requires modifications
DINA	ENEA/ Italy	Li reactions characterization	June 98	Being used for Na safety program, minor modifications req'd

Collaborations for EVP Tasks

- The Target group strongly agrees that collaboration is essential to the success of the EVP tasks
  - Resources and expertise optimized
  - Duplication should be avoided
- Possible forms of collaboration:
  - Joint design of facility
  - Joint planning/ execution of experiments
  - Exchange of personnel
  - Contribution of hardware such as fabrication of test section
- Host institute of a test facility will have primary responsibility to provide a safe and operating test facility. Aspects related to testing may be shared by all parties

Cost Estimate for Target Facility EVP Activities

Activity	Ave Cost/yr ($K)	# of years	Total
Target Assembly			
- Water Tests	600	3	1,800
- Li Tests	1,020	4	4,080
Impurity Monitoring & Control	800	3	2,400
Li Safety	220	3	660
		Total	8,940

Total cost for each activity includes design, analysis, construction, operation and testing

IFMIF Design Integration Meeting May 1996 JAERI, Japan

Test Facilities - Cost Estimate

- Practically all elements of the present WBS are included
- Cost estimates are available down to level 4 of the WBS (only one exception)
- More than 150 pages (worksheets) were prepared. Input came from
  - ORNL
  - FZK (Institute of Materials Research, Hot Cells, Tritium Laboratory)
  - German Industry
  - JAERI
  - ENEA
- Quality of estimate: The estimate should be credible because
  - Practically all completely individual devices and modules are estimated in detail
  - Other expensive components could be estimated from existing facilities.

IFMIF Design Integration Meeting May 1996 JAERI, Japan

Test Facility Design - Update of Technical Issues

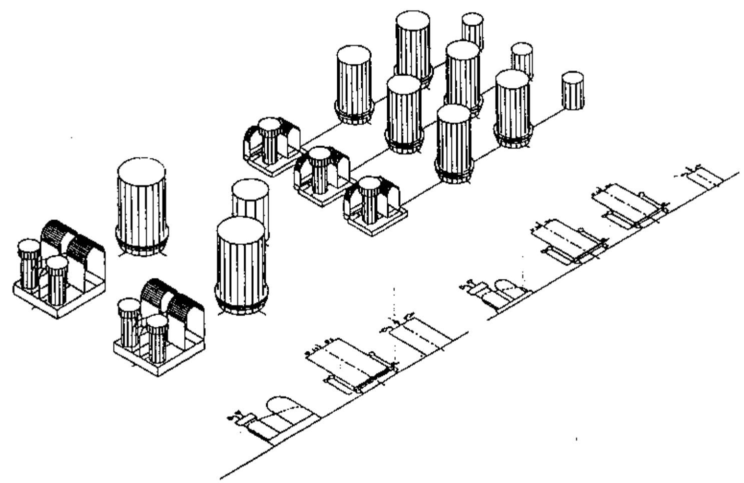
Test Cell:
- Complete design concepts are available
- 3 VTAs are sufficient for the 4 flux regimes (simplifies design, saves costs
- Feasibility study for medium flux regime: 2 test modules on 1 VTS?
- Important to note: The present baseline design meets all essential requirements of the users community

All Hot Cells: Designs are available for all major structures and components

Tritium Laboratory: Detailed design concept from JAERI is available
However, the cost estimate completely governs the Test Facility costs

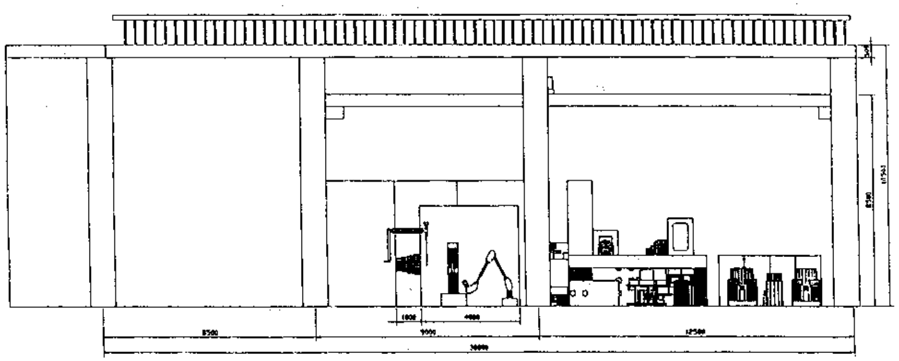
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Bird's view of Tritium removal equipments



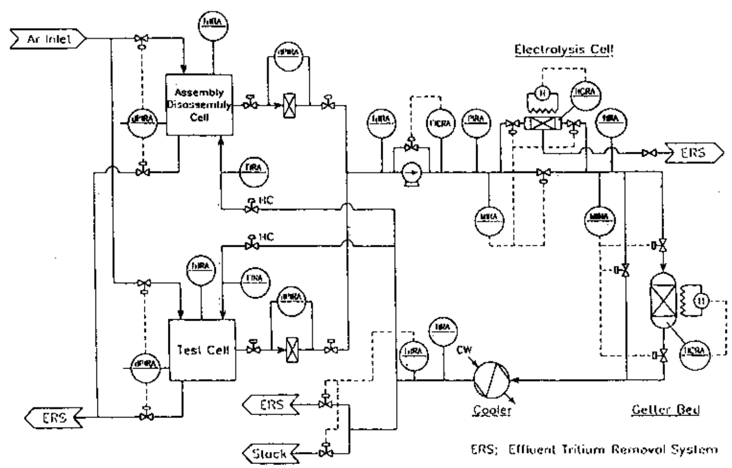
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Elevation View of Tritium Laboratory



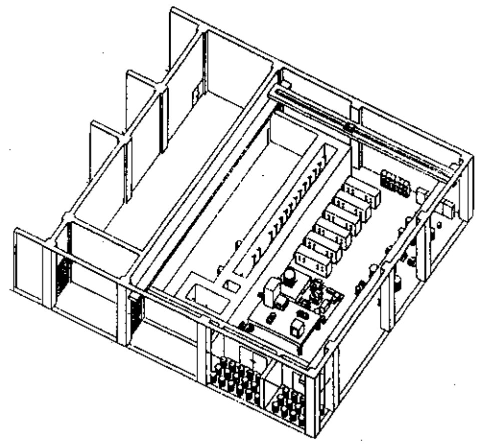
IFMIF Design Integration Meeting May 1996, JAERI, Japan

IFMIF Detritiation System Flow-Diagaram



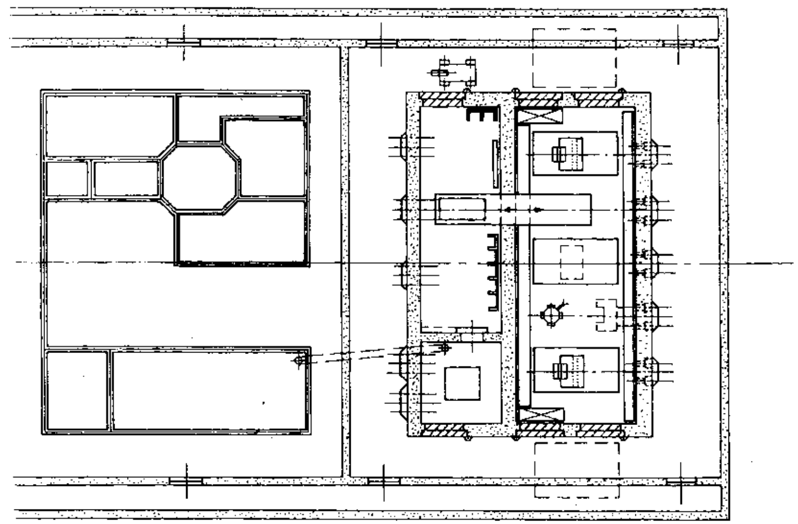
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Bird's view of Tritium Laboratory



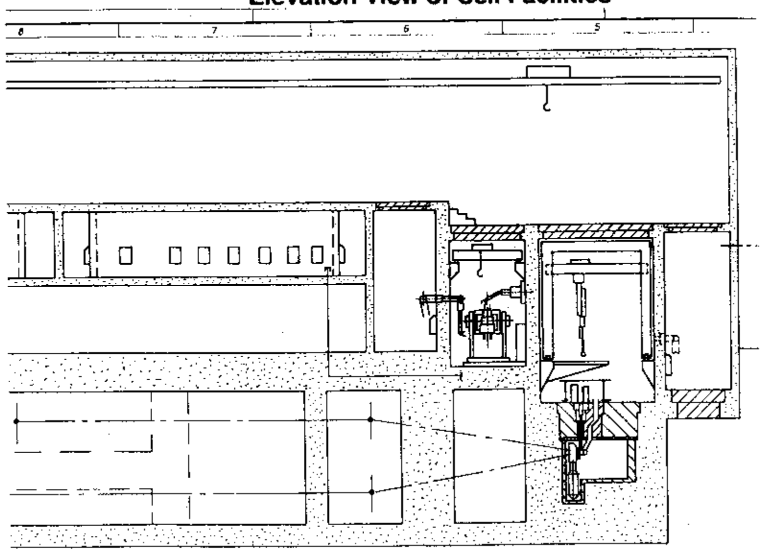
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Plan View of Cell Facilities



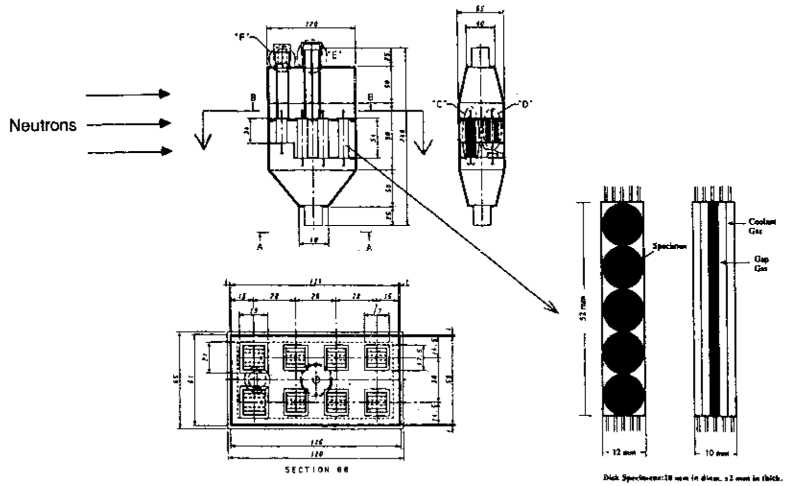
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Elevation View of Cell Facilities



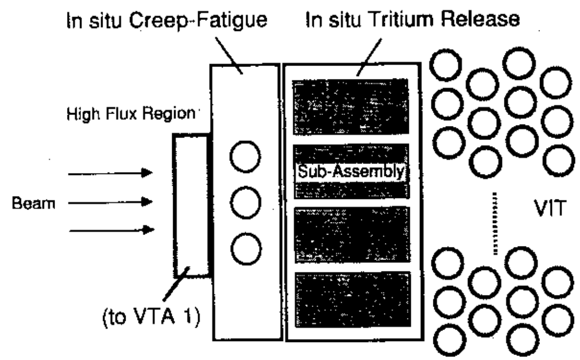
IFMIF Design Integration Meeting May 1996, JAERI, Japan

Sub-assembly of the In situ Tritium Release Experiment for VTA 2

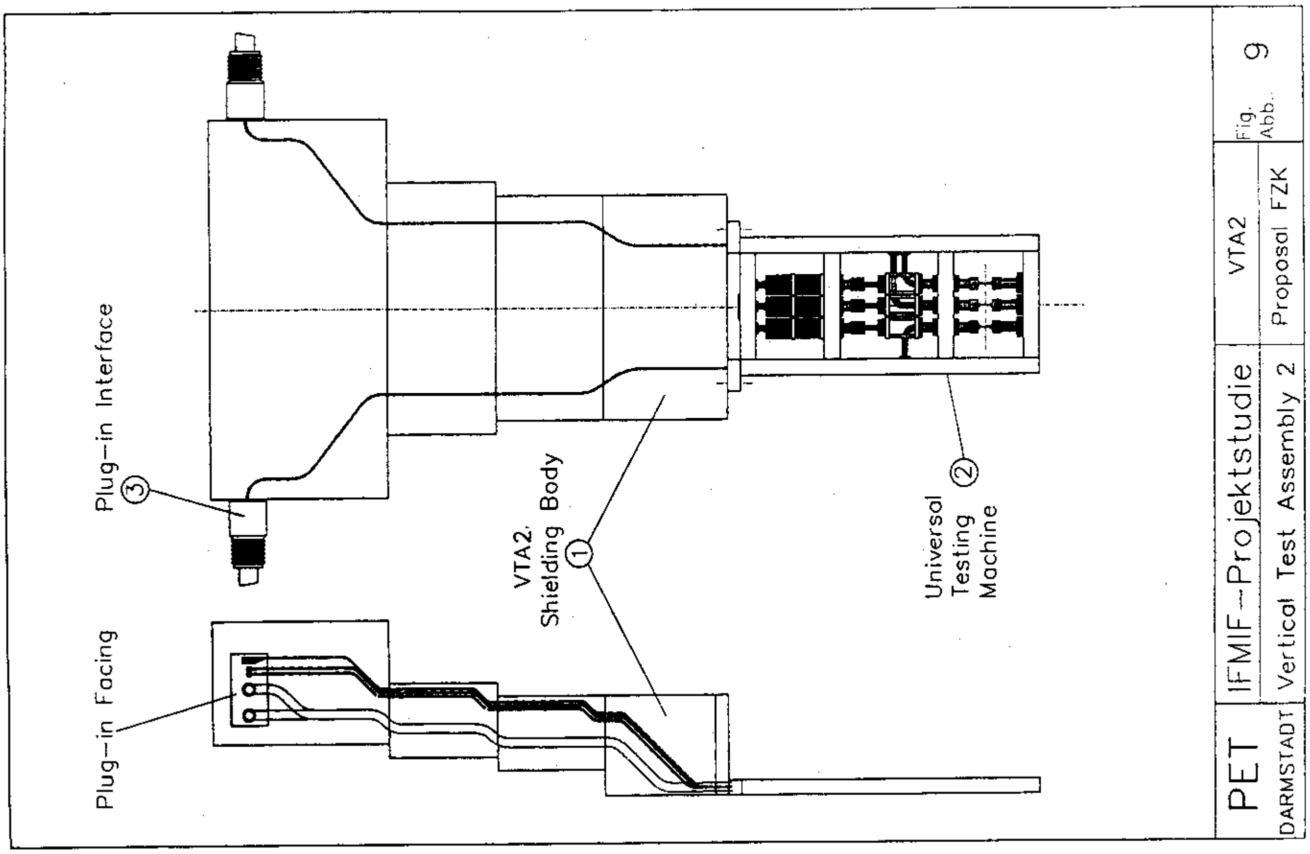


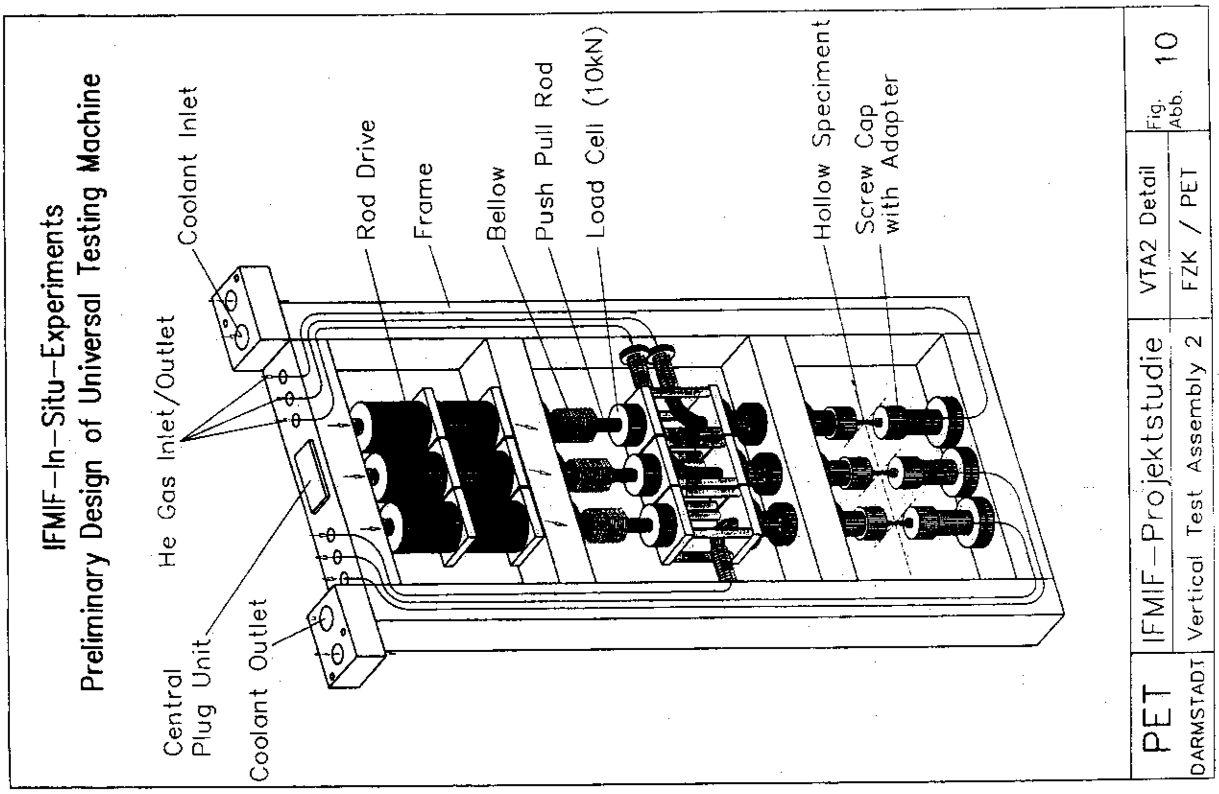
IFMIF Design Integration Meeting May 1996, JAERI, Japan

A Schematical Layout of Sub-assemblies for VTA 2



Sub-Assemblies (VTA 2)


Plug-in Interface
③
Plug-in Facing
VTA2.
Shielding Body
①
Universal
Testing
Machine
②
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 2
VTA2
Proposal FZK
Fig.
Abb.
9

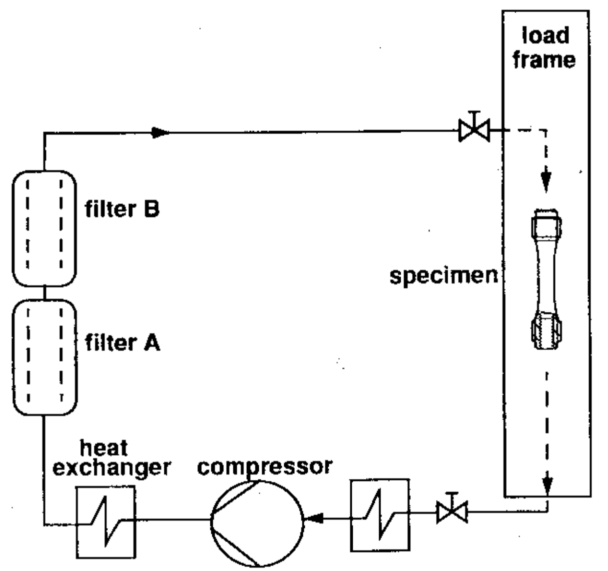

IFMIF-In-Situ-Experiments
Preliminary Design of Universal Testing Machine
Central
Plug Unit
Coolant Outlet
He Gas Inlet/Outlet
Coolant Inlet
Rod Drive
Frame
Bellow
Push Pull Rod
Load Cell (10kN)
Hollow Speciment
Screw Cap
with Adapter
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 2
VTA2 Detail
FZK / PET
Fig.
Abb.
10

Helium gas coolant loop

Long-term experience for He-loops operating in neutron and light ion irradiation facilities is available.

According to the proposed in-situ fatigue design, the following lay-out of a He-gas loop was found to be sufficient ($T_{specimen} \geq 250$ °C) for the med-flux region (≤8 dpa/year) of IFMIF downstream the P.I.E. module:

- **He inlet (pressure pipe)** **≤ 2.5 bar_{abs}** **25 °C**
- **He outlet (suction pipe)** **≥ 1.5 bar_{abs}** **≤35 °C***
- **He pressure drop (specimen & rods)** **≤0.9 bar**
- **He-gas throughput** **12×10^{-3} kg/s**
- **Compressor size** **240 m^3/h** **25 kW**
- **He-gas purity (C, N, O)** **≤ 0.1 appm**



* at specimen outlet

Volume considerations

Typical volume fractions within the rigs:

	A	B	C
Helium for gas gaps	23%	26%	36%
rig and capsule	35%	37%	38%
specimens	42%	37%	26%

Because both the rigs and capsules will likely consist of materials very similar to the specimens itself, the following volume fractions for the neutron scattering can beused:

A:	77% structural material	23% void
B:	74% structural material	26% void
C:	64% structural material	36% void

Volume fractions within the high flux volume:

8 rigs for A :	39% of total vessel volume
8 rigs for B:	14% of total vessel volume
8 rigs for C:	12% of total vessel volume
Vessel structure:	10% of total vessel volume
He gas coolant:	25% of total vessel volume

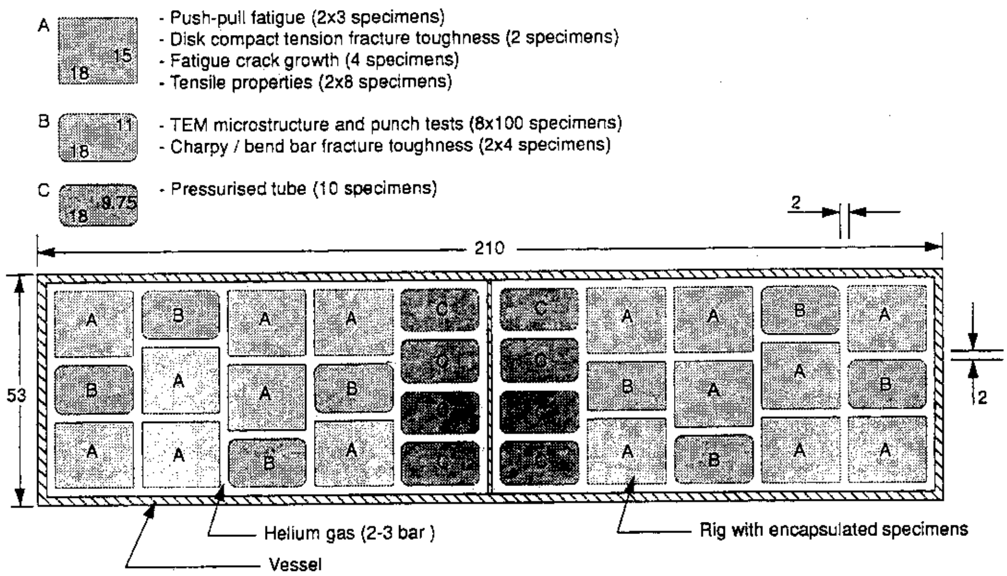
Therefore, the following averaged volume fractions can be considered as typical for the high flux test module:

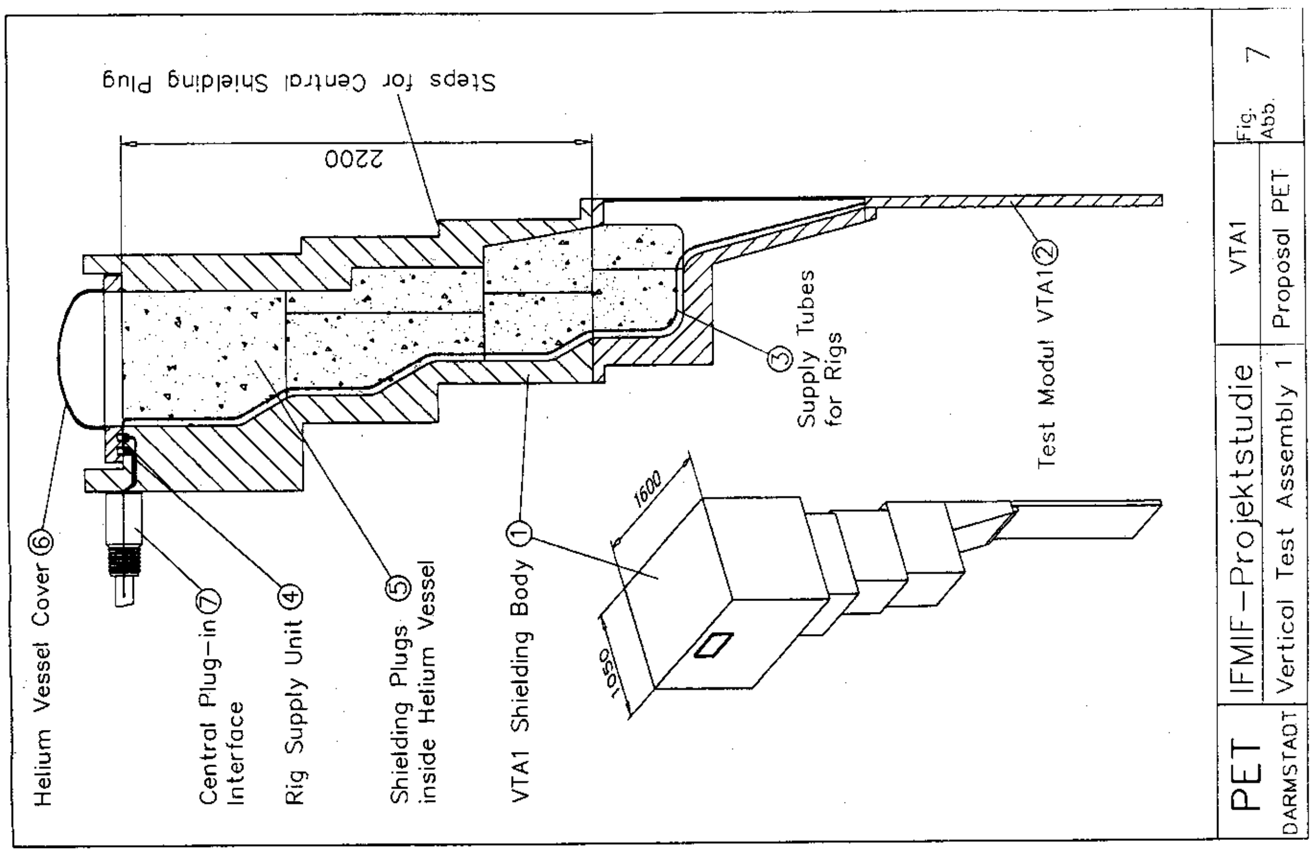
	Volume fraction
He-gas (coolant and gas gaps)	42 %
Material (specimens, rigs, capsules, vessel)	58 %

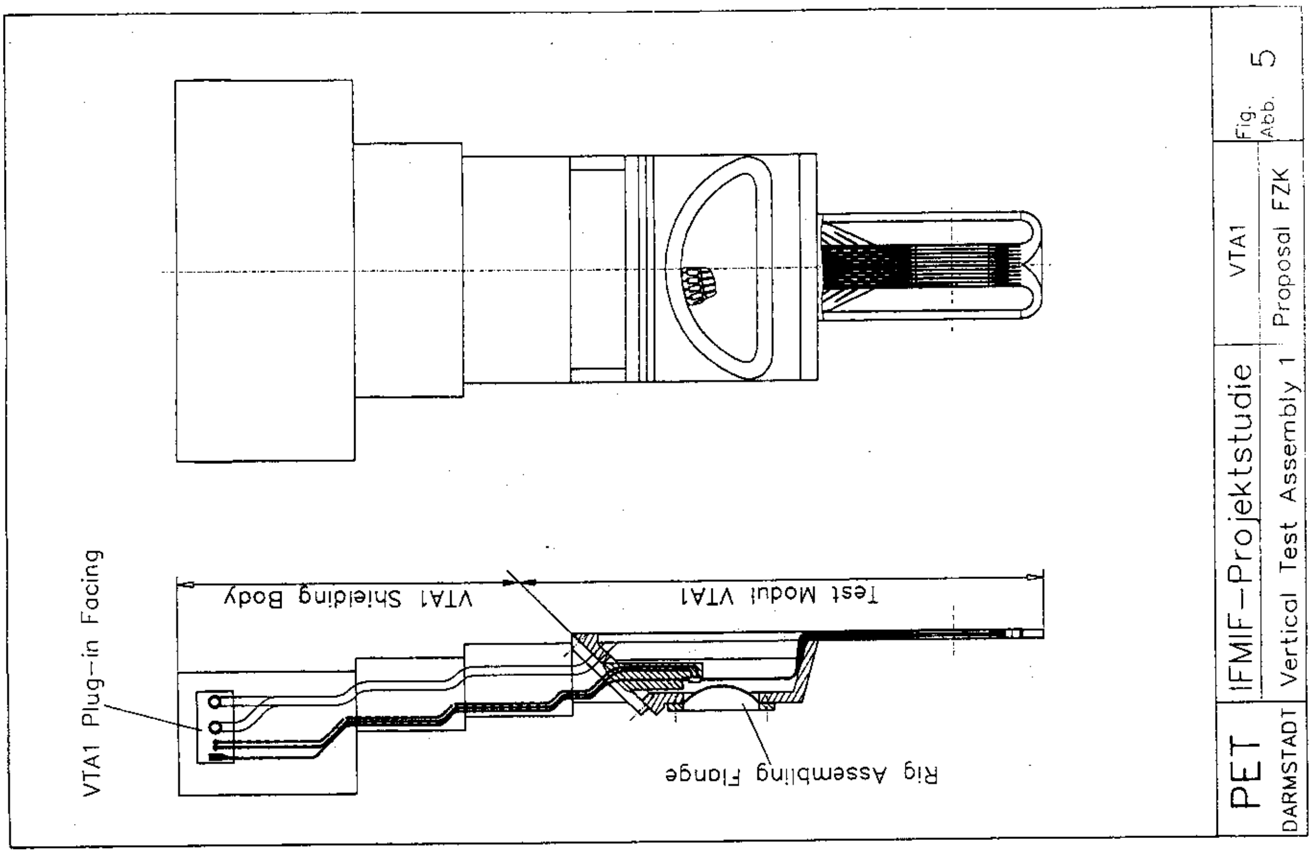
Forschungszentrum Karlsruhe
Technik und Umwelt

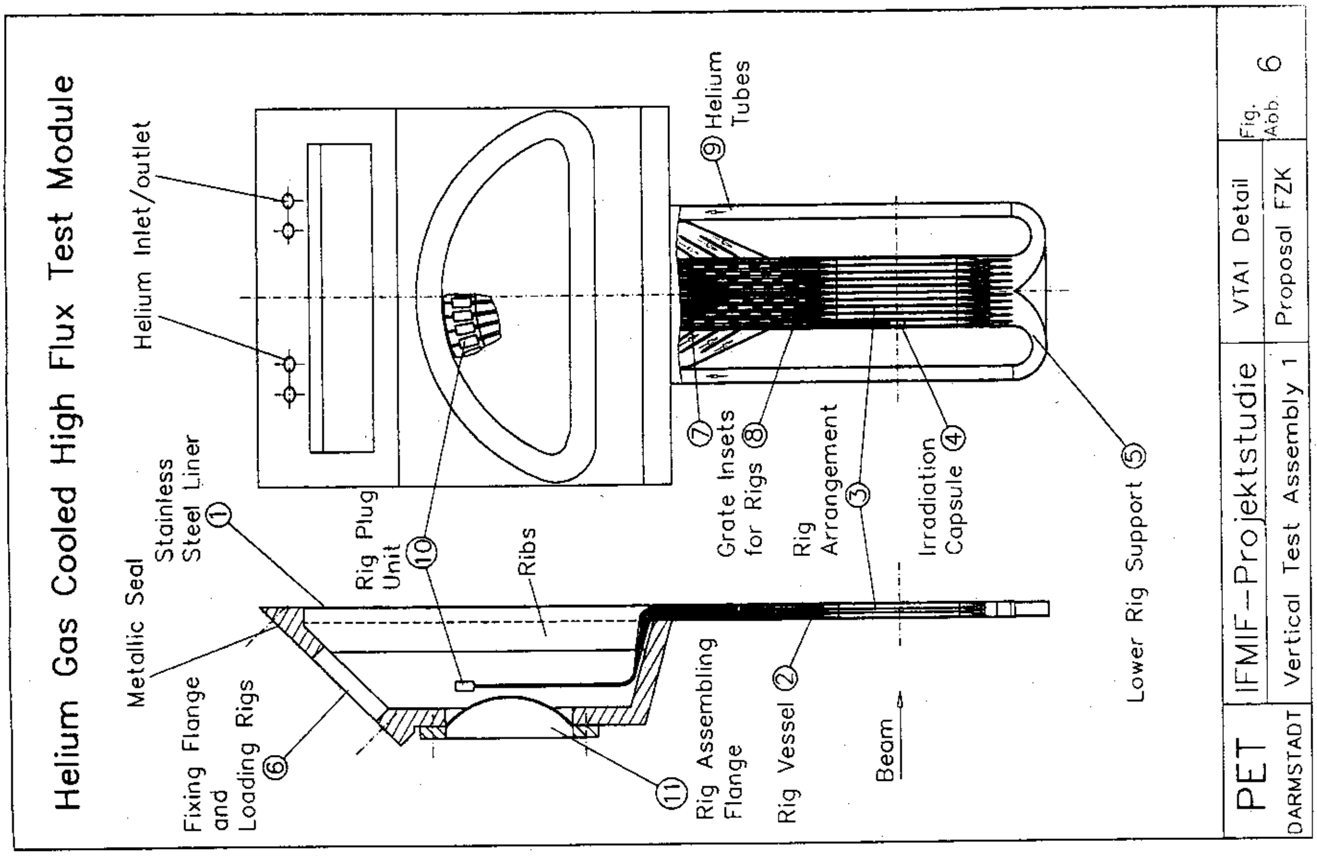
A.M. 04. 1996

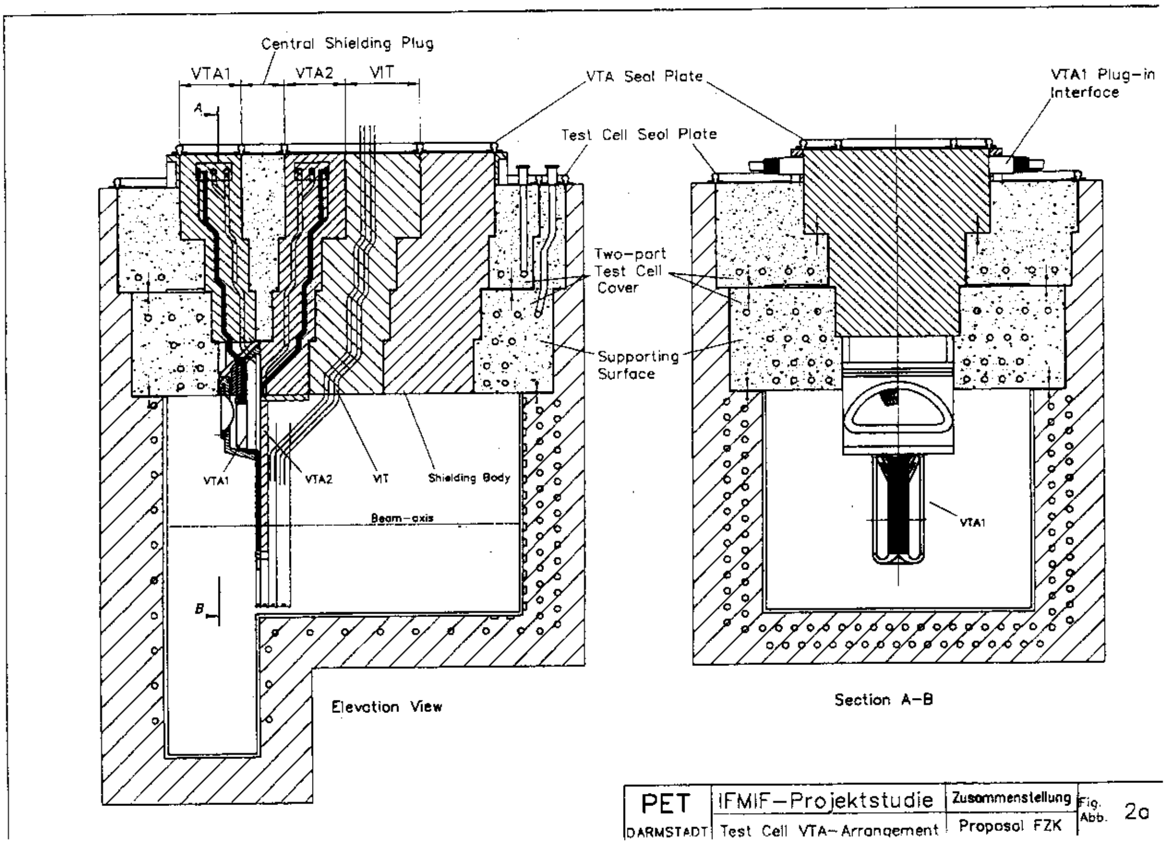
Cross section of helium gas cooled high flux test module - DRAFT -

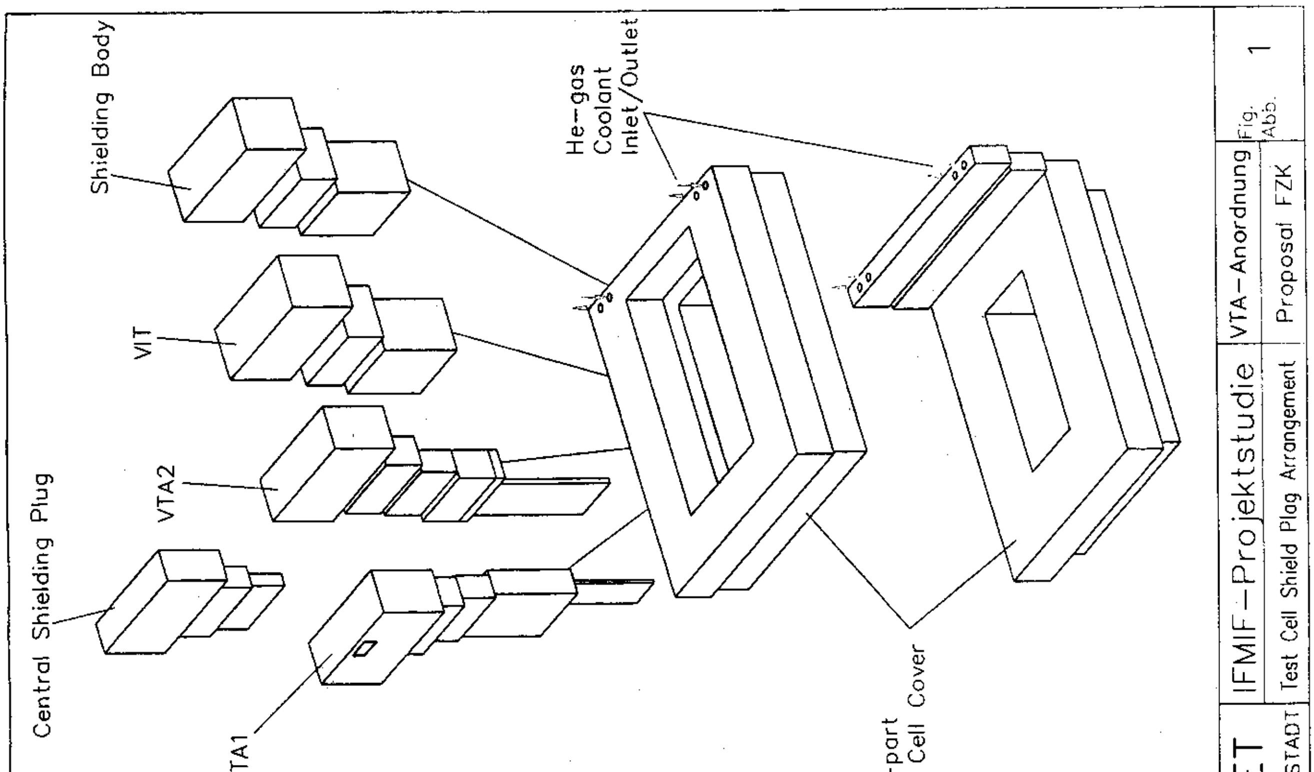





VTA1 Plug-in Facing
VTA1 Shielding Body
Test Modul VTA1
Rig Assembling Flange
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1
Proposal FZK
Fig.
Abb.
5


Helium Gas Cooled High Flux Test Module
Helium Inlet/outlet
Stainless Steel Liner ①
Metallic Seal
Fixing Flange and Loading Rigs ⑥
Rig Plug Unit ⑩
Ribs
⑪ Rig Assembling Flange
Rig Vessel ②
Beam
⑨ Helium Tubes
⑦
Grate Insets for Rigs ⑧
Rig Arrangement ③
Irradiation Capsule ④
Lower Rig Support ⑤
PET
DARMSTADT
IFMIF-Projektstudie
Vertical Test Assembly 1
VTA1 Detail
Proposal FZK
Fig.
Abb.
6


Central Shielding Plug
VTA1
VTA2
VIT
VTA Seal Plate
VTA1 Plug-in Interface
Test Cell Seal Plate
Two-part Test Cell Cover
Supporting Surface
Shielding Body
Beam-axis
Elevation View
Section A-B
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell VTA-Arrangement
Zusammenstellung
Proposal FZK
Fig.
Abb.
2a


Shielding Body
VIT
VTA2
Central Shielding Plug
VTA1
He-gas Coolant Inlet/Outlet
Two-part Test Cell Cover
PET
DARMSTADT
IFMIF-Projektstudie
Test Cell Shield Plag Arrangement
VTA-Anordnung
Proposal FZK
Fig.
Abb.
1

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Shielding Plug Arrangement (ORNL)

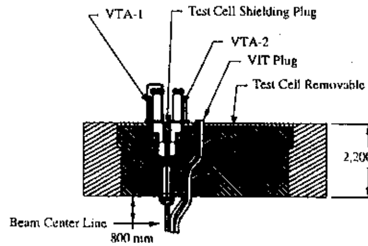


Figure OF Test Cell Shielding Plug Arrangement

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Vertical Irradiation Tube Plug VIT (ORNL)

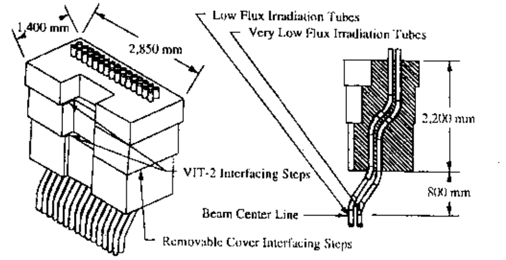


Figure Of The Vertical Irradiation Tube Plug

IFMIF Design Integration Meeting May 1996, JAERI, Japan

NaK Controlled Vertical Test Assemblies VTA-1 and VTA-2 (ORNL)

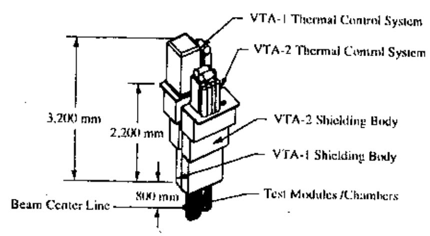


Figure Of NaK Thermally Controled Vertical Test Assemblies VTA-1 and VTA-2

IFMIF Design Integration Meeting May 1996, JAERI, Japan

Test Cell Liner and Heat Shield (ORNL)

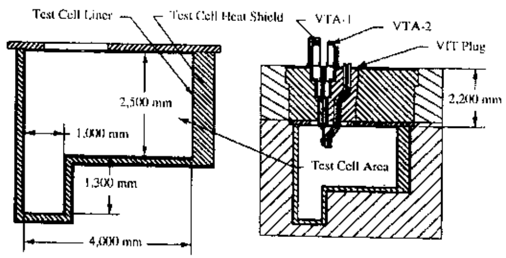
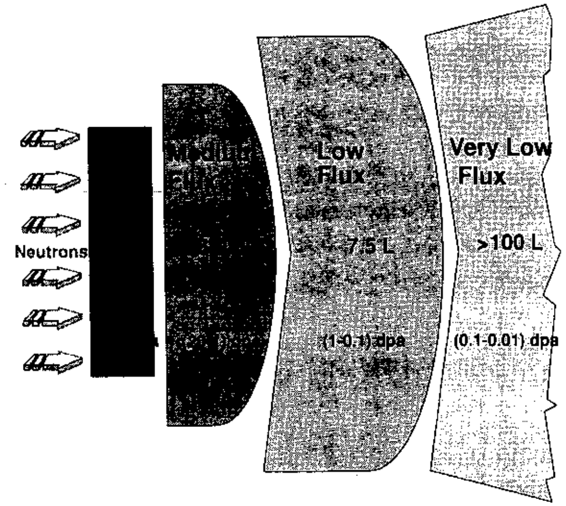


Figure Of Test Cell Liner And Heat Shield

International Fusion Materials Irradiation Facility IFMIF

Test Cell Zones



Associazione EURATOM ENEA sulla Fusione ENEA

1

IFMIF Design Integration Meeting May 1996 JAERI, Japan

TEST CELL GROUP REPORT

Presented by Anton Möslang

- Test Cell Design Progress: Review and update of technical issues
- Cost Estimation: General statements
- Proposal for Engineering Validation Phase

Associazione EURATOM ENEA sulla Fusione ENEA

2

4th IFMIF-CDA Executive Subcommittee Meeting May 1996, Tokai

Conventional Facility Group Report

Presented by

M. Martone

DI Meeting. Tokai, May 1996

Contents

- Outline of the System
- Significant Changes since IFMIF Interim Report
- Major Issues
- Comments on Cost Estimate

• Remaining Work of CDA

Associazione EURATOM ENEA sulla Fusione

DI Meeting, Tokai, May 199

3

• Plant Services

Power System
Heating Ventilation and Air Conditioning System
Heat Rejection System

Associazione EURATOM ENEA sulla Fusione

DI Meeting, Tokai, May 1996

4

Conventional Facilities

• Buildings

Accelerator Complex
Target Complex
Test and Examination Complex
Support Facilities Buildings

and cranes

• Addition of an High Bay with a bridge crane for simplifying maintenance

• Cells for only one Li-loop

Associazione EURATOM ENEA sulla Fusione

DI Meeting, Tokay, May 1996

5

Significant Changes since IFMIF Interim Report

• Accelerator closer together but longer (+10 m), feeded trough a central pipe chase

• Accelerator components removal through shaft

• Identification of the functions of Ventilation System and Gas Effluent Treatment System.

- Identified the function for the former
- Assigned to a Japanese Expert the analysis of the latter

Associazione EURATOM ENEA sulla Fusione

DI Meeting,Tokai, May 1996

6

Major Issues

Comments on Cost Estimate

7

- Costing shared out between US and UE
- No appreciable difference between the cost estimate of buildings
- Japanese cost estimate of buildings appreciably higer (about a factor 3)

Associazione EURATOM ENEA sulla Fusione ENEA

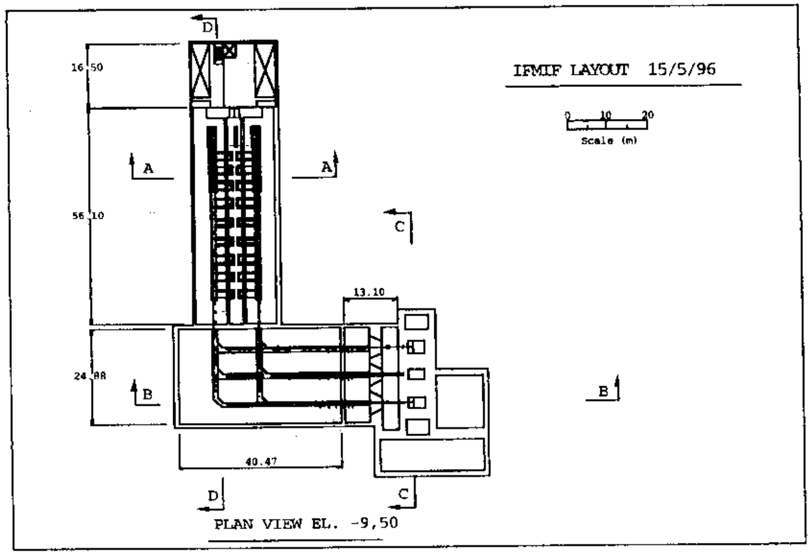
DI Meeting, Tokai, May 1996

8

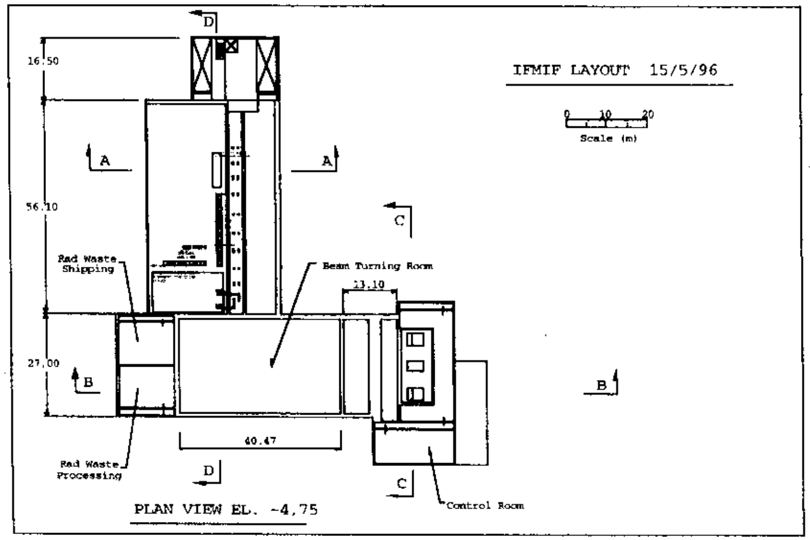
- Updating Building and Service Design and Cost Estimates according to Facility modifications
- Preparation of maintenance analysis for the Plant Services
- More detailed Cost Estimates for expensive systems

Remaining Work of CDA

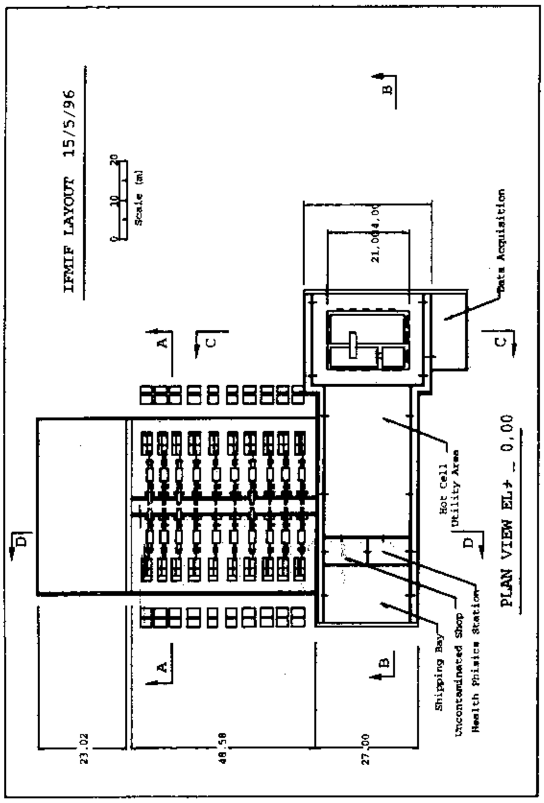
9



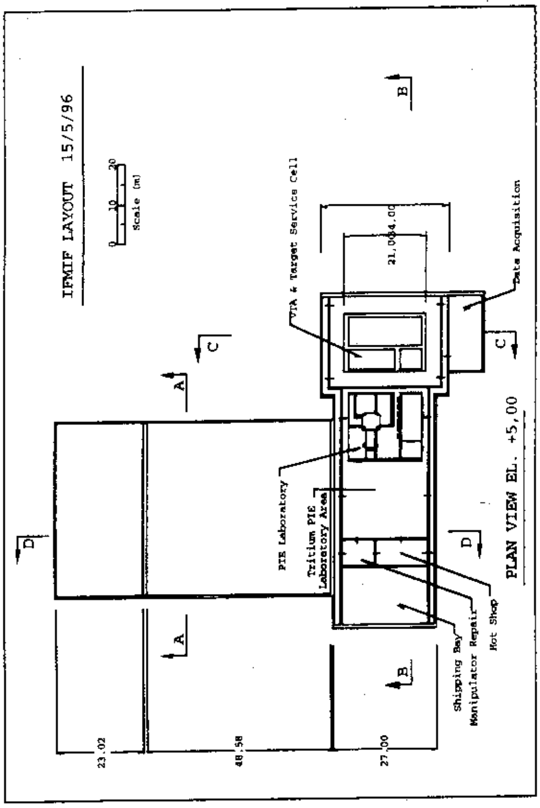
10



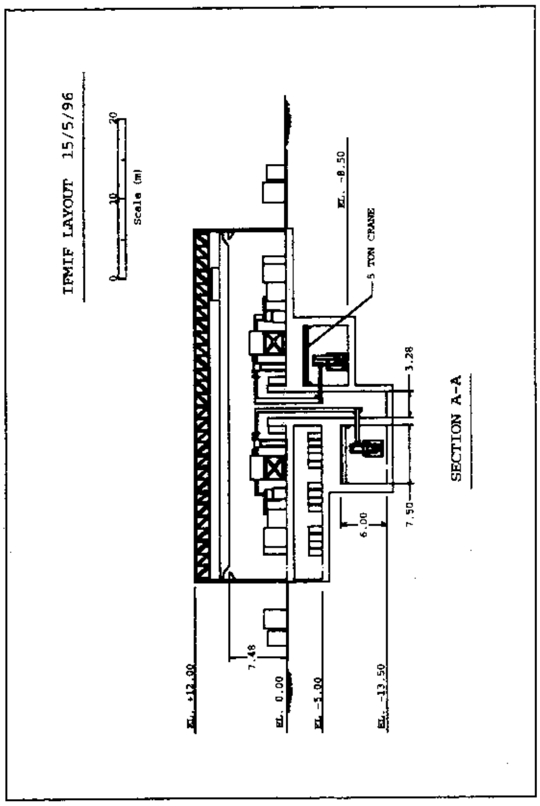
11


IFMIF LAYOUT 15/5/96
Scale (m)
PLAN VIEW EL+ 0,00
Data Acquisition
Hot Cell Utility Area
Shipping Bay
Uncontaminated Shop
Health Phisics Station
23.02
48.58
27.00
21,00
4.00

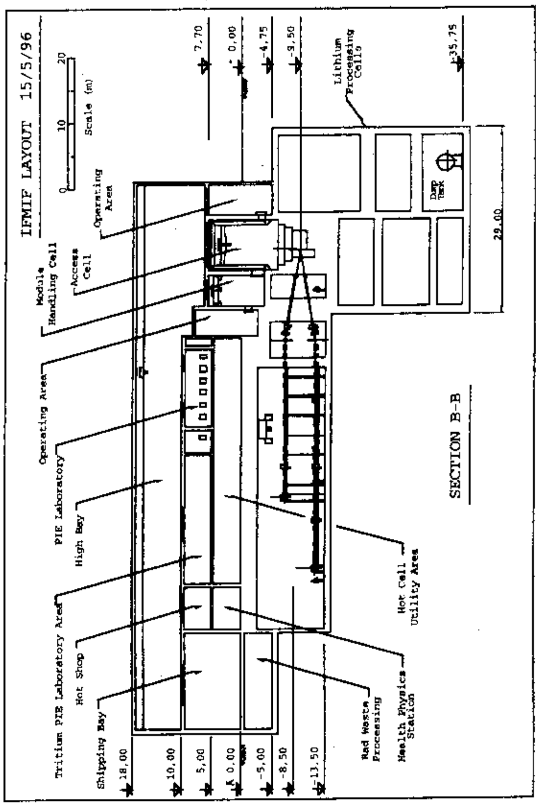
12


IFMIF LAYOUT 15/5/96
Scale (m)
PLAN VIEW EL. +5,00
TTA & Target Service Cell
Data Acquisition
PIE Laboratory
Tritium PIE Laboratory Area
Shipping Bay
Manipulator Repair
Hot Shop
23.02
48.58
27.00
21,00
4.00

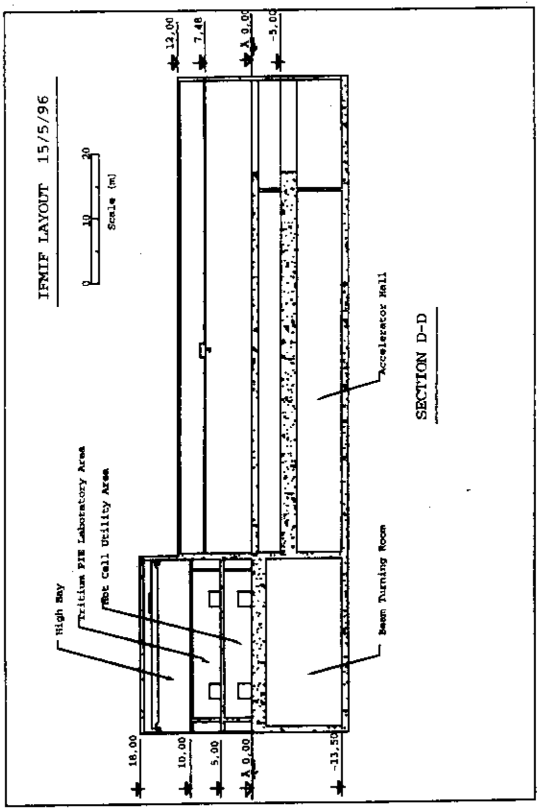
13


IFMIF LAYOUT 15/5/96
Scale (m)
SECTION A-A
5 TON CRANE
EL. -8.50
EL. +12.00
EL. 0.00
EL. -5.00
EL. -13.50
7.48
6.00
7.50
3.28

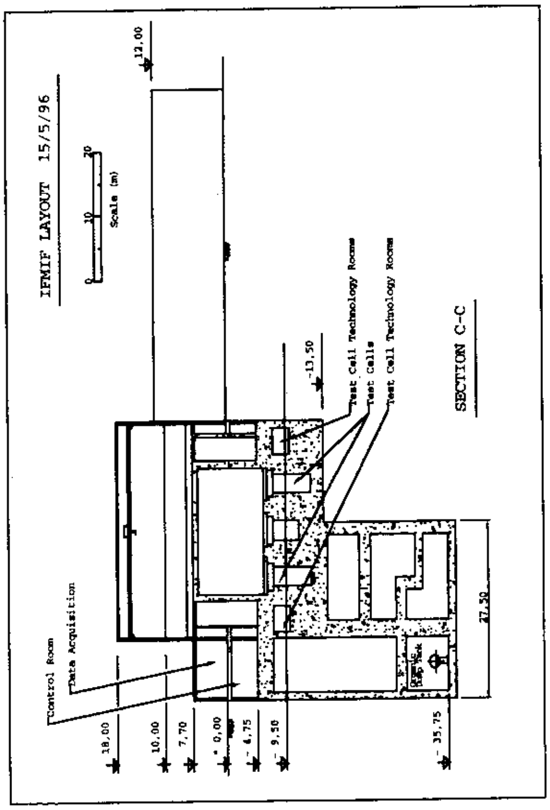
14


IFMIF LAYOUT 15/5/96
Scale (m)
SECTION B-B
Lithium Processing Cells
Dump Tank
Operating Area
Access Cell
Module Handling Cell
Operating Area
PIE Laboratory
High Bay
Tritium PIE Laboratory Area
Hot Shop
Shipping Bay
Rad Waste Processing
Health Physics Station
Hot Cell Utility Area
29.00
7.70
0.00
-4.75
-9.50
-35.75
18.00
10.00
5.00
0.00
-5.00
-8.50
-13.50

16


IFMIF LAYOUT 15/5/96
0 10 20
Scale (m)
High Bay
Tritium PIE Laboratory Area
Hot Cell Utility Area
Beam Turning Room
Accelerator Hall
SECTION D-D
12.00
7.48
0.00
-5.00
18.00
10.00
5.00
0.00
-13.50

15


IFMIF LAYOUT 15/5/96
0 10 20
Scale (m)
Control Room
Data Acquisition
Test Cell Technology Rooms
Test Cells
Test Cell Technology Rooms
SECTION C-C
12.00
-13.50
18.00
10.00
7.70
0.00
-4.75
-9.50
-35.75
27.50

Common Instrumentation & Central Control

Report to 4th IFMIF-CDA Executive Subcommittee

Presented by

MAEKAWA, Hiroshi
Design Integration Group

May 28, 1996
4th IFMIF-CDA Executive Subcommittee
JAERI/Tokai

CI & CC Report to IFMIF-CDA Subcommittee
May 28, 1996, JAERI/Tokai

Outline

- WBS has been modified from the Interim Report, based on the results of Preparation Meeting held at ORNL March 4 - 8, 1996, and on the additional considerations.
- Radiation Monitering System is designed based on the experiences of ENEA and JAERI.
- Safety and Emergency Equipments are includes in Common Instrumentation.
- Interface to the conventional facility has been discussed:
  - space of control room,
  - space for gas sampling devices, etc.,
  - sharing, e.g., cable tray, pipe chase ==> conventional facility
    wiring, piping ==> common instrumentation
- The boundary to the accelerator facility is also discussed.
- Two task are proposed for EVP. 1.14 M-ICF (120 M-Yen)

IFMIF WBS (revised at May 27, 1996)

Level						*Element*
1.	*2.*	*3.*	*4.*	*5.*	*6.*	
6.	**0.**	**0.**	**0.**	**0.**	**0.**	**Common Instrumentation and Central Control Systems**
	1.	**0.**	**0.**	**0.**	**0.**	**System Management**
		1.	**0.**	**0.**	**0.**	**Project Management and Administration**
			1.	0.	0.	Administration
			2.	0.	0.	Cost Control
			3.	0.	0.	Schedule
			4.	0.	0.	Documentation
		2.	**0.**	**0.**	**0.**	**Systems Engineering**
			1.	0.	0.	Design Integration
			2.	0.	0.	Systems Analysis
			3.	0.	0.	Requirements/Specs
			4.	0.	0.	RAM Analysis
		3.	**0.**	**0.**	**0.**	**Environmental, Safety & Health Documentation**
		4.	**0.**	**0.**	**0.**	**Quality Assurance**
	2.	**0.**	**0.**	**0.**	**0.**	**Common Instrumentation Subsystems**
		1.	**0.**	**0.**	**0.**	**Beam Instrumentation**
			1.	0.	0.	On-Target Profile Monitor
		2.	**0.**	**0.**	**0.**	**Radiation Monitoring**
			1.	0.	0.	Radiation Monitor
			2.	0.	0.	Device Controller
		3.	**0.**	**0.**	**0.**	**Video Monitoring**
			1.	0.	0.	ITV Camera (Low Radiation Area)
			2.	0.	0.	ITV Camera (High Radiation Area) - nc -
			3.	0.	0.	Display
			4.	0.	0.	Device Controller
		4.	**0.**	**0.**	**0.**	**Access Control**
			1.	0.	0.	Door Limit Switch
			2.	0.	0.	Keybank
			3.	0.	0.	Warning Light
			5.	0.	0.	Emergency Stop Switch
		5.	**0.**	**0.**	**0.**	**Announciator**
			1.	0.	0.	Speaker
			2.	0.	0.	Device Controller
		6.	**0.**	**0.**	**0.**	**Information Display Stations**
			1.	0.	0.	CATV Network
			2.	0.	0.	Controller
			3.	0.	0.	Display Terminals
		7.	**0.**	**0.**	**0.**	**Safety and Emergency Equipments**
			1.	0.	0.	Oxygen Deficit
			2.	0.	0.	Fire-proof
			3.	0.	0.	Radio Active Gas Leak
	3.	**0.**	**0.**	**0.**	**0.**	**Central Control Subsystems**
		1.	**0.**	**0.**	**0.**	**Central Control**
			1.	0.	0.	Computer System
			2.	0.	0.	Data Storage
			3.	0.	0.	Uninterruptable Power Supply
			4.	0.	0.	Operator Interface _1_
		2.	**0.**	**0.**	**0.**	**LAN**

IFMIF WBS (revised at May 27, 1996)

Level 1.	2.	3.	4.	5.	6.	Element
			1.	0.	0.	Network (Ethernet)
			2.	0.	0.	Substation Interface
			3.	0.	0.	Network Printer
		3.	0.	0.	0.	**Interlock Logic**
			1.	0.	0.	Hardwired Logic
			2.	0.	0.	Logic & Status Display
			3.	0.	0.	Interface for Computer Control
		4.	0.	0.	0.	**Central Display Panel**
			1.	0.	0.	Subsystem Status (150")
			2.	0.	0.	Radiation/Access Status (150")
		5.	0.	0.	0.	**Sequence Synchronizer**
			1.	0.	0.	Timing Data Generator
			2.	0.	0.	Interface for Computer Control
		6.	0.	0.	0.	**Dummy Substation**
			1.	0.	0.	Computer System
			2.	0.	0.	Operator Interface
			3.	0.	0.	Interface for Computer Control
		7.	0.	0.	0.	**Operation and Configuration Control**
			1.	0.	0.	Operation and Configuration Control Softwares
	4.	0.	0.	0.	0.	**System Installation and Checkout**
		1.	0.	0.	0.	**Installation and Test**
			1.	0.	0.	Common Instrumentation Subsystem
			2.	0.	0.	Central Control Subsystem
			3.	0.	0.	Data Operations
		2.	0.	0.	0.	**System Verification Testing**
			1.	0.	0.	Subsystem Testing
			2.	0.	0.	Facility Services/Interlock Testing
			3.	0.	0.	Integrated System Testing
			4.	0.	0.	Operational Startup
						Total
	5.	0.	0.	0.	0.	**Maintenance**
		1.	0.	0.	0.	**Operational Maintenance**
			1.	0.	0.	Computer System
			2.	0.	0.	Central Control Subsystem
			3.	0.	0.	Data Operations
		2.	0.	0.	0.	**System Update**
			1.	0.	0.	
			2.	0.	0.	
			3.	0.	0.	
						CC Total
						1 m.y

- 2 -

IFMIF Site and Building Health Physics Monitors

Type	Location	Number	Distance*	Remarks
Hand & Foot Monitor	Entarance of Controlled Area	2	15 m	
	Rad Waste Processing	1	30 m	
GM Survey Meter	Entarance of Controlled Area	6		
Dose Meter (γ & β)	Entarance of Controlled Area	6		
Neutron REM Counter	Entarance of Controlled Area	3		
Surface Tritium Survey Meter	Entarance of Controlled Area	3		
Potable Tritium/Gas Monitor	Entarance of Controlled Area	2		
Pocket Dosemeter	Entarance of Controlled Area	25		with alarm
Personnel Glass Dosemeter	Entarance of Controlled Area	100		γ, X, n_{th}
Reader for Glass Dosemeter	Entarance of Controlled Area	1		> 100
Liquid Scintillation Counter	Entarance of Controlled Area	1		Ultra-Low Level
Stack Gas Monitor	Ventilation Stack	1	30** + 40 m	
Stack Dust Monitor	Ventilation Stack	1	30** + 40 m	
Integral Tritium Monitor	Ventilation Stack	1		L.S.C. is needed.
Room Gas Monitor	PIE Laboratory Areas	2	60** + 40 m	
	LI Process Area	1	30** + 40 m	
	Target Acess Rooms	2	30** + 40 m	
Neutron Area Monitor	Control Room	1	20 m	
	Beam Turning Areas	2	60 m	
	Test Cell Technology Rooms	2	30 m	

* Distance between detector head and controller/recorder
** Distanses between sampler head and deterctor, and between detector and controller/recorder

IFMIF Site and Building Health Physics Monitors (continued)

Type	Location	Number	Distance*	Remarks
Gamma Area Monitor	Accelerator Rooms	4	120 m	
	Beam Turning Area	2	60 m	
	RF Power Bay	4	120 m	
	Test Cell Technology Rooms	2	30 m	
	Control Room	2	20 m	
	PIE Laboratory Areas	4	40 m	
	Hot Shop	2	80 m	
	Maniplator Repair	1	80 m	
	Rad Waste Processing	2	50 m	
	Rad Waste Shipping	2	60 m	
Monitoring Post (n & γ)	Outside	2	150 m	for Skyshine
Leak Detector (γ & β)	Organic Loop	1	30 m	

Basic Idea of Common Instrumentation & Central Control
Revised on May 27, 1996 JAERI

Common Instrumentation & Central Control

Introduction

Purpose of this document is to specify the boundary of "Common Instrumentation & Central Control" from the other systems such as accelerator system. The following idea is base on the Section 2.8.2 of IFMIF-CDA Interim Report.

Common/Central Instrumentation

Based on the Section 2.8.2 of IFMIF-CDA Interim Report, the following devices are selected as the common/central instrumentation. The selection principle is "the item may not be considered in the other systems".

(1) On-line Neutron Yield Monitor

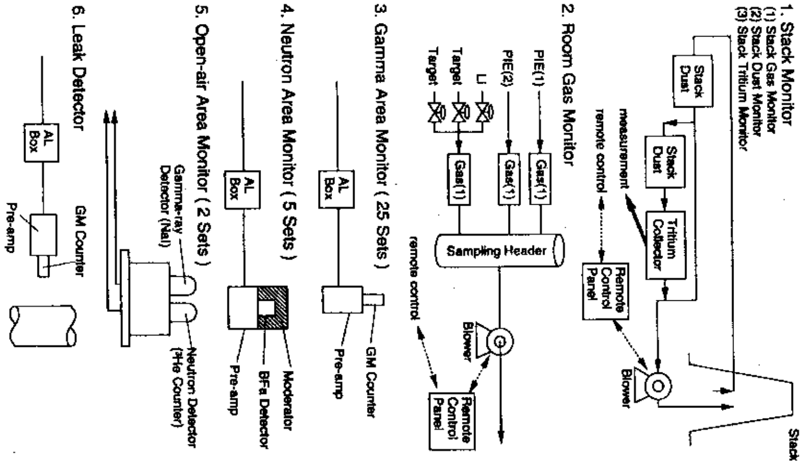
(2) Beam Position/Profile Monitor on the Target
* Neutron Radiography
* Gamma-ray Radiography
* Spot-on-Target Viewing

(3) Monitor for Radiation due to Beam-loss

The following devices would be covered by the other systems:

* Beam Profile Monitor along the beam line ==> Accelerator System
* Neutron Dosimeter ==> Test Cell/User
* Interlock Indicator ==> Central & Each Sub-System

Radiation Monitors for IFMIF



Safety and Emergency Equipments at IFMIF Site and Building

Type	Location	Number	Distance*	Remarks
Oxygen Monitor	Accelerator Rooms Li Process Area Target Acess Rooms	4 2 2	120 m 40 m 40 m	
Fire-proof Protective Clothing	Entarance of Controlled Area	10		fire accident
Self-Contained Breathing Appratus	Entarance of Controlled Area	10		radioactive gas Li accident
Escape Mask for Oxygen Deficit	Each Room to be expected	10		for evacuation
Oxygen Rescue	Entarance of Controlled Area	2		oxygen accident

Central Control System

(1) Basic Concepts

(a) IFMIF control system consists of Central Control System (Main Computer & 2 Support Computers) and 4 (?) Subsystems (Accelerator, Target, Test Cell/Experiment, Conventional Facility , and ?). Coverage of the Central Control System is shown in Fig.1 attached.
(b) In normal operation phase, Central Control distributes request for states (e.g., STANDBY, READY and RUN) to Sub-Systems and gather status and diagnostics of Sub-Systems.
(c) Sub-Systems should have predefined functions and sequences corresponding to the requested state. In normal operation phase, Sub-Systems should execute these operations synchronously according to timing signal.
(d) Control parameters in Sub-Systems should also be controllable by Central Control.
(e) Communications via LAN
 * down-load instrumentation of Sub-Systems
 * set point control
 * gather and store status and diagnostics of Sub-Systems and beam (period : TBD)
(f) Central Control provides hardwired logic fast protect function to shut down deuteron beam and Sub-Systems.
(g) Central Control accepts only a few important interlock signals from Sub-Systems, such as "Stop Beam!" Namely, all Sub-System have own interlock logic.
(h) Interlock logic in Central Control serves Interlock signals to Target Control and Test Cell/Expr. Control according to the condition of Facility Service
(i) Central Control provide timing signals for controlling, synchronized operations and data acquisition sequence

(2) Central Control System Including

(a) central computer
 * system monitoring,
 * network communication,
 * set point control,
 * data base management,
 * data storage to hard disk
(b) support computer
 * data base processing
 * status display on graphic display
 * report generation
 * software development
 * data logging to mass storage (MO, etc.)
 * back-up central computer

(c) interlock logic
 * personal access safety logic ... limiting area access
 * plant interlock logic... according to facility condition(vacuum, coolant, etc.)
 * fast beam interrupt logic
  fast beam shut down for conditions of beam and all subsystems

(d) timing signal control

(e) local area network
 * Ethernet TCP/IP network, Fiber-optic network, etc.

(f) graphic display (status display)
 * large screen high resolution display and/or LED illuminated display

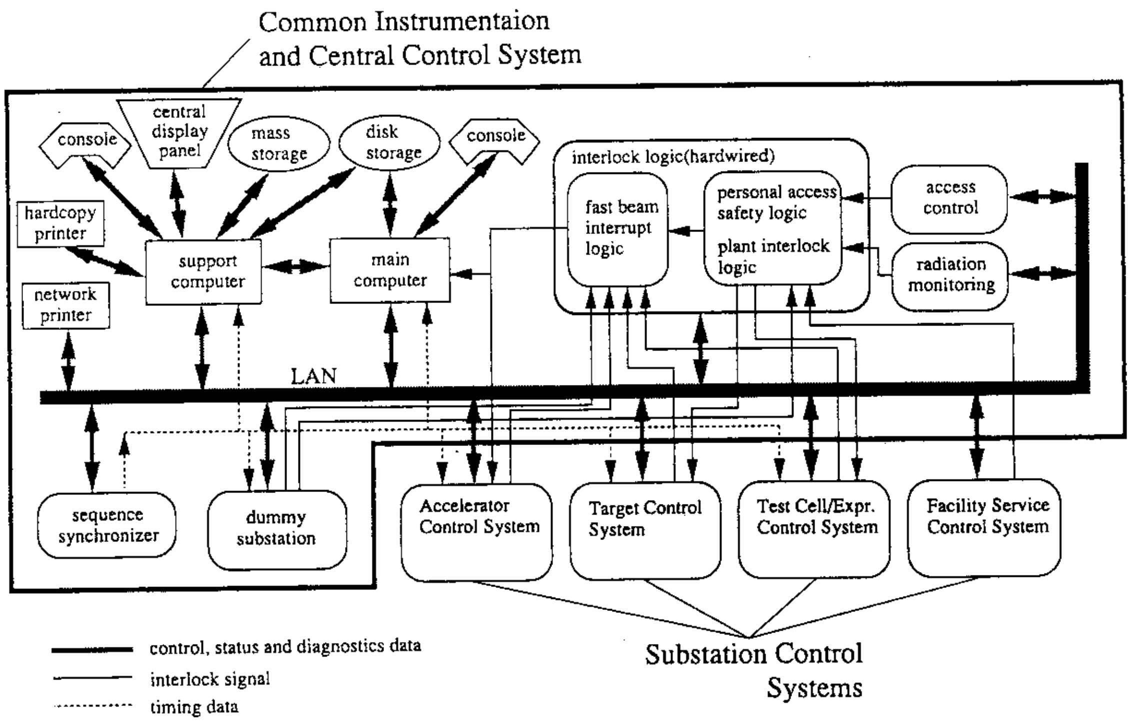
(g) software
 * operating system (UNIX, etc.)
 * control and data acquisition software (EPICS, etc.)
 * high level language and compiler (FORTRAN, C++, etc.)
 * network communications and control software
 * analysis and presentation application

(3) requirements

(a) for control and data acquisition software
 * functions
  device control
  set point control
  system monitoring
  data storage
 *perator interface
  status display
  report generation
  data base management,
  data base processing
 * minimize development
 * "turn-key" contact with a commercial vendor and/or easy to customize

(b) for subsystems
 * control parameters in subsystems should be controllable by central control
 * status and diagnostics in subsystems should be accessible by central control
 * provide predefined sequences and functions corresponding to states requested by central control (state: STANDBY, READY and RUN)

(c) for component drivers
 * intelligent to accept computer control (VME, VXI, etc.)
 * provide predefined functions corresponding to functions served by central and subsystem control



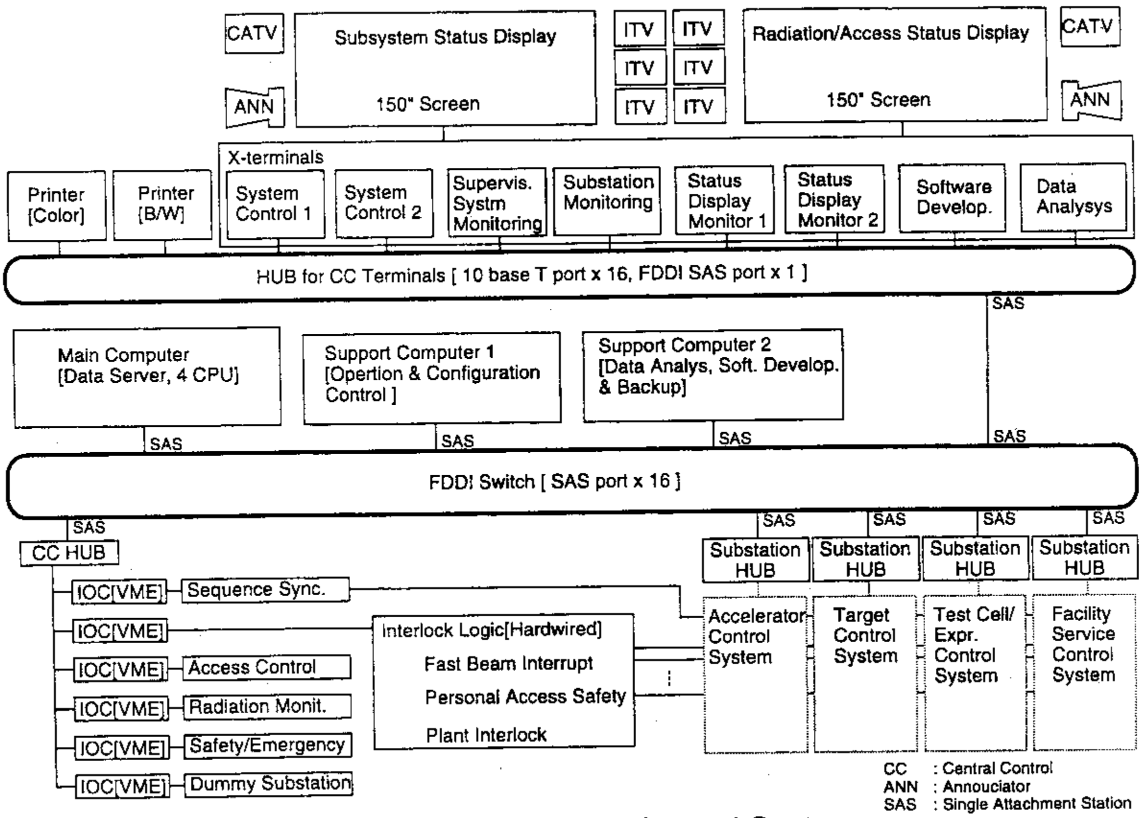


Fig. IFMIF Central Control System