JAERI-Conf
95-019

IFMIF-CDA TECHNICAL WORKSHOP ON LITHIUM TARGET SYSTEM

July 18-21, 1995, JAERI, Tokai, Japan

September 1995

IFMIF-CDA Target Group

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(株)

IFMIF-CDA Technical Workshop on Lithium Target System
July 18-21, 1995, JAERI, Tokai, Japan

IFMIF-CDA Target Group*

Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received August 18, 1995)

An intense neutron source, International Fusion Materials Irradiation Facility (IFMIF) is planned under the collaborative program by International Energy Agency (IEA), and the Conceptual Design Activity (CDA) started in February 1995. US, Japan and EU are responsible to take a lead in coordinating accelerator, target and test cell design, respectively. In order to exchange the current results of the study and to coordinate the activities for the design integration, the first technical workshop on the lithium target system was held in the period of July 18 - 21 at the Tokai Research Establishment of the JAERI. This publication summarizes the materials presented in this meeting. The presentations and discussions were organized with the identified CDA tasks. It was confirmed that the reference design of the IFMIF target based on the previous studies under FMIT and ESNIT, elaborated to meet IFMIF parameters, is reasonable and feasible. It was pointed out that the interface between accelerator and test cell subsystems should be carefully investigated to avoid technical conflicts. Some design options such as nozzle, backwall and lithium jet geometry, lithium purity control, and

* IFMIF-CDA Target Group Members
H. Katsuta (Department of Materials Science and Engineering), Y. Kato (Department of Reactor Engineering), H. Maekawa (Department of Reactor Engineering), S. Konishi (Department of Materials Science and Engineering), H. Nakamura (Department of Reactor Safety Research), M. Ida (Department of Reactor Engineering), K. Noda (Department of Materials Science and Engineering), Y. Hoshi (Ishikawajima Harima Heavy Industry), A. Inoue (Tokyo Institute of Technology), M. Takahashi (Tokyo Institute of Technology), T. Shannon (The University of Tennessee), D. Smith (Argonne National Laboratory), A. Hassanein (Argonne National Laboratory), T. Hua (Argonne National Laboratory), L. Green (Westinghouse Electric), S. Cevolani (ENEA), G. Benamati (ENEA), W. Cherdron (ENEA)

lithium vapor control, based on the current technology were proposed to improve the integral target system function, and further R&D studies were suggested for design integration.

Keywords: Fusion Material, Neutron, Irradiation, Radiation Damage, Lithium, Liquid Target, Hydraulic Analysis, CDA, IFMIF, FMIT, ESNIT

JAERI-Conf 95-019

ＩＦＭＩＦ－ＣＤＡ　Ｌｉ－ターゲットワークショップ報告
1995年７月18～21日、東海研究所、東海村

日本原子力研究所東海研究所
ＩＦＭＩＦ－ＣＤＡターゲットグループ*

（1995年８月18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がＩＥＡ協力で国際核融合材料照射施設（ＩＦＭＩＦ）として計画されており、概念設計活動（ＣＤＡ）が95年２月より行われている。米国、日本、ＥＵはそれぞれ加速器、ターゲット、テストセルについての概念設計のとりまとめに責任を持つ。この流動Ｌｉターゲットシステムに関する第１回の技術会合を95年７月18～21日、原研東海研において開催した。本報告は、この会合において、主要設計課題について、日本、米国、ＥＵの担当者が設計の現状を情報交換するとともに、設計統合へ向けての調整、検討を行なった発表資料をまとめたものである。議題はほぼＣＤＡのタスクに沿って設定された。ＩＦＭＩＦターゲットおよびループ構成の基本設計はＦＭＩＴ、ＥＳＮＩＴに基づくもので、技術的妥当性が確認され、また加速器、テストセルとの整合性に関する問題点が摘出された。ノズル、リチウムジェット形式、バックウォール、純度管理、蒸発制御などについてオプションが提案され、今後Ｒ＆Ｄを通じて設計に反映される。

東海研究所：〒319－11　茨城県那珂郡東海村白方白根２－４
＊ＩＦＭＩＦ－ＣＤＡターゲットグループメンバー
勝田博司（材料研究部）、加藤義夫（原子炉工学部）、前川　洋（原子炉工学部）、小西哲之（材料研究部）、中村秀夫（原子炉安全工学部）、井田瑞穂（原子炉工学部）、野田健治（材料研究部）、星　有一（石川島播磨重工業㈱）、井上　晃（東京工業大学）、高橋　実（東京工業大学）、T. Shannon（テネシー大学）、D. Smith（アルゴンヌ国立研究所）、A. Hassanein（アルゴンヌ国立研究所）、T. Hua（アルゴンヌ国立研究所）、L. Green（ウェスチングハウス）、S. Cevolani（ENEA）、G. Benamati（ENEA）、W. Cherdron（ENEA）

Contents

目　　次

I. Agenda

IFMIF-CDA Li-Target System (Final)
Workshop on July 18 - 21,1995

1st IFMIF-CDA Technical Workshop on Li Target System

July 18 - 21, 1995
Conference Room No. 6 in Research Bld. No. 1
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, 319-11Japan

July 18 (Tuesday)

{The planning meeting for Design Integration Meeting in U. S. will be held parallel with the target workshop in this afternoon }

9:30 **Opening plenary session** Chairman : H. Katsuta

18-1 Welcome address N. Shikazono

18-2 Status of CDA-Activities T. Shannon

18-3 Brief report of the workshop on test cell at FZK K. Noda

18-4 Discussion for this meeting schedule

10:40 Coffee Break (20 min.)

11:00 **Session of the perspective of target system**
(Budget, Collaboration structure etc.) Chairman : T. Shannon

18-5	**EU**	:	S. Cevolani
18-6	**US**	:	D. Smith
18-7	**J P**	:	H. Katsuta

12:00 - 12:40 Lunch (Box lunch at the same room)
12:40 - 13:20 Tour "Water Loop Facility"

13:20 **Session of Discussion(I)** Chairman : Y. Hoshi

18-8 Preliminary analysis for the Li- target (CDA-T-I-1)
•Dynamic and thermodynamic stability of lithium jet T. Hua (US)
•Thermal -hydraulic analysis of lithium jet with incident beam
I. Gomes (A. Hassanein, US)

15:30 Coffee Break (20 min.)

15:50 **Session of Discussion(I) (Continue)**
- •Overview and relation with anather tasks — Y. Kato (JA)
- •Thermal and Fluid dynamics of Li target flow — M. Ida (JA)
- •Thermal hydraulic analysis of the lithium jet — S. Cevolani (EU)

18:20-20:00 **Welcome Party (JAERI Akogi-gaura Club)**

<u>July 19 (Wednesday)</u>

9:10 **Session of Discussion (II)** Chairman : D. Smith

19-1 Preliminary analysis and conceptual design for target assembly (CDA-T-I-1)
- •Neutronics analysis of the lithium target — T. Hua (US)
- •Some comments on the backwall swelling — H. Katsuta (JA)

10:15 Coffee Break (15 min.)

10:30 **Session of Discussion (II)** (Continue)

- •Target assembly design: some parametric evaluations — S. Cevolani (EU)
- •Proposal of the JAERI water loop test and target design — H. Nakamura (JA)
- •Concept design for lithium target assembly — T. Hua/D. Smith (US)

12:00 Lunch (JAERI Akogi-gaura Club)

13:20 **Session of Discussion (III)** Chairman : S. Cevolani

19-2 Preliminary conceptual design for Li loop system layout and its component design (CDA-T-II-1,-2)

- •IFMIF Li system layout and some component proposals — Y. Hoshi (JA)
- •Preliminary conceptual design for Li-loop system layout — L. Green (US)
- •Lithium loop component design and evaluation — L. Green (US)

15:30 Coffee Break (15 min.)

15:45 **Session of Discussion (III)** (Continue)

19-3 Evaluation and specification of Accelerator - Target - Test Cell interface (CDA-T-I-2)

- Lithium vaporization from free surface — A. Hassanein (US)
- Some comments on the lithium vapor pressure control — T. Konishi (JA)
- Investigation of the Li-evaporation rate — W. Cherdron (S. Cevolani) (EU)

17:40 Departure to hotel

July 20 (Thursday)

9:10 **Session of Discussion (IV)** Chairman : Y. Kato

20-1 Li purification system design (CDA-T-II-3)

- System design concept — T. Konishi (JA)
- Proposal of on-line hydrogen isotope detectors and experimental plan — T. Konishi (JA)
- Lithium loop at TIT — A. Inoue (JA)

10:20 Coffee Break (15 min.)

10:35
- Requirements and preliminary design for monitoring and Li chemistry process system — L. Green (US)
- Hydrogen/tritium recovery system — D. Smith (US)

11:40 Tour "Proton Linac Facility"
12:20 Lunch (Box lunch at the same room)

13:00 **Session of Discussion (V)** Chairman : L. Green

20-2 Preliminary safety analyses for the Li-system (CDA-T-V)

- A review of liquid lithium reactivity — G. Benamati (S. Cevolani, EU)
- Liquid metal systems safety requirements — G. Benamati (S. Cevolani, EU)
- Concepts for the chemical hazard and radiological hazard — T. Konishi (JA)

20-3 Design items and schedules of the experimental facilities for IFMIF - EDA (CDA-T-VI)

- Requirements for Li-technology test loop and beam-on target experiment — Y. Kato (JA)
- Requirements for water jet simulation test — T. Hua (US)

15:45 Coffee Break (15 min.)

16:00 **Session of Discussion (VI)**

20-4 Data base for Li and its compounds (CDA-T-VII)

- Lithium data base: Status report — S. Cevolani (EU)
- Review of existing data base on lithium properties — T. Hua (US)

20-5 Identification and prioritizing of major technical issues and problems

- Improvement of the work breakdown structure — H. Katsuta (JA)

17:40 Departure to hotel

July 21 (Friday)

9:10 **Summary Plenary Session** Chairman : D. Smith / H. Katsuta

21-1 Summary Report

- Conceptual design and analysis for the Li target system
- Clarify the each homework items until next meeting
- Design Integration Meeting

21-2 Closing Remarks

11:30 Departure to Hitachi Kamine Hill for "Tea Ceremony"

II. Opening and Plenary Session

T. E. Shannon
The University of Tennessee

1. Status of CDA Activities

IFMIF-CDA Technical Workshop
Li-Target System
Tokai-mura, Japan
July 18-21, 1995

BASELINE DESIGN STRATEGY

1. Major System Workshops

• Test Cell	July 3-6	FZK-Germany
• Lithium Target	July 18-21	JAERI/Tokai-Japan
• Accelerator	September 11-13	Santa Fe, NM-USA
• Design Integration	October 16-27	ORNL-USA

2. Workshop Objectives

- Technical Review of Tasks Defined at KfK, Sept '94

- Define Concept for Baseline Design
  - Review WBS
  - List Requirements
  - List Design Parameters
  - Define Configuration

- Document Meeting
  - Summary of Findings and Conclusions
  - Copy of all Presentations

BASELINE DESIGN STRATEGY
(Continued)

3. **Define Li-Target Tasks for Remainder of 1995**

   - Provide Information for Design Integration Workshop in October
     - Equipment Layout
     - Facility and Utility Requirements
     - Interface Requirements

   - Document Baseline Design Description by 12/95

4. **Design Integration Meeting Later Today with Drs. Kondo and Maekawa**

   - Additional Guidance Following Meeting

Major Conclusions from Test Cell Workshop
FZK, July 3-6, 1995

- Test Volume low at 35 MeV
  Recommend 40 MeV for 0.5 L >2MW/m^2
- 5x20 Spot size looks good.
- Possible interface problems for overhead access to Test Assembly and Lithium Piping
- Sensitivity Analysis required to determine impact of cross-section variation >~~40~~ 20 MeV
- He Cooling may be best choice for Test Assembly

2. Report of the First IFMIF-CDA Technical Workshop on Test Cell System at FZK

K. Noda
Japan Atomic Energy Research Institute

The First IFMIF-CDA Technical Workshop on
Li Target System

July 18-21, 1995

Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai, Japan

Report of The First IFMIF-CDA Technical Workshop on Test Cell System at FZK

The first IFMIF-CDA technical workshop on Test Cell System organized by Dr. Moslang (Deputy Leader for Test Cell System) was held from July 3 to July 6, 1995 at FZK in Karlsruhe, Germany.

20 specialists attended the workshop from EU, Japan and US.
-EU: 14 people, Japan: 2 people, US: 4 people

Presentations and discussion on 11 tasks (CDA-D-1 to CDA-D-11) including 4 neutronics tasks, 4 test matrix/users tasks and 3 test cell engineering tasks were performed, to show that significant progress in these three fields and extract action items for next step (Integration works in October, 1995).

Neutronics Tasks

CDA-D-1:To provide neutron source function for given target-, beam- and energy parameters.

CDA-D-2:Detailed neutronics analysis and other parameters for test cell with standard loading condition.

CDA-D-7:To provide processed nuclear data between 20-50 MeV for relevant elements.

CDA-D-10:To define design concept for dosimetry.

Neutronics Tasks

CDA-D-1:To provide neutron source function for given target-, beam- and energy parameters.

CDA-D-2:Detailed neutronics analysis and other parameters for test cell with standard loading condition.

CDA-D-7:To provide processed nuclear data between 20-50 MeV for relevant elements.

CDA-D-10:To define design concept for dosimetry.

Test Matrix/Users Tasks

CDA-D-3: To define standard geometry of miniaturized specimens and to develop a loading for high flux region.

CDA-D-5: To define necessary in-situ experiments for all classes of materials investigated and to develop concepts for in-situ test facilities.

CDA-D-8: To identify requirements for a common facility for materials testing at the IFMIF-site and to define test equipments required.

CDA-D-9: To develop an overall test matrices.

Test Cell Engineering Tasks

CDA-D-4: To develop engineering concept for "standard loading" including provisions for instrumentation and cooling.

CDA-D-6: To develop design concepts for typical test modules and their interface with test cell.

CDA-D-11: To develop design concept of entire test cell.

Summary of Presentation and Discussion
-Neutronics Tasks-

(1) Neutron source terms provided by Japan and US were compared and an improved souece was requested.

(2) Initial neutronic analyses on collided neutron field characteristics (flux distribution, test volume, spectra) and damage parameters (dpa, He/dpa, solid transmutants, etc.) for standard loading conditions were presented for d^+ energy range 30-40 MeV by Japan and US.

The results showed that beam foot print of 5x20 cm^2 is a good compromise between materials testing and target technology requirements, although some differences between US and Japanese results were found.

(3) Operation at 40 MeV or increase of current was proposed to secure required high flux test volume, but concern on high energy tail effects for ceramics was shown.

(4) Uncertainty analyses for high energy tail effects, neutron source terms, neutron spectra/nuclear response evaluated by Japanese and US neutron source terms were requested.

(5) Calculation of dpa distribution for the very low flux region (at least 0.1 dpa) was requested for irradiation of ceramic materials, etc.

(6) Status of nuclear data in the range 20-50 MeV and JAERI's and FZK's activities for development of processed nuclear data in the range 20-50 MeV were presented.

Int. collaboration for development of a suitable IFMIF library for neutron transport calculations was arranged.

(7) Design concept for dosimetry was discussed, and an activity will be coordinated by EU with Japan.

Summary of Presentation and Discussion
-Test Matrix/Users Tasks-

(1) Miniaturized specimen geometries proposed by US/Japan were adopted as reference geometries with a change in the push-pull fatigue specimen.

(2) Irradiation temperatures: 250 to 1000 C

(3) Max. dose: 100 to 150 dpa

(4) Total test volume for structural materials (ferritic steel, V alloy,SiC/SiC composite) development will be about 1L. High flux irrad. volume (15 dpa/y, 70% avail.) of about 0.5L is considered to be minimum requirement.

(5) Reference operation scenario and conditions need further work. Flexible operation may be desirable from standpoint of materials testing.

(6) Temperature control scenario during beam interruption should be developed.

(7) Further work is needed to define acceptable range of dose rates (interchanging specimen to increase irrad. volume).

(8) To define acceptable ranges of He/dpa, H/dpa and solid transmutants/dpa for structural materials.

(9) Necessary in-situ experiments were proposed for all kinds of materials and they will be performed in medium and low flux regions. Further works are needed to define requirements for irradiation conditions, test volume and out-of-cell equipments.

(10) Requirements for PIE facility at IFMIF site and required PIE equipments were proposed. Further work to establish requirements for PIE and hot cell is necessary.

Summary of Presentation and Discussion
-Test Cell Engineering Tasks-

(1) Advanced design concept based on NaK temp. control system was proposed for high flux test modules and instrumented tests in lower flux region. NaK system is suitable for metallic materials test temp. regime and its heat capacity may lead good temp. control during irradiation / beam interruption.

(2) He gas temp. control concepts for test modules were proposed based on reactor experience and calculation.
-He gas controls specimen temp.
-He gas cools nuclear-heated specimens.

He gas temp. control system may have capability for high flux region and advantages, e.g., compatibility with various specimens, safety, etc.

Further development of He gas temp. control test module concepts, transient thermal analysis for beam interruptions, integration of test module concepts with test cell and establishment of installation/removal approach of test module were requested.

(2) Vertical access was proposed for handling test assembly.

Selection of approach and definition of equipment requirements for test assembly handling are necessary.

To define hot cell requirements for test assembly maintenance is also requested.

(3) To develop layout for PIE and hot cell for test cell operation and to develop test cell design parameters are required.

Technical Interface Items between Test Cell/Users Activity and Li Target System

(1) Deuteron beam energy: 30 to 40 MeV
-40 MeV operation is desired for metallic materials to secure required minimum test volume in high flux region. (High energy tail effects has to be checked.)
-30 MeV operation is required for ceramic materials to avoid high energy tail effects.

(2) Beam foot print:20x5cm (ref.), 10x10/40x2.5cm (backup)
-Beam foot print of 40x2.5cm may not be acceptable from standpoint of small test volume and large flux gradient.
-Square like beam foot print is preferable to obtain required test volume in high flux region.
-Beam foot print of10x10cm may not be acceptable from standpoint of Li flow stability.

(3) Beam current: 250 mA (current specification)
-Evaluation of feasibility of increasing beam current above 250 mA in Li target and accelerator technologies is desirable to obtain required test volume especially for ceramic materials.

(4) Specimen temperature: 250 to 1000 C
-Temperature of test module affects target backwall temperature which is one of determinant factor for backwall life time.
-Max. temperature of test module structure acceptable for Li target backwall should be defined.

(5) Compatibility between test cell structure/test assemblies which meet materials testing requirements and Li target system configuration/maintenance system for Li target has to be secured.

IFMIF-CDA Technical Workshop on Test Cell System

Karlsruhe, July 3-6, 1995

Summary (draft)

After a Conceptual Design Activity (CDA) study on an International Fusion Materials Irradiation Facility (IFMIF) has been launched under the auspices of the IEA, working groups and relevant tasks have been defined and agreed in an IEA-workshop that was held September 26-29 1994 at Karlsruhe. For the Test Cell System 11 tasks were identified which can be grouped into the three major fields neutronics, test matrix/users and test cell engineering. In order to discuss recently achieved results and to coordinate necessary activities for an effective design integration, a technical workshop on the Test Cell System was initiated. This workshop was organized on July 3-6 1995 by the Institute for Materials Research I at the Forschungszentrum Karlsruhe and attended by 20 representatives from the fusion materials and blankets programs in the European Union, Japan, and the United States of America.

The presentations and discussions during this workshop have shown together with the elaborated lists of action items, that on the basis of already existing concepts and computer codes significant progress has been achieved in all three fields, and that from the future IFMIF experimental program for a number of materials a database covering widespread loading conditions up to DEMO-reactor relevant end-of-life damage levels can be expected.

<u>Neutronics:</u>

On the basis of available neutron source functions, initial neutronic analyses for deuteron beam energies between 30 and 40 MeV have been performed for standard loading concentrations of the high flux test cell region. The calculations also confirmed earlier recommendations that a beam spot size of 5x20 cm^2 is a good compromise between maximum test volume, small flux gradients and flexibility of the test cell configuration. Although an increase of beam energy from 30 to 40 MeV roughly duplicates the high flux test volume, serious reservations with respect to the correlated increased high energy tail in the neutron spectra could not be dissipated. Therefore, uncertainty analysis mainly on gas production and transmutation rates taking into account neutron energies from 20-50 MeV are urgently needed. These calculations imply ongoing efforts in establishing processed nuclear data for key nuclides in this energy range in order to ensure that IFMIF adequately simulates the nuclear environment in a fusion reactor.

Test Matrix / Users:

For the high flux region, equivalent to >2 MW/m^2 first wall neutron loading, detailed specimen loading matrixes have been elaborated. Assuming a beam-on-target availability of 70%, in this high flux test volume of 0.5-1 liter an average damage level of 15 dpa/year can be achieved. The present loading matrix is based on 7 miniaturized specimen geometries, it allows within a ten years program the irradiation up to DEMO-relevant lifetime doses in a wide temperature range, and includes different heats from all three reference materials ferritic/martensitic steels, vanadium alloys and SiC/SiC composites. In contrast to former concepts the specimens are encapsulated to avoid a direct interaction with the coolant.

While the high flux region has to provide a materials data base based on postirradiation examinations, the medium and low regions are important to perform selected in-situ tests for a design data base on structural materials and to allow instrumented tests on special purpose materials (e.g. Rf windows, diagnostic materials, ceramic breeding materials). Although such experiments often implies sophisticated techniques, significant progress has been achieved the last few months. Even for in-situ tests with controlled mechanical loadings design concepts are available meanwhile. However, a comprehensive matrix of reference in-situ and instrumented tests including out-of-cell equipment requirements, has still to be established.

Initial listings of the equipment necessary to perform the various postirradiation tests on minaturized specimens show, that beside standard hot cells with estimated area requirements of nearly 500 m^2 additional space will be necessary for tritium handling hot cells at the IFMIF facility.

Test Cell Engineering:

An advanced design concept based on NaK as coolant is available for the high flux test chamber which also can be applied for conventional instrumented tests in lower flux test regions. NaK is suitable within the temperature regime of interest for metallic structural materials, and it's heat capacity guarantees sufficiently good temperature control during beam-on and beam-off periods. On the other hand, experience with various helium gas cooled reactor and accelerator devices have shown together with recent calculations, that helium gas as coolant offers similar package densities in the high flux region, but might have advantages e.g. with respect to the allowable temperature window, safety considerations or overall test cell flexibility. However, additional investigations for the helium cooled option are urgently needed to guarantee temperature stability for "loss of beam" conditions and to establish an integrated test assembly design. A competing assessment of both concepts necessary for a design integration therefore was postponed a few months.

Finally, design concepts for the entire set of test assemblies were discussed and preliminary shielding analyses including estimations of the thickness of the test cell walls were performed. A more realistic analysis can be done only after a reference test cell configuration is established.

AM

3. U.S. Perspective on Lithium Target System

presented by

Dale L. Smith
Argonne National Laboratory

presented at

1st IFMIF-CDA Technical Workshop on
Li-Target System

Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

July 18-21, 1995

Li Target

Initial Work - Packages as Agreed at KfK Workshop

CDA-T-I-1	Preliminary analysis and concept design for Li target assembly
CDA-T-I-2	Evaluation and specification of target-beam-test cell interfaces
CDA-T-II-1	Preliminary conceptual design for Li loop system lay-out
CDA-T-II-2	Li loop component design: evaluation and specification of component design and performance
CDA-T-II-3	Li chemistry process system: define requirements and develop preliminary design
CDA-T-IV	Remote handling system (no effort during initial phase)
CDA-T-V	Preliminary safety analysis/evaluation
CDA-T-VI	Design of experimental facilities: preliminary evaluation of experimental facilities
CDA-T-VI	Review and evaluate existing data base on Li properties

IFMIF-CDA: Tasks of Lithium Target System*

	I-1	I-2	II-1	II-2	II-3	V	VI	VII	Other Items (Update)
EU	•	•				•	•	•	
US	•	•	•	•	•			•	US-1
JP	•	•	•	•	•	○	•		JP-1 JP-2 JP-3

*Specified as Work Package in the IFMIF-CDA Workshop at Karlsruhe, Sept. 1994

JP: ○: Tritium Safety, JP-1: Water Experiment, JP-2: Basic Li Purification Experiment, JP-3: Detailed WBS

US-1: JET Experiment

⇒ Please confirm/update the dots ○, and if necessary add to other items like JP column and its footnotes.

Primary Objectives of U.S. Conceptual Design Effort on Lithium/Target System

- Review FMIT design and develop improvements in design wherever possible
- Simplify/optimize maintenance and change out of lithium target assembly in order to enhance lieftime and reliability and improve machine availability
- Evaluate larger beam spot/targets, higher energy beam; and higher beam current in order to enhance test volume and flux gradients
- Improve analysis and evaluation of lithium jet stability under projected IFMIF conditions so as to relax unnecessary design constraints
- Define interface requirements with accelerator/beam line and test assembly
- Evaluate safety-related issues to ensure that design meets current requirements
- Identify and prioritize major technical issues and development/demonstration requirements

Japan-IFMIF-7/95-2

U.S. Design of Lithium-Target System

- Evaluation of three target design options
- FMIT-type which requires periodic replacement of entire target assembly
- Option B which provides for mechanical attachment and periodic replacement of backplate only
- Option C which provides for free jet (no backwall) and eliminates need for periodic replacement of target system or backwall.

Japan-IFMIF-7/95-10

US IFMIF Tasks
Lithium Target System

CDA-T-I-1: Preliminary analysis and concept design for Li target assembly

- Dynamic and thermodynamic stability of lithium jet — Hua
- Thermal-hydraulic analysis of lithium jet with incident beam — Hassanein
- Concept design for lithium target assembly — Hua/Henry/Smith
- Maintenance/lifetime issues — Hua/Henry/Smith

CDA-T-I-2: Evaluation and specification of target-beam-test cell interfaces

- Lithium vaporization from free surface — Hassanein/Hua
- Neutronic analysis of the lithium target — Gomes

CDA-T-II-1: Preliminary conceptual design for Li loop system lay-out

- Preliminary conceptual design for Li-loop system layout — Green
- Remote handling issues — Green

CDA-T-II-2: Li loop component design: evaluation and specification of component design and performance

- Lithium loop component design and evaluation (EM pump, etc.) — Green

CDA-T-II-3: Li chemistry process system: define requirements and develop preliminary design

- Requirements and preliminary design for Li chemistry process system — Green
- Tritium/deuterium processing system — Sze/Smith

CDA-T-VI: Data base on lithium properties

- Review of existing data base on lithium properties — Hua/Billone

Key Issues: CDA-T-I-1 Lithium Target

- Determine stability requirements for lithium jet
  - Velocity, size, temperature
  - Curvature and backplate requirements
  - Validity of water simulation
- Determine nozzle geometry and entrance requirements
  - Vibration
  - Corrosion/erosion
- What are geometric and backwall requirements?
- Volumetric energy deposition in jet for beam energy and size
  - Beam parameters (energy, etc.)
- Thermal response of Li jet with beam
- Beam momentum transfer on jet stability
- Surface temperature and vaporization rates
- Peak temperature and nucleate boiling
- Response to beam edge effects
- Design issues for target system
- Maintenance scenario for target system
- Lifetime and materials issues for target system and backplate
  - Stress on wall
  - Radiation damage
  - Compatibility
- Neutron damage rate for target system components
- Isotope generation in Li targets
- Auxiliary cooling requirements of target system
- Safety-related issues

Japan-IFMIF-7/95-4

Key Issues: CDA-T-I-2: Interfaces

- Vaporization rates and effects on vacuum and beam line
- Impact of vapor deposition and recovery/ removal
- Vacuum boundary and interface with test assembly cell (impact on maintenance)
- Ambient environment considerations
- Neutron damage and activation for system components
- Design interface with test assembly

TeamMtgANL-6/95-2

<u>Key Issues: CDA-T-II-1: Li Loop System</u>

- Design layout of Li loop
- Maintenance requirements for loop system
- Design parameters for loop system

<u>Key Issues: CDA-T-II-2: Loop Components</u>

- Optimization of lithium pump design and configuration
- Secondary coolant selection
- IXH design considerations

TeamMtgANL-6/95-3

<u>Key Issues: CDA-T-II-3: Li Processing System</u>

- Containment/control/recovery of tritium from system
- Requirements for deuterium control/recovery

* Radioactivity transport and control (including Be)

- Instrumentation and on-line monitoring requirements

<u>Key Issues: CDA-T-VII</u>

- Compilation of consistent set of lithium property data
- Design data for lithium system

TeamMtgANL-6/95-4

(presented at 1st IFMIF-CDA Technical Workshop on Li-Target System, July 18-21, JAERI, Tokai, Japan)

4. Perspective of IFMIF Li-Target System of Japan

H. Katsuta
IFMIF Target System Group of JAERI

1. Budget for IFMIF-CDA (without Personnel Expense)

PY 1995: 0.4M$
PY 1996: 1.6M$(Requested)

2. Organization

JAERI IFMIF Group
Department of Materials Research and Engineering
Materials Innovation Lab. (about 2fpy)
*Planning and Promotion
*Testcell/Users

Department of Reactor Engineering
Intense Neutron Source Lab. (about 4fpy)
*Li-target System
*Accelerator System

Nuclear Materials Research Committee(Dr. A.Miyahara)
JAERI, Universities, Companies

3.Perspective to IFMIF-EDA

Procedure to IFMIF-EDA
(1)Establishment of IFMIF-EDA Agreement(IEA) (1997.2 ?)
(2)Approval for Reviewing Committee of JAERI International Collaborations
(3)Budget Request
JAERI HQ --> STA --> Finance Ministry

4. Technical Perspective of Li-target System of Japan

(1) Computer Analysis: Thermal and fluid dynamic analysis of Li-target flow **(18-8)**
(2) Experiment with a water loop: JAERI water loop test and target design**(19-1)**
(3)Experiment with a Li-loop: on-line hydrogen isotope detectors and experimental plan**(20-1)** (under the collaboration with Tokyo Institute of Technology)
(4) Analyses and conceptual design: Li-system, Components**(19-1,2,3; 20-1,3)**
(5)Preliminary safety analysis: Chemical and radiological hazard(**20-2**)
(6) Li-data base; Li-vaporization rate

Ⅲ. Technical Sessions

1. Preliminary Analysis and Conceptual Design of Target Assembly

1.1 Conceptual Design for Lithium Target Assembly

Thanh Hua
Dale Smith
Argonne National Laboratory

Robert Henry
Fauski and Associates Inc.

Raymond Bradley
Globetrotters Engineering Corporation

presented at

1st IFMIF-CDA Technical Workshop on
Li-Target System

Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

July 18-21, 1995

REVIEW OF FMIT TARGETS

- Two target assemblies were fabricated and tested
- The first target (Mark I) had a symmetrical nozzle. The design resulted in a bulge above the high flux test volume, and restricted access to this region
- The second target (Mark II) used a nozzle that was asymmetrical. The bulge was eliminated
- Both target assemblies were tested in water and in lithium. Both produced stable and steady state high velocity jets
- Target lifetime was estimated at 9 months which is believed to be an overestimation for stainless steel

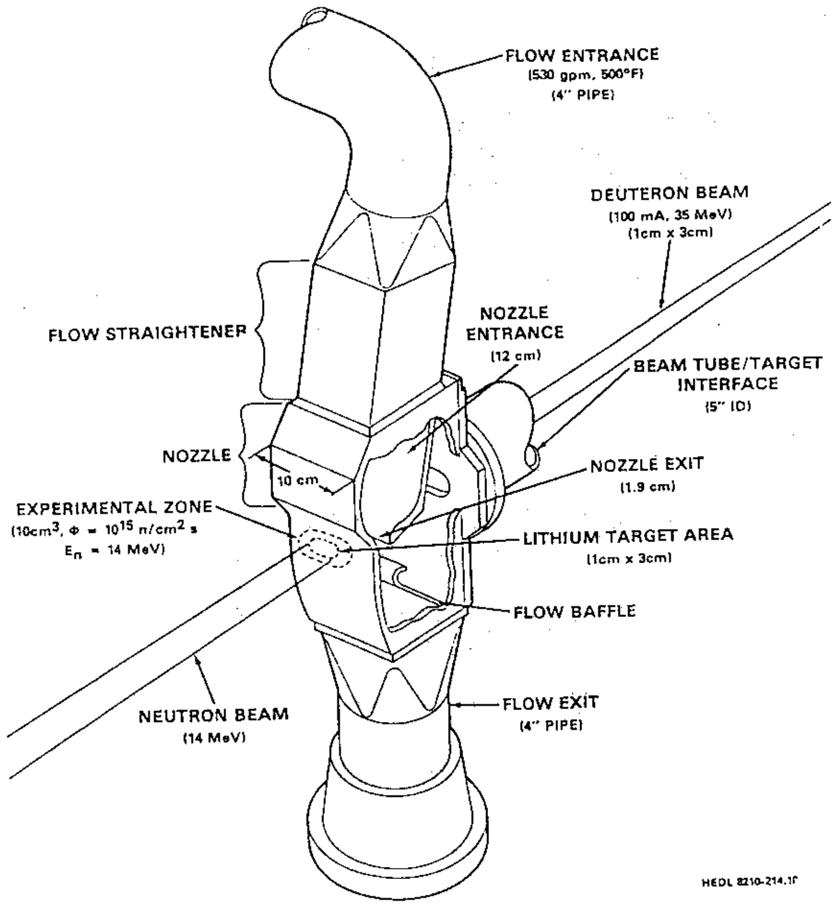


FIGURE 6. FMIT Lithium Target -- First Generation Design (Mark I).

33

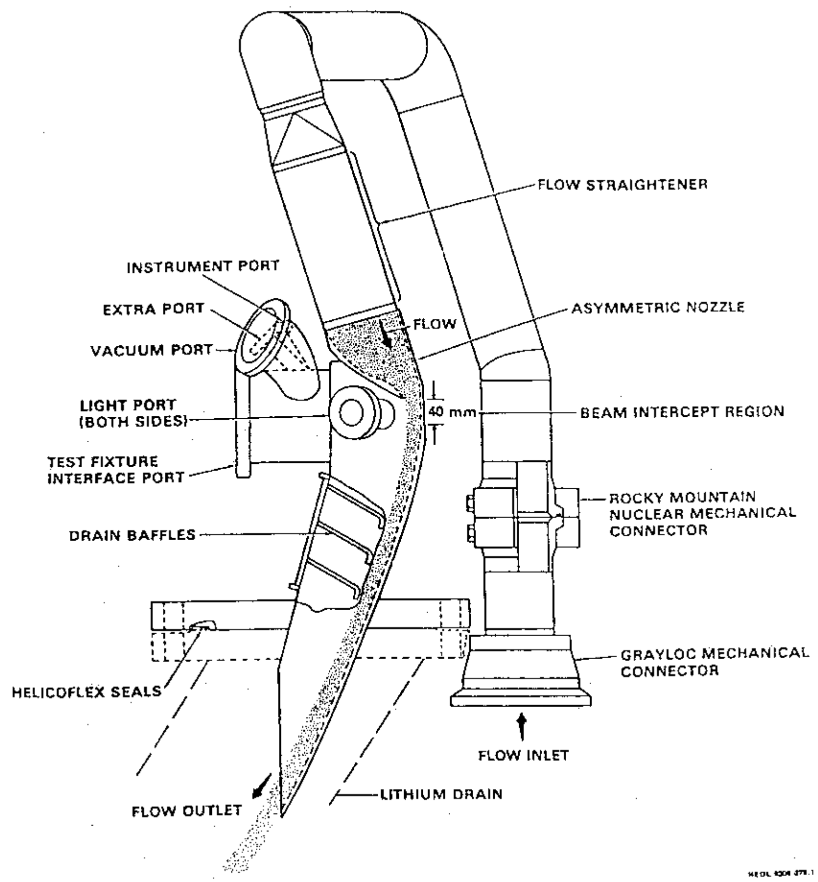


FIGURE 7. FMIT Lithium Target -- Second Generation Design (Mark II).
Neg 8308374-1cn

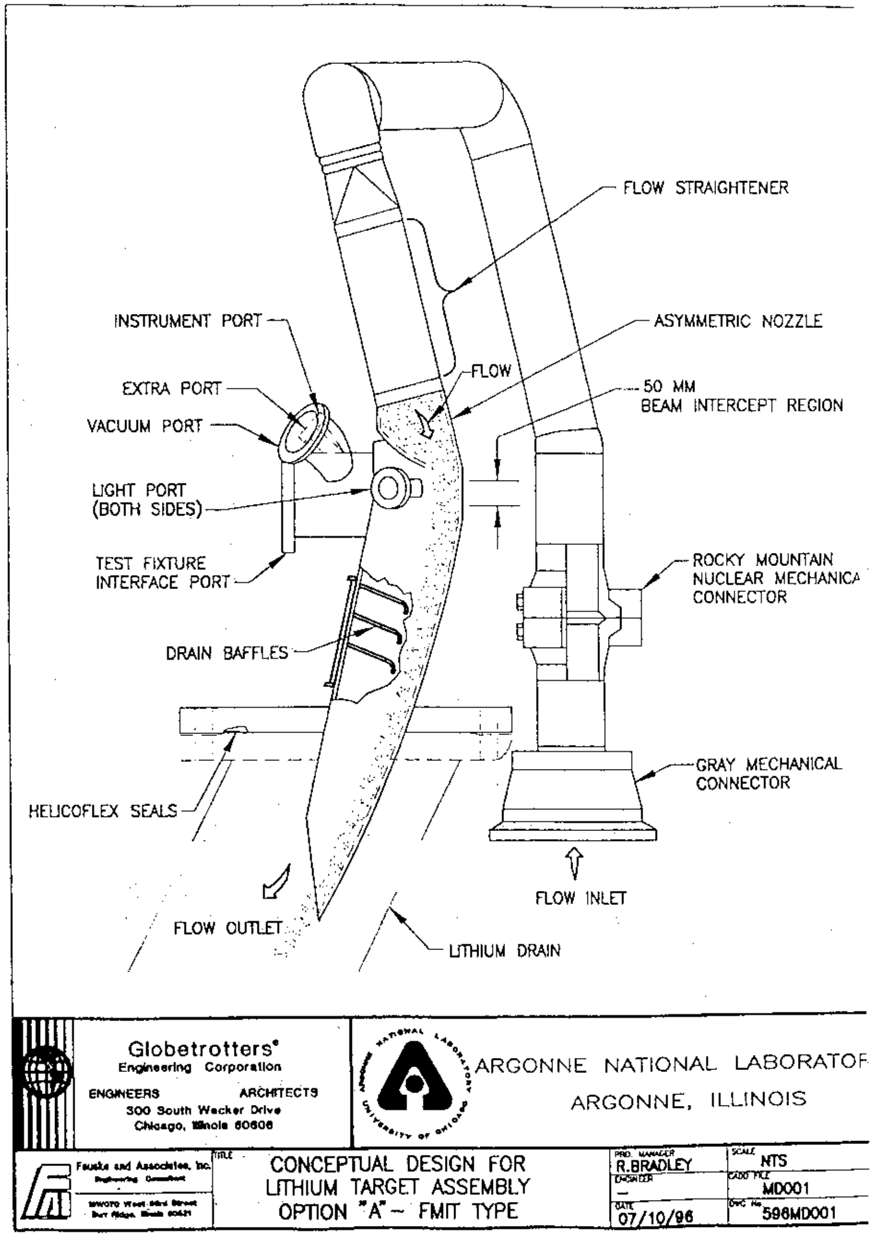
34

MATERIALS ISSUES FOR TARGET SYSTEM

- Target backplate is exposed to the most severe neutron damage and is the most vulnerable component of the target system
  - May have limited lifetime (< 1 yr)
  - Will require frequent replacement
  - Will require remote maintenance
  - Affect facility availability
- Backplate parameters
  - Temperature 220 - 300°C
  - Neutron damage rate ~ 60 dpa/fpy
  - High He and H transmutation rates
  - Compatible with Li
  - Thermal stress from nuclear heating
  - Pressure stress from jet and test cell
  - Periodic transients (Startup/ shut down)
- Data base inadequate to determine lifetime
  - Swelling
  - Embrittlement
  - Irradiation creep
- Can not reweld material exposed to significant neutron flux
  - ITER assumes < 1 appm He for rewelding of austenitic steel
- Potential candidate materials
  - Austenitic steel
  - Ferritic steel
  - Vanadium

U.S. DESIGN OF IFMIF Li-TARGET SYSTEM

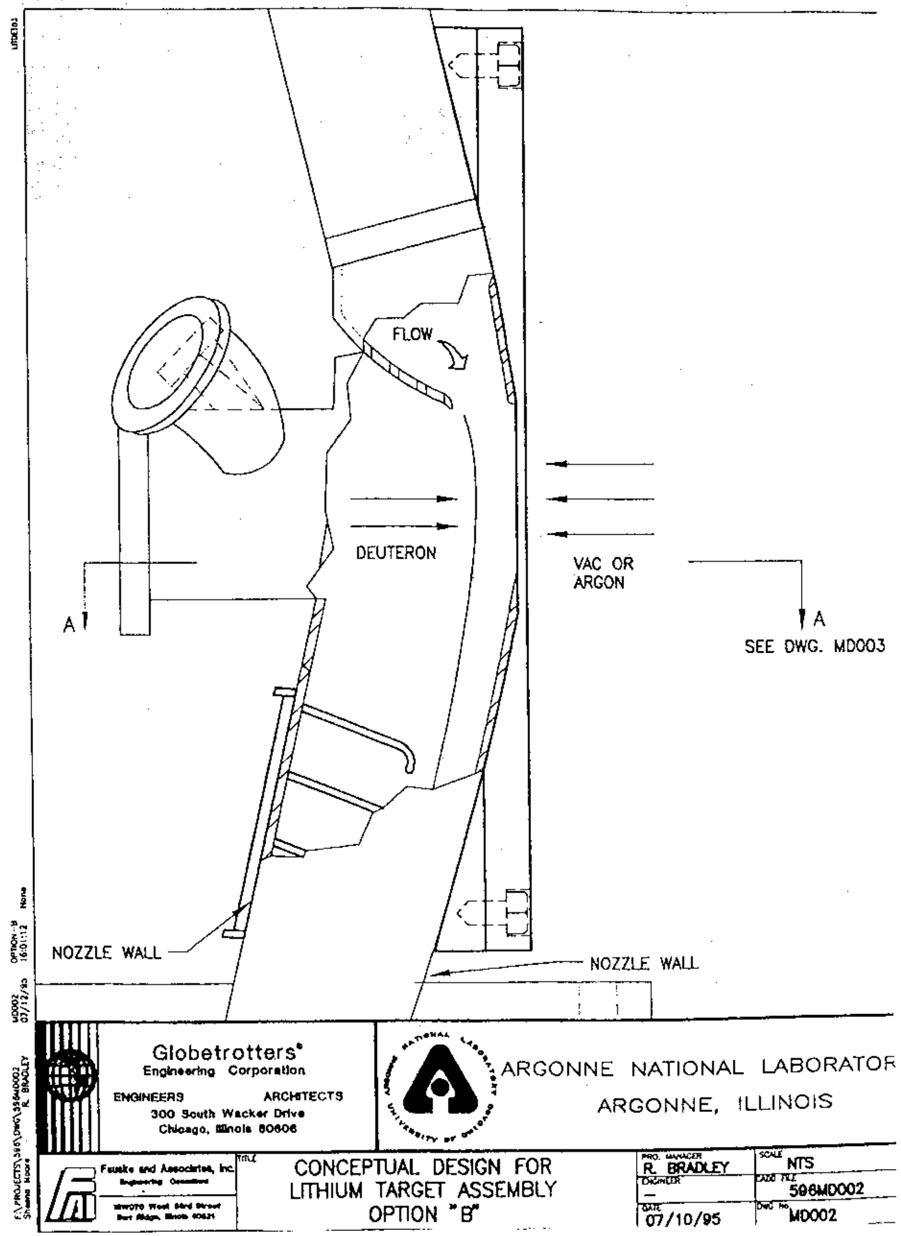
- Evaluation of three target design options
- FMIT-type (Option A) which requires periodic replacement of entire target assembly
- Option B which provides for mechanical attachment and periodic replacement of backplate only
- Option C which provides for free jet (no backwall) and eliminates need for period replacement of target system or backwall

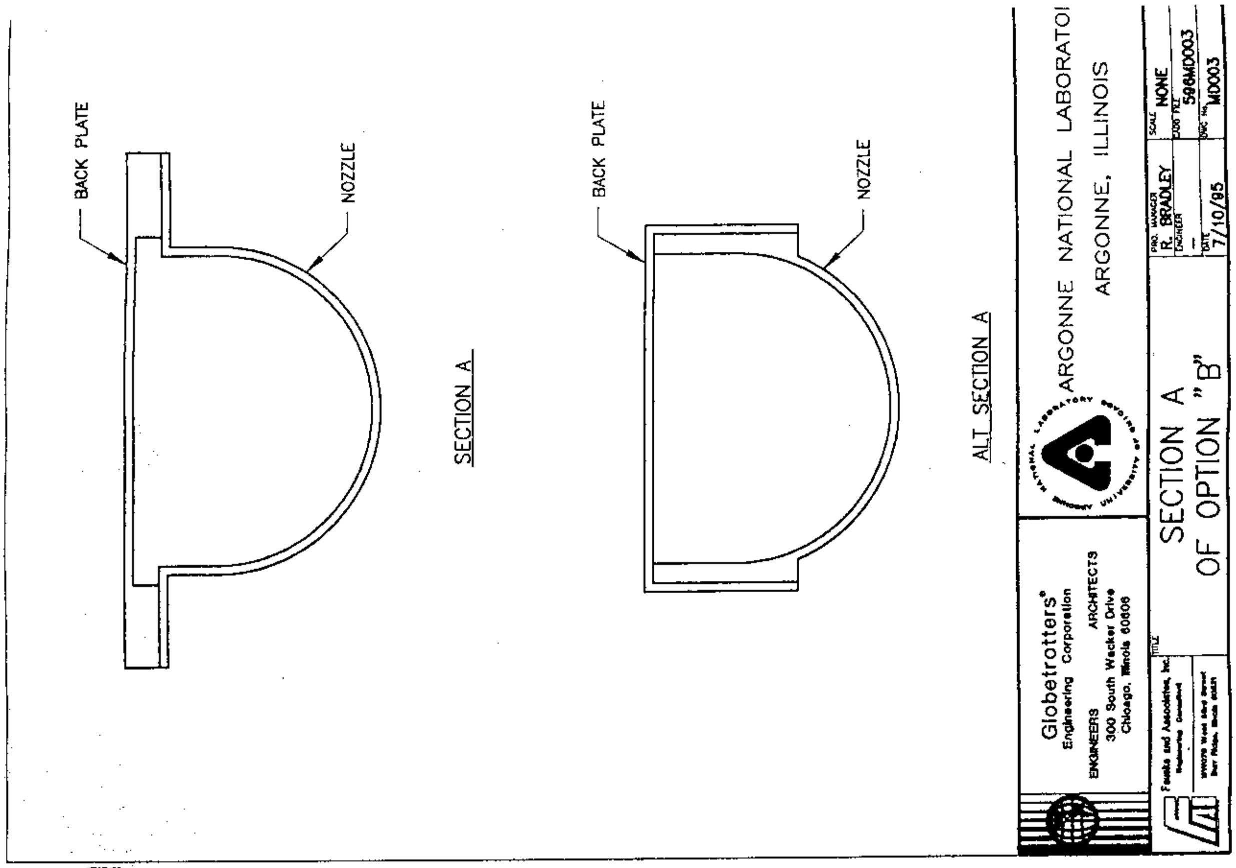


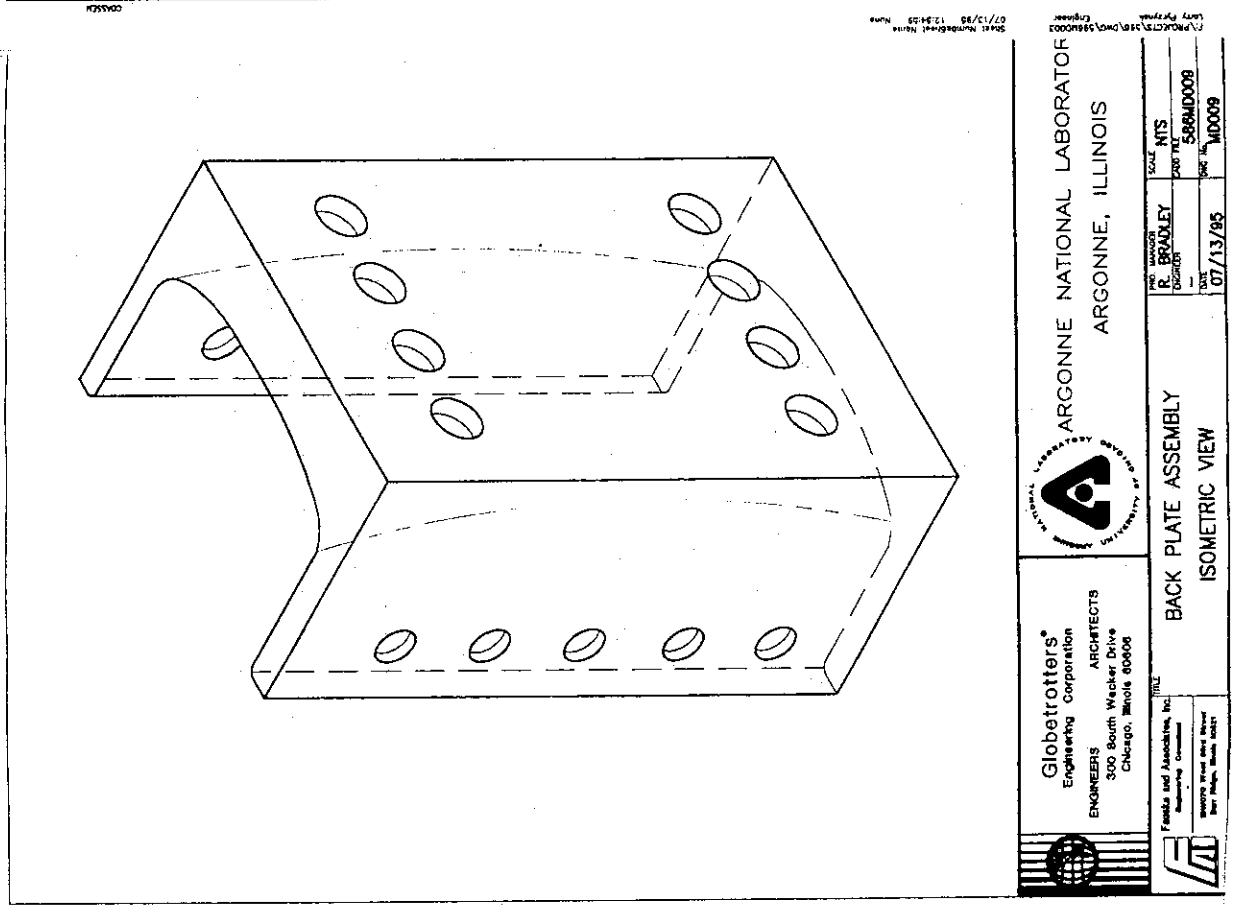
DESIGN OPTION A : FMIT-TYPE

- Advantages:
  - FMIT design experience
  - Hydraulic and lithium testing demonstrated for small target

- Disadvantages/Unresolved issues:
  - Limited lifetime, frequent replacement
  - Requires replacement of entire target assembly
  - Difficult and time consuming replacement and maintenance
  - High cost of entire target assembly
  - Generates large volume of radioactive waste
  - Risk of backplate rupture if atmospheric pressure is maintained in test cell
  - Curvature reduces high flux test volume and increases flux gradient in test assembly for large beam spot



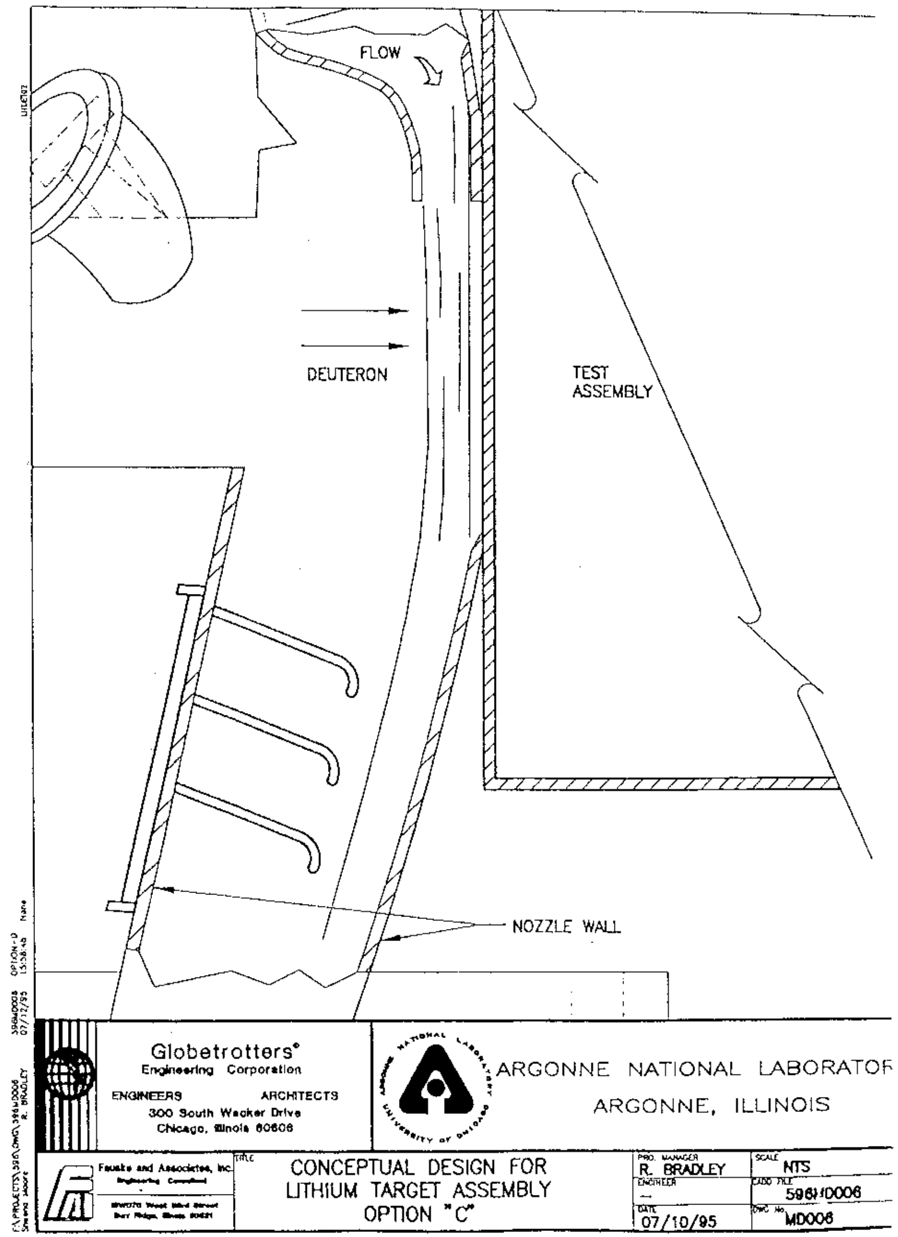

BACK PLATE
NOZZLE
SECTION A
BACK PLATE
NOZZLE
ALT SECTION A
ARGONNE NATIONAL LABORATO
ARGONNE, ILLINOIS
Globetrotters
Engineering Corporation
ENGINEERS ARCHITECTS
300 South Wacker Drive
Chicago, Illinois 60606
SECTION A
OF OPTION "B"
R. BRADLEY
7/10/95
NONE
596MD003
MD003


ARGONNE NATIONAL LABORATOR
ARGONNE, ILLINOIS
Globetrotters
Engineering Corporation
ENGINEERS ARCHITECTS
300 South Wacker Drive
Chicago, Illinois 60606
BACK PLATE ASSEMBLY
ISOMETRIC VIEW
R. BRADLEY
07/13/95
NTS
586MD009
MD009

DESIGN OPTION B

- Advantages:
  - Replace backplate only
  - Mechanical attachment, no welding
  - Simple replacement/maintenance scheme
  - Faster replacement
  - Lower replacement cost
  - Long lifetime for rest of target assembly
  - Reduces radioactive waste

- Disadvantages/Unresolved issues:
  - Requires more development
  - Requires seals around backplate
  - Risk of backplate rupture if atmospheric pressure is maintained in test cell



DESIGN OPTION C

- Advantages:
  - No backwall replacement
  - Long lifetime for target assembly
  - Minimal effect on facility availability
  - Reduces replacement cost
  - Minimal waste
  - Avoids potential contamination/damage of accelerator by fracture of backplate
  - No curvature effects on flux volume and flux gradient
- Disadvantages/Unresolved issues:
  - Requires more development
  - Requires good vacuum in test cell and/or seals at target assembly/test assembly interface

SUMMARY

- While option A enjoys the FMIT design philosophy and experience, the potential requirement for frequent replacement of entire target assembly makes it unattractive for IFMIF
- Options B and C need further evaluation and engineering details, but offer major advantages in maintenance/replacement scheme, longer lifetime for target assembly, higher availability, lower replacement cost, and less radioactive waste
- Vacuum in test cell avoids possibility of contamination/damage of accelerator in the event of fracture of backplate
- Interaction with test assembly group is essential to target design activities

1.2 Dynamic and Thermodynamic Stability of Li Jet

Thanh Hua
Argonne National Laboratory

presented at

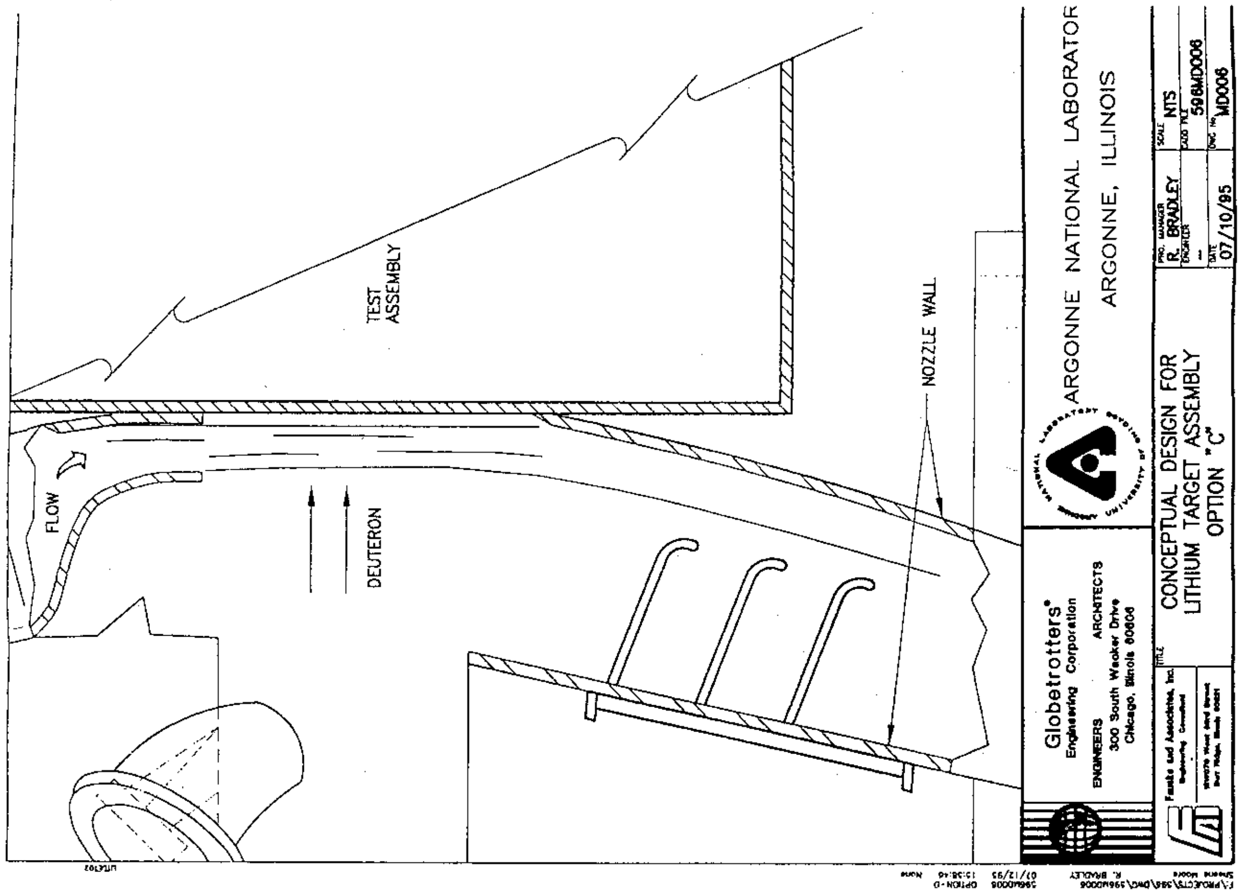
1st IFMIF-CDA Technical Workshop on
Li-Target System

Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

July 18-21, 1995

INTRODUCTION

- Three Li-target design options are being evaluated (Task CDA-T-I-1.3, U.S. presentation at this workshop); two of the options have a backwall and the third employs a free jet concept
- Analysis and experiments have been performed for the FMIT curved wall jet and being pursued by the parties for IFMIF target size. Stability of the Li jet was sufficiently demonstrated for FMIT
- The present work focuses on the dynamic and thermodynamic stability of free jet



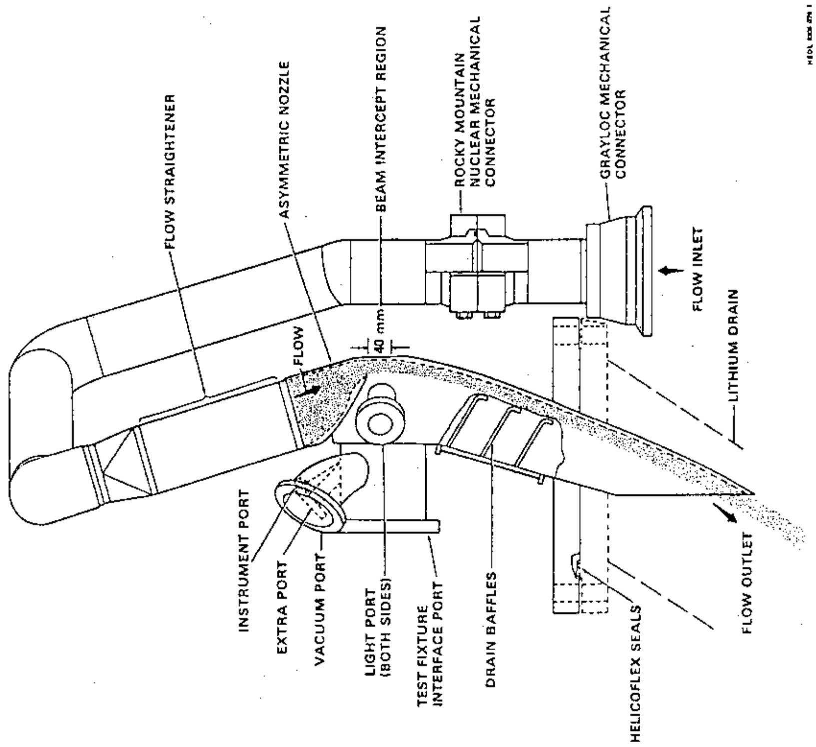


FIGURE 7. FMIT Lithium Target -- Second Generation Design (Mark II).
Neg 8308374-1cn

34

REASONS FOR USE OF CURVED BACKWALL IN FMIT

- Jet stability

  * Water testing of straight wall target showed rough free surface with rapidly increasing wave amplitude

  * Water and lithium testing of curved wall targets(Mark I and II) showed significant improvement, surface being much smoother. Jet thickness variance was within acceptable limit

- Suppression of Li boiling

  * The peak Li temperature approaches 820°C, much higher than the saturation temp of 300°C at 10^{-4} Pa

  * The wall curvature maintains sufficient centrifugal pressure in lithium to keep it subcooled

WHY CONSIDER FREE JET OPTION?

- Eliminate disadvantages associated with backwall (discussed in presentation of Task CDA-T-I-1.3)

- No backwall replacement, longer target assembly lifetime, higher facility availability, and less radioactive waste

- Key issues:

  - Jet dynamic stability
  - Thermodynamic stability
  - Beam momentum on jet (jet deflection)
  - Integration with test assembly

CONSIDERATIONS OF SOME KEY ISSUES

- Jet dynamic stability is strongly dependent on ambient pressure. Lithium jet in vacuum is significantly more stable than water jet in air

- Peak lithium temperature is substantially lower than that of the FMIT reference design

  - For IFMIF conditions of 35 MeV Gaussian D^+ beam and 250 mA beam current, the peak temperature is 410°C at 15 m/s, 500°C at 10 m/s

  - This is because of the larger beam size (33 times), lower beam power density (13 times)

- Nucleate boiling is predicted not to occur under IFMIF conditions

- Beam momentum on jet results in less than 1 mm deflection

EFFECTS ON JET DYNAMIC STABILITY

- Nozzle:
  - Shape
  - Flow straightener
  - Precise machining of internal wall surface
  - Vibration-free support

- Aerodynamic interaction:
  - Jet surrounding medium, pressure
  - Properties of liquid
  - Velocity

- Velocity relaxation and turbulence intensity in nozzle

- The principal cause of instability is due to the interaction of the jet with the surrounding atmosphere

ANALYSIS FOR CIRCULAR JET

- Stability analysis was performed for laminar Newtonian jets based on an extension of Weber's analysis

- A surface disturbance may be written as a Fourier series including terms of the form

$$\bar{\delta} = \bar{\delta}_{\circ}\, e^{\alpha\tau + ikx}$$

- The characteristic equation for α, the disturbance growth rate, is

$$\alpha^2\left[\frac{\xi I_0(\xi)}{2I_1(\xi)} + \frac{\hat{\rho}\xi K_0(\xi)}{2\rho K_1(\xi)}\right] + \alpha\left\{\frac{\mu\xi^2}{\rho a^2}\left[2\xi\frac{I_0(\xi)}{I_1(\xi)} - 1\right]\right\}$$

$$= \frac{\sigma}{2\rho a^3}\left(1-\xi^2\right)\xi^2 + \frac{v^2\hat{\rho}\xi^3 K_0(\xi)}{2a^2\rho K_1(\xi)} \qquad (1)$$

where:

ξ = ka, wave number
a = radius of nozzle
σ,μ = surface tension, viscosity of fluid
$\rho,\hat{\rho}$ = density of jet fluid, ambient density
v = jet mean velocity
I_0, I_1 = modified Bessel functions of the 1st kind
Ko, K_1 = mod. Bessel functions of the 2nd kind

- The largest growth rate, α^*, from eq. (1) will eventually dominate the jet breakup.

- If the initial disturbance has amplitude $\bar{\delta}_{\circ}$, and grows to magnitude "a" in time t*, then

$$t^* = \frac{1}{\alpha^*}\, ln\left(\frac{a}{\bar{\delta}_0}\right)$$

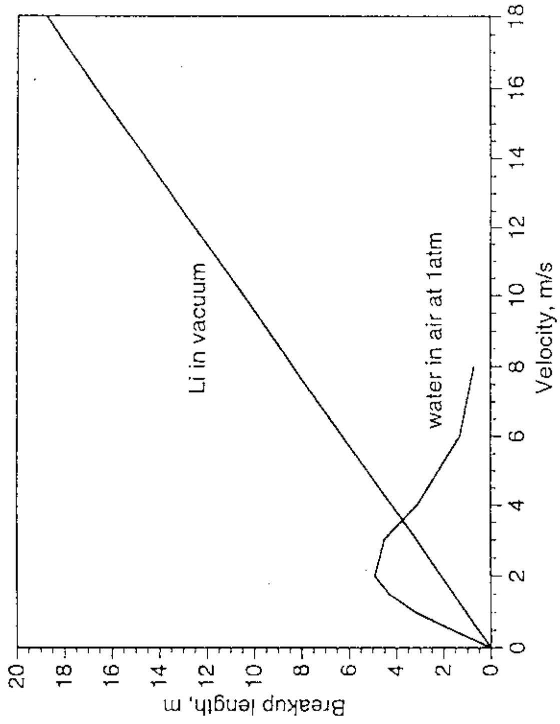
The jet length will be:

$$L = vt^* = \frac{v}{\alpha^*}\, ln\left(\frac{a}{\bar{\delta}_0}\right)$$

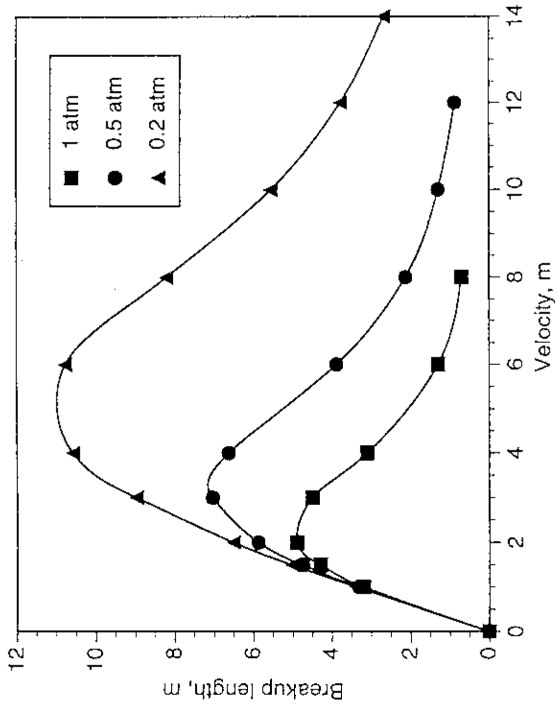
- The value for $\gamma = ln\left(\frac{a}{\bar{\delta}_0}\right)$ depends upon the vibration and noise and the extent to which the apparatus is isolated from such disturbances.

- Previous experiments have found $\gamma = 10 - 14$.

Breakup length of water jet in air and Li jet in vacuum
Jet diameter = 2 cm



Breakup length of water jets in air at various ambient pressures, jet diameter=2 cm



JET EXPERIMENTS

- R. Fenn,III and S. Middleman, A.I.Ch.E. J. Vol 15, 379 (1969)

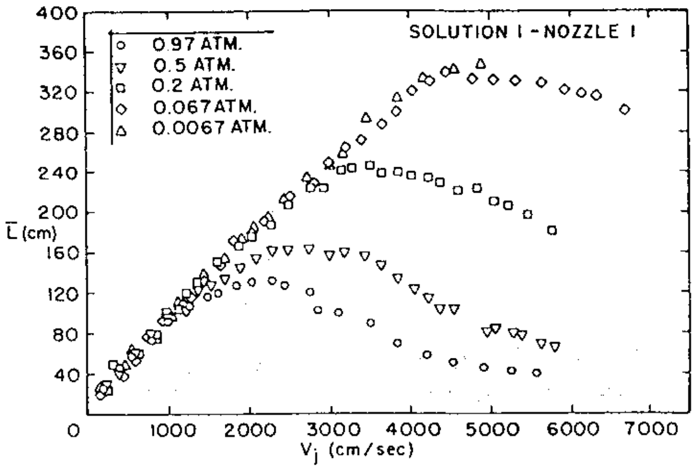


Fig. 3. Breakup curves as a function of ambient pressure.

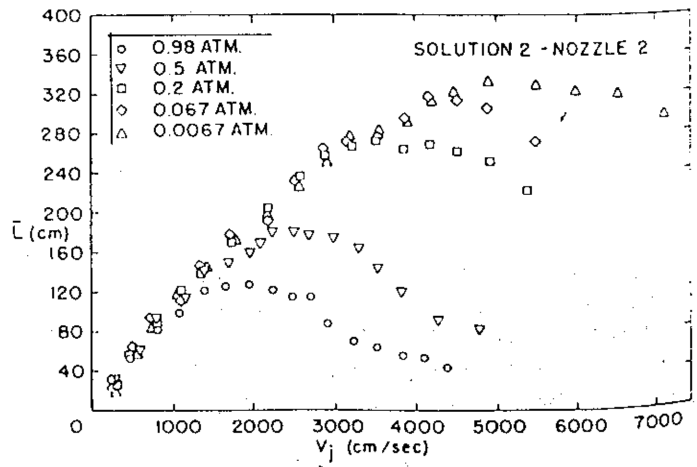
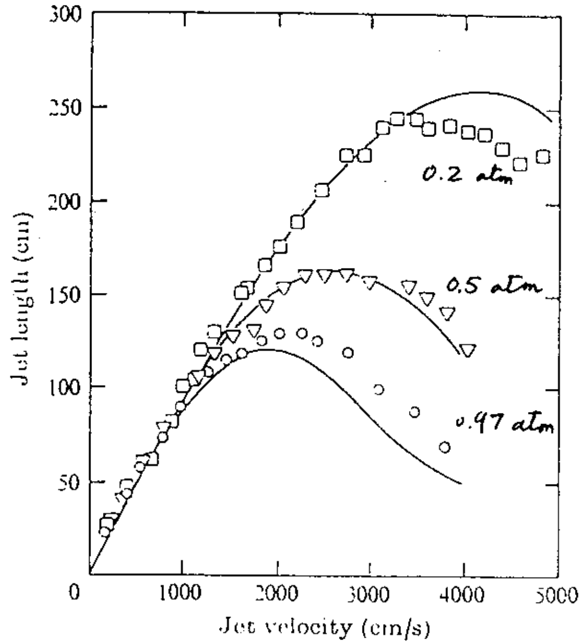


Fig. 4. Breakup curves as a function of ambient pressure.

COMPARISON WITH MODIFIED WEBER THEORY



ANALYSIS FOR LIQUID SHEETS

- Stability analysis was performed for liquid sheet of infinite extent inter-relating the forces caused by gas pressure, surface tension, liquid inertia, and viscosity. The liquid sheet was subjected to sinusoidal wave disturbance

- The sheet is unstable if

$$n < \frac{\hat{\rho} v^2}{\sigma}$$

where n is the wave number, $\hat{\rho}$ is ambient density and σ is surface tension

- For an inviscid fluid, the wave number and growth rate for maximum growth (instability) is

$$n = \frac{\hat{\rho} v^2}{2\sigma}$$

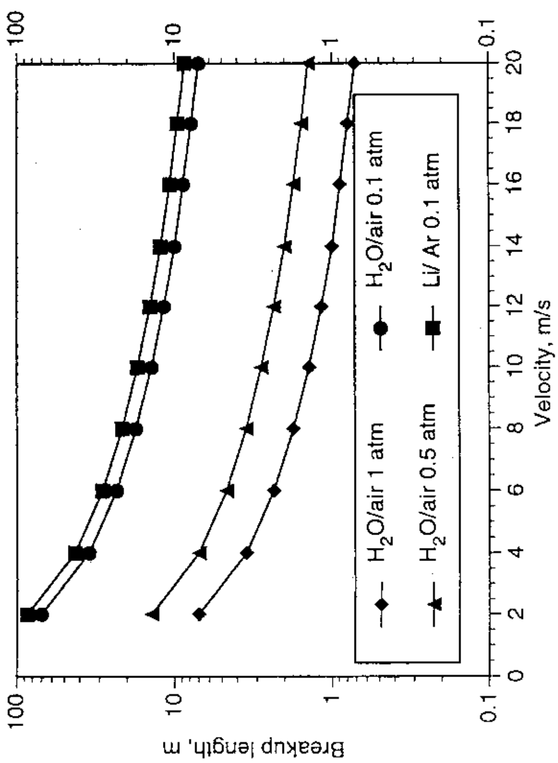
$$\alpha = \frac{\hat{\rho} v^2}{\sqrt{2h\rho\sigma}}$$

h = sheet thickness
ρ = liquid density

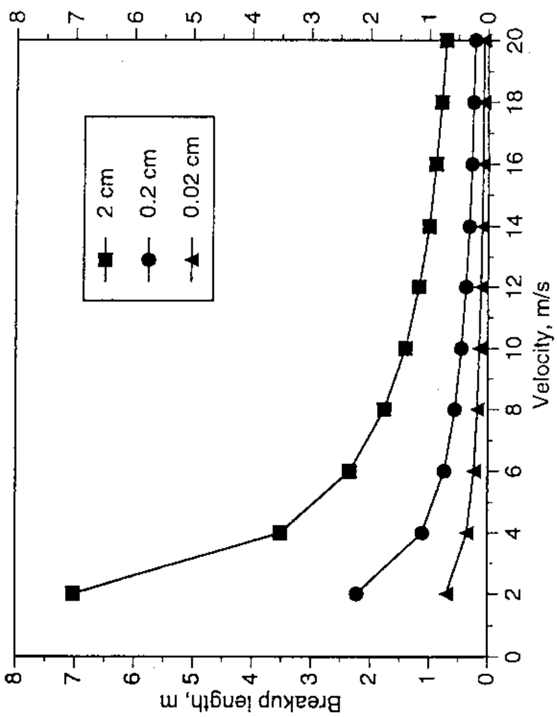
- Neglecting viscosity effect, the disturbance amplitude of a 2-cm thick water sheet in air, flowing at 20 m/s grows by 1150-fold at 20 cm from the nozzle

- For a viscous sheet, the growth depends on both the wave number and sheet thickness

Breakup length of liquid sheets of infinite extent at various ambient pressures, sheet thickness = 2cm



Effect of sheet thickness on instability of water sheet in air at 1 atm pressure



WATER SHEET JET EXPERIMENTS

- H. Asare, R. Takahashi, M. Hoffman J. Fluids Engr. Vol 103 (1981)

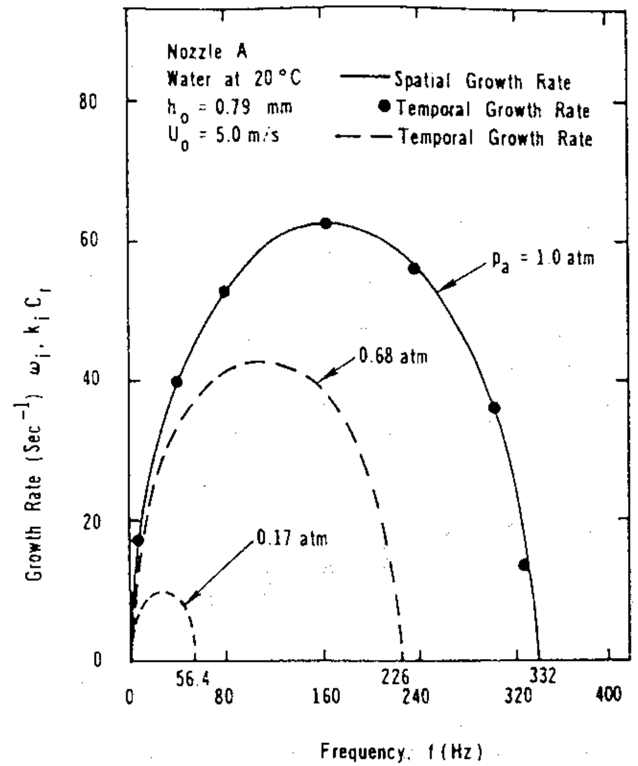


Fig. 2(a) Comparison of growth rates for the water jets from Nozzle A predicted by the linear temporal and linear spatial stability theories for three representative experimental conditions

WATER SHEET JET EXPERIMENTS (continued)

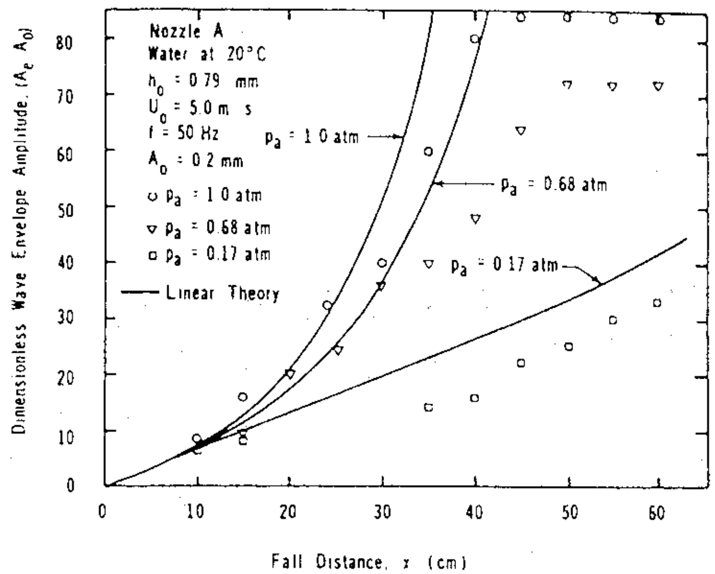


Fig. 10 Comparison of the linear theory to the experimental data for Nozzle A for three ambient pressures

EFFECT OF D+ BEAM MOMENTUM ON JET

- Pressure from D+ beam on Li jet:

$$P = m_D v_D \Phi, \qquad \Phi = D^+ \text{ flux}$$

- Force on jet: $F = \frac{P}{A,}$

- Acceleration of jet in beam direction:

$$\omega = \frac{F}{Ah\rho}, \qquad h = \text{jet thickness}$$

- Displacement of jet in beam direction:

$$\Delta Z = \omega \left(\frac{L_B}{v} \right)^2, \qquad L_B = \text{beam length}, \quad v = \text{jet velocity}$$

- For 35MeV D+ beams with total current of 250 mA, beam area A= 0.05x0.2 m2, jet thickness h=2 cm and velocity v=15 m/s:

$$P = 30 \text{ Pa}$$
$$\Delta Z = 0.03 \text{ mm}$$

- Since the beam does not transfer all its momentum to the surface, Δz will be larger, but should be less than 1 mm

THERMODYNAMIC STABILITY CONSIDERATIONS

- At the target vacuum condition of 1.e-4 Pa, the saturation temperature of Li is ~300°C

- The internal peak Li temperature can be substantially higher, raising concerns about the possibility of nucleate boiling in the jet

- Thermal hydraulic analysis of the jet with incident beam is needed to evaluate its thermodynamic stability

Li JET THERMAL RESPONSE

- Jet thermal response was computed using the BKHEAT code[+] (3D thermal hydraulic code developed for fusion liquid metal blankets) assuming slug flow profile

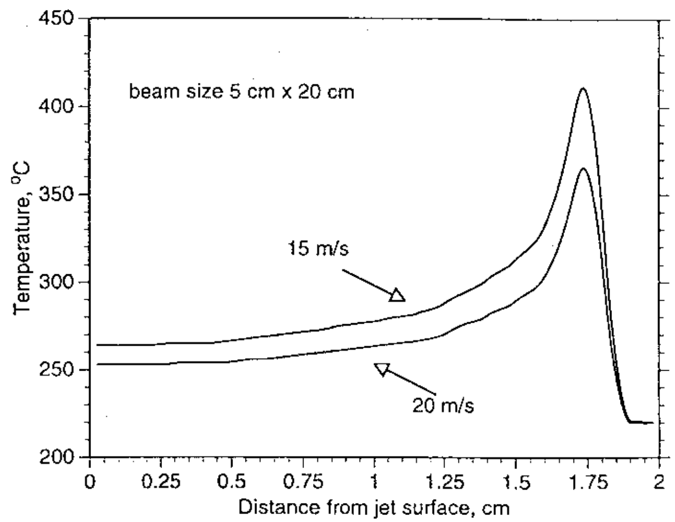
- Results agree well with A. Hassanein's thermal hydraulic analysis (Task CDA-T-I-1.2, presentation at this workshop)

- Temperature of importance:

    - surface temperature, determines vaporization rate

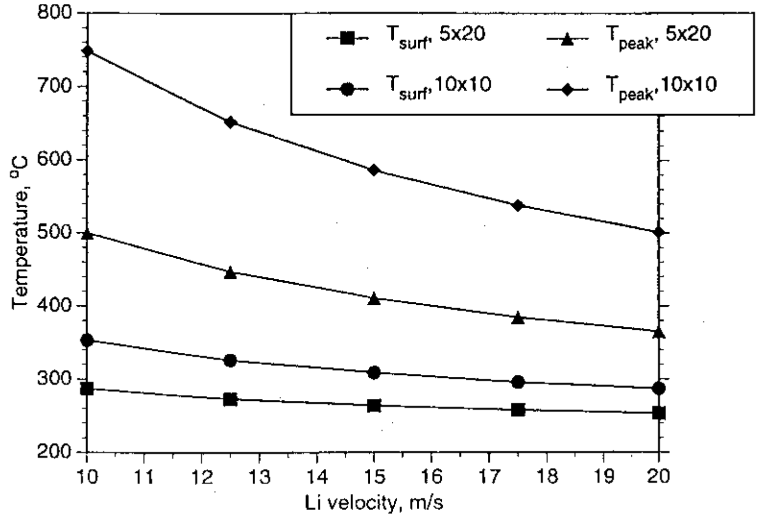
    - peak temperature, superheat and nucleate boiling possibility

Peak temperature profile in Li jet, inlet temp=220 C
beam current=250 mA, 35MeV Gaussian beam



[+] T. Hua and B. Picologlou, *Fusion Technol.*, Vol 15, No. 2, Part 2B (1989)

Peak and surface temperatures for 2 different beam sizes:
5 cm x 20 cm, and 10cm x 10 cm
35 MeV, 250 mA, Tin = 220 C



THERMODYNAMIC STABILITY - BULK NUCLEATE BOILING

- Simple force balance of vapor buble:

$$p_v - p_\ell = \frac{2\sigma}{r}$$

$\log p_v = 15.124 - 1.640 \log T + 2.597 \times 10^{-4}\, T$ T in K

$\sigma = 1.6 \times 10^{-4}\, (3550 - T) - 9.5 \times 10^{-2}$

- At 800°C (FMIT Li jet peak temperature), p_v = 370 Pa, p_l = 1.e-4 Pa, σ = 0.30 N/m,

$\rightarrow$ r = 1.6 mm

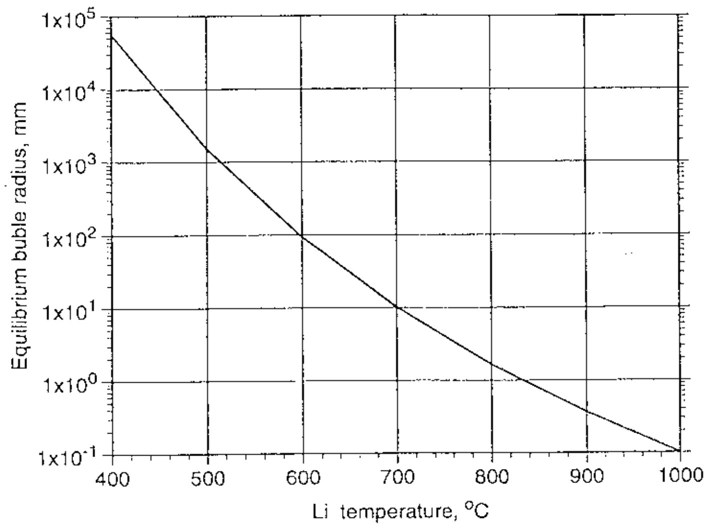
nucleate boiling is possible

- At 500°C (IFMIF conditions), p_v = 0.5 Pa, p_l = 1.e-4 Pa, σ = 0.35 N/m,

$\rightarrow$ r = 1.4 m

bulk nucleate boiling will not occur

Buble Radius under Condition of Mechanical Equilibrium



THERMODYNAMIC STABILITY - HETEROGENEOUS NUCLEATION

- In heterogeneous nucleation, boiling may be initiated by tiny gas bubles (mixture of vapor and inert gas). Then

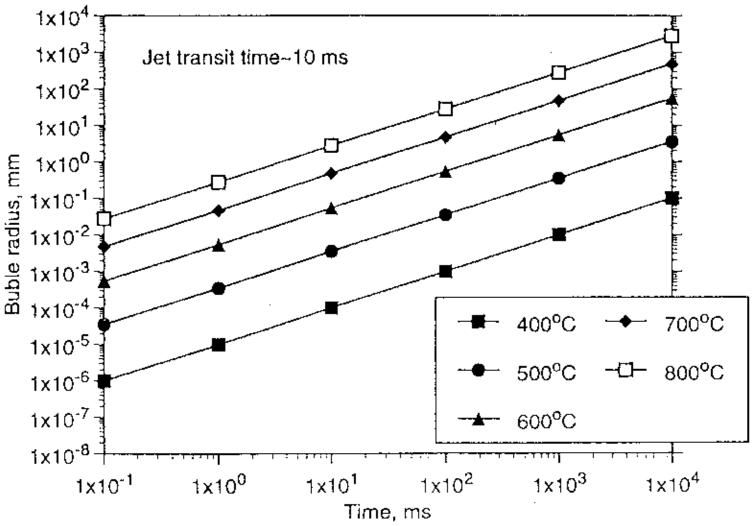
$$p_v - p_\ell = \frac{2\sigma}{r} - p_G$$

p_G is the partial pressure of the inert gas

- A slight increase in p_v will make the buble unstable and cause it to grow

- The growth of these bubles are computed for various Li temperatures

Buble growth rates in Li jet at peak temperature
Ambient pressure = 1.e-4 Pa
Saturation temp = 300 C



CONCLUSIONS

- A free jet may be a viable option for the target. The jet appears to be dynamically and thermodynamically stable under IFMIF operating conditions

- The free jet concept offers major advantages including longer target lifetime, higher facility availability, simple maintenance scheme, and reduced radioactive waste

- Hydraulic stability testing will be needed, preferably using Li or a comparable fluid in a low pressure environment

- Lithium flow velocity as low as 10 m/s is sufficient provided the lithium vaporization rates are acceptable

- Issues of interface between target system and test assembly for free jet option need to be investigated

1.3 Thermal Hydraulic Analysis of Lithium Jet with Incident Beam

Ahmed Hassanein

Argonne National Laboratory
USA

Presented at the 1st IFMIF-CDA Technical Workshop on Li Target System

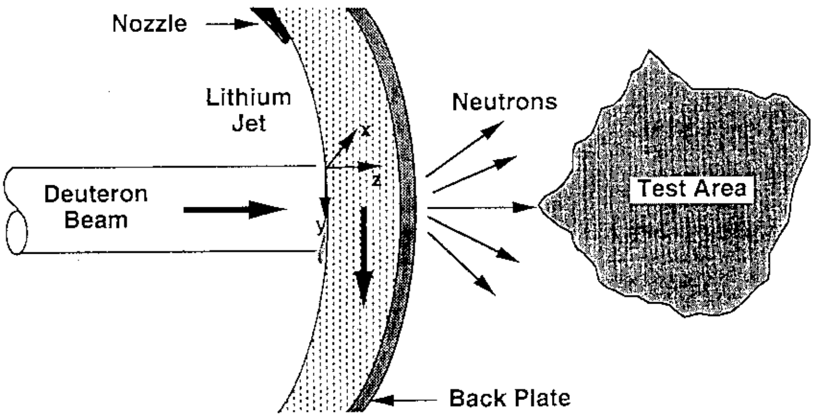
July 18-21, 1995

JAERI, Japan

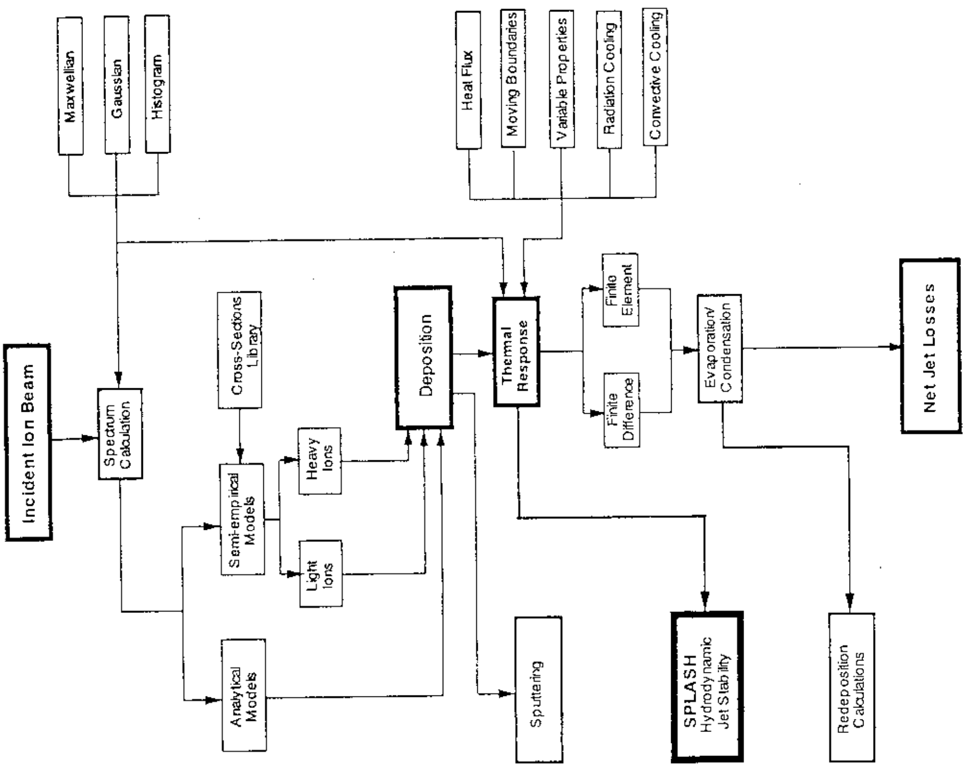
Analysis

- The deposition and the response of lithium jet due to bombardment of high-energy deuterons are modeled with the HIJET code.
- The code uses several analytical models to calculate the energy loss of ion beam through both electronic and nuclear stopping powers.
- The code then calculates detailed thermal response of the jet (and the supporting back plate) using several numerical methods.
- Models to calculate net surface evaporation rate of the Li jet are also implemented in the code.
- Jet mass and momentum conservation equations are solved to evaluate jet stability.

Schematic Illustration of Beam-Target Interaction for a Neutron Source Test Facility



HIJET Computer Code



A. HASSANEIN (ANL)
JAPAN 7-95

Beam on Target Interactions

I. Energy Deposition
- inelastic interactions
- elastic collisions

II. Thermal Response of Li Jet

III. Jet Thermal Expansion

IV. Jet Mechanical Response

I. Energy Deposition

- The general Bethe equation is used to describe the bound-electron stopping power and has the form

$$\frac{dE}{dx} = \frac{4\pi N_o Z_{eff}^2 \rho e^4 Z_2}{m_e c^2 \beta^2 A_2} \left[\ln\left(\frac{2 m_e c^2 \beta^2 \gamma^2}{i} \right) - \beta^2 - \sum_i c_i / Z_2 \right],$$

where,

Z_{eff}	=	effective charge of the projectile ion,
N_o	=	Avogadro's number,
ρ	=	density of the stopping medium,
A_2	=	atomic weight of the stopping medium,
Z_2	=	atomic number of the stopping medium,
β	=	(particle velocity)/c,
c	=	velocity of light in vacuum,
m_e	=	electron rest mass,
i	=	average ionization potential,
$\Sigma c_i / Z_2$	=	sum of the effects of shell corrections on the stopping charge, and
e	=	electronic charge.

I. Energy Deposition (continued)

- For low-energy ions, Bethe theory is not appropriate and instead Lindhard model is used. The electronic stopping power is given by:

$$\frac{dE}{dx} = C_{LSS}E^{1/2},$$

where C_{LSS} is a constant.

- Nuclear stopping due to elastic collisions becomes significant at low ion energies and is given by:

$$\frac{dE}{dx} = \rho C_n E^{1/2} \exp\left[-45.2(C_n' E)^{0.277}\right],$$

where

$$C_n = \frac{4.14\times10^6}{A_1^{1/2}}\left(\frac{A_1}{A_1+A_2}\right)^{3/2}\left(\frac{Z_1Z_2}{A_2}\right)^{1/2}\left(Z_1^{2/3}+Z_2^{2/3}\right)^{-3/4},$$

$$C_n' = \frac{A_2}{(A_1+A_2)}\frac{1}{Z_1Z_2}\left(Z_1^{2/3}+Z_2^{2/3}\right)^{-1/2}.$$

- The total stopping power is given by taking the minimum of either Bethe or Lindhard electronics stopping power and then adding to it the nuclear stopping power.

II. Thermal Response

- The thermal response of the Li jet is calculated by solving a time-dependent heat conduction equation which is given by:

$$\rho C_p \frac{\partial T}{\partial t} = \nabla\cdot(K\nabla T) + \dot{q}\,(y,Z,t)$$

where,

T is temperature,

ρ is density,

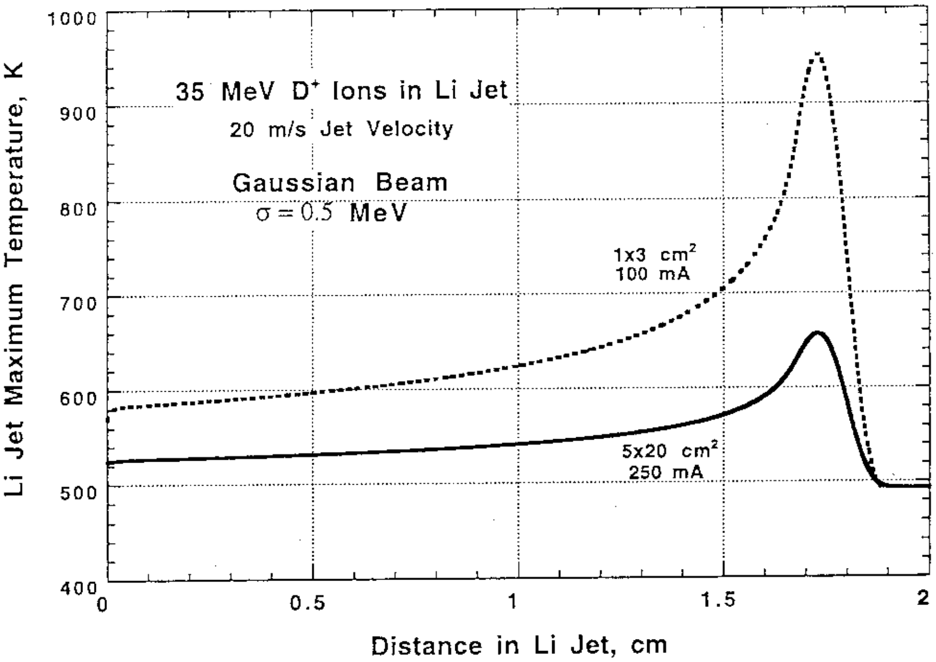
C_p is specific heat,

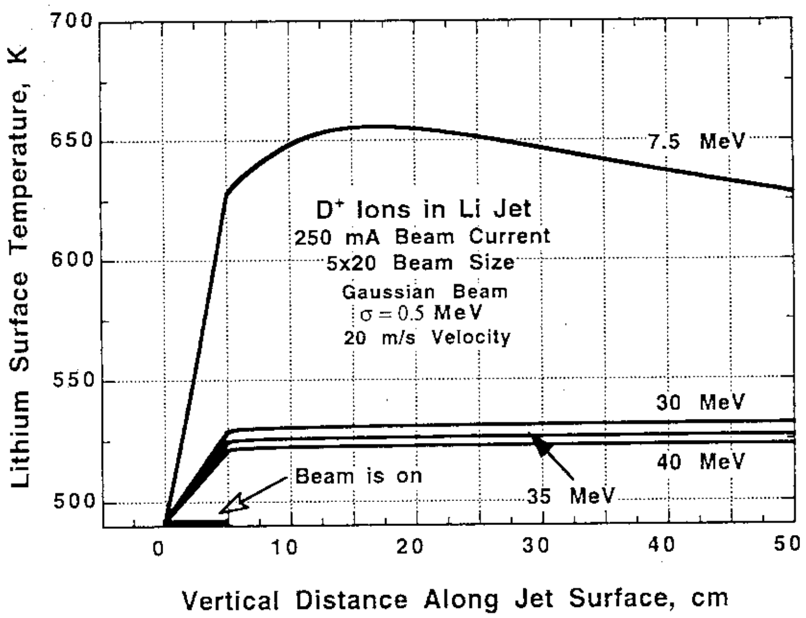
K is thermal conductivity, and

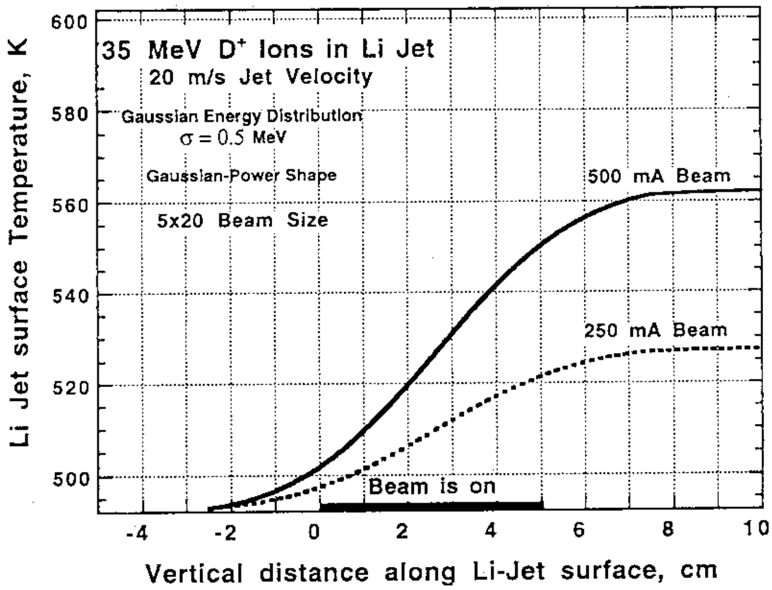
$\dot{q}$ is the volumetric energy deposition rate of the incident deuteron beam.

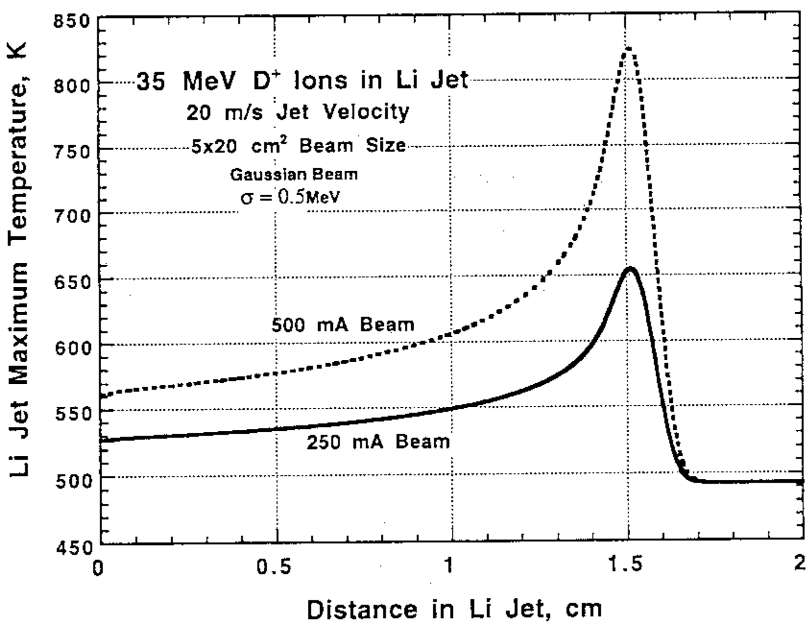
- All thermophysical properties are assumed to be a function of local temperature.

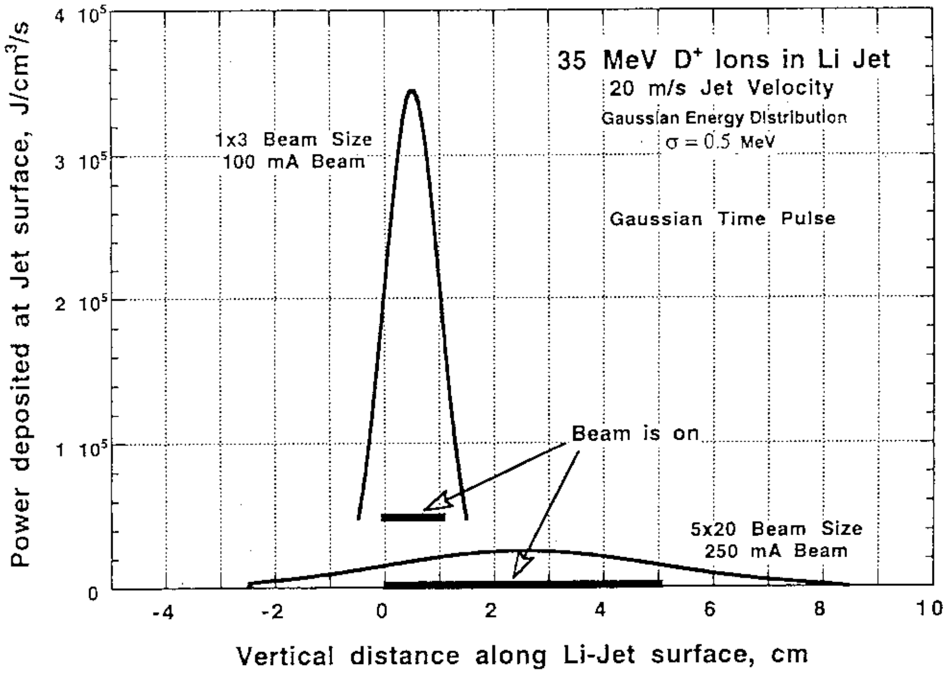
- Several boundary conditions can be used to evaluate different design options such as free jet or a back-plate supported jet.


35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
Gaussian Beam
σ = 0.5 MeV
1x3 cm2
100 mA
5x20 cm2
250 mA
Li Jet Maximum Temperature, K
Distance in Li Jet, cm

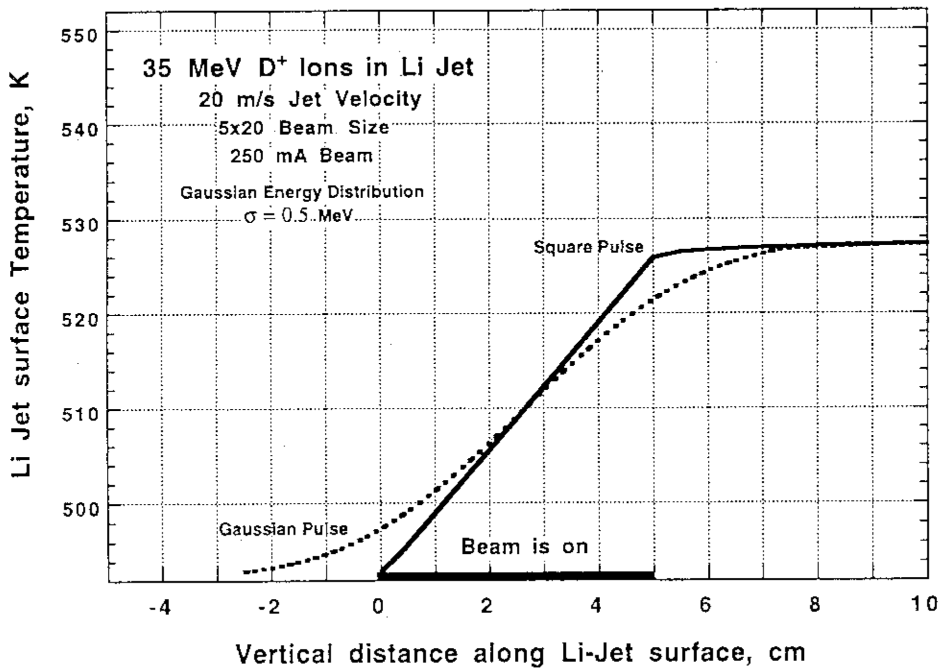

7.5 MeV
D+ Ions in Li Jet
250 mA Beam Current
5x20 Beam Size
Gaussian Beam
σ = 0.5 MeV
20 m/s Velocity
30 MeV
40 MeV
Beam is on
35 MeV
Lithium Surface Temperature, K
Vertical Distance Along Jet Surface, cm


35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
Gaussian Energy Distribution
σ = 0.5 MeV
Gaussian-Power Shape
5x20 Beam Size
500 mA Beam
250 mA Beam
Beam is on
Li Jet surface Temperature, K
600
580
560
540
520
500
-4
-2
0
2
4
6
8
10
Vertical distance along Li-Jet surface, cm

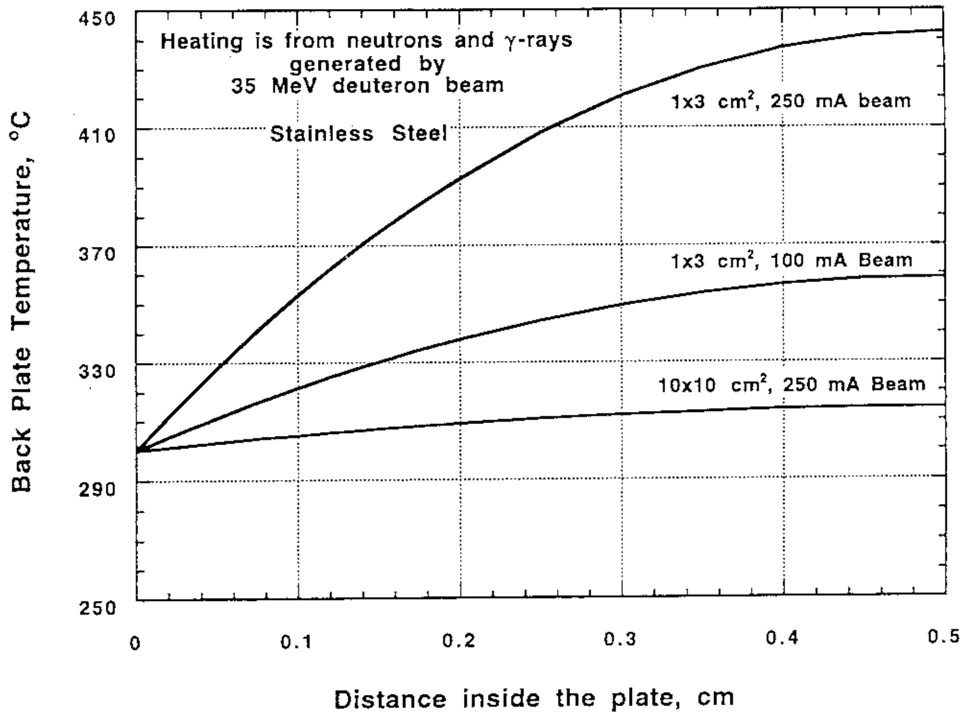

35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
5x20 cm2 Beam Size
Gaussian Beam
σ = 0.5MeV
500 mA Beam
250 mA Beam
Li Jet Maximum Temperature, K
850
800
750
700
650
600
550
500
450
0
0.5
1
1.5
2
Distance in Li Jet, cm

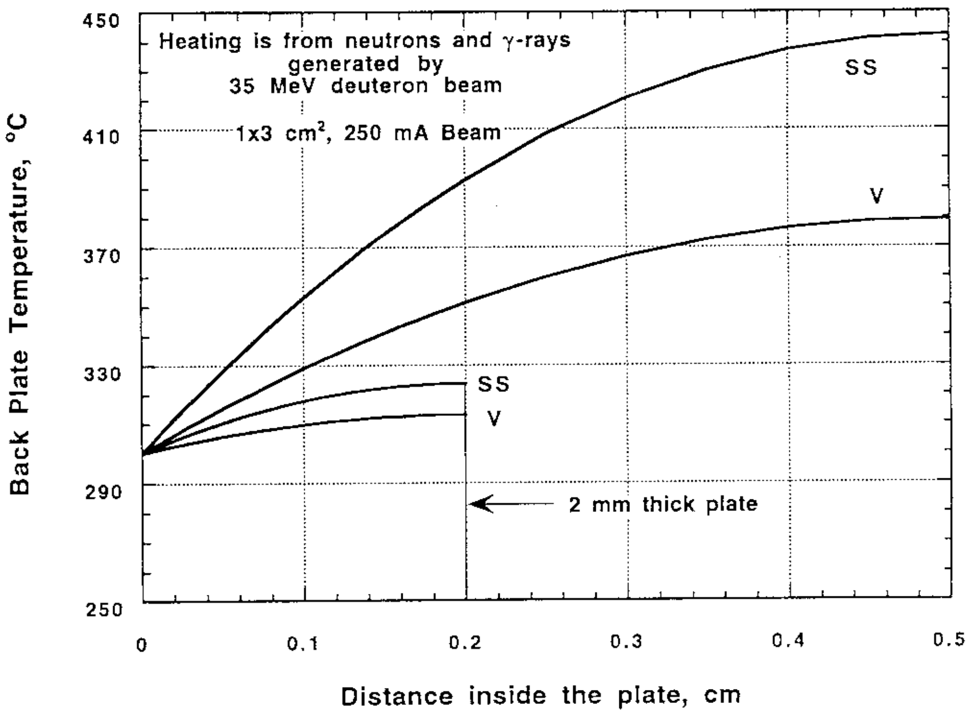


35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
Gaussian Energy Distribution
σ = 0.5 MeV
Gaussian Time Pulse
1x3 Beam Size
100 mA Beam
Beam is on
5x20 Beam Size
250 mA Beam
Power deposited at Jet surface, J/cm3/s
4 10^5
3 10^5
2 10^5
1 10^5
0
-4
-2
0
2
4
6
8
10
Vertical distance along Li-Jet surface, cm



35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
5x20 Beam Size
250 mA Beam
Gaussian Energy Distribution
σ = 0.5 MeV
Square Pulse
Gaussian Pulse
Beam is on
Li Jet surface Temperature, K
550
540
530
520
510
500
-4
-2
0
2
4
6
8
10
Vertical distance along Li-Jet surface, cm


Heating is from neutrons and γ-rays generated by 35 MeV deuteron beam
Stainless Steel
1x3 cm², 250 mA beam
1x3 cm², 100 mA Beam
10x10 cm², 250 mA Beam
Back Plate Temperature, °C
450
410
370
330
290
250
0
0.1
0.2
0.3
0.4
0.5
Distance inside the plate, cm


Heating is from neutrons and γ-rays generated by 35 MeV deuteron beam
1x3 cm², 250 mA Beam
SS
V
SS
V
2 mm thick plate
Back Plate Temperature, °C
450
410
370
330
290
250
0
0.1
0.2
0.3
0.4
0.5
Distance inside the plate, cm

Conclusions

- Deuteron energy deposited and the resulting Li target heating calculations seem to be manageable for beam and jet parameters analyzed.

- Larger beam sizes reduce thermal load inside the jet and increase available test volume.

- Thermal loads in the supporting back plate are more tolerable with thinner plates.

- Velocity perturbations resulting from jet-thermal expansion and from beam deposited-momentum seem to be small and may not threaten beam stability.

1.4 Overview and Relation with Another Tasks

IFMIF-CDA Li-target System Task Document (CDA-T-I-1)

Preliminary analysis for the Li - target (JAERI T. W. 18-8)

Y. Kato
IFMIF Target System Group of JAERI/JAPAN

1. Introduction

For the IFMIF reference target of 5 x 20 cm^2, analysis of the thermal and fluid dynamics have been made on the bases of the FMIT and ESNIT models. However, these analyzes are limited in the phenomena of the inside lithium jet flow. Other important problem, the stability of free surface lithium jet, is one of the critical issue of the target design and it could be only confirmed by the experiment. Some water loop experiments will be started in JAERI from this fall.

2. Overview of the thermal and fluid dynamics

Following conditions have been assumed in the analysis for the 35MeV (30-40 MeV), 250 mA deuteron beam:

a) Asymmetric nozzle
b) Stability of the free surface of jet flow is well satisfied
c) Backwall curvature of 25 cm
d) Adiabatic heat condition of the backwall
e) Swelling of the backwall is small enough
f) Beam intensity is uniform and the energy is modulated to have $\sigma = 0.5$ MeV on gaussian spectrum.
g) Lithium vapor pressure near the free surface is 10^{-4} Pa

Under these conditions, the results of analysis for the IFMIF reference target (total current: 250 mA, beam on target area: 5 x 20 cm^2) shows that the boiling margin at the peak of deuteron beam energy deposition is large enough but rather severe at the near surface region.

The maximum limit of deuteron beam current can be tentatively defined by the boiling margin at the near free surface and the results are shown in (JAERI T.W.18-8, M. Ida et al.). We can see that the maximum current of about 320 mA will be possible in the case of deuteron energy of 35 MeV and average lithium flow velocity is 20 m/s. The value of this maximum current seems to be conservative. Because the restriction effects by surface tension of the lithium and by short time of passing the target region for the void nucleation and growth are not considered in these evaluations

The another methods to be able to get the increased deuteron current are:

I) Increase the free surface velocity of target jet flow
II) Increase the vapor pressure near by the free surface of jet flow

Above ideas will be proposed and discussed in (JAERI T.W. 18-8), (JAERI T.W. 19-1) and (JAERI T.W. 19-3) respectively.

3. Plan of water experiment in JAERI

To confirm the stability of target jet flow for the IFMIF reference target we plan to do the simulation by JAERI water test loop. This experiments include the following test items as options:

a) symmetric nozzle with 2-step reducer
b) down flow diffuser for recovering the static pressure

For the item a) some experiments with simple reducer had been performed in FMIT but it was not adopted by some reasons. Now we reconsider these problems and propose a new reducer to get easy design parameter of the nozzle shape and to increase the free surface velocity (JAERI T.W. 19-1, H, Nakamura).

For the second item b), some basic studies have been made by K. Miyazaki of Osaka Univ. He confirmed the condition of stable flow and pressure recovering. If the Li-system is designed and operated to satisfy this condition the static pressure of 1atm can be obtained at the diffuser outlet. It means that the pressure of quench tank cover gas is able to set 1atm and then the height of the Li loop system can design to be shorter than the case of FMIT type target assembly. This is because the suction side of EMP need not to get the static pressure by the Li height to avoid cavitation.

4. Plans to the next stage

Some nozzle models (symmetric and asymmetric) will be analyzed corresponding with the water experiment plan. The 3-dimensional flow analysis will also be made for the estimation of the side wall effect.

The results of the water experiment will be made feedback to the design of target assembly and we will make its further structural design considering the exchange by remote handling . The target assembly of FMIT type(reference type) and new JAERI type(option) will be both considered in our design work until next summer and the final decision will be made after discussion with each other till next fall.

1. 5 Thermal and Fluid Dynamics of Li Target Flow

IFMIF-CDA Li-Target System Task Document (CDA-T-I-1)

Preliminary analysis for the Li-Target (JAERI T. W. 18-8)

M. Ida, Y.Kato, H.Nakamura
IFMIF Target System Group of JAERI/Japan

1. Introduction

For Li target, two kinds of analysis are described in this paper. The first one is an analysis of the thermal and fluid dynamics with a specific type of asymmetric nozzle. The second one is an analysis of the fluid dynamics with a another type of symmetric nozzle.

For IFMIF reference target of 50 x 200 mm^2, we should make certain of no boiling in Li jet. The first analysis was made in order to find whether boiling may occur or not. A specific type of asymmetric nozzle was chosen tentatively. Calculated Li temperature was compared with boiling point obtaind by calculated pressure.

As the result of the first analysis, it is found that there would be no boiling. To get more current of D^+ beam, we need an adequate nozzle with higher Li velocity at free surface and uniformity of velocity distribution. The second analysis was made in order to get an adequate nozzle. We propose a double reducer type symmetric nozzle. The water loop test (JAERI T.W. 18-8) is now under planning to use this nozzle too.

2. Analysis of the Thermal and Fluid dynamics for Li-Target

Following 4 cases of analysises were made.

Case 1 : E=35MeV, V=20m/s
Case 2 : E=35MeV, V=17m/s
Case 3 : E=30MeV, V=20m/s
Case 4 : E=30MeV, V=17m/s
(E : D^+ energy, V : average Li flow velocity)

The analysis consists of following 2 steps for the precision in calculation.

Step 1 : analysis of fluid dynamics for nozzle and jet region (Fig.1)
Step 2 : analysis of thermal and fluid dynamics for jet region (Fig.2)

Using the code FLOW-3D, static and 2-dimensional analysis have been made.

2.1 Inputted and Assumed Condition

a) Velocity distribution : Uniform at the inlet of Step 1
b) Heat condition : Adiabatic on the backwall and free surface
c) Properties of Li : Constant in Step 1 (temperature is 500K)
Function of temperature in Step 2
d) Estimation of viscosity : k-e turbulent model
e) Compressibility : Incompressible
f) Temperature of Li : 220C at the inlet
g) Heat distribution generated by D^+ beam :
Energy of D^+ : 35MeV (Case 1, Case 2)
30MeV (Case 3, Case 4)
(modulated to have SD=0.5MeV on Gaussian spectrum)
Current of D^+ beam : 250mA
Width of D^+ beam : 200mm
Height of D^+ beam : 50mm

2.2 Results

(1) Velocity distribution (Fig.3 , Fig.5)

The profile in Case 1 was nearly similar to the one in Case 2 and the profile in Case 3 was nearly similar to the one in Case 4. Therefore, we can see that these velocity distributions depend on the nozzle shape and jet thickness rather than the value of average velocity.

Affected by the boundary layer formed in the nozzle region, the velocity at free surface also as at backwall is lower than that in bulk Li. In the D^+ irradiation range, the velocity at free surface is 46~72% of average flow velocity in Case 1.

(2) Temperature of Li (Fig.4 , Fig.6)

The temperature distributions in jet region are shown in Fig.4. With the lower velocity, the temperature at free surface is a little higher than flat temperature region nearby the surface. The maximum value of Li temperature were shown at the location of 14.8mm depth (Case 1, Case 2) and of 11.0mm depth (Case 3, Case4). These locations nearly agree with the D^+ energy deposition peaks.

In the width of about 2mm inside of the backwall, Li temperature is 220C. Therefore, an analysis with assumption of heat conductivity on backwall will show the same result as this one.

(3) Boiling margin (Fig.6)

The distributions of Li temperature and boiling point are shown in Fig.6. The boiling point is the function of calculated pressure in Li jet. At the free surface, the boiling margin is not so much as at the maximum temperature point in Li jet. Therefore, with these nozzles and these D^+ energy deposition curves, the maximum limit of D^+ beam current is defined by the boiling margin near the free surface. Within this analysis (with the assumption of stability of the free surface of jet flow), we can see that the boiling does not occur in any case. (see Table 1)

2.3 Summary of the first analysis

In this analysis, we can summarize as follows :

(1) Affected by the boundary layer formed in the nozzle region, the velocity at free surface is lower than that in bulk Li. However, a velocity distribution depends on a nozzle shape and jet thickness.

(2) For these beam condition (E=35MeV,30MeV I=250mA on 50 x 200mm^2) and the average flow velocity of more than 17m/s, with those nozzles, the boiling of Li does not occur in spite of lower velocity at free surface.

(3) The maximum current of 320mA will be possible in the case of D^+ energy of 35MeV and average Li flow velocity of 20m/s.(see Table1) We can get the increased D^+ current with increased velocity at free surface (with improved nozzle).

Table 1 Boiling Margin and Maximum Limit of D^+ Beam

	at Free Surface			at Max. Temp. Point			Max. Limit of D. Beam Current
	T	dT	B.M.	T	dT	B.M.	
Case1	281C	61K	19K	381C	161K	726K	320mA
Case2	291C	71K	9K	408C	188K	668K	280mA
Case3	285C	65K	15K	373C	153K	703K	300mA
Case4	299C	79K	1K	399C	179K	645K	250mA

T : Li Temperature dT : Increase by D. Beam B.M. : Boiling Margin

3. Analysis of the Fluid dynamics for Symmetric Nozzles

We can get more current of D^+ beam by increasing Li velocity at free surface. This analysis was made in order to get an adequate nozzle installed in upstream of the jet (see Fig.7). As a adequate nozzle with high velocity at free surface and uniform velocity distribution, Shima's nozzle (an improved but simplified the Goldstein model based on potential flow theory) was chosen in this analysis.

In this analysis, following 2 types of Shima's nozzles were chosen.

Nozzle 1 : single reducer (Fig.8)
Nozzle 2 : double reducer (Fig.9)

Using the code PHOENICS with body fitted coordinates mesh, static and 2-dimensional analysis have been made.

3.1 Inputted and Assumed Condition

a) Velocity distribution : Uniform at the inlets (Z=300mm)
b) Property of the fluid : Constant as 20C Water
c) Estimation of viscosity : k-e turbulent model
d) Compressibility : Incompressible

3.2 Results

(1) Momentum thickness (Fig.10)

We can see that a thin boundary layer in a nozzle region makes a high velocity at free surface. But, it is difficult to get the precise value of the thickness of boundary layer, which is defined by the location where the velocity is 99% of maximum velocity. Therefore, we estimate the efficiency of nozzle by using the momentum thickness.

After the flow is reduced, both nozzles have very small momentum thickness (0.2mm ~0.3mm at Z=-300mm) . From this point of view, we can choose both nozzles.

(2) Transverse component of velocity (Fig.11, Fig.12)

We can define the "nozzle outlet" as the location where the velocity distribution is uniform. The locations are Z=-60mm for Nozzle 1, and Z=-20mm for Nozzle 2.

At the nozzle outlet, U_2(transverse component of velocity) in Nozzle 2 is smaller than U_1 in Nozzle 1. U_2 soon decreases along flow, but U_1 dose not decrease so soon as U_2. From this point of view, we can see that Nozzle 2 is more desirable than Nozzle 1, because the component U may raise the instability on jet flow.

3.3 Summary of the second analysis

(1) Because of the smooth reducing effect, Nozzle 2 is more desirable than Nozzle 1.

(2) With Nozzle 2, we can get higher velocity at free surface than the asymmetric nozzle which was chosen tentatively in the first analysis.

4 Conclusion

(1) Affected by the boundary layer formed in the nozzle region, the velocity at free surface is lower than that in bulk Li. However, a velocity distribution depends on a nozzle shape and jet thickness

(2) For the IFMIF reference target, the boiling of Li does not occur in spite of using a tentative asymmetric nozzle.

(3) We can get the increased D^+ current with increased velocity at free surface (with improved nozzle).

5 Plans to the Next Stage

(1) Evaluation of the relation between the nozzle shape and the velocity distribution (the velocity distribution near the free surface especially) to get the optimum nozzle with high velocity of the free surface and stability

(2) Stability examination of the free surface with reference target area (confirmed by the water loop test and analysis), which consists of examinations of 3D effect (effects of sidewall, effects of velocity distribution) and time dependent fluctuations

(3) Examination of the maximum value of velocity with stable free surface within the capacity of Li circulation loop

(4) Estimation of super sonic pressure caused at the edge of D^+ beam profile

(5) Error estimation to confirm the boiling margin, which consists of errors in manufacture, fluctuations under operation, and errors in numerical simulation

(6) Verification of the results in this analysis compared with the results in the water loop test.

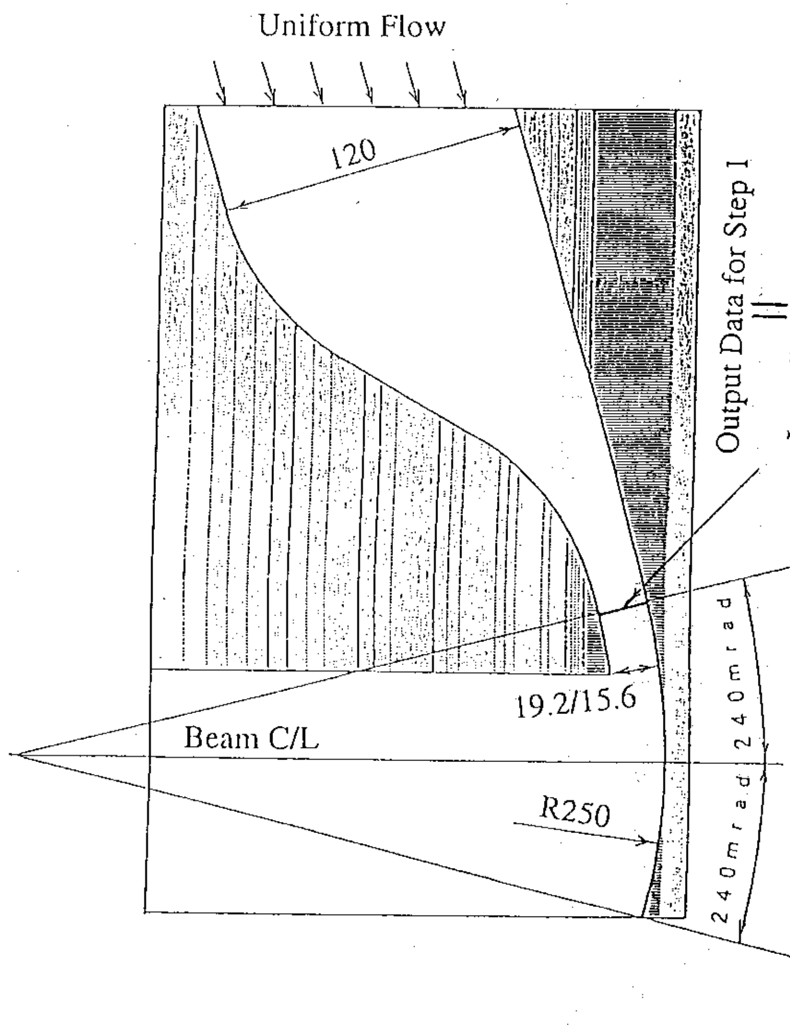


Fig.1 Layout for Analysis-Step 1

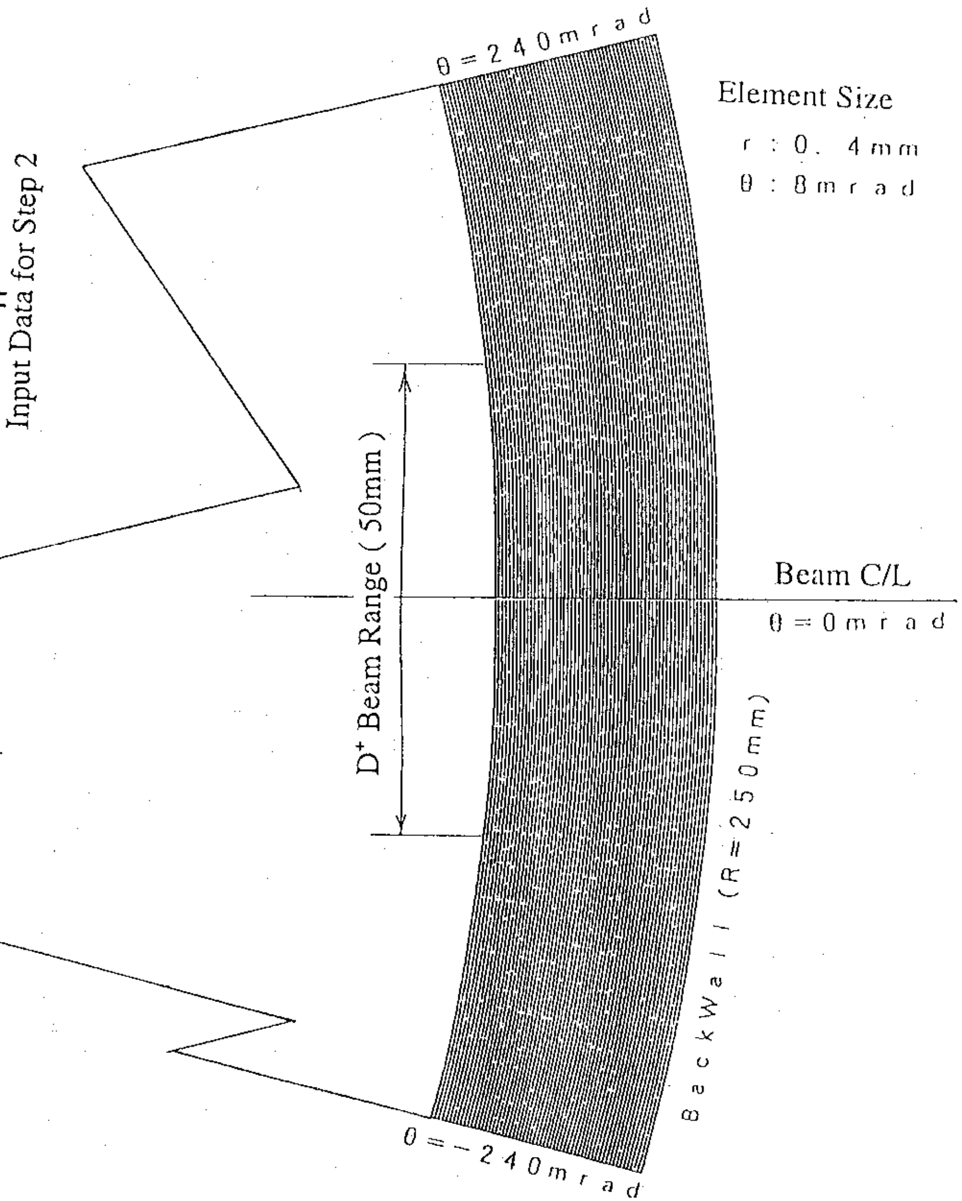


Fig.2 Elemental Layout for Analysis-Step 2

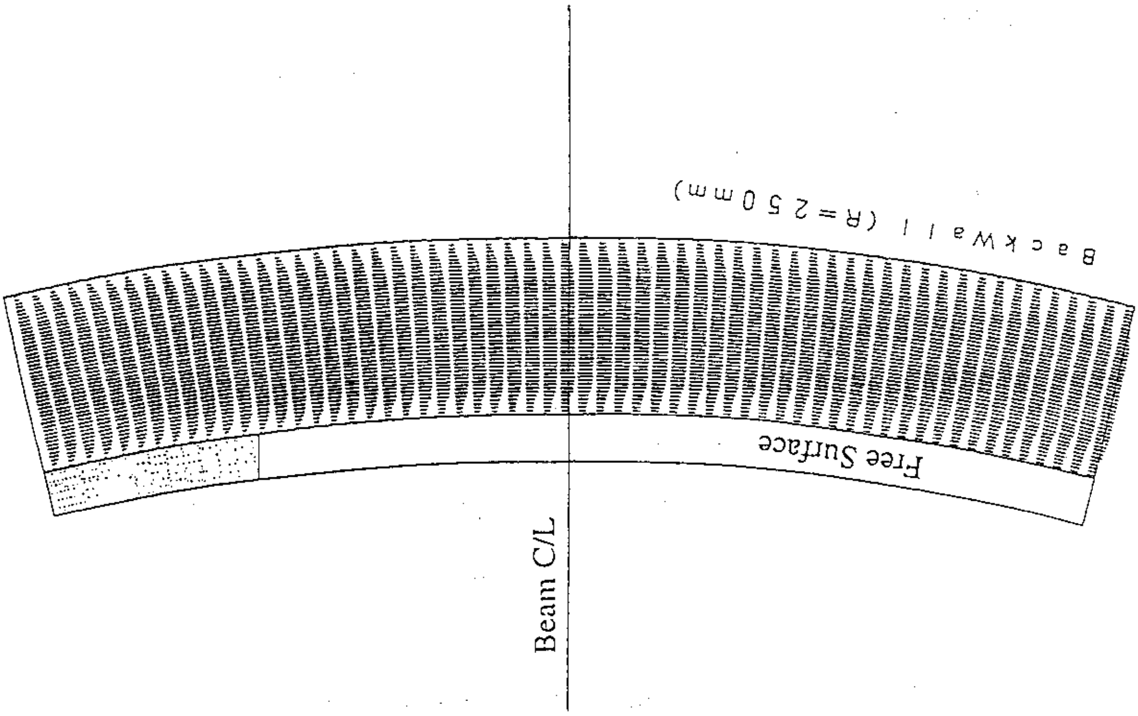


Fig.3 Velocity Vectors in jet region (Case 1)

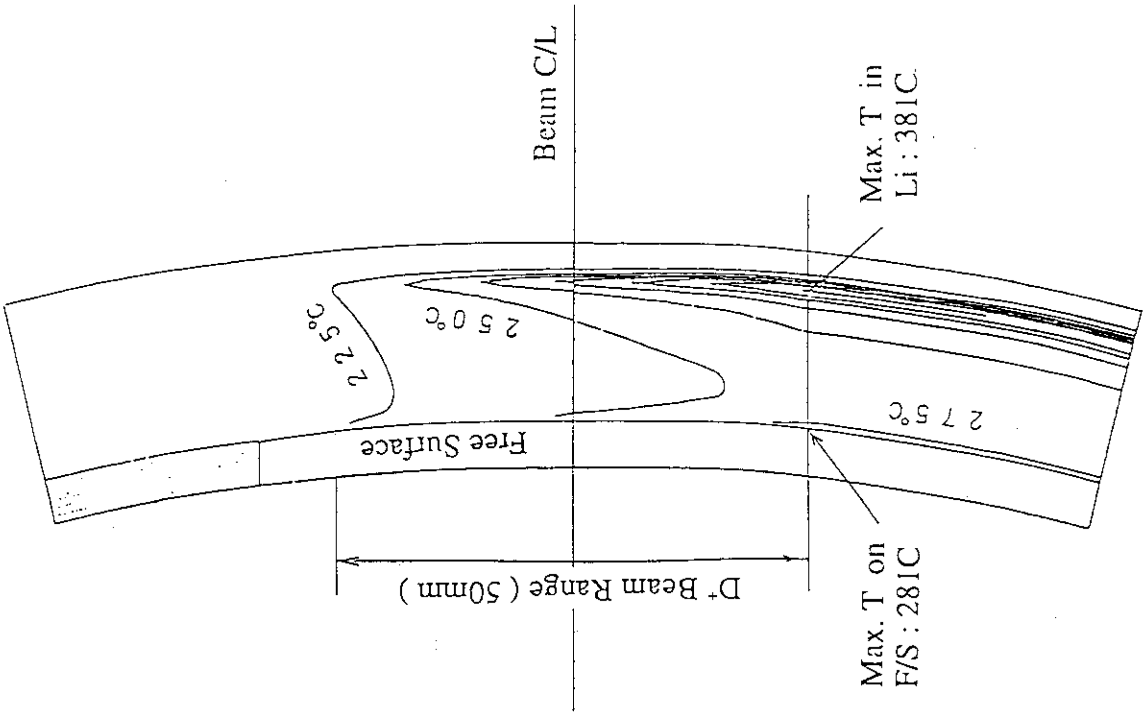


Fig.4 Isotherms for Li jet (Case 1)

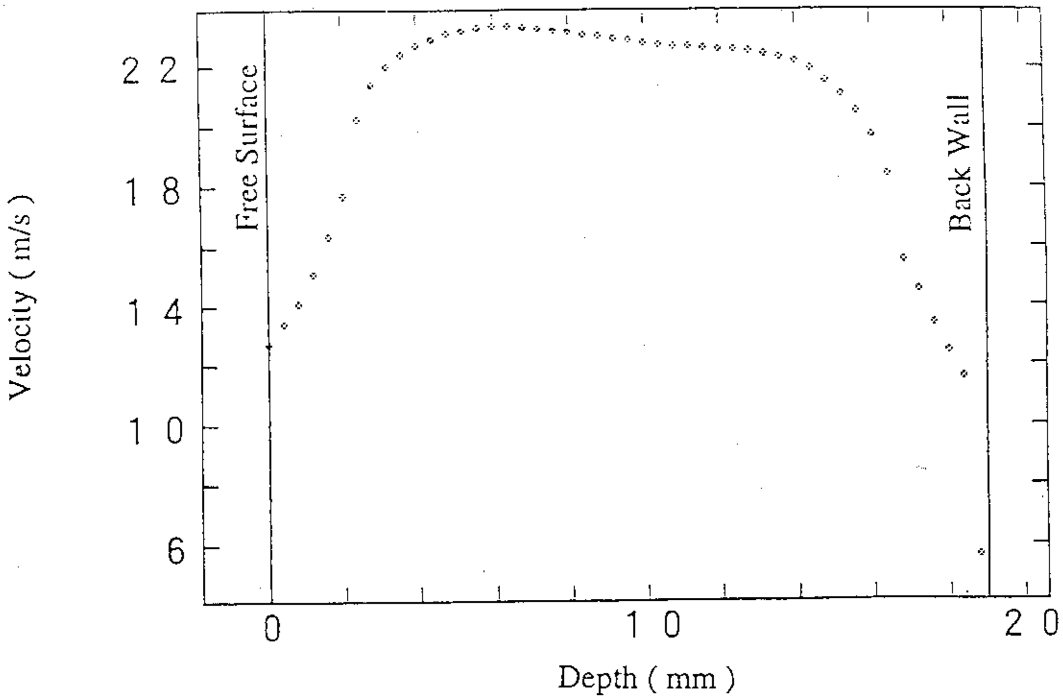


Fig.5 Velocity Distribution at Beam Centerline (Case 1)

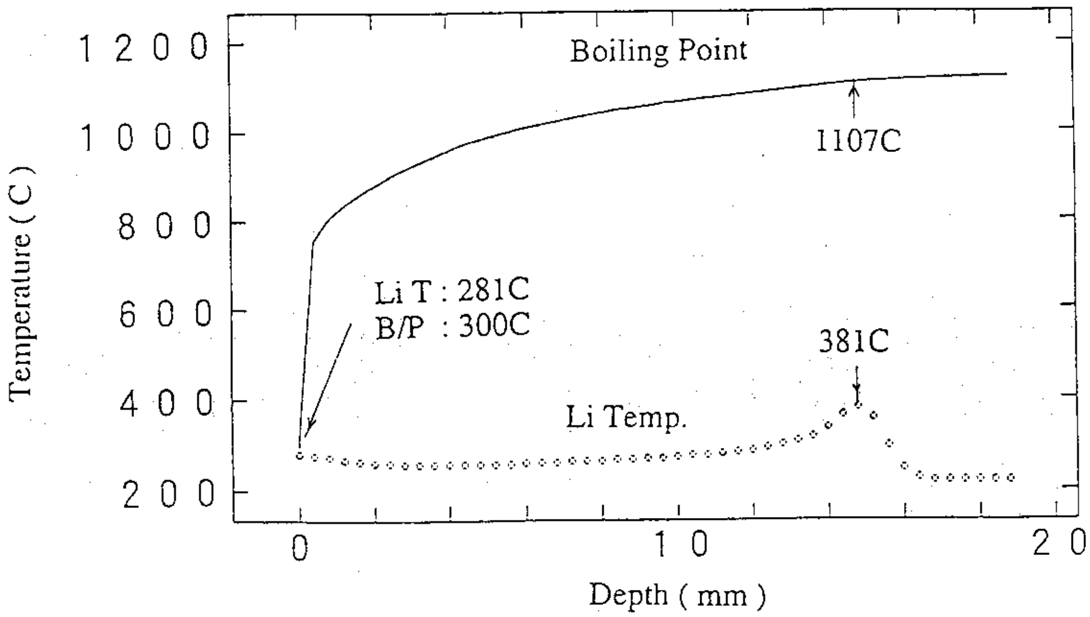


Fig.6 Distribution of Li temperature and boiling point
at Downstream Edge of D+ Irradiation Region (Case 1)

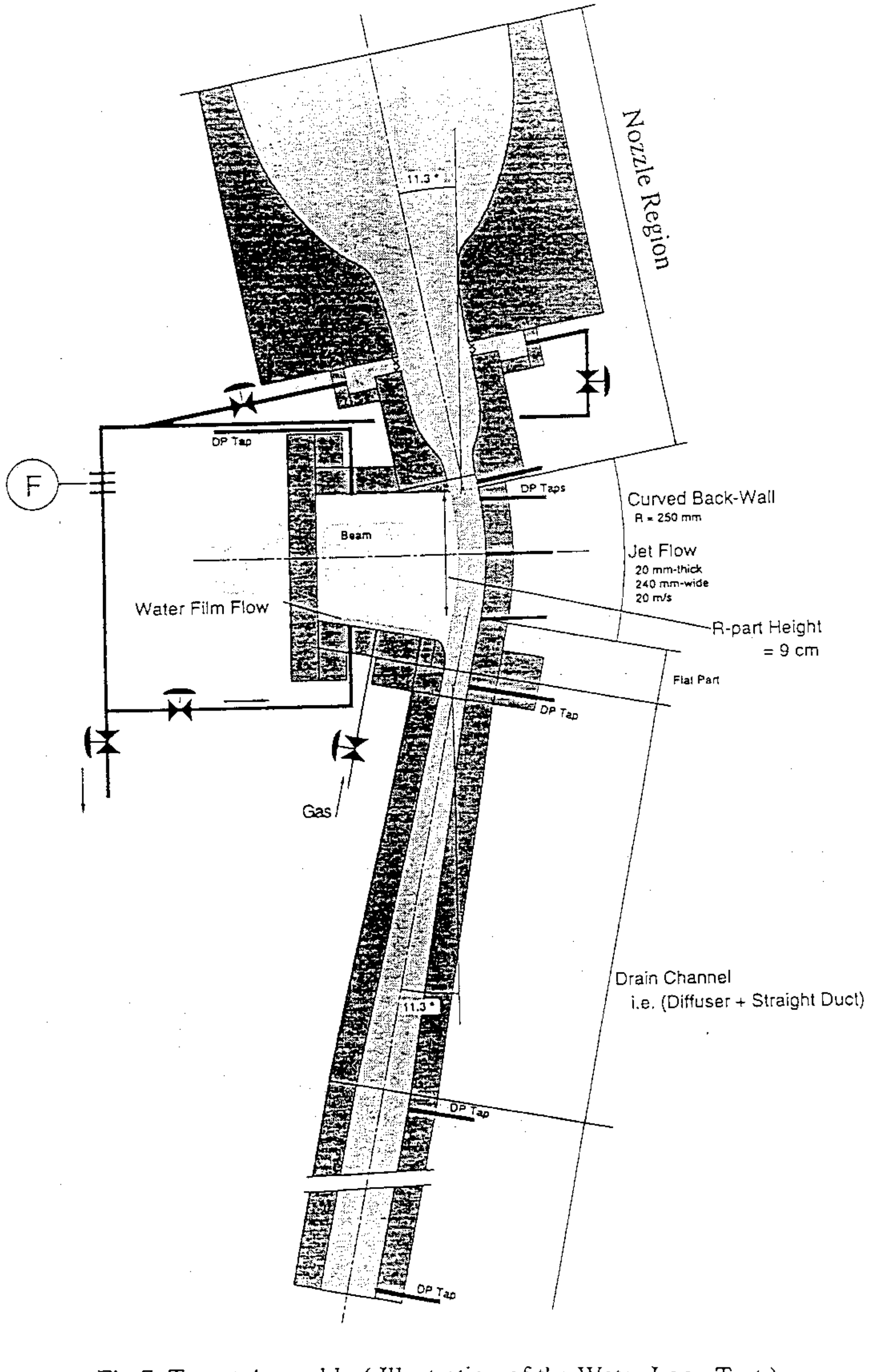


Fig.7 Target Assembly (Illustration of the Water Loop Test)

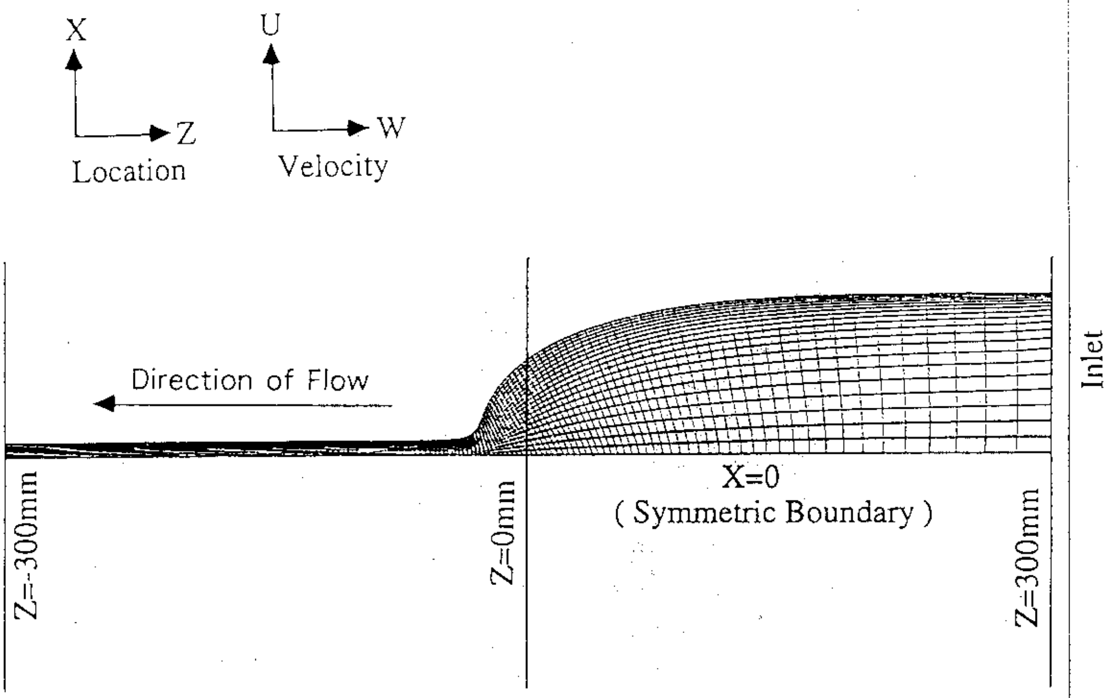


Fig.8 Elemental Layout for Nozzle 1
(a half region is shown)

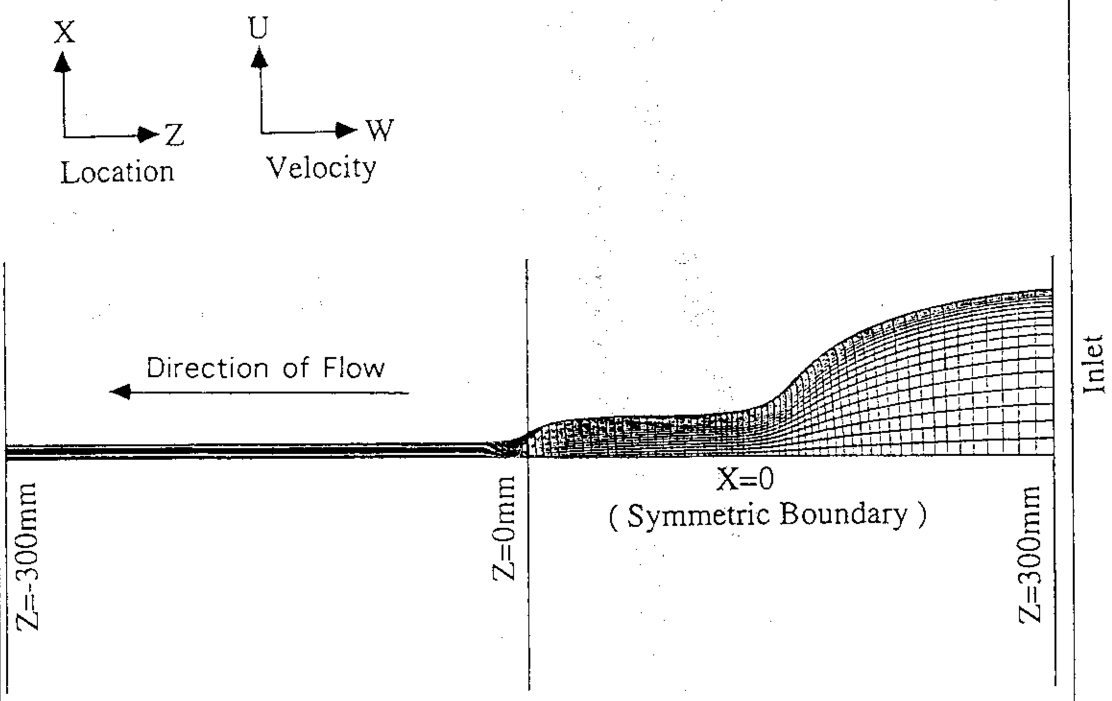


Fig.9 Elemental Layout for Nozzle 2
(a half region is shown)

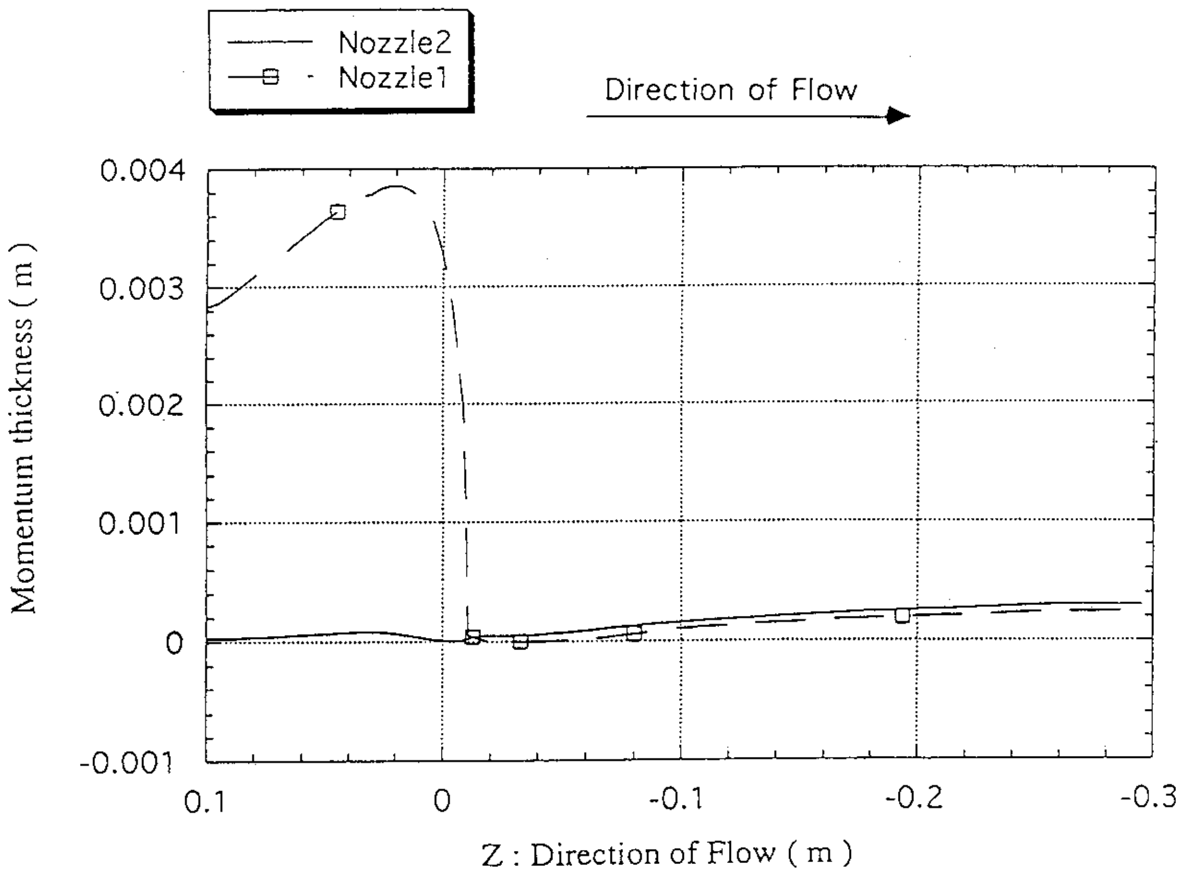


Fig.10 Momentum Thickness along flow

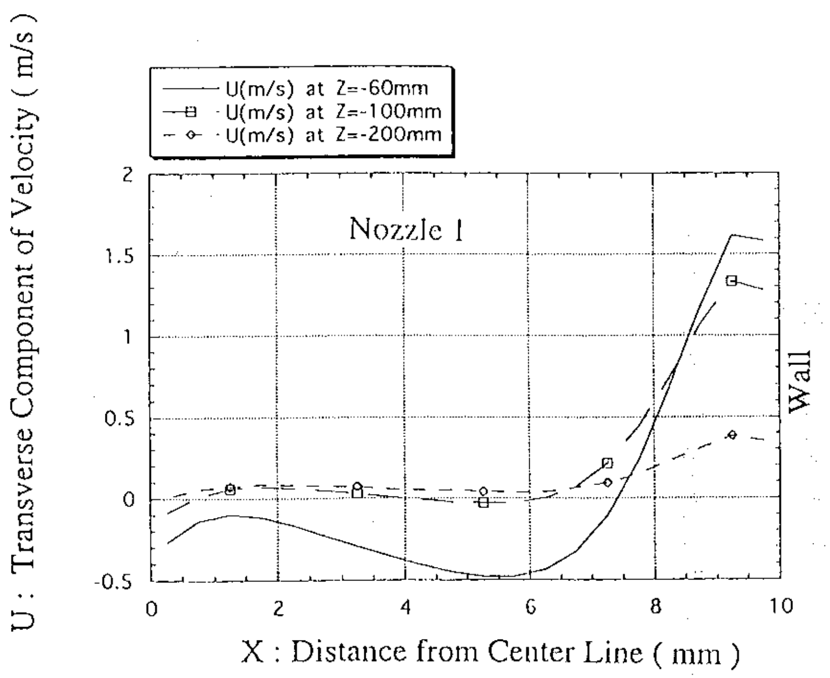


Fig.11 Distribution of Transverse component of velocity at locations from nozzle outlet (Nozzle 1)

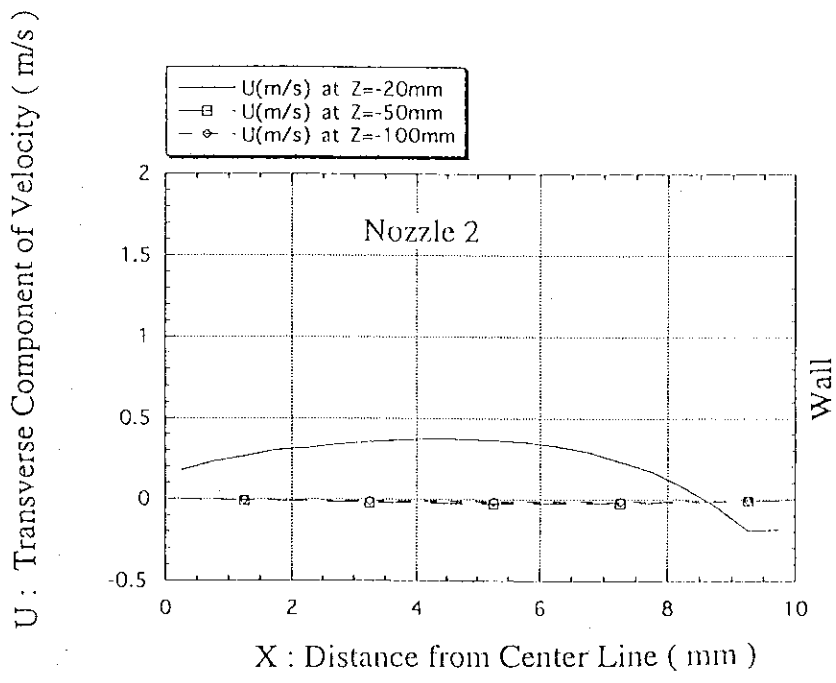


Fig.12 Distribution of Transverse component of velocity at locations from nozzle outlet (Nozzle 2)

1.6 Thermal-hydraulic Analysis of the Lithium Jet

by

S. Cevolani

Objective:	Preliminary thermal hydraulic analysis of the Lithium jet
Design parameters:	as resulting from the Karlsruhe meeting or attempt values
Calculation model:	RIGEL code
Determination of:	- velocity profile - pressure profile - temperature profile - boiling margin profile - evaporation rate

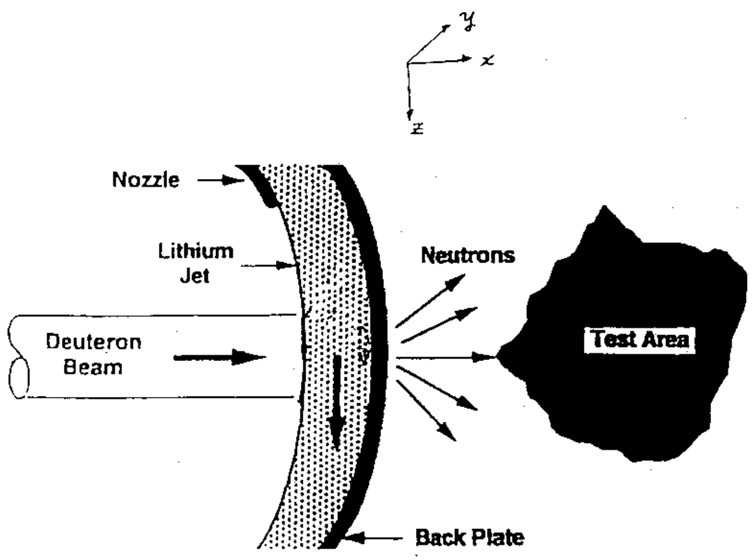


Fig. 1 Lithium Jet Geometry

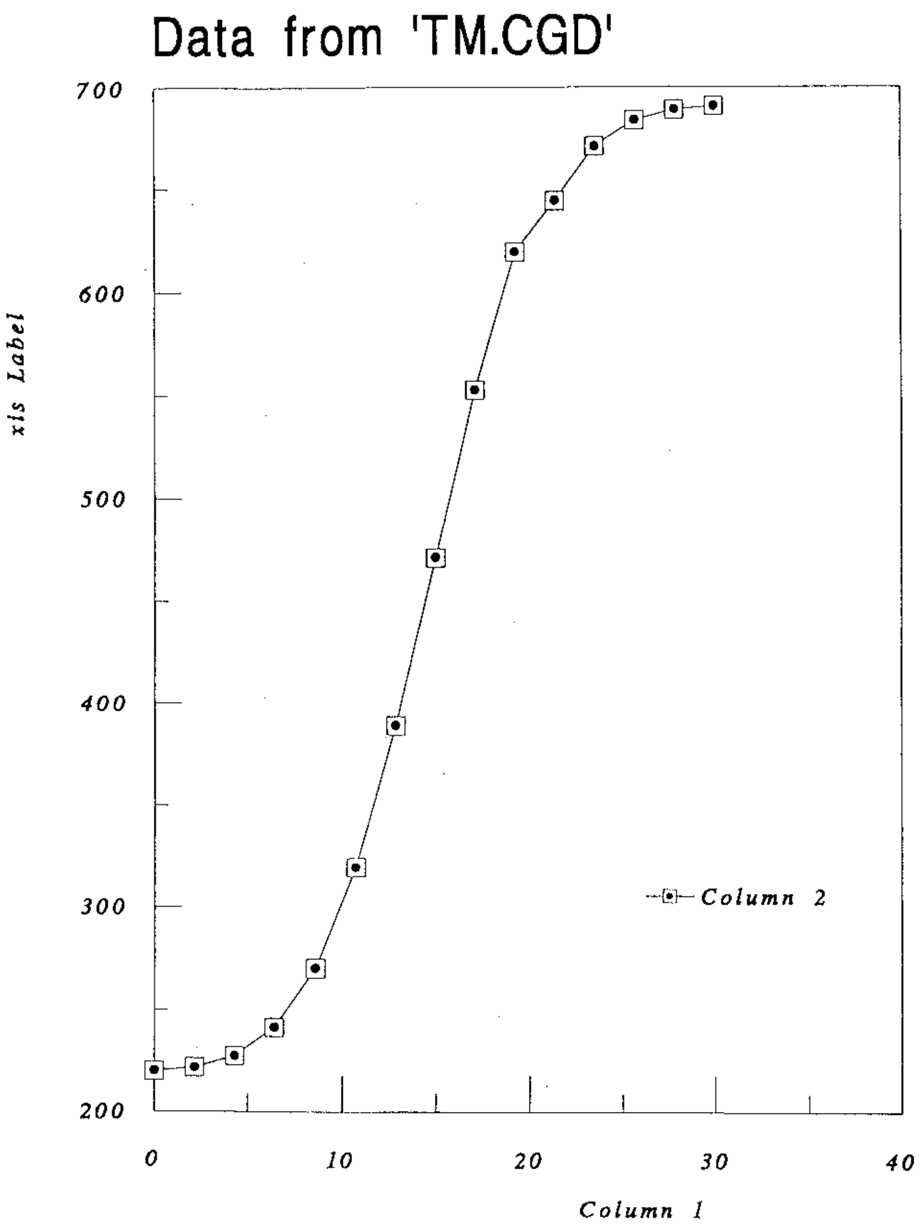
Reference Beam and Jet Parameters as defined during the Karlsruhe Meeting

Reference Beam Interface Parameters:

Beam Current:	250 mA
Beam Width:	20 cm
Beam Height:	5 cm
Beam Distribution:	
Horiz:	Flat (edge peaks are undesirable)
Vert:	Flat with Gaussian edges (sharp gradients are undesirable)
Beam Tails:	TBD (<20 w/cm2) (Beam tails, halos, etc are very undesirable)
Beam Energy:	35 MeV (30 & 40 MeV alternate energies)
Energy Dist.	500 keV 1-sigma gaussian or equivalent (greater may be unnecessary)
Alternate Beam Shapes:	2.5 x 40 (issue: structural stability of wide backwall, pumping power required) 10 x 10 (issue: stability of the jet surface)

Reference Target Parameters:

Jet Width:	22 (to 24 cm)
Jet Height:	7 (to 9 cm)
Jet thickness:	1.9 cm (nominal)
Jet Velocity:	17-20 m/s
Flowrate:	75 - 100 l/s
Inlet Temperature:	220 C
Mixed Outlet Temp:	~ 270 C
Target Material:	TBD
Target Goal Lifetime:	9 full-power months



	unit	value
jet width	mm	220
jet height	mm	70
jet thikcness at the nozzle outlet	mm	19
jet average velocity	m/sec	17
jet temperature at the nozzle outlet	°C	220
beam energy	MeV	35
beam energy distribution (1σ)	KeV	500
beam current	mA	250
heat deposition in lithium	MW	8.75
beam distribution: horizontal (y)	-	flat
beam distribution: vertical	-	gaussian σ=10 mm
backplate curvature radius	mm	250
backplate thickness	mm	3
backplate power generation	KW	4.96
backplate power generation distrib.	-	gaussian σ=10 mm
void chamber pressure	Pa	1.0e-4
jet average outlet temperature	°C	277
jet maximum temperature	°C	409
free surface maximum temperature	°C	261
back plate maximum temperature	°C	269
jet minimum boiling margin	°C	446
free surface minimum boiling margin	°C	24
maximum pressure difference	Pa	12409
evaporation ratio at the free surface	kg/sec	3.27e-11

Tab. Main input data and results

RIGEL

RIproduzione di un GEtto di Litio
(reproduction of a lithium jet)

Main Features:

- 3-D Steady State Thermal Hydraulic Analysis of a Curved Lithium Jet
- 2D analysis repeated *n* times in the third (flow) direction
- velocity profile evolution
- jet thickness evolution
- mixing effect on temperature
- centrifugal acceleration and pressure
- boiling margin
- evaporation from the free surface
- thermal coupling with the back plate

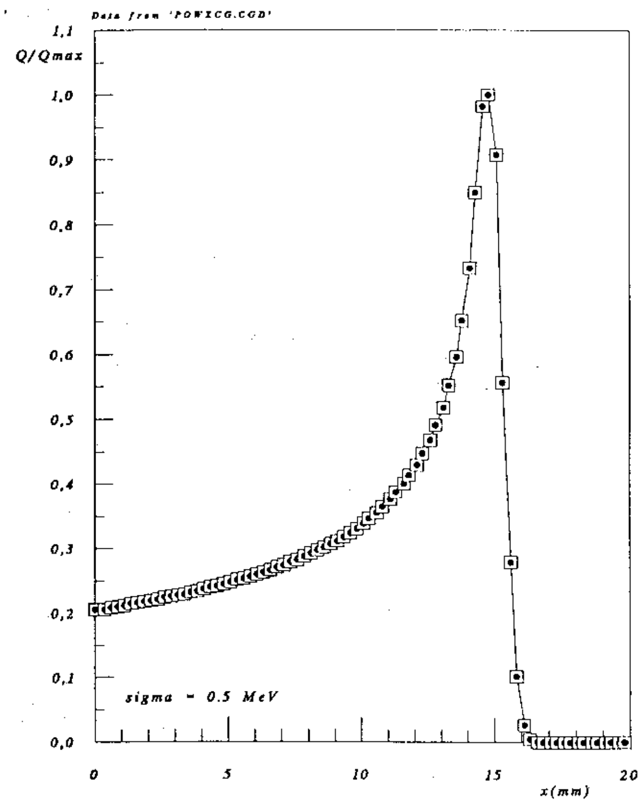


Fig. Power deposition profile along the jet thickness.

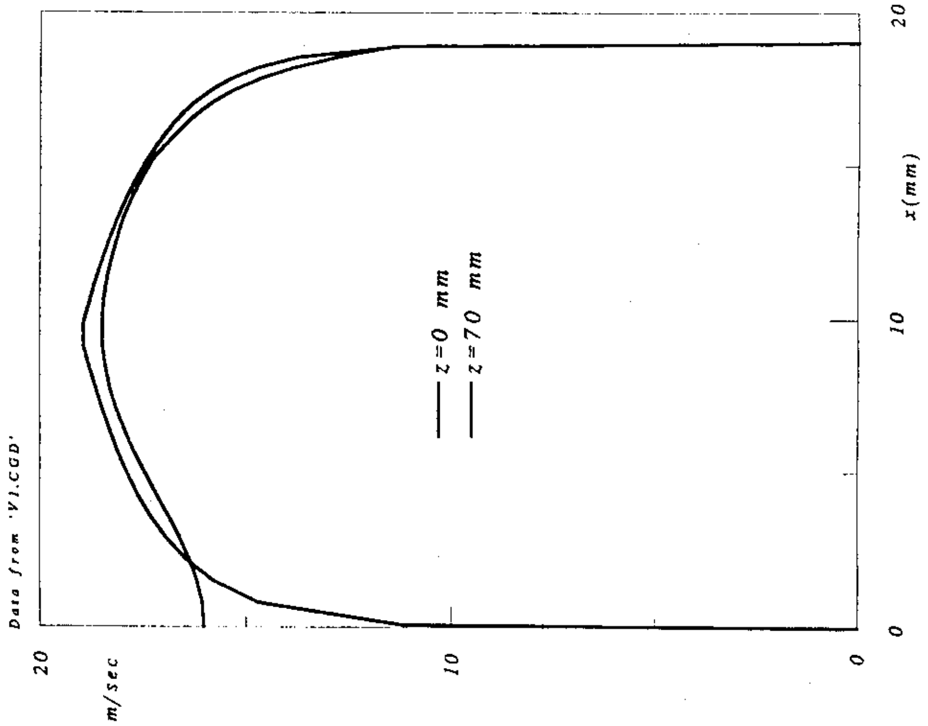


Fig. Velocity profile along the jet thickness

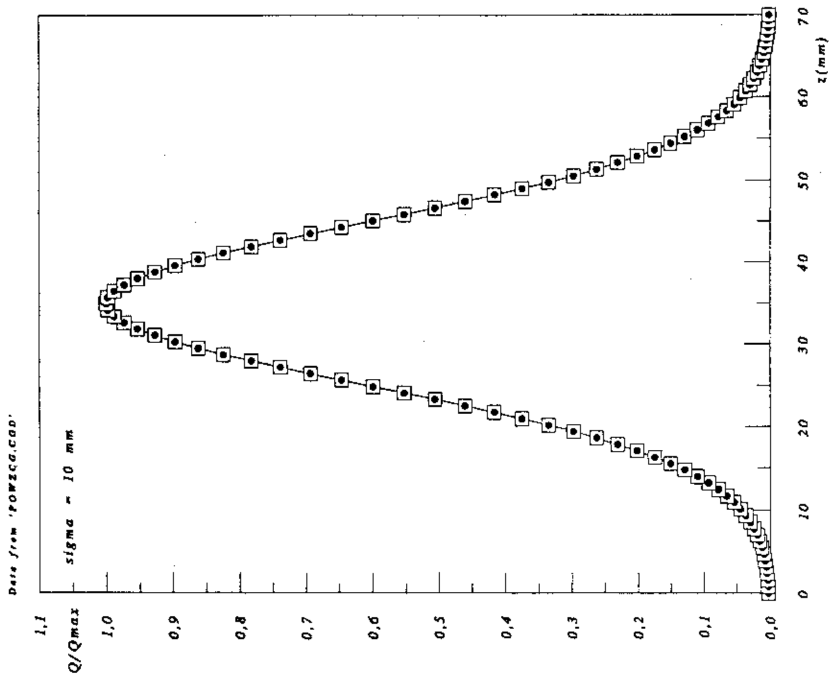


Fig. Power deposition profile along the flow direction

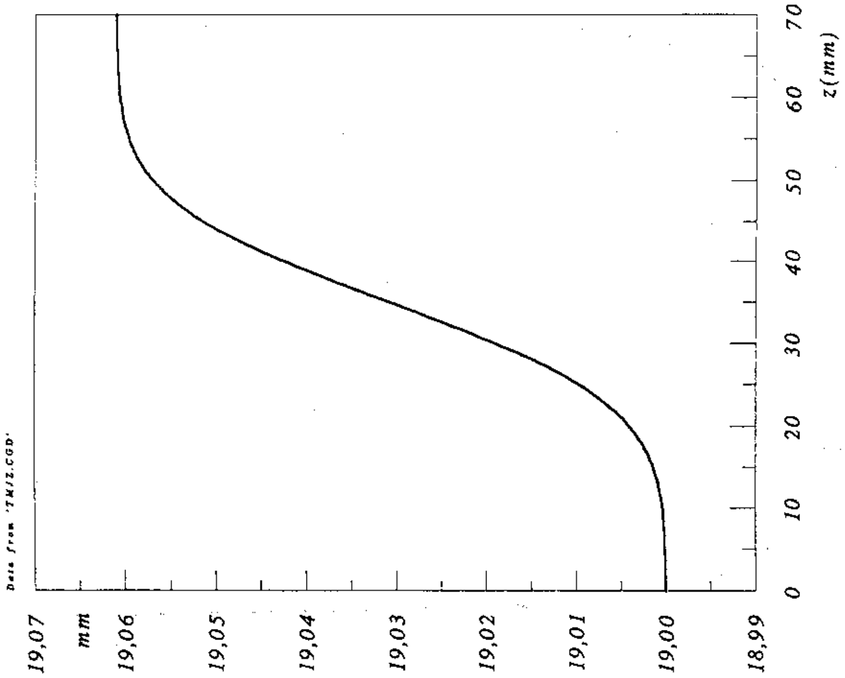


Fig. Jet thickness evolution

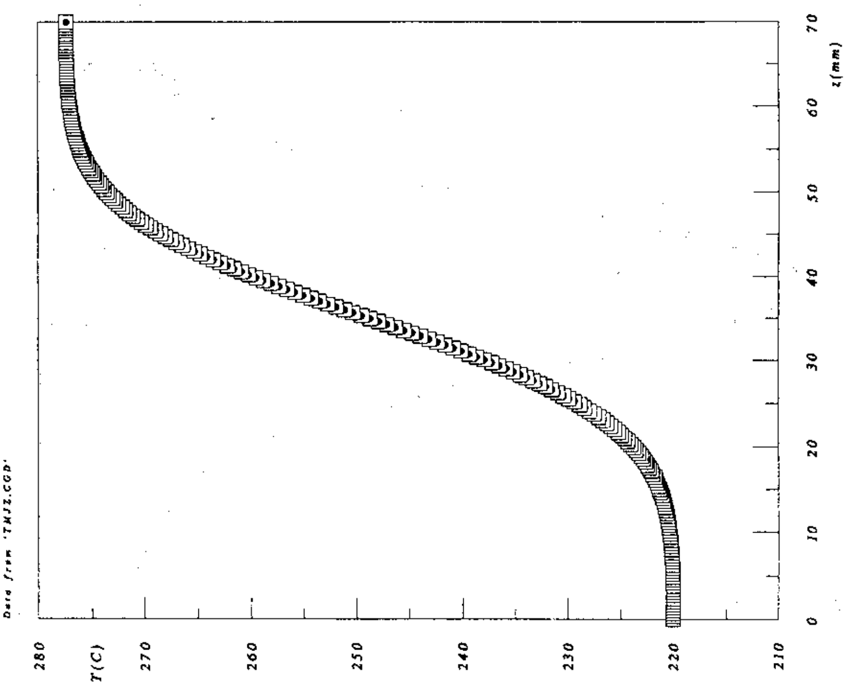


Fig. Average lithium temperature profile

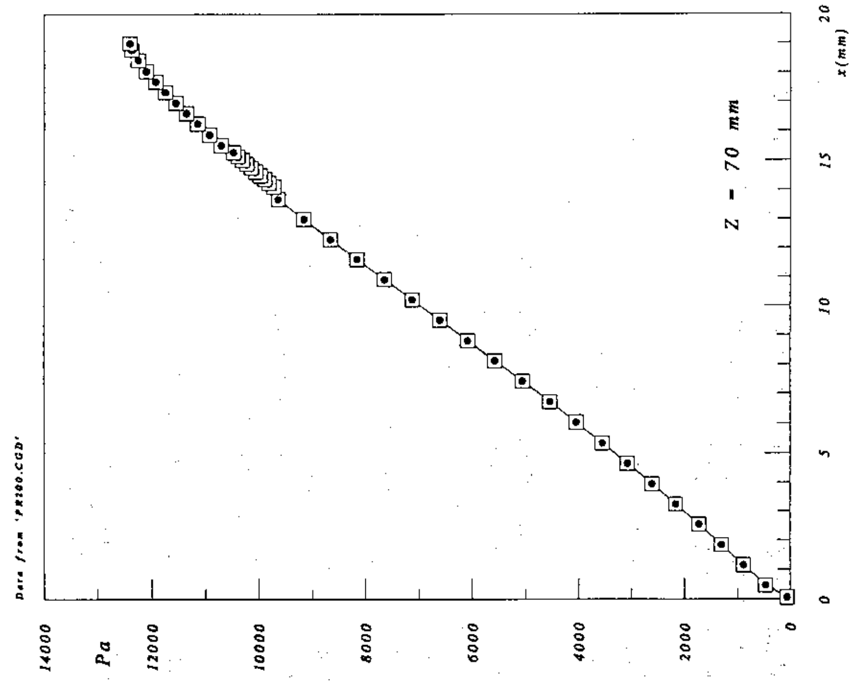


Fig. Pressure profile along the thickness direction

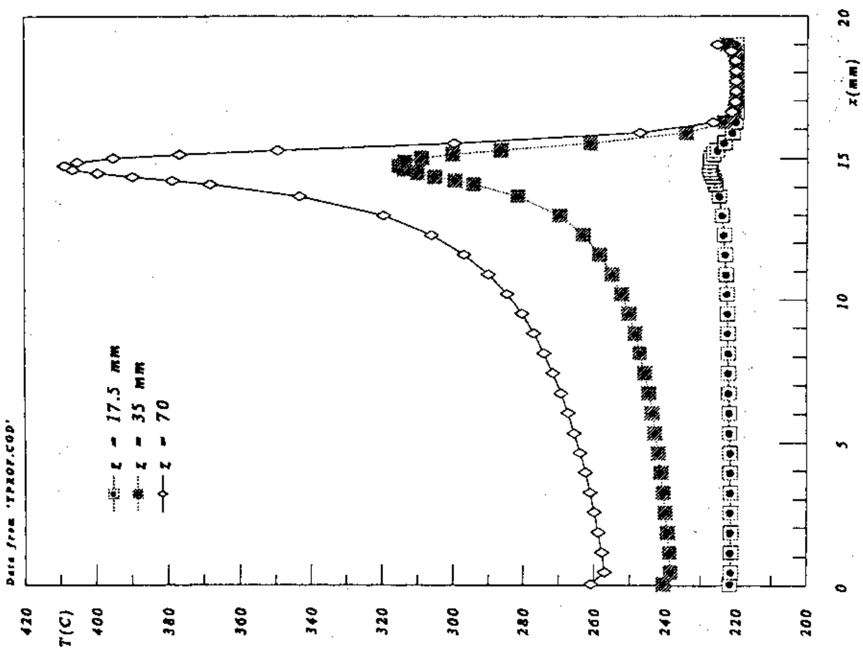


Fig. Temperature profiles along the jet thickness

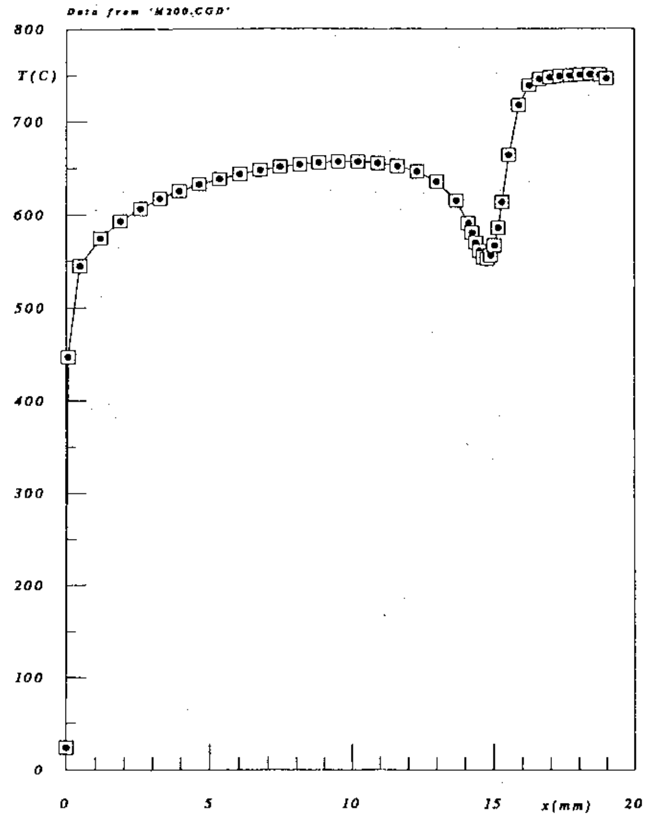


Fig. Boiling margin along the jet thickness

Conclusion

1. Positive result of the TH Analysis referred to the Reference Design Parameters. The limiting item seems to be the Lithium boiling at the free surface.

2. With respect to the Reference Design Parameters, following items are to be confirmed and/or defined:

   2.1. beam profile in z direction
   2.2. beam profile in y direction
   2.3. beam energy distribution

   2.4. jet geometry

   2.5. back plate curvature radius
   2.6. back plate thickness
   2.7. back plate power deposition

   2.8. void chamber pressure

   2.9. safety criteria (boiling margin ...)
   2.10. interfaces (allowed evaporation rate...)

19-1-1

1.7 Neutronic Analysis of the Target System

IFMIF Li Target Workshop
Tokai - Japan

Itacil C. Gomes
presented by
Ahmed Hassanein
Argonne National Laboratory
July 17-20, 1995

I.C.Gomes - Argonne National Laboratory

Highlights of the Neutronic Activities for the Target System

- **Impurities production in the lithium jet due to the D-Li reaction.**
- **Nuclear Responses (damage/gas production/ heating deposition) on the target system.**
- **Interface target system/test assembly**
- **Volume/gradient penalty due to curved back plate.**

I.C.Gomes - Argonne National Laboratory

Impurities Production from the D-Li Reaction

- **Tritons:** Produced by the **(d,np)** reaction and the consequent breakup of the excited Li-7 nucleus [Li-7(d,np)Li-7* => **T**+ He4]. The estimated **rate of production = 0.03** tritons per incident deuteron. **Additional** production of **tritons** will come from **neutron** interaction with the lithium.
  A total production of 15g/fpy is estimated as an upper limit.

I.C.Gomes - Argonne National Laboratory

Impurities Production from the D-Li Reaction

- **Be-7**: Produced from **Li-7(d,2n)Be-7** and **Li-6(d,n)Be-7**. The **measured** production rate is **0.0027** atoms per incident deuteron [$t_{1/2}$ = ~53days].
- **Protons:** Produced by the **(d,xp)** reactions. The estimated rate of production is **0.06** protions per incident deuteron.

I.C.Gomes - Argonne National Laboratory

Impurities Production from the D-Li Reaction

- **Deuterons:** All deuterons impinged in the lithium jet will be dissolved in the lithium.
- **Helium:** Reactions: Li-7(**d,np**) Li-7* => T+ **He4** and Li-7(**d,2n**) Be-7* => **He3** + **He4.** The estimated reaction rate per deuteron for each reaction is 0.03. The total production of Helium is **0.09 He** per deuteron

I.C.Gomes - Argonne National Laboratory

Impurities Production from the D-Li Reaction

- **Hydrogen:** Accounting for protons, deuterons, and tritons. Total production rate is ~ 1.0 hydrogen per incident deuteron.
- **Gas Production:** Additional gas production is expected from the interaction of **neutrons** with the liquid **lithium.**
  Example: Li-7(n,g) Li-8 => He4 + He4
  [cross section = 30 mbarns].

I.C.Gomes - Argonne National Laboratory

Nuclear Responses on the Lithium System

- **Back-Plate**
- **Nozzle**
- **Structure**
- **Activation of Replaceable Parts**
- **Activation of the Lithium Impurities**

I.C.Gomes - Argonne National Laboratory

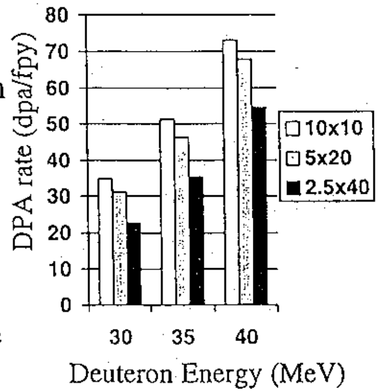
Nuclear Responses on the Lithium System

- **Back-Plate:** The back-plate (or the wall material between the lithium jet and the test assembly) is going to have the highest damage level of all system. Typical He/DPA ratio of ~12 for SS-316, at this position, gives a high helium production. H/He ratio of ~ 4.6 also gives a high hydrogen production rate.

I.C.Gomes - Argonne National Laboratory

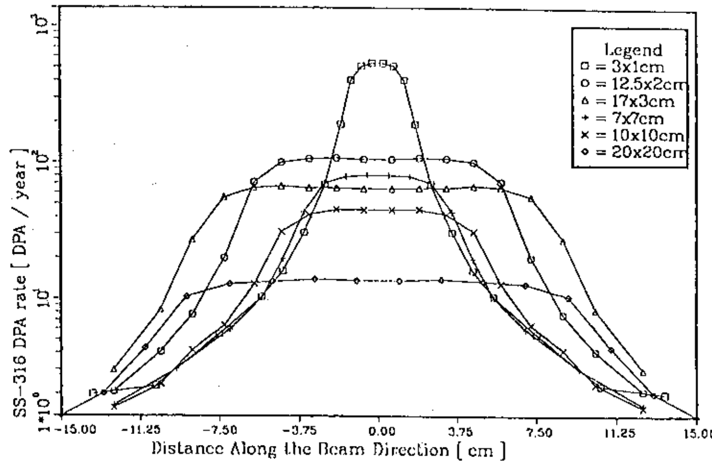
Maximum DPA Rate for Different Beam Spot Shapes

- An Iron DPA rate of ~70 dpa/fpy for a 40MeV deuteron beam is estimated at the back-plate for a 5x20 beam footprint.
- At 35MeV deuterons ~50 dpa/fpy is estimated for the same case as above.



I.C.Gomes - Argonne National Laboratory

Gradient of the SS-316 DPA rate Perpendicular to Beam
Beam Current = 250mA – Deuteron Energy = 35 MeV



ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

Nuclear Responses in the Lithium System

- **Nozzle:** Depending on the distance from the nozzle to the upper edge of the beam, the damage/gas production rate can be significant in the nozzle. At a distance of ~15 cm from the center of the beam the damage rate is ~ 1dpa/fpy. At a distance of 5 cm, for a 5x20 beam, the damage rate is ~ 7 dpa/fpy for a 40MeV deuteron beam.

I.C.Gomes - Argonne National Laboratory

Nuclear Responses on the Lithium System

- **Structure: Nuclear Heat** deposition due to **neutrons and gamma-rays** may be a problem in specific locations of the target system, such as flanges, elbows, piping etc. As a consequence, **nuclear heat deposition/ temperature profile** has to be analyzed throughout the structure and active cooling may be required.

I.C.Gomes - Argonne National Laboratory

Nuclear Responses in the Lithium System

- **Activation of Replaceable Parts:** Parts which are designed to be replaced during the lifetime of the machine have to be analyzed in terms of the waste volume and activation levels. The replacement of large parts of the structure will produce undesirable waste management problems.

I.C.Gomes - Argonne National Laboratory

Nuclear Responses in the Lithium System

- **Activation of Lithium impurities:** The lithium will have a certain level of impurities associated with it. Activation of such impurities may cause shielding problems around the lithium loop and restrict access to maintenance areas. Also, long-lived isotopes must be considered. Examples: H-3, Ne-23, F-20, Na-22, Na-24, Ar-39, corrosion products, etc.

I.C.Gomes - Argonne National Laboratory

Interface Target System - Test Assembly

- The **target system** must ensure that only neutrons/gamma-rays are going to reach the test assembly region - **no charged particle.** This translates in having the jet thick enough to stop deuterons and secondary particles.
- **Vacuum boundary** - The interface must ensure the integrity of the accelerator/beam vacuum system.

I.C.Gomes - Argonne National Laboratory

Interface Target System - Test Assembly

- Importance of the damage and gas production in designing the interfaces in terms of the lifetime integrity of such parts.
- If in any case rewelding is to be a replacement option for some parts of the system, the gas production in such parts has to be carefully analyzed.

I.C.Gomes - Argonne National Laboratory

Interface Target System - Test Assembly

- Shielding of the penetrations for ducts and instrumentation. Penetrations and pipes carrying lithium must be design to avoid radiation streaming to other areas.

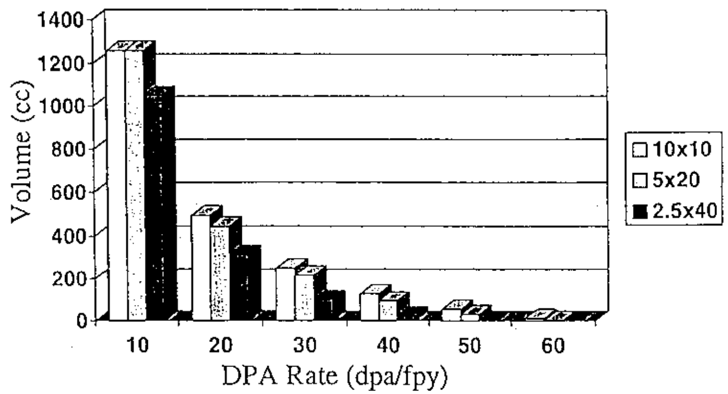
I.C.Gomes - Argonne National Laboratory

Volume/ Gradient Penalty Due to the Curved Back-Plate

- Back Plate with small radius of curvature is going to generate a penalty on both, volume and flux gradient.
- Increasing the radius of curvature of the back-plate reduces the impact of the back-plate on both, volume and flux gradient.
- Studies have been carried out but no result is available yet.

I.C.Gomes - Argonne National Laboratory

Variation of the Testing Volume with the Beam Cross-Sectional Shape - 40 MeV Deuterons - 250 mA Current



I.C.Gomes - Argonne National Laboratory

Proposed Monitoring System for Corrosion/Flow in the Lithium Loop

- Corrosion products can be detected, on line, by monitoring the radiation field from the flowing liquid lithium. The build-up of some products will produce detectable signals in the monitoring system [1].
- A variation of the lithium flow or beam power also can be detected on line with such a system.

[1] Donald Smith and Itacil Gomes - to be published

I.C.Gomes - Argonne National Laboratory

Conclusions

- A throughout neutronic analysis of the lithium target system has be carryed out to ensure:

  1. Integrity of the components (damage, gas production, nuclear heating, etc.)
  2. Impurity control in the lithium loop
  3. Adequate shielding.
  4. Thermal expansion limits respected.
  5. Interface with the irradiation volume.

I.C.Gomes - Argonne National Laboratory

1.8 Some Comments for the Backwall Swelling

H. Katsuta,Y.Kato
IFMIF Target System Group of JAERI

1. Introduction

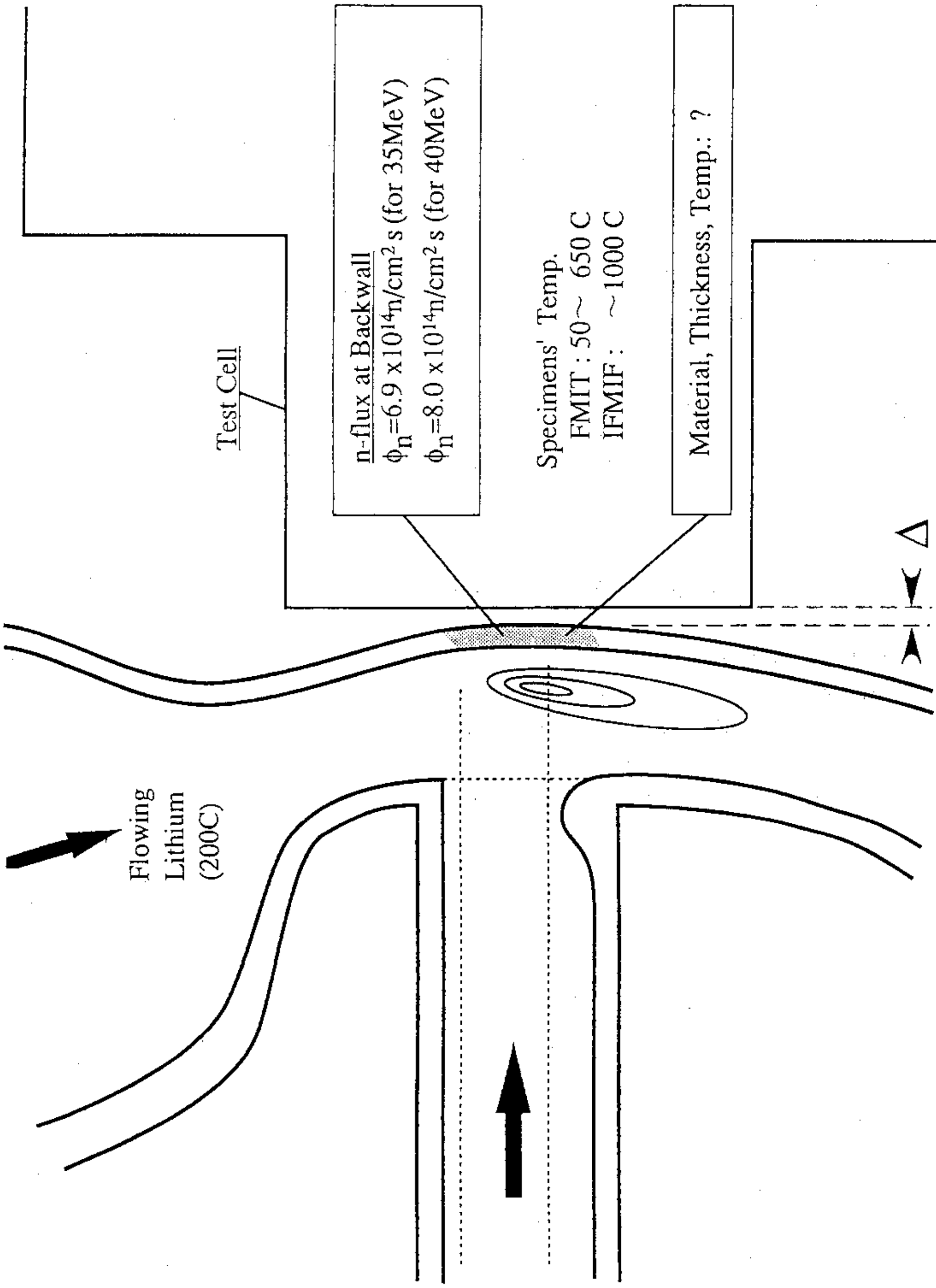
Li-target will have a limited life and must be designed for periodic remote replacement. The life will be determined by the backwall integrity for the operation.

(1) off-normal events:
*target backwall rupture or structural damage by disruption of the Li-jet or a significant change in flow patterns for even a few millisecond.

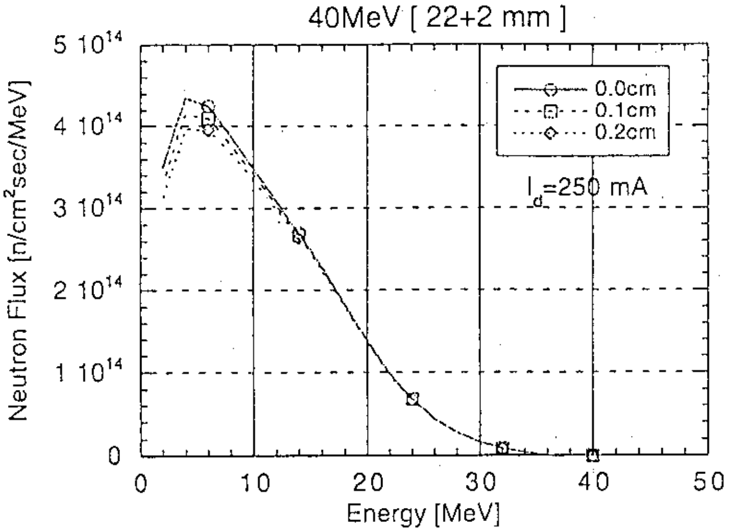
(2)normal operation:
* radiation induced distortion of the structure
* the critical dimension of the target structure will be affected by erosion and corrosion of the backwall

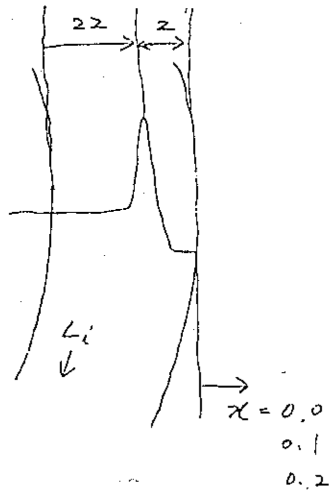
2.Review of the deasign data of FMIT-backwall

(1) d-beam: 35MeV, 100mA
(2) Beam Window: 10mmx30mm(gaussian)
(3) Neutron Flux: Max.:3×10^{15}n/cm^2 s (62dpa/y 6cc, 38dpa/y 20cc)
(4) Material: 316SS
(5) Thickness: 1.6mm(Li-jet: 19mm , Li-velocity: 17m/s)
(6) Temperature:
(Test specimens: 50 to 650 C, the chamber is designed to contact with the backwall when operating)
(7) Swelling:___%
(8) Deformation:___mm/y at center of the beam window on the backwall
(9) Life time: deformation limit of 2mm at center of the beam window on the backwall (9month (plant availability)



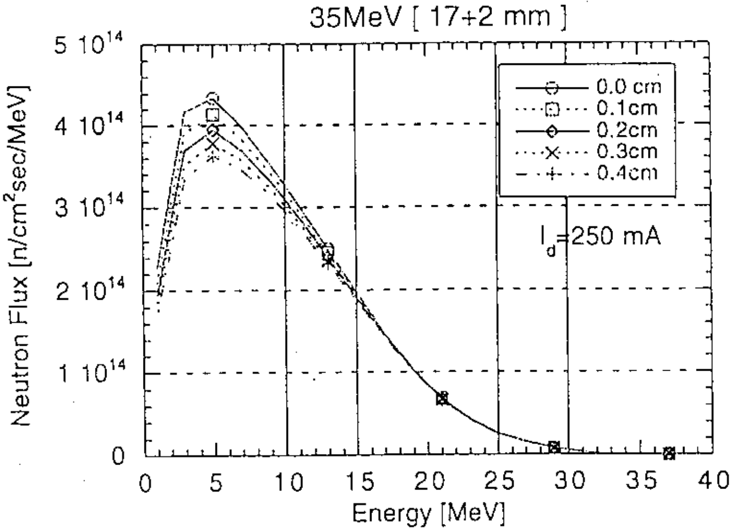
Li - TARGET & TEST CELL

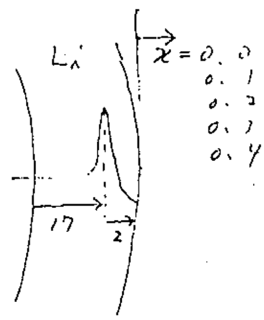




Backwall Center:

$\Phi = 8.0 \times 10^{14}$ n/cm²·s





Back wall Center:

$\Phi = 6.9 \times 10^{14}$ n/cm²·s

3. Design data of IFMIF-backwall

(1) d-beam: 30 to 40 MeV, 250mA

(2) Beam Window: 50mmx200mm

(3) Neutron Flux: $6.9 \times 10^{14} n/cm^2 s$ (for 35MeV)
$8.0 \times 10^{14} n/cm^2 s$ (for 40MeV)
evaluation at about 15dpa(10month operation)

(4) Material(canndidate)	**PCA,**	**Ferritic SS, (F82H)**	**V-alloy (V-4Cr-4Ti)**
(5) Thickness	____	________	______
(6) Temperature	evaluation for the maximum temperature of **300 C**		
(Test Specimens: Max. about 1000C)			
(7) Uniform elongation	about 0.5%	about 3%	about 8%
(8) Yield strength	800MPa	800MPa	400MPa
(unirradiated:	200MPa,	500MPa,	)
(9) Swelling (expected)	<1%	<1%	<1%
(10) DBTT	-	about50 C	−100 C

(11) Erosion and corrosion

(12) Radio-active waste

(13) Deformation (Life time)

(14) Remarks

3. Design data of IFMIF-backwall

(1) d-beam: 30 to 40 MeV, 250mA

(2) Beam Window: 50mmx200mm

(3) Neutron Flux: 6.9×10^{14} n/cm^2 s(for 35MeV)
8.0×10^{14} n/cm^2 s(for 40MeV)
evaluation at about 15dpa(10month operation)

(4) **Material(canndidate)**	**PCA,**	**Ferritic SS, (F82H)**	**V-alloy (V-4Cr-4Ti)**
(5) Thickness	____	_______	______
(6) Temperature	evaluation for the maximum temperature of **500 C**		
(Test Specimens: Max. about 1000C)			
(7) Uniform elongation	about5%	about 8%	about10%
(8) Yield strength	650MPa	480MPa	450MPa
(unirradiated:	200MPa,	480MPa,	)
(9) Swelling (expected)	<1%	<1%	<1%
(10) DBTT	-	over aging	over aging

(11) Erosion and corrosion

(12) Radio-active waste

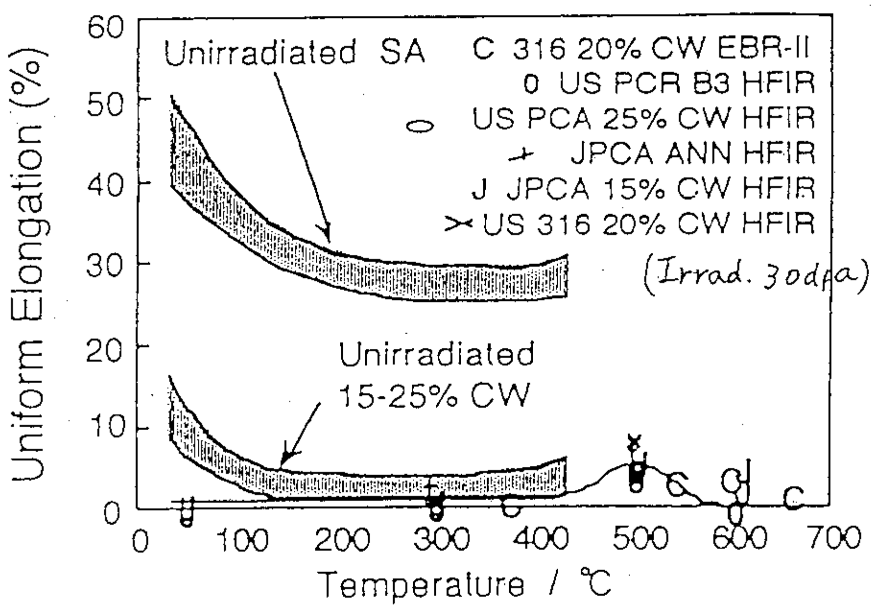
(13) Deformation (Life time)

(14) Remarks

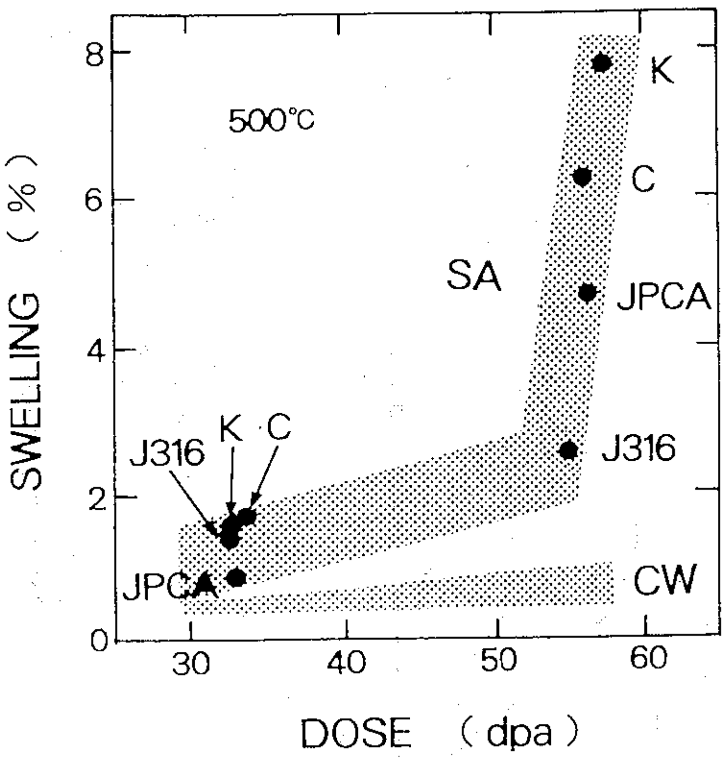
	C	Si	Mn	P	S	Ni	Cr	Mo	Ti	Nb
JPCA	0.06	0.50	1.77	0.027	0.005	15.60	14.22	2.28	0.24	
J316	0.058	0.61	1.80	0.028	0.003	13.52	16.75		0.005	
K	0.02	0.48	1.46	0.015	0.005	17.56	17.99	2.6	0.29	
C	0.02	0.51	1.56	0.017	0.007	15.6	15.4	2.4	0.25	0.08
USPCA	0.05	0.40	1.80	0.01	0.003	16.2	14.0	2.3	0.24	

	B	N	Fe	SA	CW
JPCA	0.0031	0.0039	bal	1100℃/30min.	15 %
J316	0.001	-	bal	1050℃/30min.	20 %
K	-	0.004	bal	1050℃/1hr	20 %
C	-	0.0018	bal	1100℃/1hr	20 %
USPCA	0.001	0.001	bal	1100℃/0.5hr	25 %

Chemical Composition and Heat Treatment Condition(PCA)



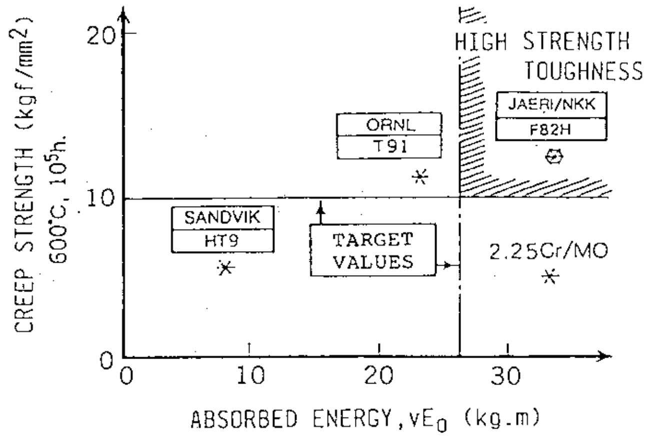
Uniform Elongation as a function of Irradiation and Testing Temp.(316S.S)



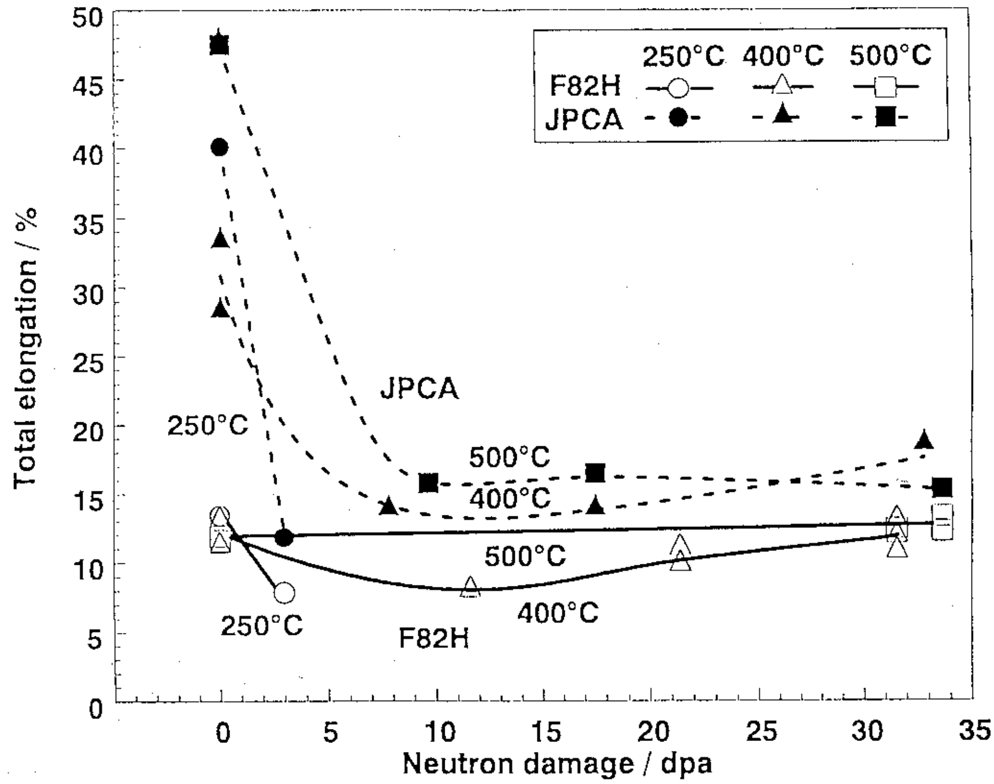
Dose Dependence of Swelling(Austenitic S.S.)

Chemical Composition of Ferritic Steels

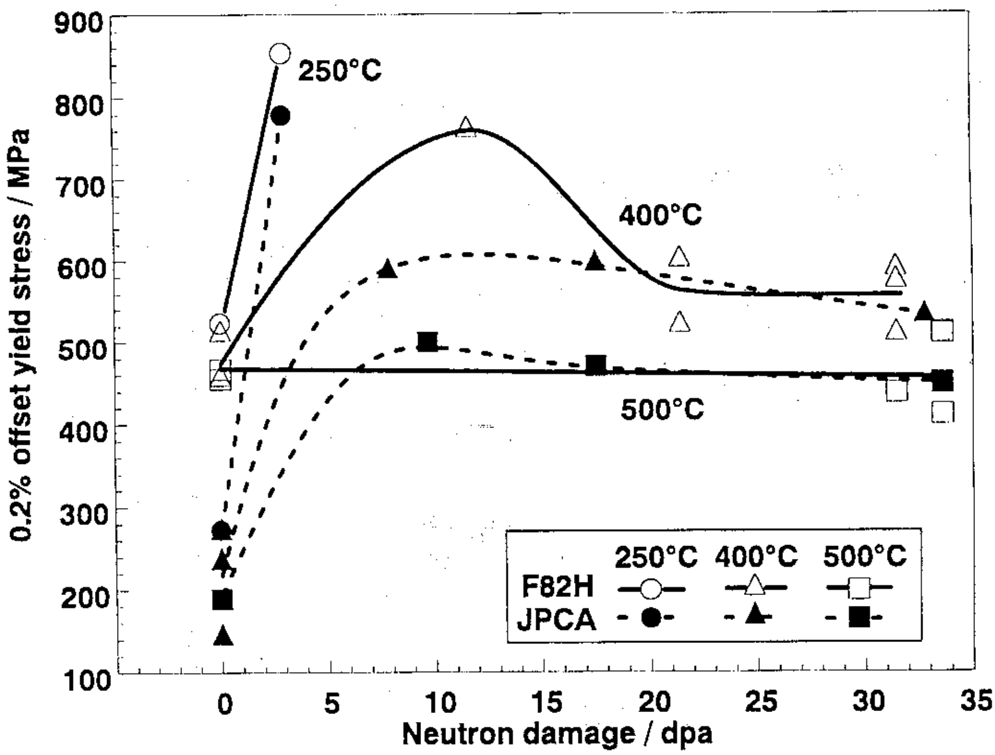
	C	Si	Mn	Ni	Cr	Mo	W	V	Ta	Nb
HT9	0.2	0.2	0.5	0.5	12.0	1.0	0.5	0.3	-	-
T91	0.1	-	-	-	8.5	1.0	-	0.2	-	0.08
F82H	0.1	0.2	0.5	-	8.0	-	2.0	0.2	0.04	-



Strength and Toughness of Ferritic Steels



Total Elongation as a function of Neutron Damage(dpa)



Yield Stress as a function of Neutron Damage(dpa)

1.9 Target Assembly Design: Some Parametric Evaluations

by

S. Cevolani

Investigated Parameters

1. Beam Energy Distrbution
2. Jet / Beam Width
3. Back Plate Curvature Radius
4. Void Chamber Pressure
5. Lithium Average Velocity

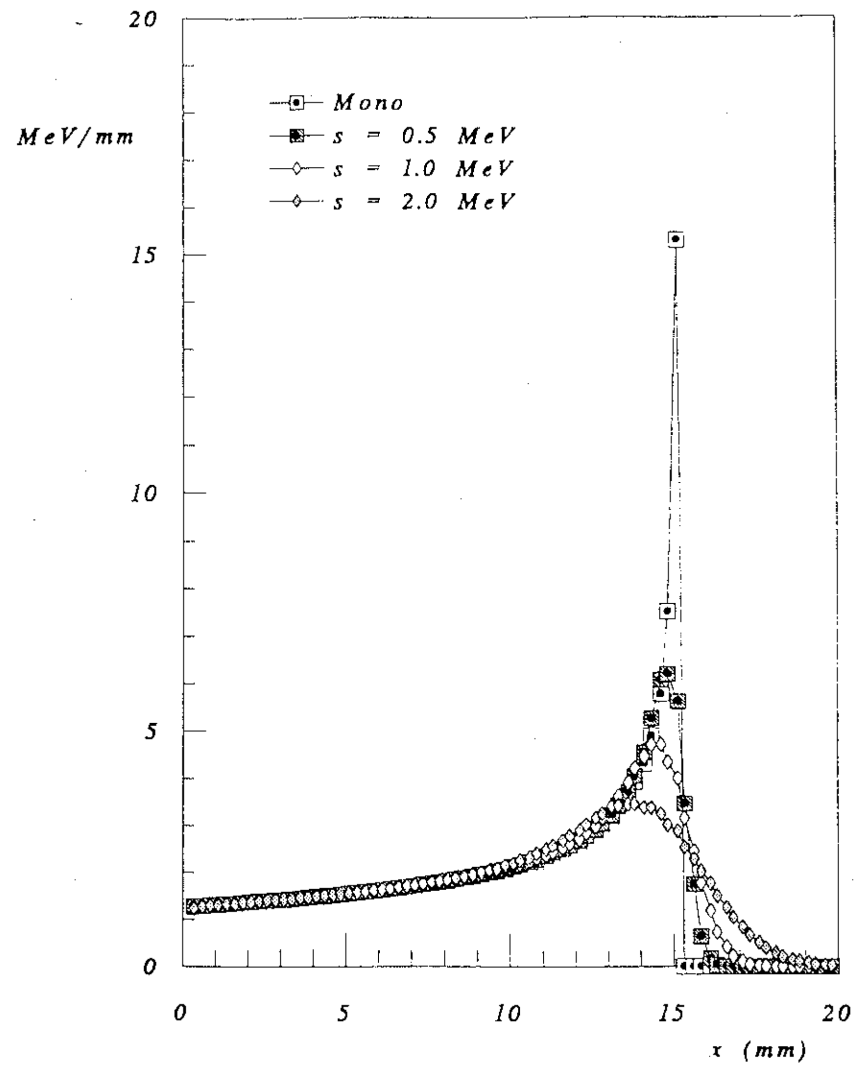


Fig. Heat deposition profile along the lithiun depth

	unit		
beam energy distribution (1σ)	KeV	500	0
jet width	mm	220	220
jet height	mm	70	70
jet thikcness at the nozzle outlet	mm	19	19
jet average velocity	m/sec	17	17
jet temperature at the nozzle outlet	°C	220	220
beam energy	MeV	35	35
beam current	mA	250	250
heat deposition in lithium	MW	8.75	8.75
beam distribution: horizontal (y)	-	flat	flat
beam distribution: vertical	-	gaussian σ=10 mm	gaussian σ=10 mm
backplate curvature radius	mm	250	250
backplate thickness	mm	3	3
backplate power generation	KW	4.96	4.96
backplate power generation distrib.	-	gaussian σ=10 mm	gaussian σ=10 mm
void chamber pressure	Pa	1.0e-4	1.0e-4
jet average outlet temperature	°C	277	277
jet maximum temperature	°C	409	523
free surface maximum temperature	°C	261	261
back plate maximum temperature	°C	269	269
jet minimum boiling margin	°C	446	439
free surface minimum boiling margin	°C	24	24
maximum pressure difference	Pa	12409	12409
evaporation ratio at the free surface	kg/sec	3.3e-11	3.1e-11

Tab. Effect of the beam energy distribution

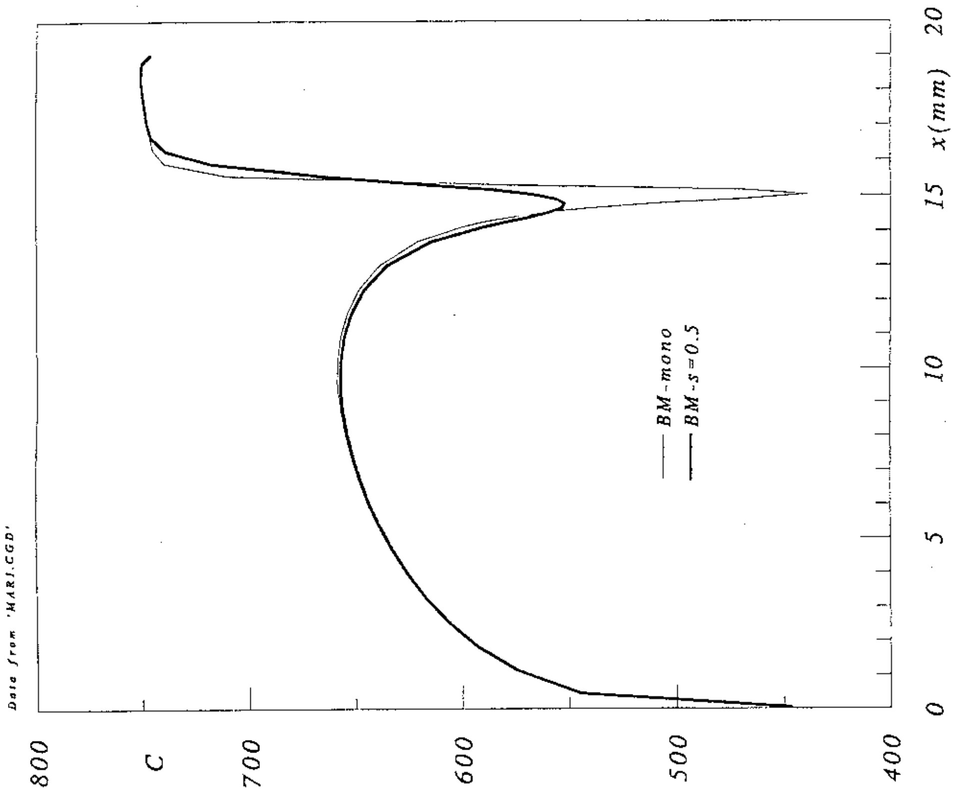


Fig. Boiling Margin Profiles

jet width	mm	220	160	110
flow rate	Kg/sec	36.4	26.5	18.2
jet average outlet temperature	°C	277	299	334
jet maximum temperature	°C	409	478	591
free surface maximum temperature	°C	261	277	303
back plate maximum temperature	°C	269	269	269
jet minimum boiling margin	°C	446	431	370
free surface minimum boiling margin	°C	24	8	-18
maximum pressure difference	Pa	12409	12443	12500
evaporation ratio at the free surface	Kg/sec	3.3 e-11	5.6 e-11	16.0 e-11

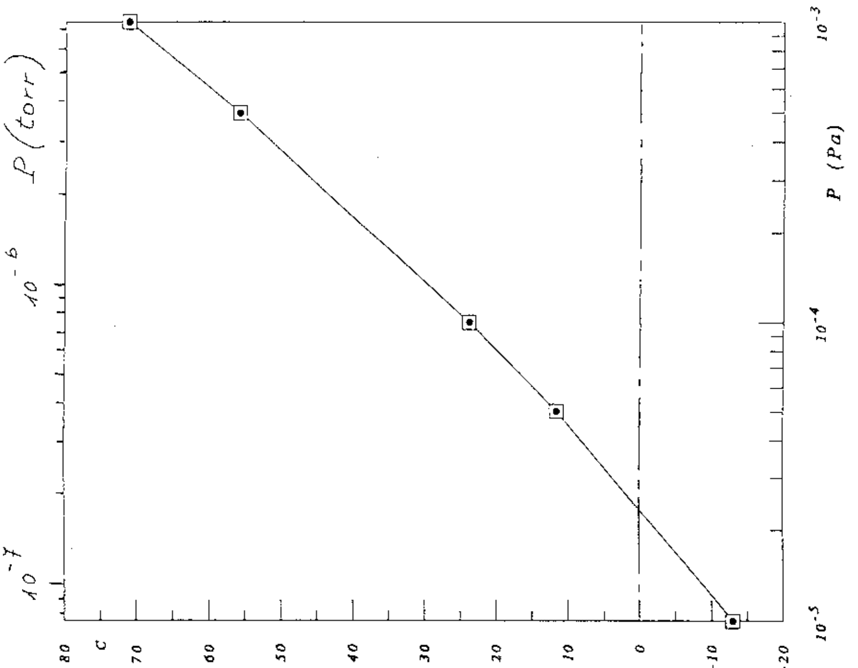


Fig. Boiling margin at the free surface as a function of the cell pressure

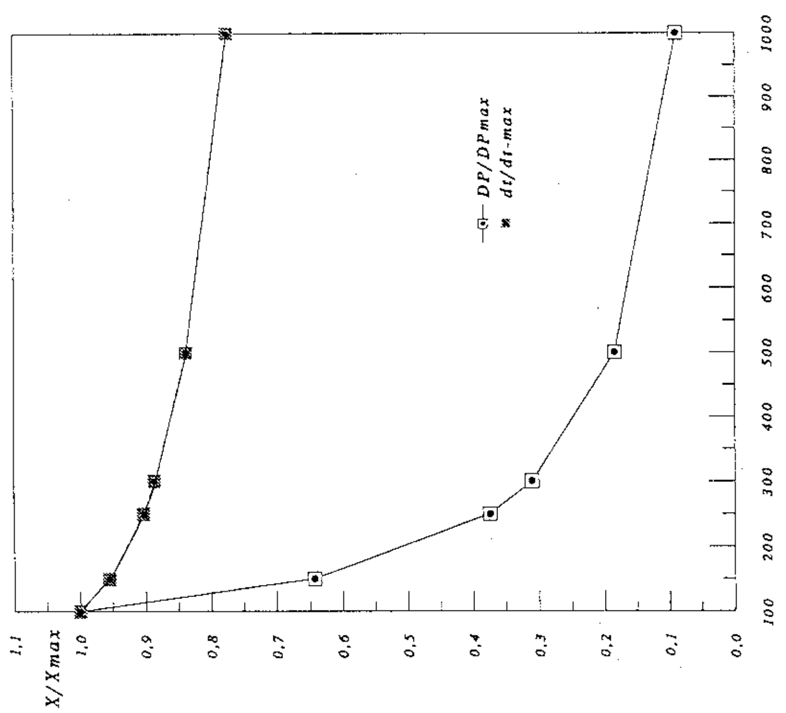


Fig. Effect of the backplate curvature radius

average jet velocity	m/sec	17	16	15	14	13	12
jet average outlet temperature	°C	277	281	285	290	295	301
jet maximum temperature	°C	409	420	433	448	465	485
free surface maximum temperature	°C	261	264	267	271	275	279
back plate maximum temperature	°C	269	269	269	269	270	270
jet minimum boiling margin	°C	446	441	435	428	421	412
free surface minimum boiling margin	°C	23.8	21.1	18.0	14.5	10.4	5.6
maximum pressure difference	Pa	12409	11003	9681	8444	7291	6222
evaporation ratio at the free surface	Kg/sec	3.3 e-11	3.8 e-11	4.5 e-11	5.5 e-11	6.9 e-11	9.0 e-11

Fig. Parametrisation of the jet average velocity

CONCLUSION

1. The parametrisation concerned with beam energy distribution, jet width, back plate curvature radius and lithium velocity confirm that the limiting issue is the boiling margin at the free surface.

2. The free surface boiling margin is mainly depending on the void chamber pressure. This effect was quantified.

3. A certain optimisation seems to be possible with respect to the parameters mentioned in item 1 (depending on the safety limits and criteria)

1.10 Proposal of Water Loop Test and Target Design

Hideo NAKAMURA, Y. KATO and M. IDA
IFMIF Target System Group of JAERI

1. Introduction (Background)

A well-defined stable Li jet with free surface to remove D^+ beam power with a minimum jet thickness is required for a controlled neutron irradiation and maximum sample volume in IFMIF.[1] Therefore, Li jet should be characterized in sufficient detail for the correct prediction of neutron flux distribution in the irradiation sample.

Large amount of experimental results were obtained for the target of FMIT.[2-12] However, there is a lack in the detailed description in the accessible information, both in the experimental conditions and obtained results for tested target models with critical design, which was empirically obtained and still under improvement. Furthermore, to furnish a larger irradiation volume, IFMIF may have taller jet flows than for FMIT, while characteristics of the Li jet flows depend highly on such target geometry.

JAERI thus plans to perform water-loop experiments simulating the IFMIF Li jet flows in the CDA, prior to the Li-loop experiments for the EDA, to acquire experiences and data of the jet flow simulated by water. The documented experiences for FMIT[2-12] give a start point for this experimental work for IFMIF.

This section summarizes a plan of the water-loop experiments, and a target design for the initial experiment currently under preparation.

2. Objectives

Objectives of the present water-loop experiments are as follows.

(1) To observe structure and stability of water jet flow along a curved back-wall, simulating the Li jet flow that covers a predetermined deuteron-beam

irradiation region of 200 mm-wide and 50 mm-high with a certain spatial margin to surrounding walls.

(2) To partially confirm the FMIT experimental results. (It is difficult to give exactly the same target geometry in the experiments without the detailed description.)

(3) To prepare data base necessary for Li-loop experiments.

Simultaneously performed numerical simulation analyses (multi-dimensional, free-surface jet flow) will provide an insight for the structure of the target jet flow for both water- and Li-loop experiments. The prototype Li target design will be defined based on these water- and Li-loop experiments with an aid of the numerical simulations.

3. Preliminary Design of Facility and Target

The initial target design for the water-loop experiments is based on the followings.

(1) Knowledge obtained by experiments for FMIT target[2-12]
(**Table 1** compares primary parameters of IFMIF and FMIT.)

(2) Existing models, correlations and data base for primary hydraulic components such as reducer, diffuser, elbows and perforated plates[13, 15]

(3) 2D preliminary numerical analysis of Li jet (i.e. **CDA-T-I-1** [2])

(4) Li jet simulation parameters -- Re, Fr (kinetic viscosity)

Table 1 Comparison of Design and Operation Conditions of Lithium Target for IFMIF and FMIT

Facility		IFMIF	FMIT
Li Flow Rate	(m^3/s)	0.096 *	0.032
Li Ave. Velocity	(m/s)	20 *	17
Inlet Temperature	(°C)	220	220
Outlet Ave. Temperature	(°C)	262	270
D^+ Beam Energy	(MeV)	30 ~ 40 (35 *)	35
Beam Size (wide x tall)	(mm)	200 x 50	30 x 10
Power Absorbed	(MW)	7.5 ~ 10.0	3.5
Ave. Power Density	(MW/m^2)	750 ~ 1,000	11,700
Jet Width	(mm)	240 *	100
Jet Thickness	(mm)	20 *	19
Jet Reynolds Number	(-)	4.0×10^5 *	3.2×10^5
Operating Pressure	(Pa)	10^{-4}	10^{-4}
Radius of Back Wall	(mm)	250 *	250

* Tentative for Initial Water Experiments

3.1 Facility Overview

The water loop is prepared by modifying the existing Air-Water Two-Phase Flow Loop in JAERI, as schematically shown in **Fig. 1**. The large water pump (water head ≤ ~40 m, flow rate ≤ ~500 m^3/h) of the water loop is used to circulate demineralized water stored in the water tank (capacity ≤ ~18 m^3). A branching pipe will be added to place the test section on the water tank. Piping of the existing chiller unit will be branched to the water tank to maintain water temperature low. To eliminate additional dissolution of air into water, returning water is ejected well below the liquid level in the water tank by extending return-pipings and furnishing a long drain channel to the test section. These loop modifications in conjunction with an installation of the initial target assembly are planned to be completed by the end of October, 1995.

3.2 Target Components

The target assembly is composed of several components as shown in **Fig. 2**. Most walls are made of transparent Acrylic resin for a visual observation of the jet flow behavior. Current design (design strategy) of each component for the initial water experiment is summarized below.

(1) Flow Straightener Duct (**Fig. 2**)

- role - vanish flow history (secondary flow etc.), and provide an uniform velocity distribution at reducer inlet
- structure - a rectangular duct containing several perforated plates (FMIT design alike)

(2) Reducer (**Figs. 3** and **4**)

- role - form a precisely defined jet with uniform velocity distribution, minimum boundary layer thickness and minimum turbulence
  - give a large space for irradiation sample as well as good accessibility
- structure - double 2D-reducers with boundary layer stripping-off system **(new design, Fig. 4)**
  - wall curve by Shima reducer model[13] (an improved but simplified Goldstein model[14] based on potential flow theory)
- notes for the new design:

(a) Measured back-wall static pressures for two FMIT target designs, shown in **Fig. 5**, suggest that the radius size at the most converging part controls static pressure profile along the reducer back-wall. Relatively large radius which is given for small convergence ratios seems to be preferable for a smooth decrease in the pressure.

(b) The Shima model gives a (x, y) curve of symmetric 2-D reducers by a set of simple equations as

$$\frac{x}{b} = \frac{1}{2\pi}\left\{\left(\frac{a}{b}+1\right)\tanh^{-1}(\cos\theta) + \frac{1}{2}\left(\frac{a}{b}-1\right)\ln[2(1-\cos 2\theta)] + \left[\sqrt{2\left(\frac{a}{b}+1\right)} - \left(\frac{a}{b}+1\right)\right]\cos\theta\right\},$$

$$\frac{y}{b} = \frac{1}{2} + \frac{1}{2\pi}\left\{\left(\frac{a}{b}-1\right)\theta + \left[\sqrt{2\left(\frac{a}{b}+1\right)} - \left(\frac{a}{b}+1\right)\right]\sin\theta\right\},$$

where a, b = width of inlet(θ=0) and outlet($\theta=\pi$). This can be one of well-defined reducer geometries. The empirically-obtained FMIT asymmetric reducer is difficult to reproduce rigorously without detailed information.

(c) The double-reducer gives larger space for irradiation sample than a single reducer (i.e. FMIT symmetric reducer[9, 16]).

(d) 2-D numerical simulations indicated that this double-reducer nozzle creates a jet flow with low turbulence and thin boundary layer. Gradual change in the velocity and pressure profiles is preferable for a stable jet flow. (see **CDA-T-I-1 [2]**)

(e) To experimentally observe the influence of boundary layer on the behavior of the high-speed jet flow, a pair of sinter-type walls is planned to apply to strip the boundary layer.

(3) Curved Back-Wall Chamber (**Fig. 3**)

- role - keep jet low-turbulent with minimum interfacial fluctuations without surface and bulk flashing.
- structure - cylindrical with inner radius of <u>250 mm</u> enclosed in uniform-thickness walls (FMIT design)
  - 240 mm-wide, 90 mm-high for back-wall part (20 mm margin to side walls)
  - Gas-phase pressure ~ water vapor pressure (diffuser case)

(4) Drain Channel (**Fig. 3**)

- role - transport high-temperature fluid away from vacuum system without reversal of vapor and droplets generated by surface and bulk flashing and/or splashing.
- structure - straight rectangular duct (FMIT design alike)
  or - <u>diffuser</u> with straight rectangular duct **(new design)**
- notes for the new design:

(a) The static pressure is expected to recover by the diffuser with no flow choking at the diffuser inlet with the nominal water jet velocity. This enables the gas pressure in the curved back-wall chamber to decrease down to the water saturation pressure when water is discharged to the water tank under atmospheric pressure. A long gradual-curved channel down to a quench tank in vacuum, employed for the FMIT target system, may cause an exposure of high-temperature Li core to vacuum and a reversal of Li mist back to the target region.

(b) The diffuser can confine the free-surface region on which evaporation of Li may take place. Recovery of the static pressure is good to avoid flashing of the high-temperature core of the Li jet flow, and contribute to increase the suction pressure of the Li loop EM pump.

(5) Other Feature

Liquid film at upstream of diffuser entrance (**Fig. 3**)

to decrease impact of free surface onto the diffuser curved-wall entrance, to clean the bottom surface and to condense vapor on the low-temperature film surface (**new design**)

- notes for the new design:

(a) This is a trial to observe the influence of the liquid film onto the diffuser inlet flow condition in the water-loop experiments.

(b) The film is expected to bring splashed and solidified Li droplets on the front wall, back to the Li jet. In the Li flow experiments for FMIT, splashing of Li was found to be unavoidable during the flow transient including the facility startup. A part of Li vapor from the elevated-temperature surface of Li jet is further expected to condense on the low-temperature Li film surface.

4. Test Items and Measurement Parameters

4.1 Test Items

High speed jet with free surface being irradiated by D^+ beam in vacuum would indicate various responses depending on the fluid condition and loop operating modes. Experienced responses in the water and Li experiments for FMIT include splashing, flashing, bubbling, ripples (changing from 2D to 3D along with the length of the jet). Most responses are expected to appear during steady operation and some transient flow conditions that are included in the usual operating procedures. The planned test items thus include

Transient operations	Startup and Shut-Down with gradual change in the flow rate	
Steady operation	Parameters :	loop flow rate (jet speed) fluid temperature

Some transient responses, for example; sudden increase/decrease in the flow rate, loss-of-flow and oscillation in the flow rate, may happen under accidental situations. Such unusual flow conditions may also be included in the water-loop experiments.

4.2 Measurement Parameters and Instrumentation

The structure of the resulted high speed jet with free surface is measured by various instruments which are basically the same as those used for the FMIT experiments. Dynamic observation of the surface fluctuation by a high-speed video will be performed with recording rates up to 40,500 frames/s.

• interfacial waves	
wave length	photograph, high-speed video
wave height	photograph, ultrasonic
• velocity	Pitot tube, photograph, high-speed video
• jet thickness	ultrasonic, photograph, high-speed video
• jet pressure	differential pressure cell, Pitot tube

5. Summary of Current Status

The water-loop facility is under modification (by the end of October) with several new designs and various measuring instrumentations for the initial target assembly mostly made of transparent Acrylic resin.

Visual observation of the jet flow behavior under various operation conditions with a quantitative measurement is planned to perform.

6. Plans to the next stage

Several target designs such as

- FMIT counterparts (an asymmetric reducer),
- those obtained by numerical simulations, and
- those in response to the experimental and analytical results

are planned to be tested.

Acknowledgment

This work is performed in collaboration with the Thermal-Hydraulic Safety Engineering Laboratory, Department of Reactor Safety Research in JAERI who undertake the water experiments by modifying their Air-Water Two-Phase Flow Loop, with necessary analyses.

References

[1] T. Kondo et al., "High-Energy/intensity neutron facilities for testing fusion materials," Fusion Engrg. and Design (1993) 117-127.

[2] W.C. Miller et al., "Testing of the Prototype FMIT Target with Liquid Lithium," Proc. 3rd Int. Conf. Liquid Metal Engrg. and Technol. vol. 2 (1984) 333-340.

[3] R.R. Miles et al., "Verification of the Hydraulic Design of the FMIT Liquid Lithium Target," Proc. 10th Symp. Fusion Engrg. vol. 2 (1983) 1120-1123.

[4] J.A. Hassberger, "Stability of the FMIT High Speed, Free Surface Liquid Jet Flowing along a Curved Back Wall," Proc. 10th Symp. Fusion Engrg. vol. 2 (1983) 1849-1853.

[5] J.A. Hassberger, "Comparison between Measured and Predicted Performance of a High Speed, Free Surface Liquid Jet Flowing along a Curved Wall," Nucl. Technol./Fusion 4 (1983) 433-438.

[6] J.A. Hassberger, "Preliminary Assessment of Interactions between the FMIT Deutron Beam and Liquid-Lithium Target," HEDL-TME 82-28 UC-20 (1983).

[7] R.R. Miles et al., "Improved Liquid-Lithium Target for the FMIT Facility," HEDL-SA-2721-FP (1982).

[8] C.E. Annese et al., "Experimental Results from a Flowing Lithium Target," HEDL-SA-2722 (1982).

[9] J.A. Hassberger et al., "Water Testing of the FMIT Lithium Target," HEDL-SA-2502 (1981).

[10] J.A. Hassberger, "Velocity Distributions in the FMIT Liquid-Lithium Target," HEDL-TME 81-32 UC-20 (1981).

[11] J.A. Hassberger et al., "Design of the FMIT Lithium Target," HEDL-SA-2394, Proc. 9th Symp. Engrg. Problems of Fusion Research vol. II (1981) 1912-1915.

[12] A.L. Trego et al., "Fusion Materials Irradiation Test Facility - A Facility for Fusion Materials Qualification," Nucl. Technol./Fusion 4 (1981) 695-700.

[13] A. Shima, " 任意のノズル形状に関する直接法及び逆法の理論 (Theory of direct and inverse methods to decide nozzle shape)," Mem. Inst. High Sp. Mech., Japan 17 (1961/62) No. 164 (in Japanese).

[14] S. Goldstein, "Notes on the Design of Converging Channels," A. R. C., R. & M., No. 2643 (1945).

[15] E. Fried and I.E. Idel'chik, "Flow Resistance: A Design Guide for Engineers," Hemisphere Publishing Co., New York (1989).

[16] M.J. Lighthill, "A New Method of Two-Dimensional Aerodynamic Design," R&M 2112, British Aeronautical Research Council, National Physical Laboratory, Teddington, Middlesex, UK (1945).

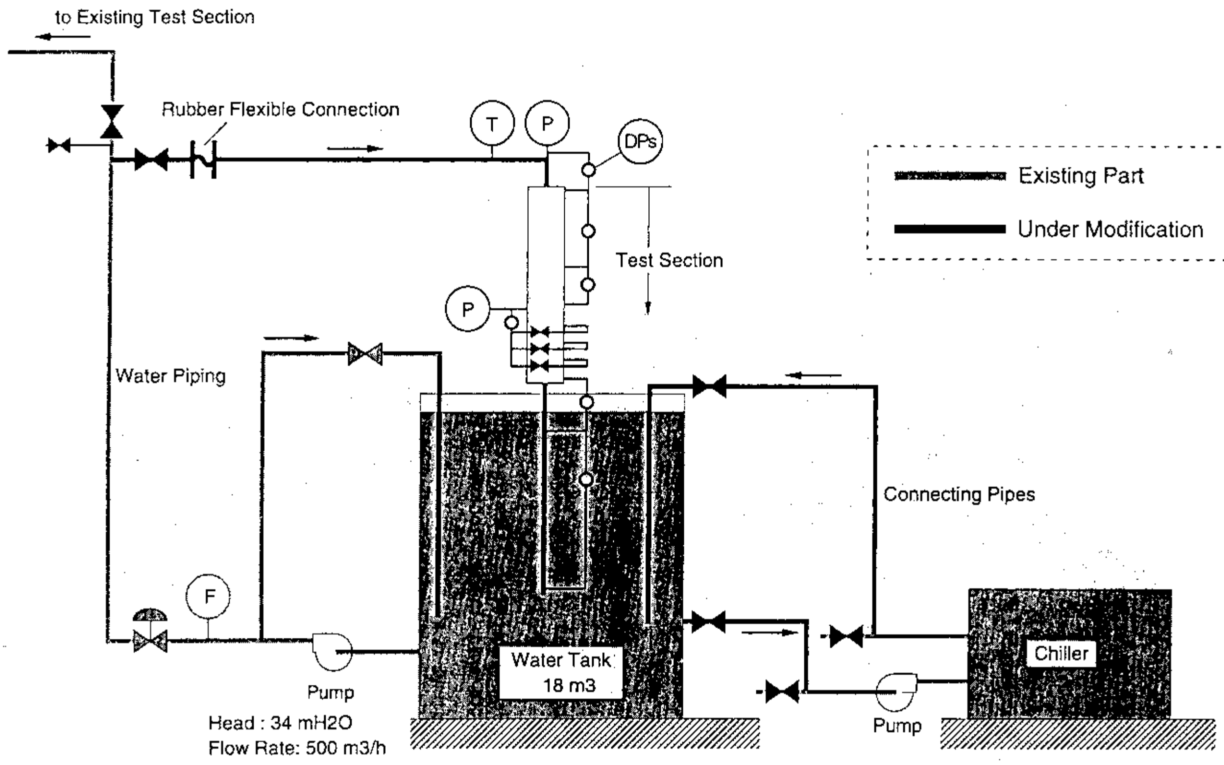


Fig. 1 Schematic Overview of Water Loop

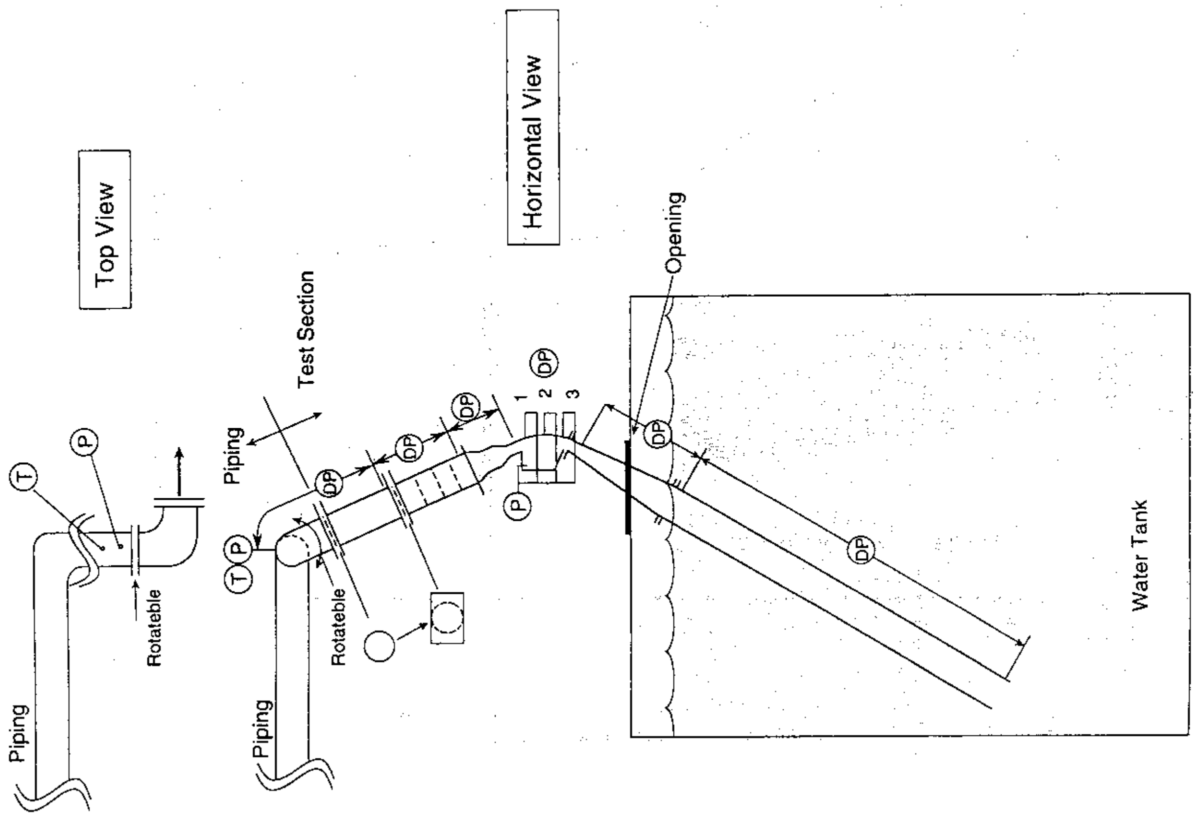


Fig. 2 Configuration of Test Section for Initial Water Experiments

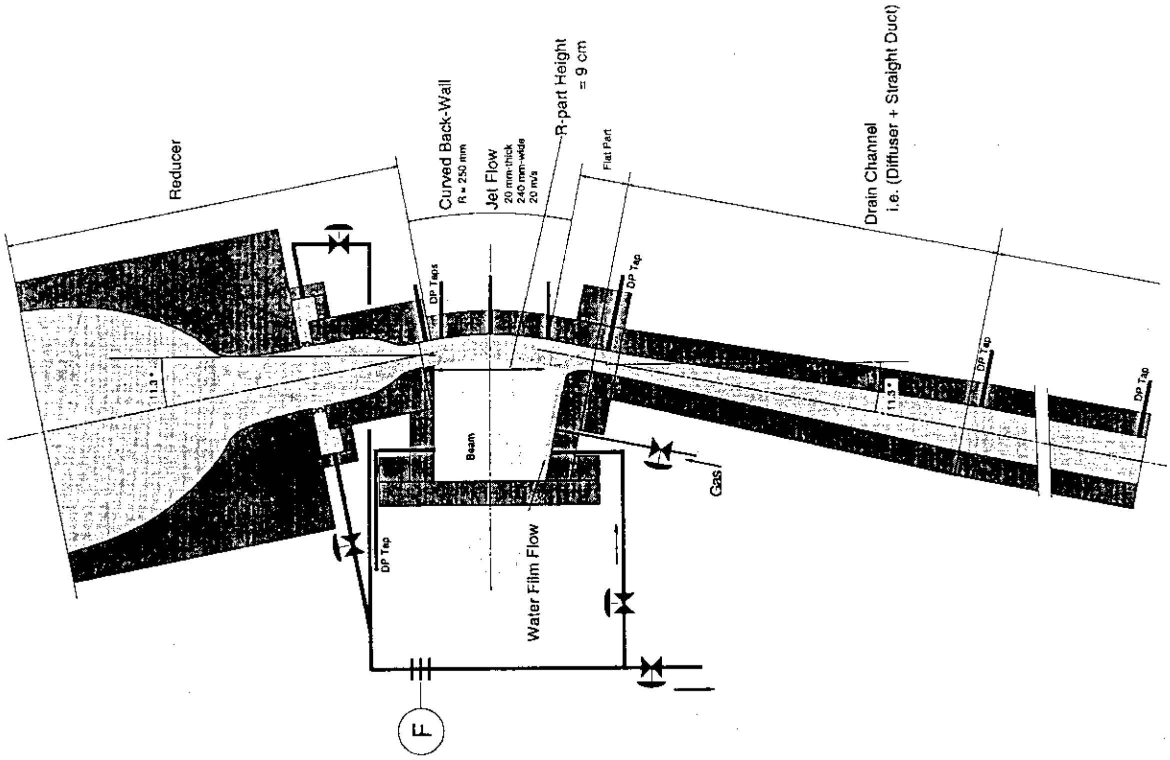


Fig. 3 Test Section for Initial Water Experiments

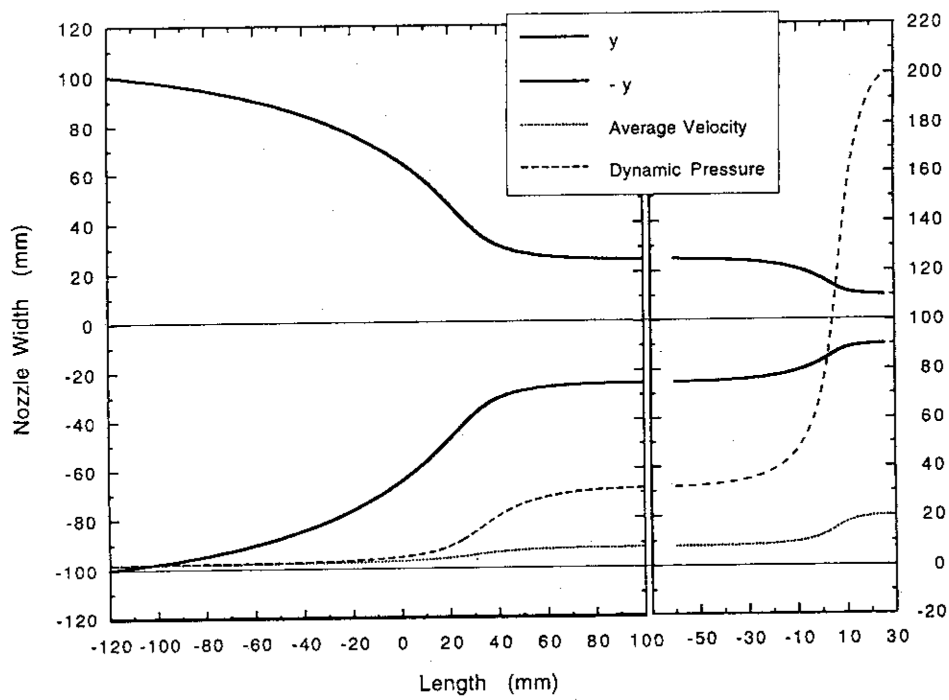


Fig. 4 Details of Double-Reducer for Converging Nozzle
(arbitrary for distance between reducers)

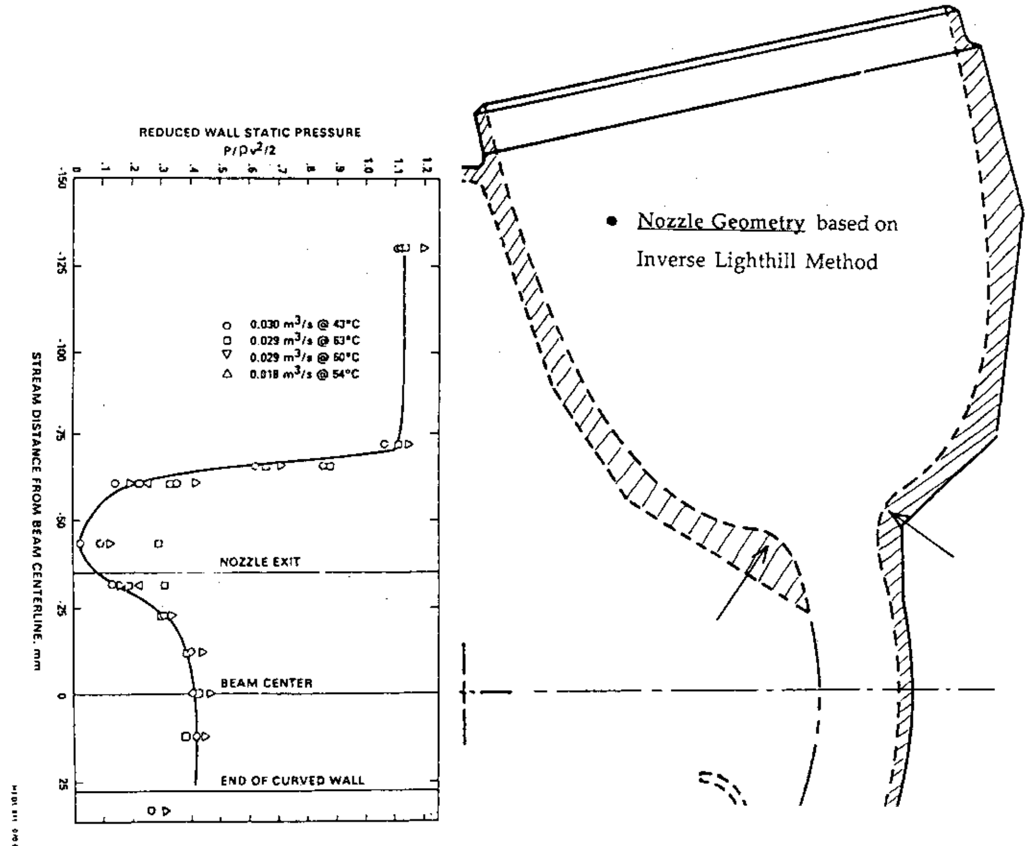


Fig. 5 (a) Reduced Back-Wall Static Pressure Profile in the FMIT Symmetric Target Nozzle

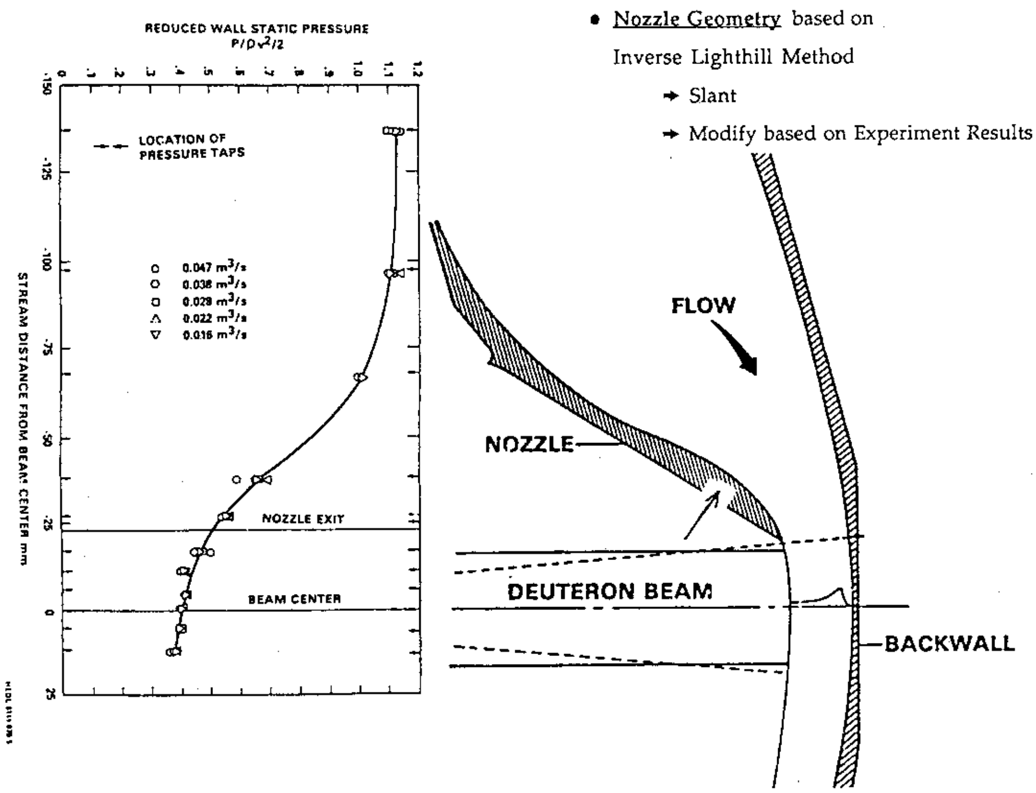


Fig. 5 (b) Reduced Back-Wall Static Pressure Profile in the FMIT Asymmetric Target Nozzle

2. Evaluation and Specification of Target-beam-test Cell

2. 1 Lithium Vaporization from Free Surface

Ahmed Hassanein

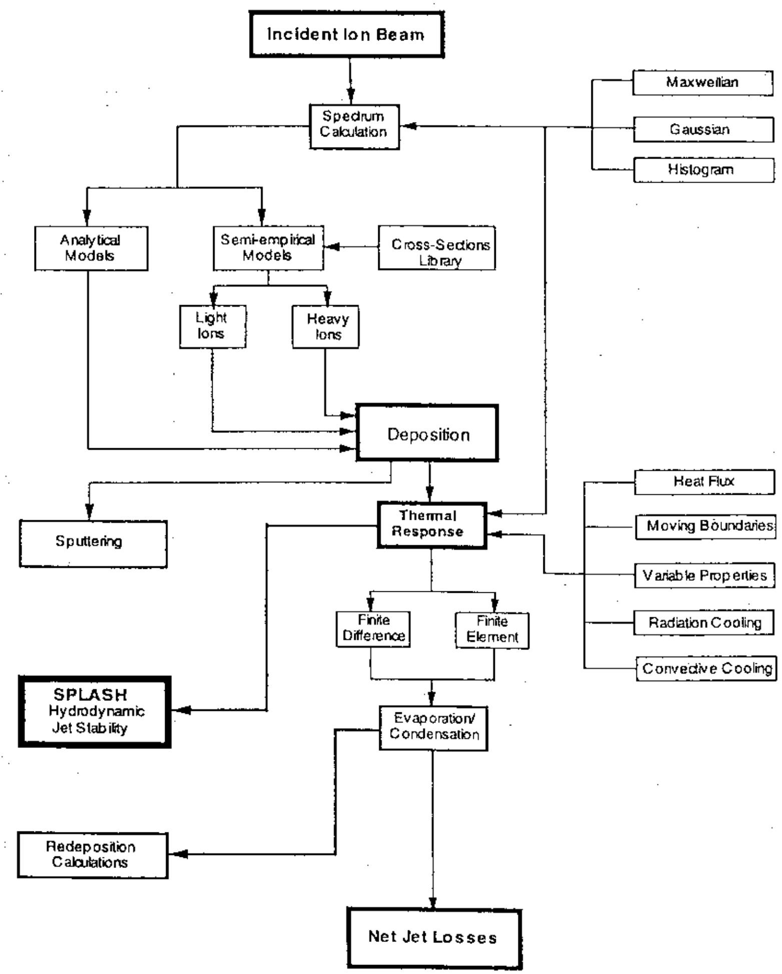
Argonne National Laboratory
USA

Presented at the 1st IFMIF-CDA Technical Workshop on Li Target System

July 18-21, 1995

JAERI, Japan

HIJET Computer Code



A. HASSANEIN (ANL)
JAPAN 7-95

II. Thermal Response

- The thermal response of the Li jet is calculated by solving a time-dependent heat conduction equation which is given by:

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (K \nabla T) + \dot{q}\,(y, Z, t)$$

where,

- T is temperature,
- ρ is density,
- C_p is specific heat,
- K is thermal conductivity, and
- $\dot{q}$ is the volumetric energy deposition rate of the incident deuteron beam.

- All thermophysical properties are assumed to be a function of local temperature.

- Several boundary conditions can be used to evaluate different design options such as free jet or a back-plate supported jet.

ah/Japan/07-95/05

Vaporization Model

- Velocity of receding surface, V (y, T) is a highly nonlinear function of temperature and is given by:

$$V(T) = 5.8 \times 10^{-2} \frac{\alpha \sqrt{A}\,(P_v(T) - P_o)}{\rho(T)\sqrt{T}} \left[0.8 + 0.2 e^{-t/10\tau_c}\right],$$

where

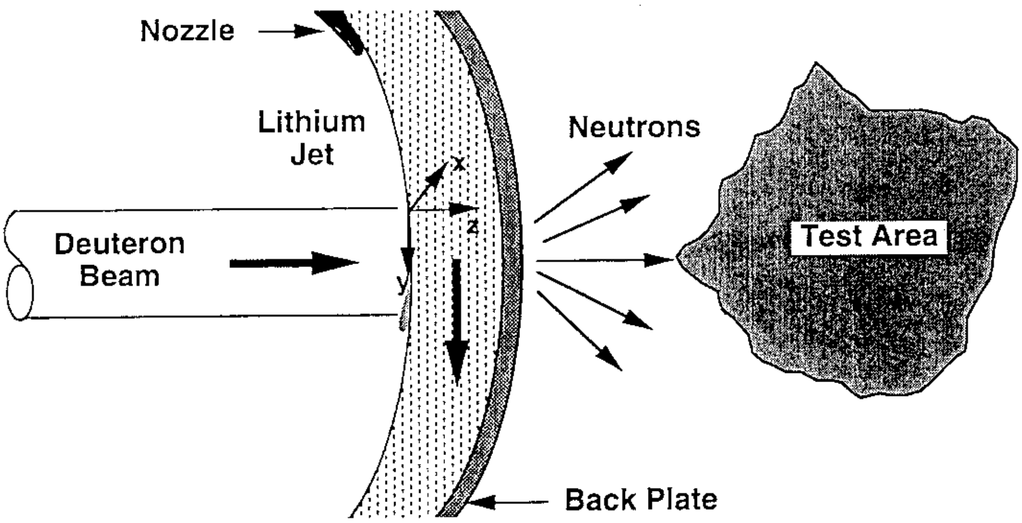
- α = sticking probability (≈ 1)
- A = atomic mass number of target material
- P_V = vapor pressure of target material (torr)
- P_o = ambient vapor pressure
- τ_C^{-1} = vapor collision frequency (s^{-1}).

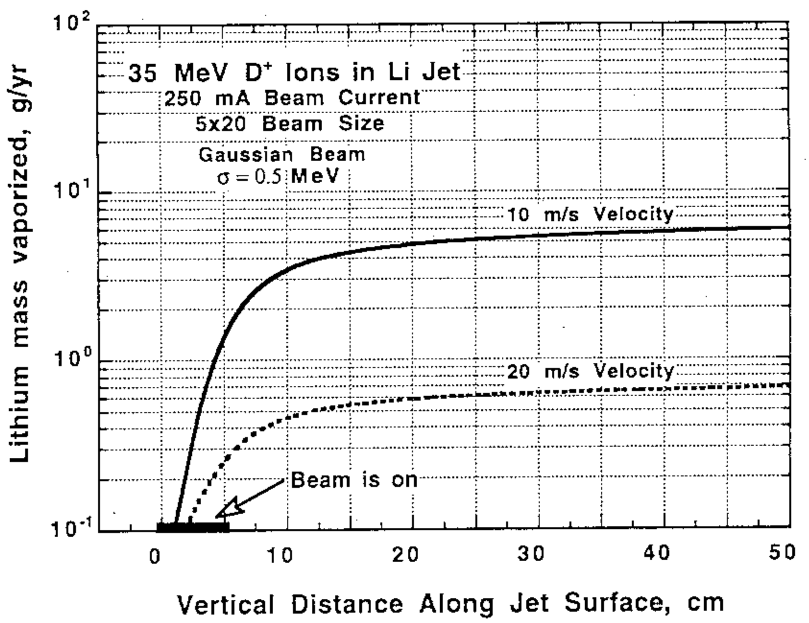
- Amount of Li vaporization, m_V, can then be given by:

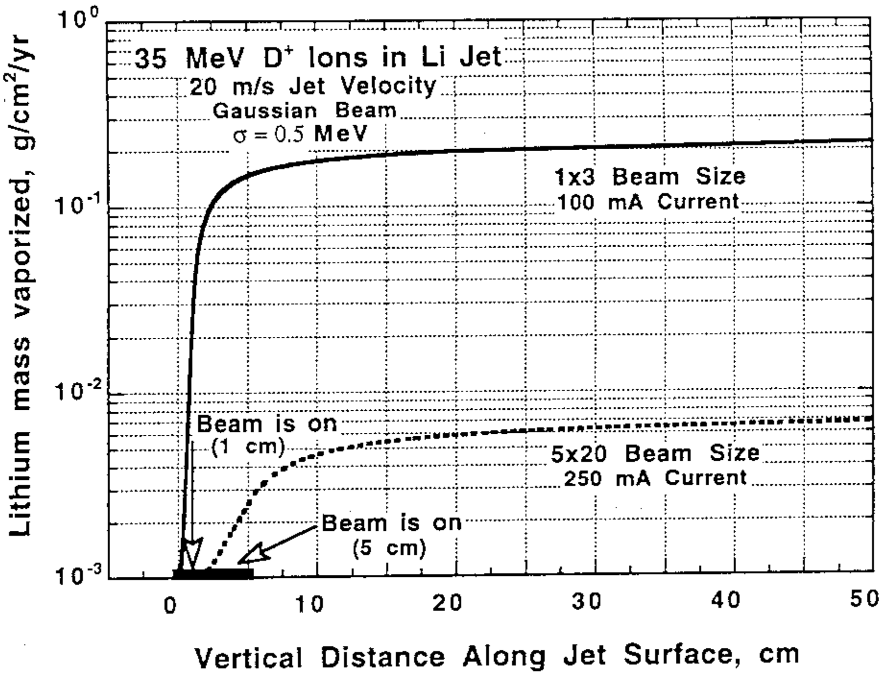
$$M_V = \int_o^y V(y, T)\,dy\ .$$

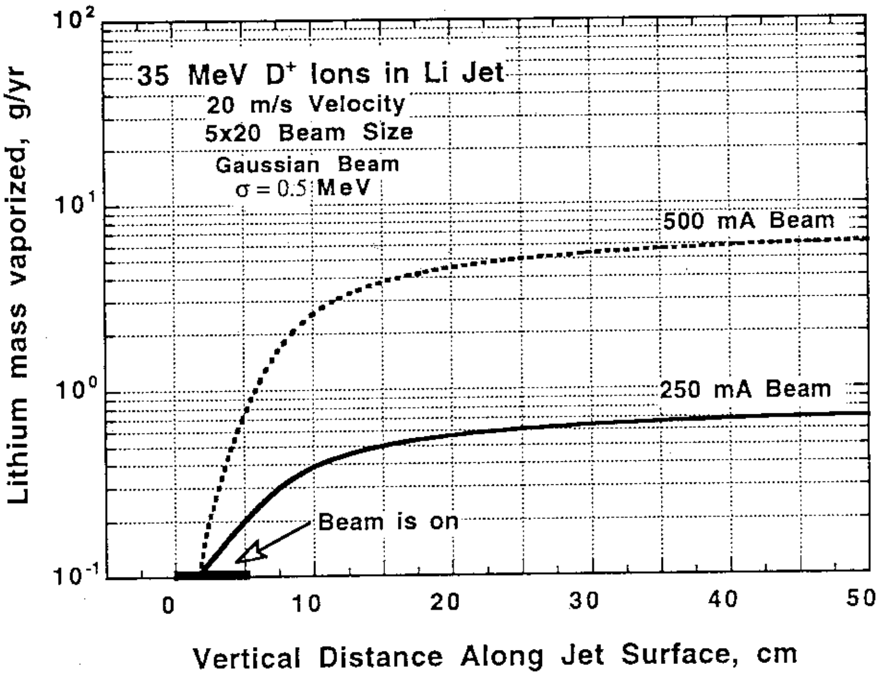
ah/Japan/07-95/08

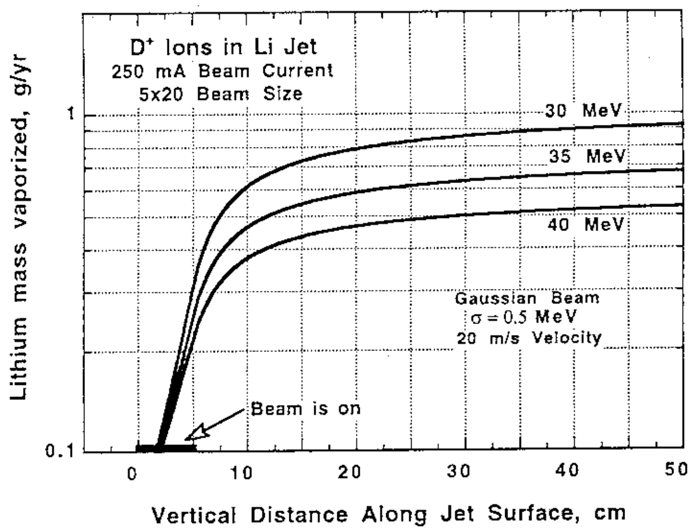
Schematic Illustration of Beam-Target Interaction for a Neutron Source Test Facility






35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
Gaussian Beam
σ = 0.5 MeV
1x3 Beam Size
100 mA Current
Beam is on
(1 cm)
5x20 Beam Size
250 mA Current
Beam is on
(5 cm)
Lithium mass vaporized, g/cm²/yr
Vertical Distance Along Jet Surface, cm


35 MeV D+ Ions in Li Jet
20 m/s Velocity
5x20 Beam Size
Gaussian Beam
σ = 0.5 MeV
500 mA Beam
250 mA Beam
Beam is on
Lithium mass vaporized, g/yr
Vertical Distance Along Jet Surface, cm



Conclusions

- Lithium jet surface evaporation depends on beam size, beam current, bean energy, and jet velocity.
- Higher beam energies, lower beam current-densities, and higher jet velocities reduce Li vaporization rate.
- Total Li vaporization can be minimized by decreasing exposed areas of the jet down stream, following beam interaction area.
- Surface vaporization in general seems to be small for beam and jet parameters studied.
- The impact of the amount of Li vaporized, its condensation and its interaction with incident beam need further analysis.

ah/Japan/07-95/10

2. 2 Some Comments for the Lithium Vapor Pressure Control

S. Konishi, Y. Kato, Y. Hoshi, and H. Nakamura
JAERI IFMIF Target System Group

1. Introduction

This topic is not an original task to be performed under the WBS, however identified as important in several of the tasks being discussed in Japan. Here, some preliminary thoughts are presented for further discussion to better define the issue and plan a study to understand and solve it in the CDA.

In order to design a consistent target system, followings are raised as concerns;

Vacuum pumping from the vicinity of the target
Lithium vapor deposition
Li spill and splash from the free surface
Processing of vacuum exhaust
Boiling margin of the free surface
Operation temperature of the lithium loop .

In this section, some concepts to improve the technical difficulties about these issues are suggested. Some R&D efforts, both designing and experimental, are being planned.

2.Objectives - Issues to be solved

Some concepts were worked out and being studied to solve the following technical issues. The results, if they are found to be effective, feasible and technically attractive, will be reflected in the target system design.

2.1 Vacuum pumping from the target

Although their is no solid boundary between the accelerator and the free surface of lithium target, as space in the vicinity of the target is usually regarded as a virtually isolated chamber. The target assembly including back wall are designed to facilitate easy replacement, while the beam transport is not. For start up, shut down and other operation of lithium loop, this target chamber should be mechanically isolated from the beam line with a gate valve. In this chamber, one of the most important species to be pumped is lithium vapor, and possibly lithium metal and compounds aerosol, mist or small particles. Lithium free surface may desorb some deuterium or tritium by vacuum extraction and bombardment by the beam. In order to maintain the good vacuum (~10^{-4} Pa) in the beam line, dedicated vacuum pumping is needed. By the reasons above, this virtual target chamber in the IFMIF system has rather unique circumstance, and thus the requirements for such vacuum pumping system are quite special and difficult to be met. Particular difficulty is related to the handling of active lithium and radioactivity of tritium.

2.2 Lithium vapor deposition

Lithium atoms evaporates from the free surface are released into the vacuum in the molecular flow region, where no collision is anticipated until such atoms hit the wall. Therefore the beam line and the wall of the target chamber are exposed to the lithium vapor that finally deposits on them. The amount of the deposit is a function of the temperature and cubic angle, and is not significant from the stand point of lithium loss. It could be a potential problem in the maintenance, because it will be a mixed waste. Lithium spill and splash in the target chamber causes similar problem. Depending on the start up scenario, inner wall of the chamber may be wet with the lithium.

2.3 Processing vacuum exhaust

Lack of the vacuum pump that is compatible with and capable to handle lithium metal requires a separation process of lithium from other vacuum exhaust, such as foreline trap. Dominant species of the vacuum exhaust from the target chamber and beam line will be, hydrogen isotopes, oxygen nitrogen and inert gas. Light hydrogen (protium) comes from nuclear reaction and residual moisture in the vacuum system that is decomposed by the reaction with lithium. Major sources of oxygen are also the moisture, oxide on the surface, and possible minor air leak. Nitrogen could come from a leak. All of these elements can react with lithium, if they are mixed with lithium vapor in the target chamber or vacuum piping from it. Therefore, exhaust gases except for inert such as helium and argon, will actually trapped as a compound with lithium. It is then rather reasonable if these species can be combined with the chemical process of the main lithium loop.

2.4 Boiling margin of the free surface

One of the major reason to limit the operation temperature of lithium target to be low is to limit the evaporation problem. Even if the boiling from the inside of the liquid film is avoided, vaporization from the free surface that increase with temperature exponentially strongly require the temperature to be kept minimal. On the other hand, lithium loop that is operated at the temperature merely above the melting point has very narrow window to stable circulate lithium. Effectiveness of the cold trap is rather poor due to the small temperature difference between the loop and trap temperature. If the loop temperature can be increased without increasing vapor pressure on the lithium target, the design and operation of the lithium loop may be easier. Under the vacuum, no lithium vapor can be expected to come back to the surface regardless of the pressure. If any molecules exist near the surface of the lithium, temperature of the lithium can be raised to the point correspondent to the effective vapor pressure. The increased margin for the boiling point will allow the operation temperature of the lithium loop to be more flexible, and relief design constraint.

3.Results of the preliminary studies

3.1Evaporation of lithium

By the simplest model, evaporation of lithium atom from the free surface exposed to a vacuum can be described by molecular kinetic theory. Flux of the molecule passes through a unit of area is written,

$$\Phi=\frac{1}{4}n\bar{v}$$

and with Boltzmann distribution, the mean velocity is,

$$\bar{v}=\int_0^\infty vf(v)dv=\sqrt{\frac{8kT}{\pi m}}\ ,\quad \int_0^\infty f(v)dv=1$$

and thus is a function of temperature and pressure. Using vapor pressure, rate of lithium evaporation is determined only by temperature. Figure 1 and 2 respectively shows the vapor pressure and flux of evaporating lithium as a function of temperature. At 300°C, vapor pressure of lithium is 10^{-6} torr and the loss from 5x20 cm area is estimated to be 0.55 g/day. This seems not a significant number, and the actual temperature of the lithium free surface is expected to be smaller. Some unexpected beam-lithium interaction other than thermalized heat such as sputtering might increase evaporation.

The direction of the lithium atom emitted from the liquid lithium is believed to obey the cosine low, and the velocity will be Maxwellian, and thus perpendicular to the surface line has the largest fraction. If the beam is injected vertically into the jet, lithium flux comes into the beam line will be maximum and cannot be pumped. Heat is removed by the kinetic energy of the evaporated gas from the lithium jet. Taking account these into the computer simulation of the lithium jet will describe the phenomena well. In the vacuum where mean free path of the lithium atom is longer than the dimension of the target chamber, evaporated Li deposits to the surrounding surface that is anticipated to be cooler than the jet. It should be noted that the movement of lithium has the preference and is not isotropic, and thus temperature and pressure cannot be defined. For instance, partial pressure and temperature of the lithium vapor from the free surface of the lithium may look like that from the temperature and saturated vapor pressure of the jet, but is not at equilibrium because nothing comes into the jet at this partial pressure and temperature .

3.2 Differential pumping of beam line - target chamber interface

The required vacuum in the beam line is 1×10^{-4} Pa, that is in the same order of lithium vapor on the 300°C surface. If the pressure in the target chamber is maintained higher, temperature of the surface can be increased. Differential pumping of the target chamber, and the interface with beam line will provide such a different pressure. The inner surface of the target cell will have to be heated to provide lithium vapor equilibrated with the chamber. Vacuum exhaust from the target chamber contains significant Li vapor, and needs separation process. Trapped lithium will finally have to be recovered.

Beam line will be equipped with several baffles to effectively isolate from the target chamber by this differential pumping. Fig.3. shows an example.

3.3 Liquid lithium flow in the target chamber

The inner surface of the target chamber will have a deposit of major part of lithium evaporated from the lithium jet. This lithium should be periodically removed and recovered. As described in the design previously reported in the plan of the water-jet experiment, small portion of liquid lithium introduced into the target chamber will trap the evaporated lithium and return it to the main loop. (Fig.4) This concept is also applicable to recover the spill and splash of lithium comes from the free surface.

3.4 Lithium diffusion pump

This concept provides the possible solution to evacuate the target chamber and beam line with reduced load for exhaust processing, completely prevent the lithium vapor flux into the beam line, and at the same time increase the boiling margin of lithium jet.

Attached figure illustrates how the lithium vapor sprayed to the liquid lithium would work. Diffusion pump, that is extensively used as commercial product of oil-diffusion pump or mercury diffusion pump utilize the flux of vapor that provide gases of momentum to desired direction for pumping. This vapor flux from the nozzle is not isotropic, just same as the evaporation of lithium from the jet, and has somewhat parallel direction. To this direction, vapor has virtual temperature of boiling liquid T1, but to the opposit direction, it is equivalent to cryogenic temperature where very few molecules come out. If this vapor jet is sprayed to the evaporating surface of the liquid lithium, lithium evaporation will be equilibrated with the flux, that is equivalent to T1. Thus, boiling margin can be increased and the lithium surface can be as hot as the temperature T1. At the back of the nozzle, no vapor of lithium come through the jet due to the collision, and thus net evaporation from the liquid lithium is zero. (In fact, negative). As a result, from the target to beam line, ideally no lithium vapor will diffuse. Moreover since this is a diffusion pump, any gas from the beam line will be transferred to the lithium jet and will be removed from the vacuum chamber.

Figure 4 shows the example of this lithium diffusion pump concept applied to the lithium target. Lithium used for diffusion-pumping can be provided from the main loop, and additionally heated to provide sufficient vapor flux.. The lithium vapor is recovered in the main loop, either directly injected to the free surface, or trapped on other surface and led to the main loop. Pumped gas such as hydrogen isotopes, oxygen, and nitrogen will react with active lithium, but they are anyway to be removed by the main chemical loop that purifies lithium. Only inert gas such as He will be pumped by additional backing pumps. Thus, lithium diffusion pump is quite suitable in the aspect of entire chemical processing of lithium and vacuum exhaust.

Diffusion pump vapor is typically at 10^{-2} torr~1 torr equivalent. With this flux, any area facing to this flux is hit and filled in 10^{-4} sec, that means the gas at the velocity of 1000 m/s can be hit at least once in 10 cm of flight. The temperature of liquid lithium in the pump boiler is therefore required to be heated to 500°C ~ 700°C.

The geometry and structure of diffusion pumps are well developed and mature technology. No difficulty is anticipated to develop the lithium diffusion pump, except for the material withstand high temperature lithium.

4. Concludint remark

Several issues related to the target and its facing vacuum system are identified, and possible methods to solve them are suggested. Although all of the proposed concepts are rather premature, some may be valuable to pursue for feasibility studies.

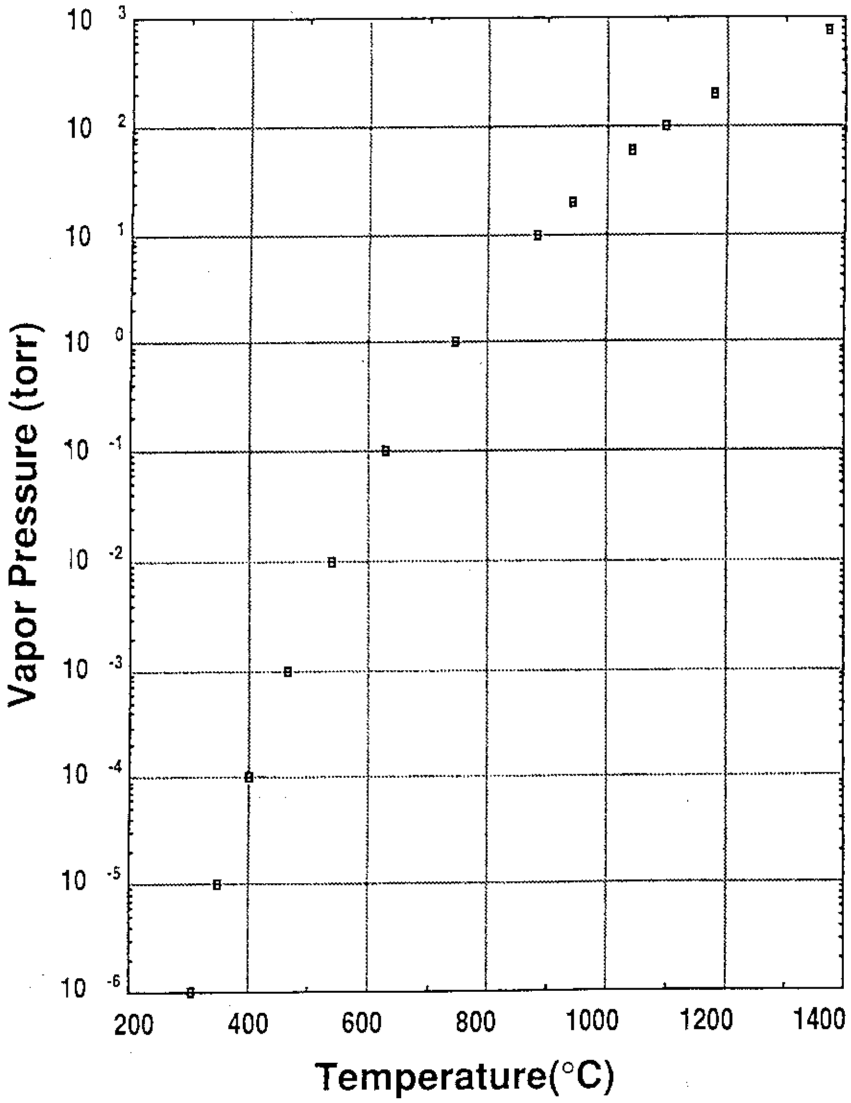


Fig.1 Vapor pressure of lithium

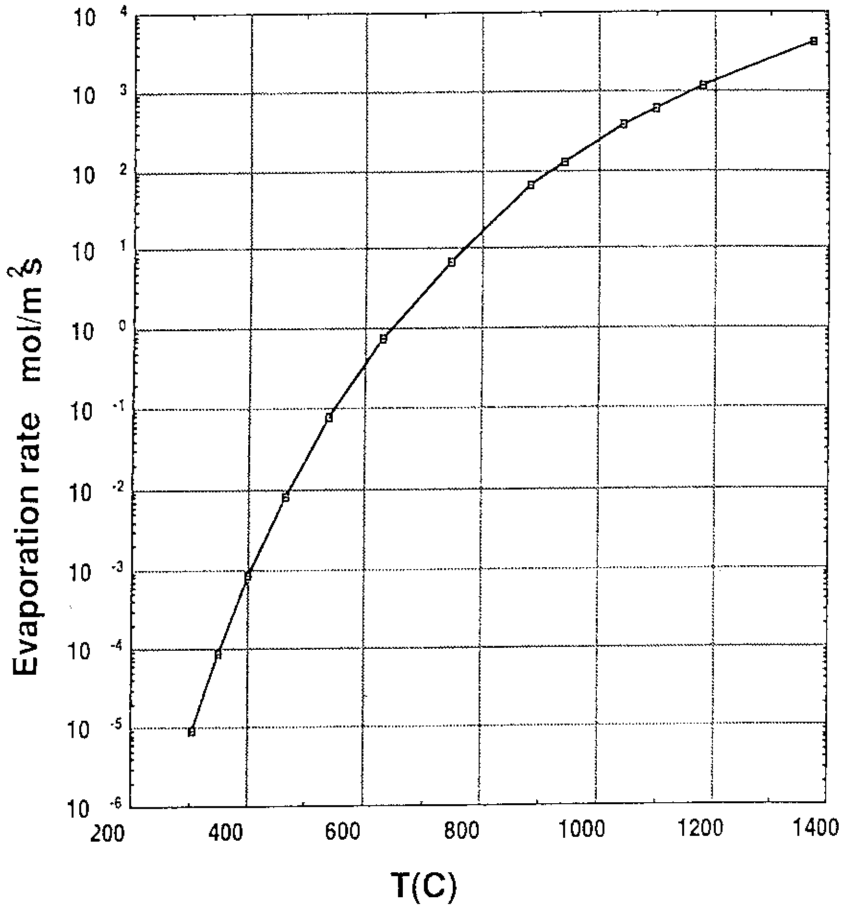


Fig. 2 Evaporation rate of lithium

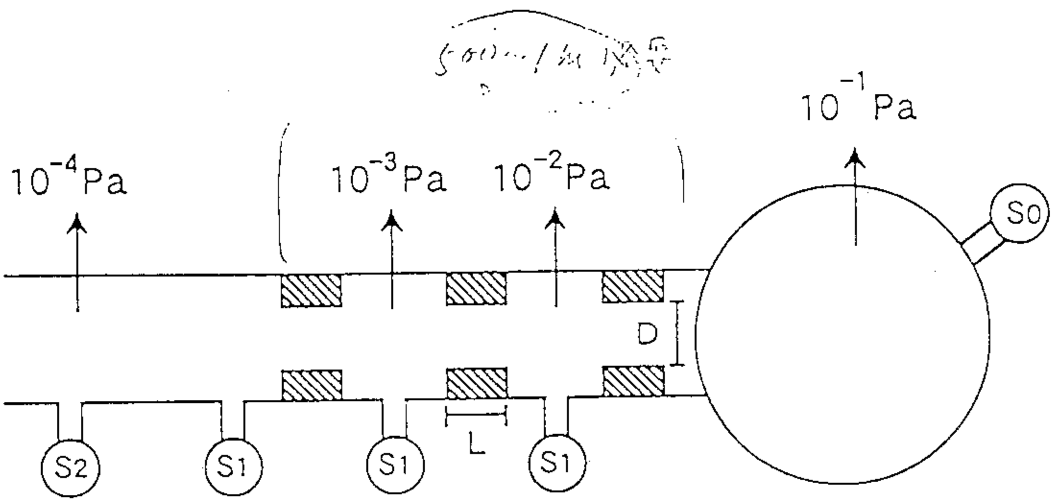


Fig. 3. Differential pumping

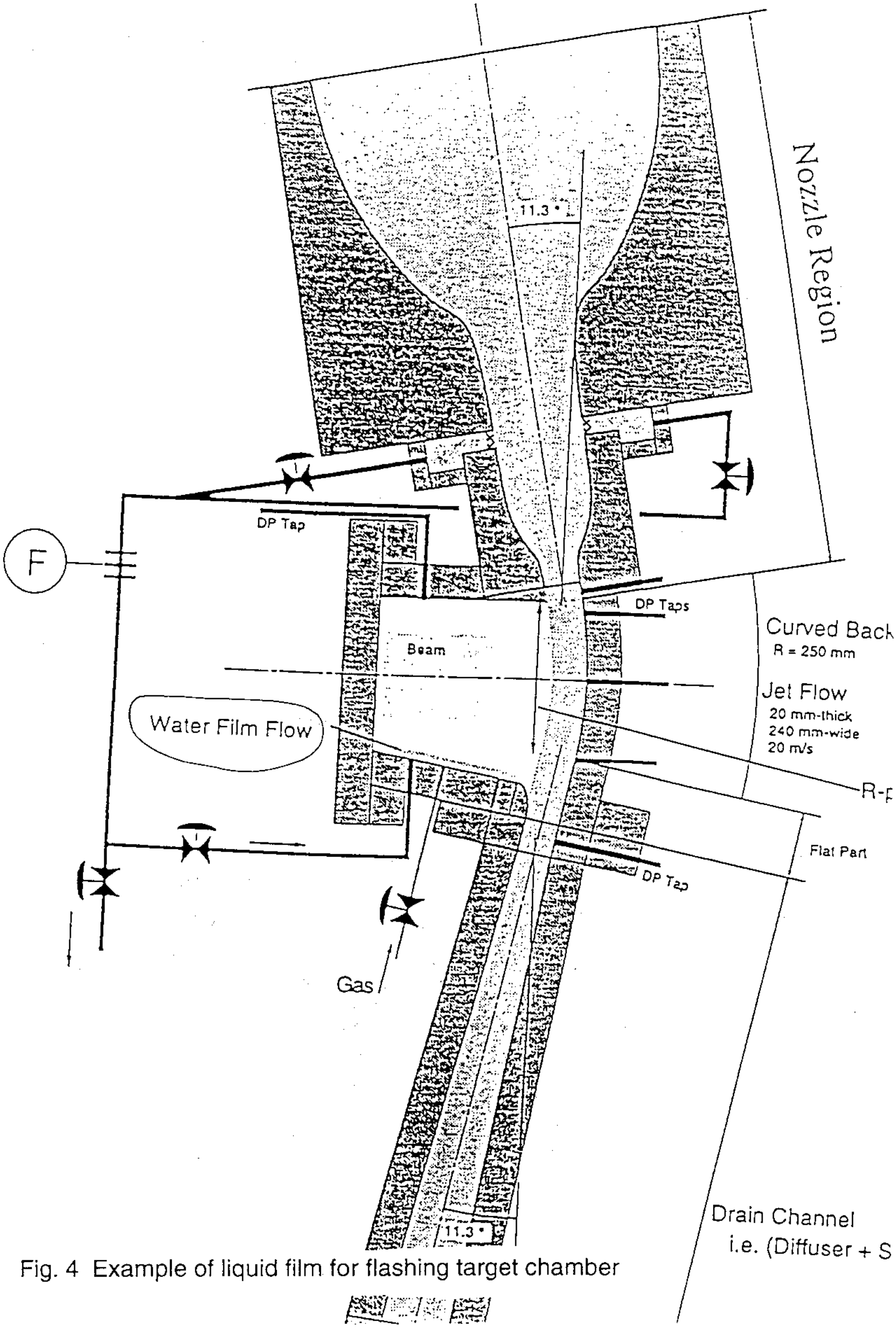


Fig. 4 Example of liquid film for flashing target chamber

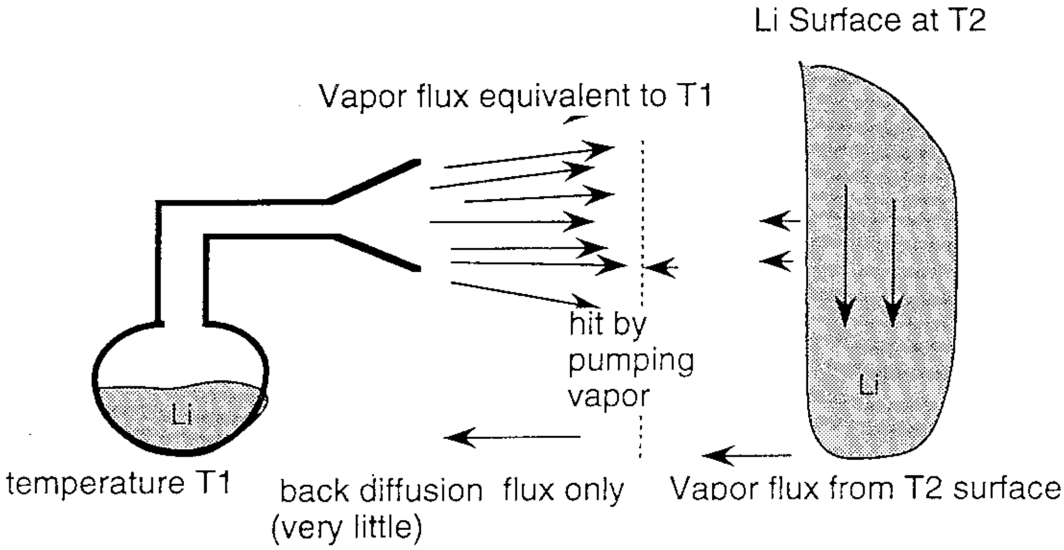


Fig.5 Principle of diffusion pumping」の原理

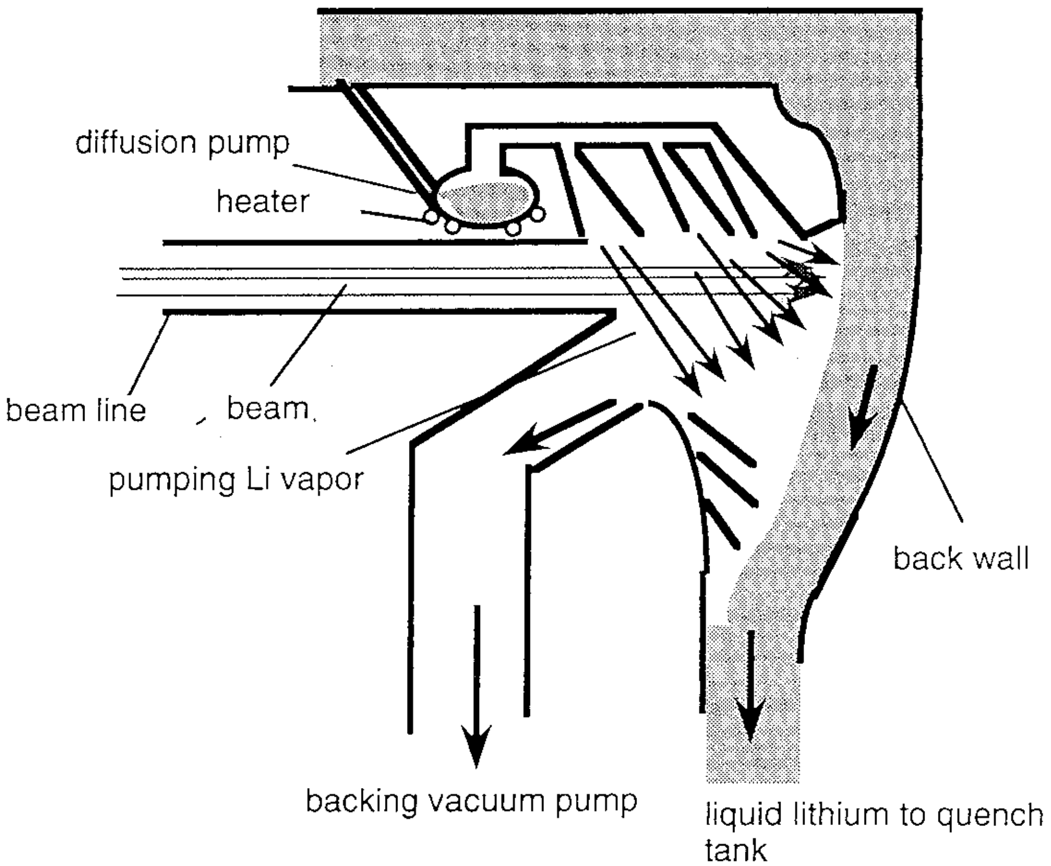


Fig. 6 Example of application of Li diffusion pump to target

2.3 Investigation of the Li Evaporation Rate

by

W. Cherdron
FKZ-IRS

Contribution to the 1st IFMIF-CDA Technical Workshop on Li-Target System
Tokai-mura (JP), July 18-21, 1995

- **Thermal hydraulic analysis of the lithium jet**

This analysis has begun with the purpose of evaluation of the lithium evaporation from the jet free surface. Later on our research will be concentrated on problems related to target interface such as: the rate of Li evaporation, aerosol formation and deposition, mass flow profiles and their perturbation when the beam is on.

The thermal hydraulic response of the Li jet target will be simulated by the finite element method (FEM) code: FIDAP (Fluid Dynamics Analysis Package). FIDAP is a commercial FEM code capable of analysing a wide range of different problems.

For the non-isothermal problem of the interaction of the deuteron beam with the Li jet target the model analysed by FIDAP contains the Navier-Stokes equations, the continuity equation and the energy equation for temperature distribution.

We decided to use the FIDAP code based on the following features:

- the FIDAP code is able to simulate both two- and three-dimensional non-isothermal fluid flow problems;
- the boundary conditions that can be applied to the fluid include: free surface with surface tension effects;
- the FIDAP code has the possibility of solving up to fifteen additional transport equations simultaneously with the Navier-Stokes and energy equations. This will allow us to implement models for the evaporation rate from the jet free surface.
- the code permits to model all the physical properties that relate to the problem being studied (fluid density, viscosity, specific heat, thermal conductivity, diffusivity etc.) with temperature dependence.

For the first step of analysis we prepare the input for two-dimensional simulations of the Li jet thermo-hydraulic response.

FIDAP is able to simulate also three-dimensional geometries. This feature will be used in a second step for the assessment of the thermal-peak effects at deuteron beam edges.

In the present phase of the analysis we need the heating power spatial distribution. Due to the lack of deuteron stopping power data with temperature dependence only a constant (not dependent on the temperature field) heating power distribution will be considered.

- **Search for advanced numerical schemes for convection dominated fluid flow modelling**

Since the simulation of the Li jet target thermal hydraulic response belongs to the class of convection dominated flow problems, numerical instabilities are expected.

In order to asses the quality of the simulation performed with the FIDAP code, in parallel with the above mentioned studies, we are searching for advanced numerical methods for solving the convection dominated fluid flow problems.

It seems that the recently introduced locally exact consistent upwind scheme of second order (LECUSSO-scheme due to Günther Cl., Int. J. Numer. Methods Eng., 34, (1992)793), now in bench-marking in our group, could provide accurate numerical results.

The work will proceed by implementing the LECUSSO scheme in an existing code or by developing a code dedicated to the simulation of the deuteron beam - Li jet target interaction.

- **Characterization of the neutron source**

The neutron flux and energy spectrum angular distribution is described by semianalytical expressions which incorporate realistic angular and energetic distribution function of the deuteron beam The d-Li differential cross section is expanded in Legendre polynomials.

3. Preliminary Conceptual Design for Li-loop System Lay-out and Component Design

3. 1 IFMIF Li System Layout and Some Components Proposal

Y. KATO, S. KONISHI, Y. HOSHI
IFMIF Target System Group of JAERI/JAPAN

1. Introduction

The proposal of Li cooling system concept and general layout of primary system, based on the design of critical components are presented in this paper.

The reference systems comprise primary, secondary and tertiary systems. The primary system has a branched subsystem "purification system". The purpose of secondary system (organic) is to avoid direct Li-water reaction in case of heat transfer tube failure. The capacity of primary loop is decided considering that lithium absorbs 8.75MW of continuous beam power. The cold leg temperature and flow rate is selected, referring to the thermo-hydraulic analysis of Li jet. The resultant average hot leg temperature is expected to be ~265°C.

The primary system operates under vacuum, but the pressure recovery system may be adopted, if the effectiveness of a diffuser is verified by hydraulic test planned in autumn.

The preliminary design of critical components, such as electro magnetic pump, lithium cooler and tanks was executed to investigate whether or not there are any technical difficulties. As a result, it proved that all components can be designed and constructed, making use of much experience with sodium, but it is desirable to clarify the uncertainties peculiar to Li environments.

The general layout of primary system, based on the above components design is given herein. However, this arrangements or floor area may change after taking into account the component maintenance and measures against Li leakage.

Finally, the authors pointed out the items which need considerable studies or have to be cleared during CDA.

2. System Design

Reference system consists of primary, secondary and tertiary loops. The final system parameters and system concept are shown in Table 19-2-1 and Fig. 19-2-1, respectively. The followings are the key features.

(1) To eliminate secondary system (for instance, to employ heat pipe or double-wall heat exchanger) may lead to simple system and low cost. However, indirect organic cooling system was selected as reference, taking the least probability of Li-water reaction more important.

(2) The reference operational pressure is 10^{-4} Pa. The pressure recovery system may be adopted, if the effectiveness of a diffuser are demonstrated by a hydraulic test.

(3) The pressure of primary loop is higher than that of secondary system at Li-cooler at any moment. This must be finally decided, however, considering that:

a. how to detect the small leak
b. radioactive materials transfer
c. separation of mixture

(4) The surge tank is installed to absorb the thermal expansion volume and uppermost piping volume or to keep stable operation of purification system. From the view point of economy, elimination of this system may be brought up for discussion.

3. Component Design

(1) Primary Pump:

Electro Magnetic Pump (EMP) was selected, compared with mechanical pump which gives impact on the system design as follows.

a. free surface requires elevated layout and lithium level control
b. lithium leaking risk
c. higher pressure drop

The experienced capacity of EMP was investigated. (See Fig. 19-2-2)

Up to about half the capacity of full flow (IFMIF), we have already experienced much with sodium in Japan. Also 10,000 ℓ/min (~3kg/cm) FLIP (Flat Linear Induction Pump) was designed, constructed and tested more than ten years ago. The largest EMP (44,000ℓ/min) manufactured by Toshiba is being tested in the United States.

So there is no difficulties with design and construction, but Toshiba says "The operational experience of small scale pump (~1,000ℓ/min) would be desirable to confirm electro-magnetic properties of Li."

(2) Electro Magnetic Flowmeter:

EMF, at present, is the best selection, because there is much experience with sodium. However, this kind of flowmeter needs absolute calibration, using gravitational flowing-down lithium. Also it is desirable to operate under lithium environment. Ultrasonic flowmeter may be the next candidate.

(3) Lithium Cooler, Tanks, Valves:

There is no serious problems with design and construction. The only data we need are corrosion rate, heat-transer characteristics and pressure drop after a long period of operation in lithium with some level of impurities. (Ref. Fig. 19-2-3)

4. Layout

The general layout of primary system is shown in Fig. 19-2-4~Fig. 19-2-9. However, this arrangements may be changed on modified as the design get into details. The matters having important effects on layout are the followings.

(1) periodical exchange of target assembly

(2) maintenance of active components (valves, pumps)

(3) adoption of pressure recovery system

(4) shielding structures of components

(5) measures against lithium leak (detection, accommodation, safety)

(6) gas evacuation system design (vacuum pump, evacuation duct)

5. Items to require great efforts

(1) gas evacuation system

a. production rate of gaseous reaction products
b. selection of vacuum pump and evacuated gas treatment (tritium)
c. low pressure drop Li vapor trap

(2) radiation damage of selected organic fluid

(3) measures against lithium leak, from the view point of detection, acomodation and safety

(4) remote handling machine (periodical exchange of target assembly and maintenance of active component)

(5) estimation of dose rate for radiation shielding design (radioactive materials deposition data)

(6) impurities removal system (acceptable level, C/T or H/T design data)

6. Conclusion

(1) There are no difficult problems to design and construct lithium components. However, lithium loop operation experience such as Li Technology Test Loop is highly desirable to reflect uncertain factors associated with lithium environments on detail design.

(2) Among 5. Items, gas evacuation system, measures against lithium leak and remote handling system are the most important ones.

(3) The major parameters, such as beam power and target size, influencing the capacity of the cooling system shall be fixed as soon as possible. Water loop test is indispensable for final judgement.

Table 19-2-1 Specification of Target Cooling System

I	Primary System (Lithium)	
(1)	Beam Power	8.75MW (35MeV x 250mA)
(2)	Flow Rate	88 ℓ/s
(3)	operating temperature	220 °C
(4)	operating pressure Vacuum at Target, Quench Tank	10^{-4} Pa
(5)	Piping Size	6B/8B
(6)	Velocity in Pipings	4.7m/s 2.7m/s
(7)	Velocity at Nozzle Exit	~20m/s (max)
(8)	System pressure drop	2.5~3kg/cm_2
(9)	Purification System Flow Rate	<5%
(10)	total inventory of primary system	~14m3
II	Secondary System:	
	Cooling Fluid	Organic Fluid Therm S-600
III	Tertiary System:	
	Cooling Fluid	Water (cooling tower)

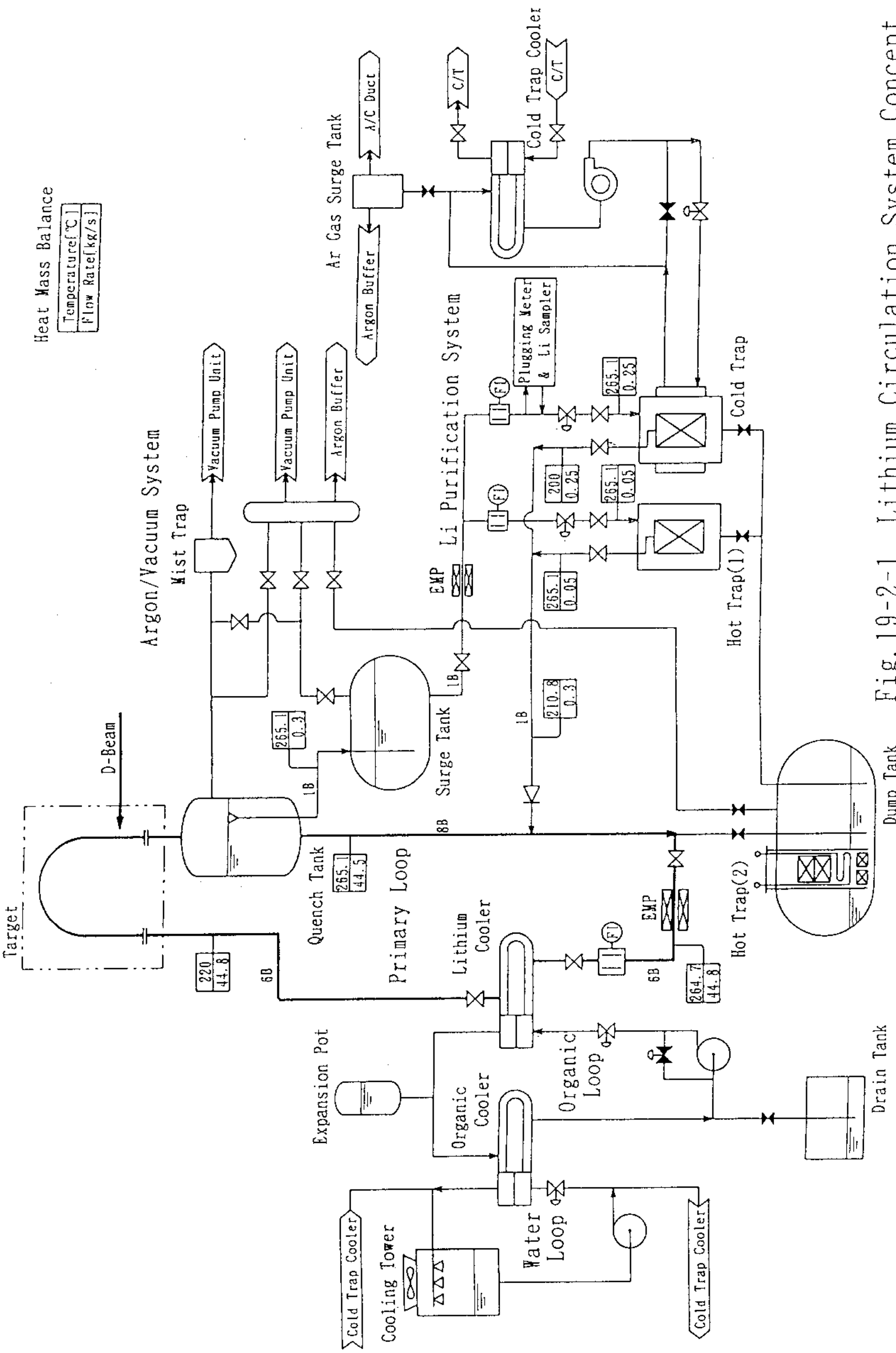


Fig.19-2-1 Lithium Circulation System Concept

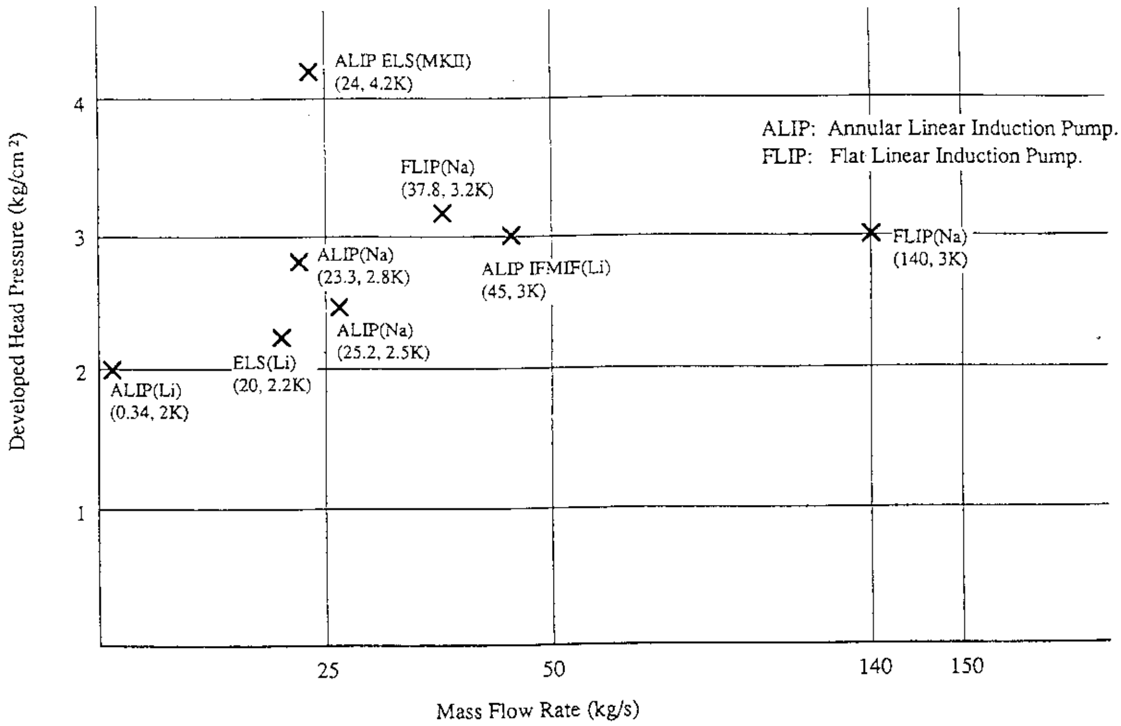


FIG. 19-2-2 ALIP or FLIP Experience

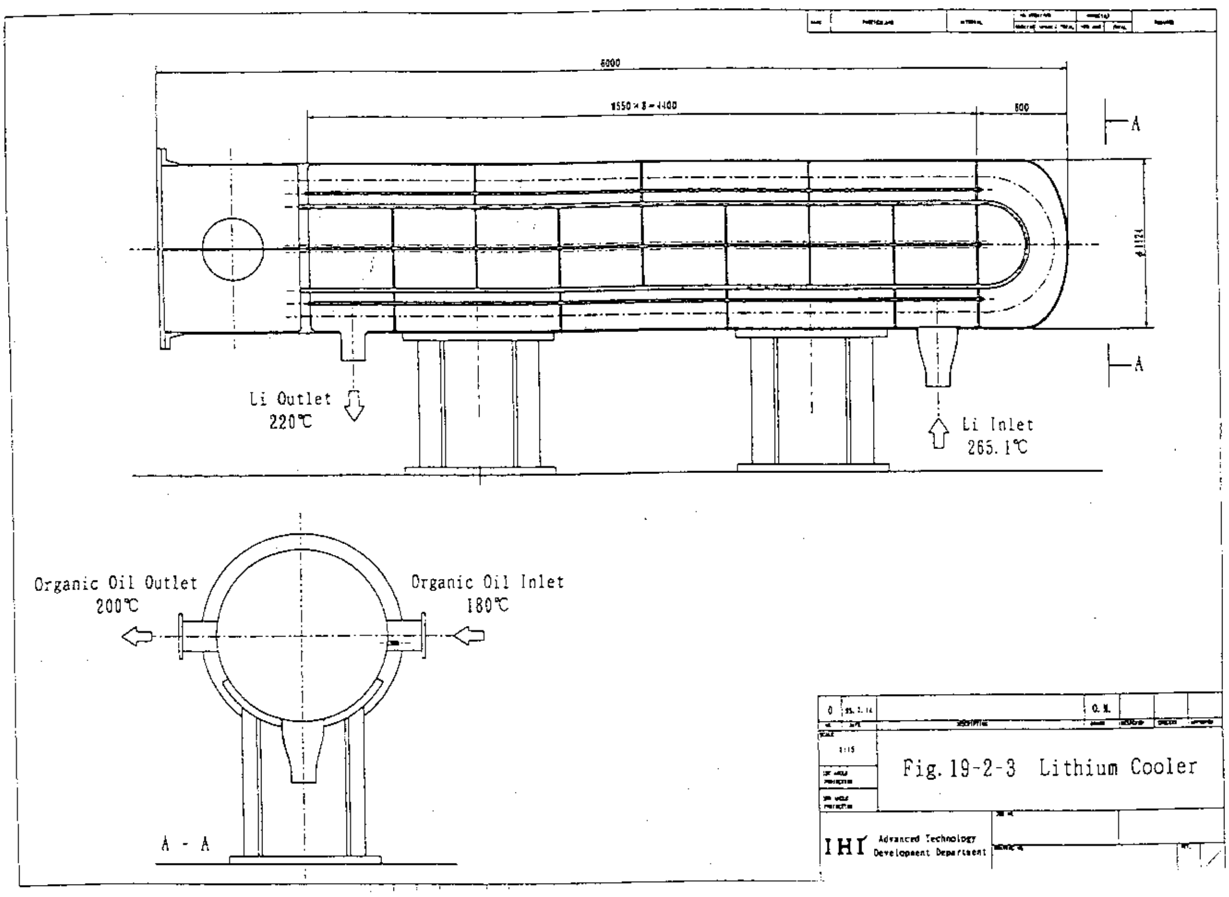


Fig. 19-2-3 Lithium Cooler

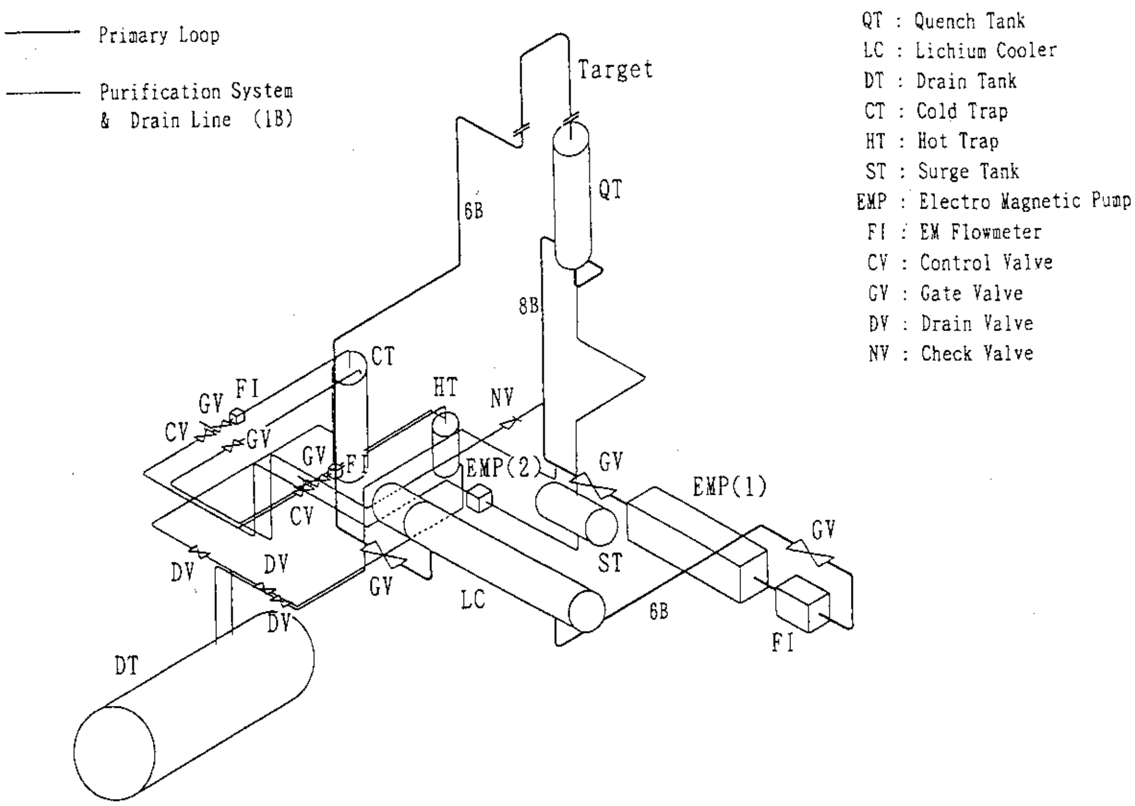


Fig. 19-2-4 Isometric View of Primary Loop

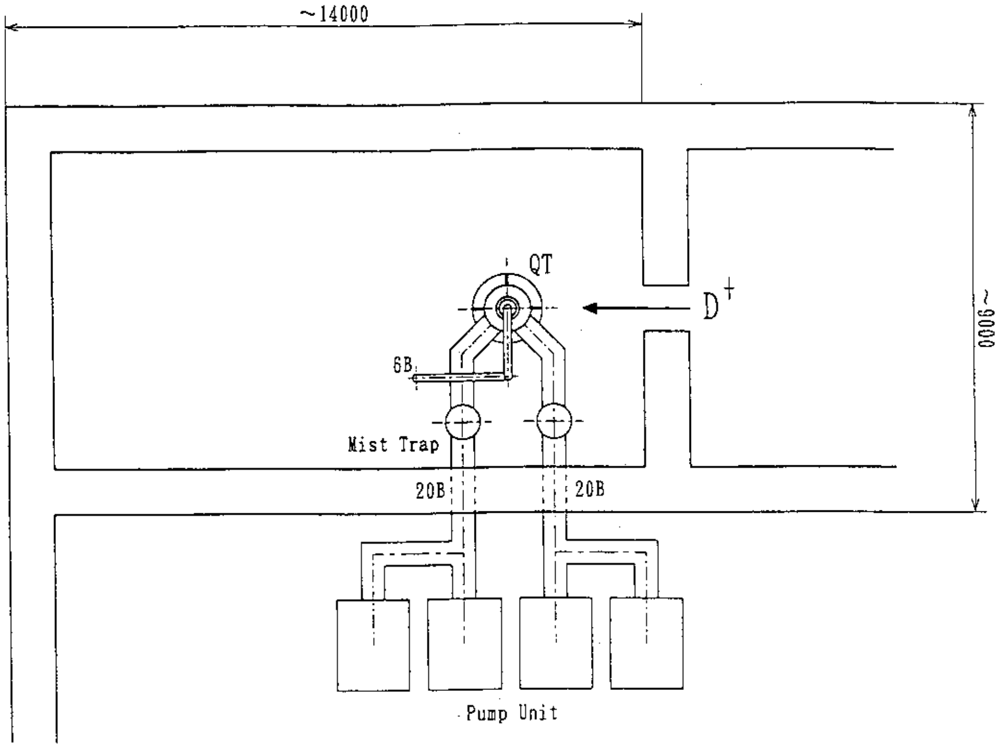


Fig. 19-2-5 Plan View of Primary Loop (3F)

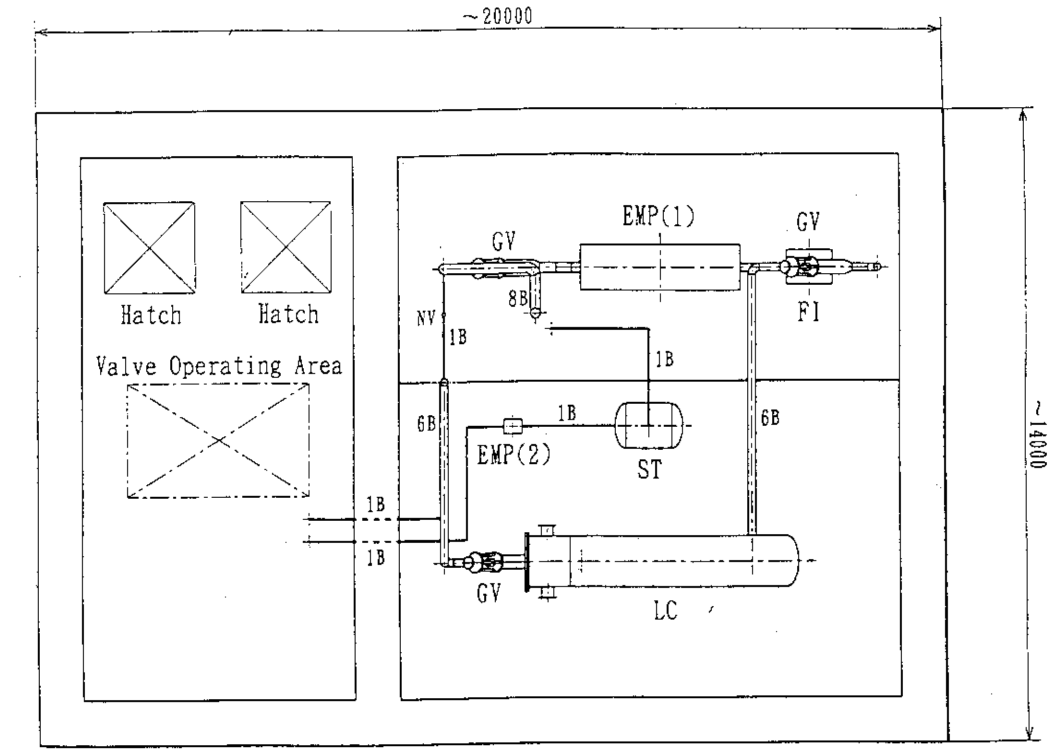


Fig. 19-2-6 Plan View of Primary Loop (2F)

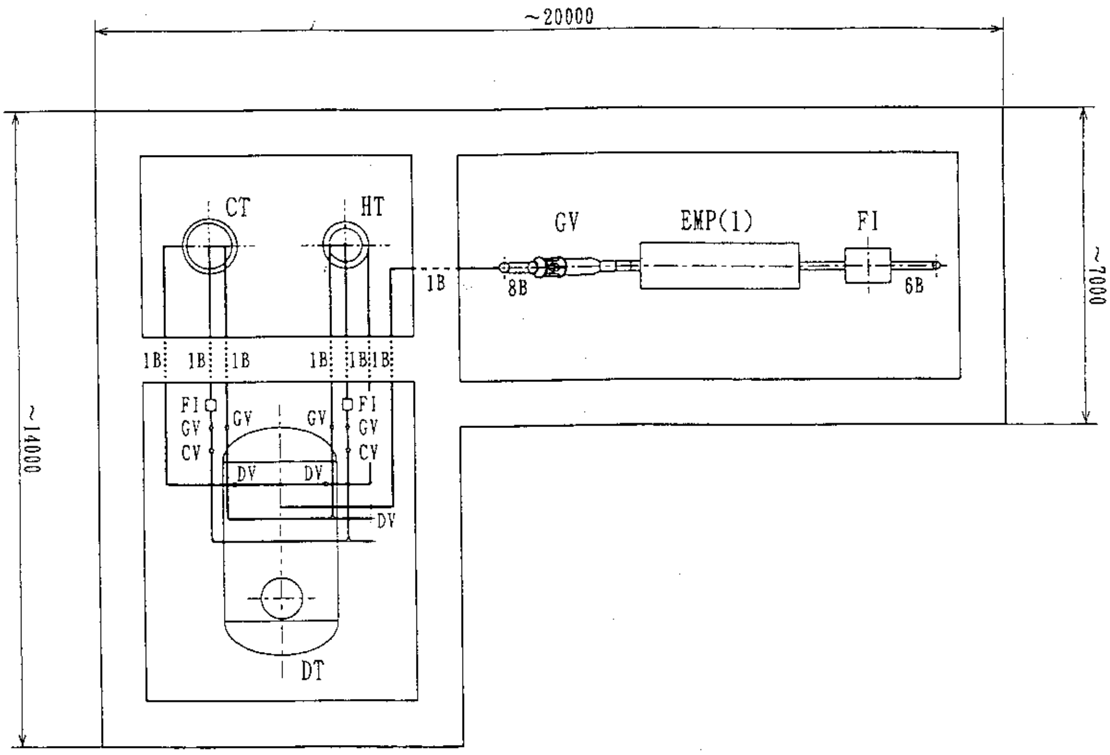


Fig. 19-2-7 Plan View of Primary Loop (1F)

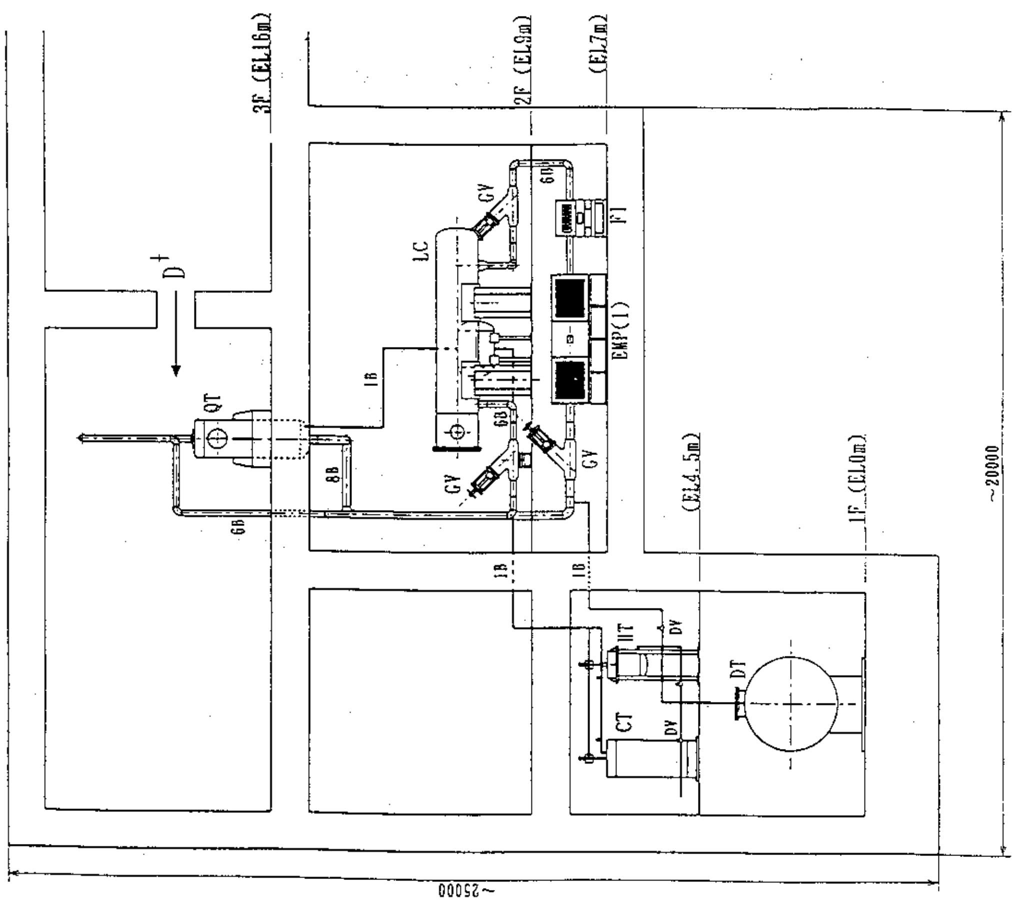


Fig.19-2-8 Cross Section of Primary Loop (A-A)

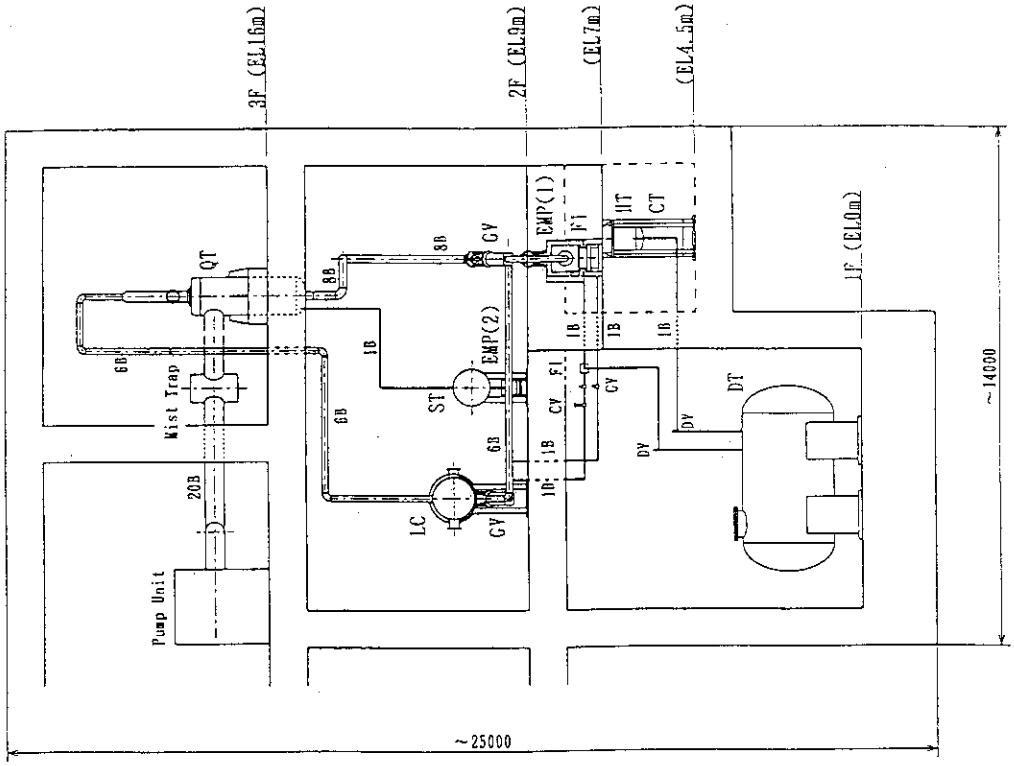


Fig.19-2-9 Cross Section of Primary Loop (B-B)

3.2 Preliminary Conceptual Li-loop Layout & Component Design and Evaluation

L. Green, G. A. Bayles, R. E. Witkowski, R. M. Slepian
Westinghouse Science & Technology Center

IFMIF-CDA Technical Workshop on Li-Target System
Tokai-Mura, Japan
July 18-21, 1995

LG Vg 1
July 18-21, 1995

Westinghouse
Science & Technology Center

LITHIUM LOOP REQUIREMENTS

Jet Width	22-24 cm
Jet Thickness	2 cm (nominal)
Jet Velocity	17-20 m/s
Flowrate	75-100 l/s
Beam Power	250 mA (upgradeable to 500 mA)
Inlet Temperature	220°C
Mixed Outlet Temperature	270°C (250 mA)

LG Vg 2
July 18-21, 1995

Westinghouse
Science & Technology Center

COMPARISON OF IFMIF LOOP REQUIREMENTS TO OTHER SYSTEMS

	ELS	ESNIT	FMIT	IFMIF
Lithium Velocity @ Target (m/s)	17		17	17 - 20
Jet Width (cm)	10		10	22-24
Jet Depth (cm)	2		1.9	2.0
Jet Height (cm)	5		5	7-9
Main Loop Lithium Circ. Rate (l/s)	38	40	33-38	80-100
Beam Power (mA)	NA	50	100	250 per target
Beam Width (cm)	NA	3 (dia)	3	20
Beam Height (cm)	NA		1	5
Cooling Heat Load (MW)	NA	2	3.5	17.5
Max. Nitrogen Conc. (wppm)	60	10	400	TBD
Max. Carbon Conc. (wppm)				TBD
Max. Oxygen Conc. (wppm)	100	10	10	TBD
Max. ^{7}Be Conc. (wppm)	NA			TBD
Max.Tritium Conc. (wppm)	NA			TBD
Max. Hydrogen Conc. (wppm)		10	60	TBD

LG Vg 3
July 18-21, 1995

Westinghouse
Science & Technology Center

LITHIUM LOOP SUBSYSTEMS

- Main lithium loop
- Chemistry purification loop
- Impurity monitoring loop
- Lithium transfer system
- Main electromagnetic pump

LG Vg 4
July 18-21, 1995

Westinghouse
Science & Technology Center

MAIN LOOP COMPONENTS

- Quench Tank
- Surge Tank
- Lithium Dump Tank
- Organic Coolant Dump Tank
- Main EM Pump
- Trace Heating, Valves
- Lithium-Organic HX
- Organic-Water HX
- Vacuum/Argon System

LG Vg 5
July 18-21, 1995

Westinghouse
Science & Technology Center

DESIGN CRITERIA & SIZE/VOLUME OF IFMIF MAIN LOOP COMPONENTS COMPARED TO OTHER SYSTEMS

	ELS	ESNIT	FMIT	IFMIF
Main Loop Lithium Circ. Rate (l/s)	38	40	33 - 38	80-100
EMP-to-Target Pipe Size (cm)	10.16	10.16	10.16	15.24
Qeunch-to-EMP Pipe Size (cm)	15.24	15.24	15.24	20.32
EMP Outlet Velocity (m/s)	4.7	4.9	4.7	4.6
EMP Inlet Velocity (m/s)	2.1	2.2	2.1	2.6
EMP-to-Target Pressure Drop (MPa)		0.077		0.088
Quench-to-EMP Pressure Drop (MPa)		0.010		0.001
Target Head Loss (MPa)		0.194		0.076
Lithium Cooler Pressure Drop (MPa)		0.019		0.034
Total Main Loop Pressure Drop (MPa)		0.300		0.2
EMP Pressure Head (MPa)	0.22	0.360	0.275 - 0.5	0.28
Main Loop Pump Suction Head (MPa)	0.04		0.04	0.043
Quench Tank Capacity (l)		1900	900	2270
Surge Tank Capacity (l)	1900			2500
Dump Tank Capacity (l)	6400	6400	6400	7000
Lithium in Piping, Heat Exch.(l)	800			3750
Total Lithium (l)	3800		4560	5940
Lithium Transfer Pipe Size (cm)	1.27			2.54

LG Vg 6
July 18-21, 1995

Westinghouse
Science & Technology Center

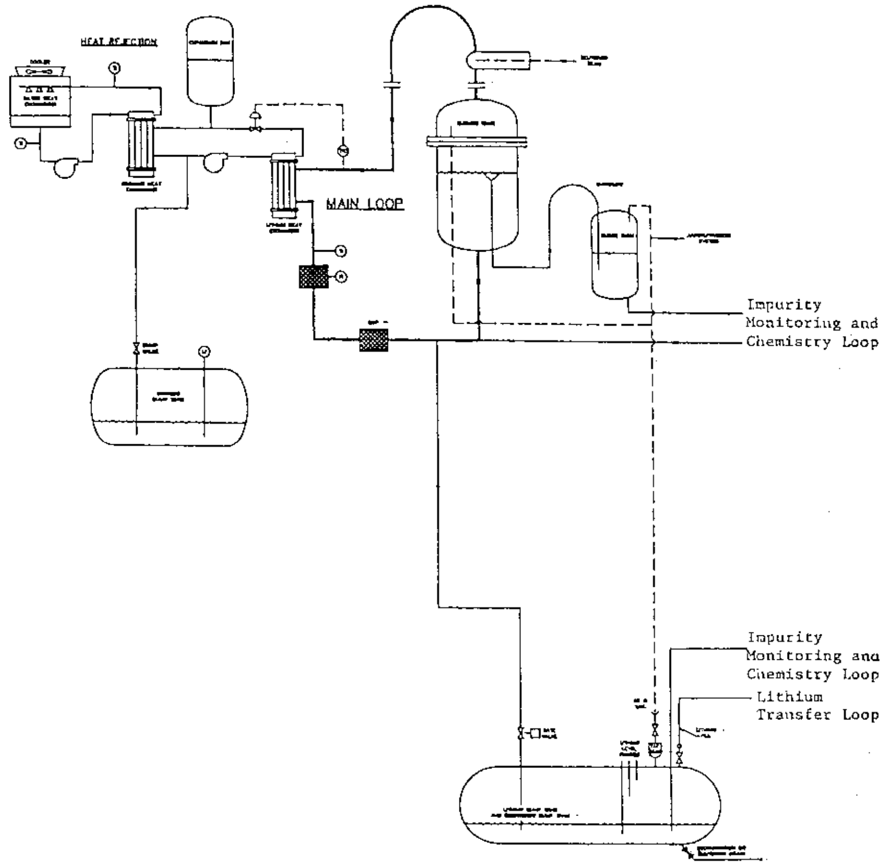
DESIGN CRITERIA & SIZE/VOLUME REQUIREMENTS FOR IFMIF MAIN LOOP HX & COMPARISON TO OTHER SYSTEMS

	ELS	ESNIT	FMIT	IFMIF
			.	
Lithium Flow Rate (l/s)	32	40	38	80-100
Cooling Heat Load (MW)	NA	2	3.5	10-20
Lithium Cooler Lithium Inlet Temp.(°C)		243	270	270-320
Lithium Cooler Lithium Outlet Temp.(°C)		220	220	220
Main Lithium Cooler Surface Area (m^2)		50.9	93	253
Lithium Cooler Organic Inlet Temp.(°C)		180		180
Lithium Cooler Organic Outlet Temp.(°C)		200		235
Lithium Cooler Dimensions (m)		0.6 OD, 3.8 L		1.5 OD, 3.8 L
Organic Coolant Specific Heat (kcal/kg °C)		0.601		0.51
Organic Cooler Organic Inlet Temp.(°C)		200		235
Organic Cooler Organic Outlet Temp.(°C)		180		180
Organic Cooler Surface Area (m^2)		53.7		341
Organic Cooler Water Inlet Temp.(°C)		32		38
Organic Cooler Water Outlet Temp.(°C)		42		66
Organic Flow Rate (kg/h)		1.65×10^5		6.3×10^5
Organic Type		Therm-S 600		Syltherm 800
Organic Cooler Dimensions (m)		0.6 OD, 4.1 L		1.5 OD, 5.5 L
Water Flow Rate (kg/h)		1.73×10^5		6.3×10^5
Maximum System Temperature (°C)	425	243	270	270-320
Minimum System Temperature (°C)	200	220	220	220
System Design Temperature (°C)	427	320	425	425
Lithium Cooler Heat Trx Coeff (W/m^2°C)		540		659
Organic Cooler Heat Trx Coeff (W/m^2°C)		243		386

LG Vg 7
July 18-21, 1995

Westinghouse Science & Technology Center

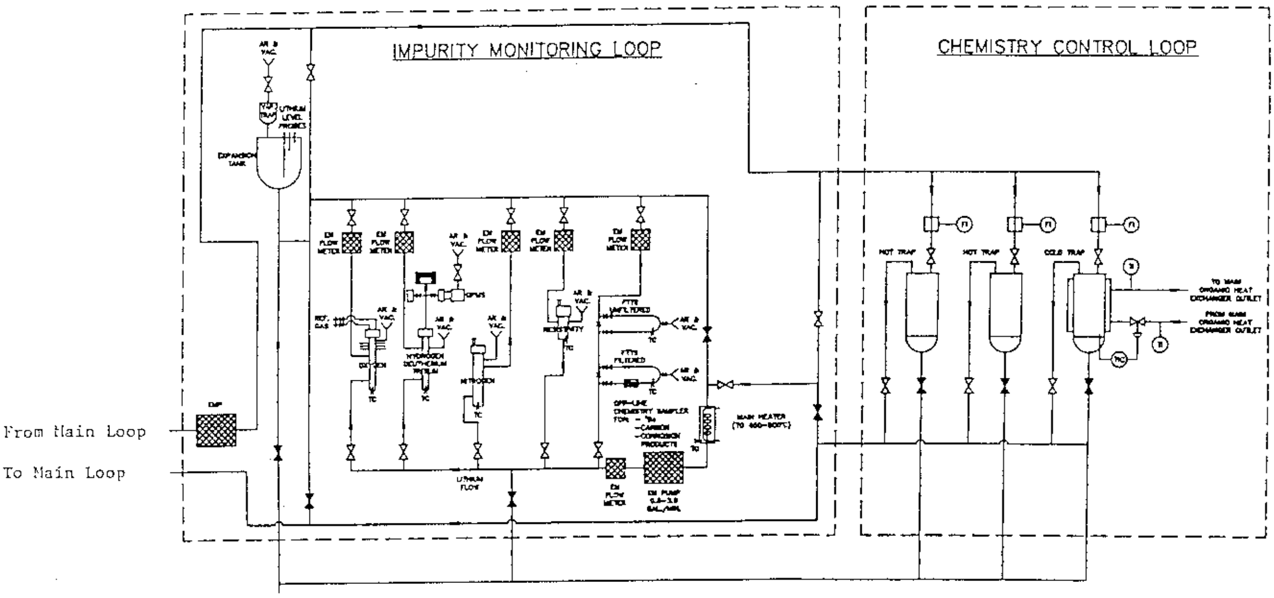
MAIN LOOP LAYOUT



LG Vg 8
July 18-21, 1995

Westinghouse Science & Technology Center

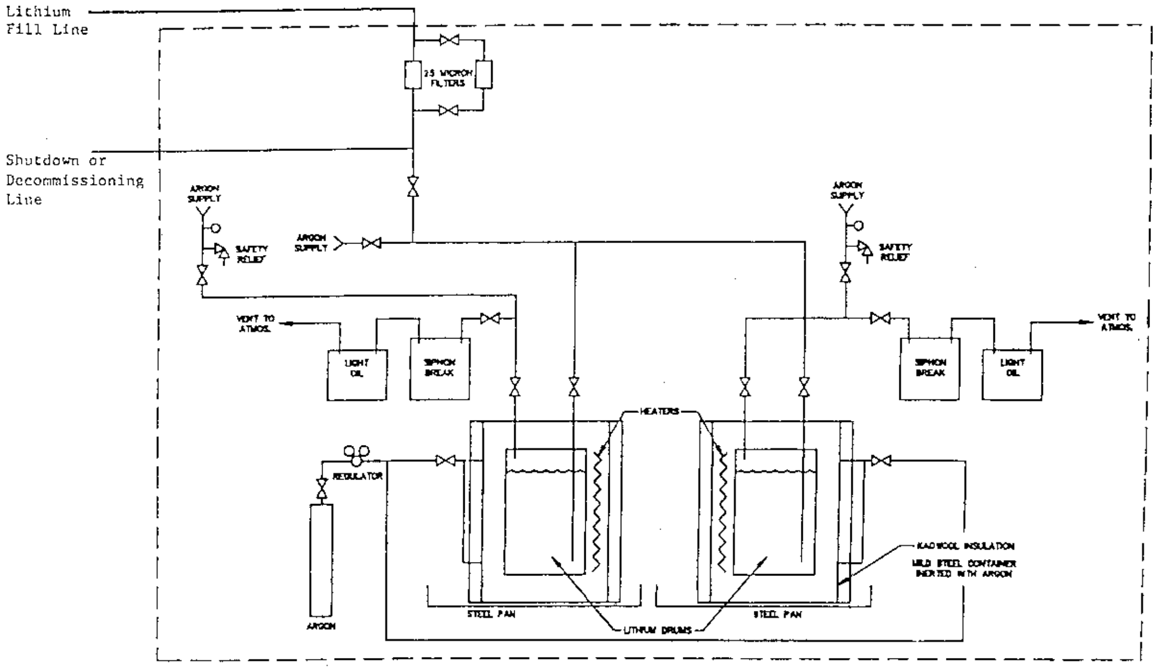
IMPURITY MONITORING AND CHEMISTRY LOOP LAYOUTS



LG Vg 9
July 18-21, 1995

Westinghouse
Science & Technology Center

LITHIUM TRANSFER SYSTEM LAYOUT



LG Vg 10
July 18-21, 1995

Westinghouse
Science & Technology Center

Design Considerations for IFMIF EM Pump

LG Vg 1
July 18-22

Westinghouse
Science & Technology Center

Major Design Objectives

- Proven Technology
- High Reliability
- Long Life
- Low Development Costs

LG Vg 2
July 18-22

Westinghouse
Science & Technology Center

IFMIF EM Pump Design Requirements
(Estimated)

• Design Flow Rate	100 l/s (1580 GPM)
• Design Pressure	0.276 MPa (40 PSI)
• Max. Lithium Velocity	10 m/s (40 ft/s)
• Operating Temperature	200-350 °C (400-660 °F)
• NPSH	8.7 m (29 ft)
• Pump Cooling	Nat'l. Convection
• Service Life	30 yr

LG Vg 3
July 18-22

Westinghouse
Science & Technology Center

Design Options

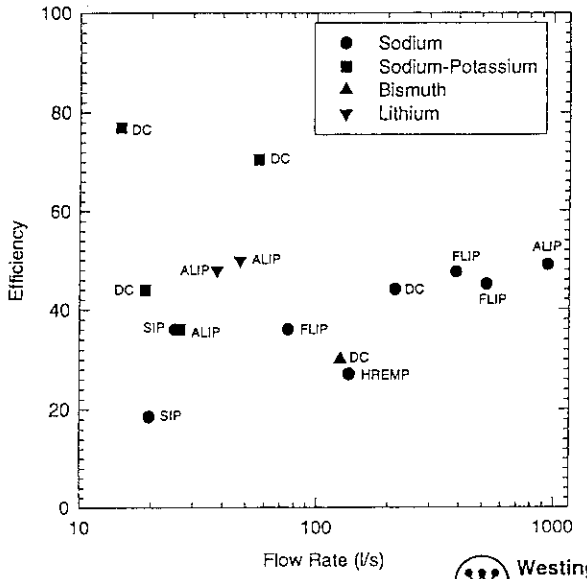
- Design & Build Single New Pump
  - ALIP
  - SIP/HELIP
- Build 2 Parallel Pumps
  - ELF Mark II
  - ALIP

LG Vg 4
July 18-22

Westinghouse
Science & Technology Center

Large EM Pumps Have Been Successful

Existing EM Pumps for Selected Liquid Metals



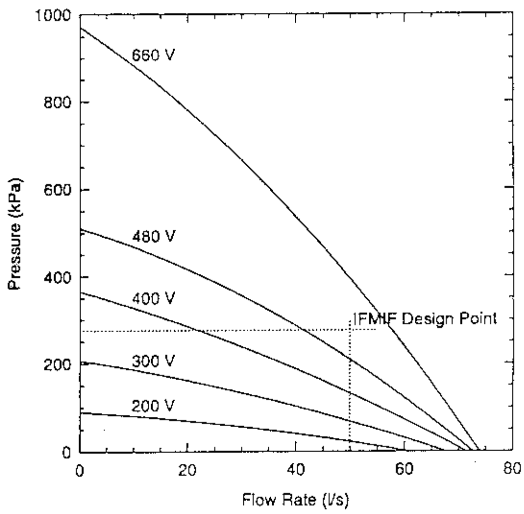
LG Vg 5
July 18-22

Westinghouse
Science & Technology Center

Design Recommendation

- Parallel Pumps
  - Proven History
  - No Development Required
  - 61% Cost of Single Pump
  - Meets All Requirements
  - Length: 2.13 m (84 in)
  - Diameter: 0.213 cm (16 in)
  - Weight: 614 kg (1350 lb)

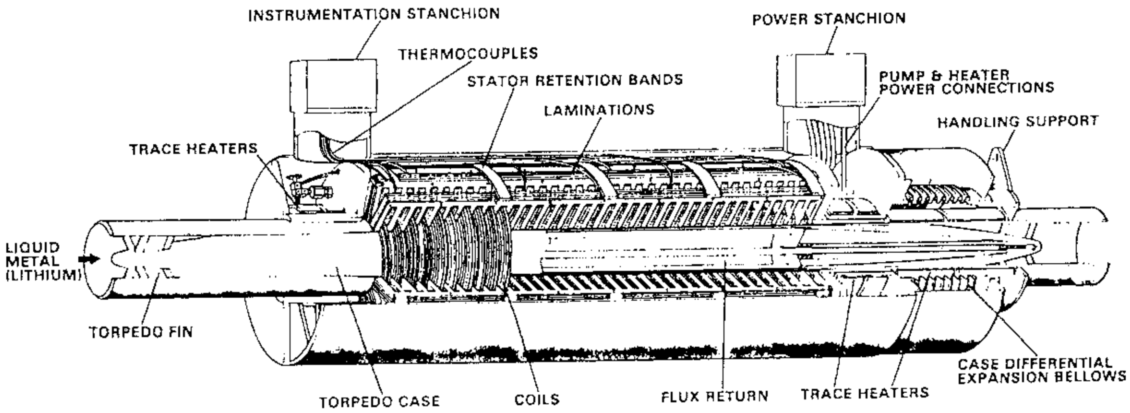
ELF Mark II Performance

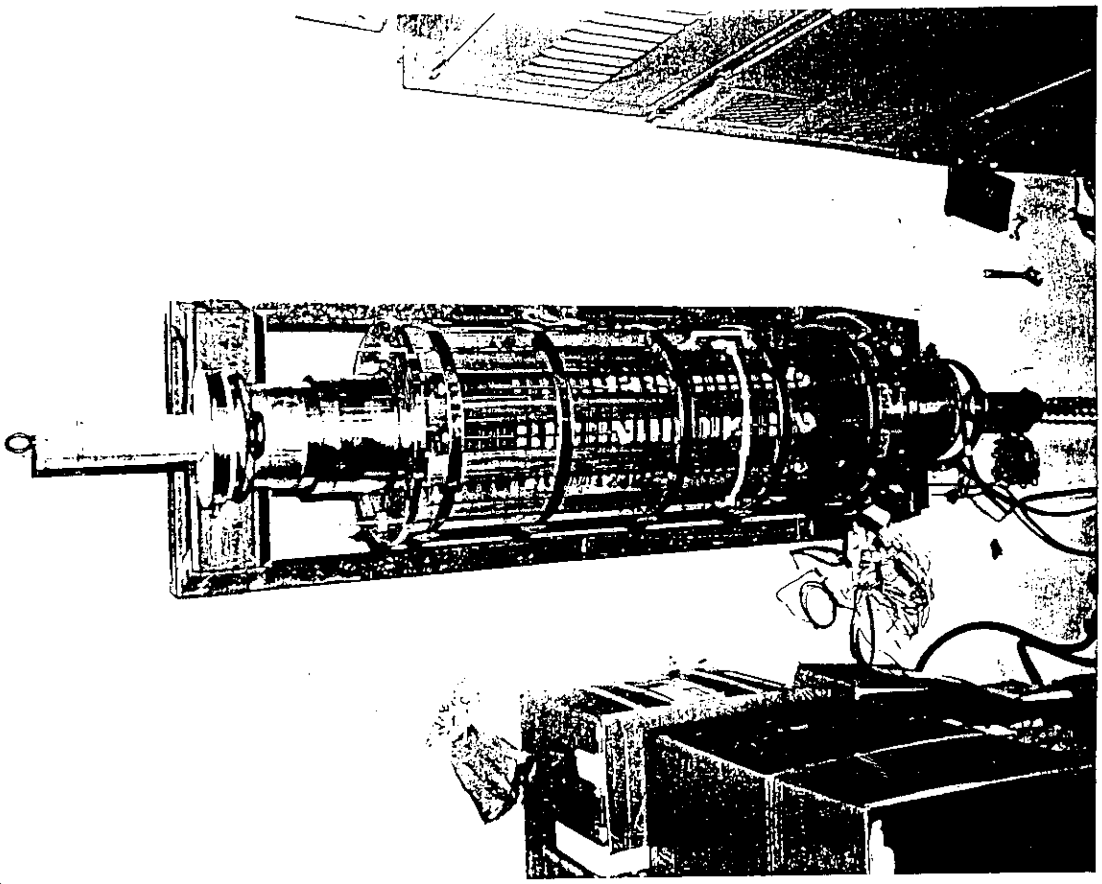


LG Vg 6
July 18-22

Westinghouse
Science & Technology Center

ANNULAR LINEAR INDUCTION PUMP
EXPERIMENTAL LITHIUM SYSTEM (ELS)
MARK II





MAIN LOOP ISSUES

- Material Choice
  - SS316 L
- EM Pump
- Organic coolant radiation damage
- Shielding requirements

OTHER AREAS CONSIDERED

- Loop Enclosure
  - Carbon steel lining in test cell and lithium cell
  - Nitrogen inerting/heat removal from normal operation
  - Argon injection under accident conditions
- Remote Maintenance Considerations
  - Dominated by ^{7}Be activity
  - Significant potential contributions from ^{22}Na, ^{24}Na, corrosion products
  - Large uncertainties in solution and plating out of ^{7}Be
  - Local shielding of large surface area components (LHX, Traps, EM pump, drain valve)

OTHER AREAS CONSIDERED (cont'd)

- Safety Features
  - Steel module enclosures, modular design
  - Lithium ionization detectors (LIDs) for leak detection and location (feasibility demonstrated)
  - Ionization smoke detectors
  - Argon flood system
  - Fast main dump valve
  - Carbon microspheres for fires

LG Vg 13
July 18-21, 1995

Westinghouse
Science & Technology Center

OTHER AREAS CONSIDERED (cont'd)

- RAM
  - Loop availability requirement ~95% for system availability at 70%
  - Access to LHX tubes required for plugging/sleeving
  - Tradeoff of maintenance vs redundancy
- Shutdown and decommissioning

LG Vg 14
July 18-21, 1995

Westinghouse
Science & Technology Center

4. Li Purification System Design

4.1 IFMIF Chemical System and R&D Proposal

S. Konishi, Y. Kato, and M. Takahashi
JAERI IFMIF Target System Group

1.Intropduction

The Objective of this task is to provide a database on closed lithium loop for purity control and impurity processing in the IFMIF target system. In order to stably operate the target and reduce the radiological hazard, it is necessary to maintain the purity of the liquid lithium. For the design of the lithium circulation system, both impurity detection and removal technologies should be developed and evaluated. It is considered that the IFMIF community shares the accomplishment of the liquid lithium loop technology achieved as the prototype FMIT loop in early 1980s. Also, Japan has established a design data base for ESNIT lithium loop. The activity of this task is therefore focused on evaluation of integrity and improvements of some key issues to meet the modern and realistic requirements to be applied for future IFMIF loop. Both designing and some experiments are being performed .

2.Technical outline of task

Evaluation of existing technology of impurity detection and processing is being performed with the reference design based on the results of ESNIT design study. Some of the critical components are considered to require R&D activity. This task pursues the hot and cold trap design for removal of impurity such as Be, O and N. Detection and removal of DT by some other approaches is considered. Experiments are planned to verify the feasibility of some techniques to be reflected to improve the design in the CDA phase.

Actual handling of lithium loop is planned in the part of this task using an apparatus operational in the Tokyo Institute of Technology.

3.Plan and current status

3.1 Lithium loop design study

Design of the lithium chemical subloop for ESNIT is being reviewed and modified to meet the requirements for IFMIF. Evaluation of Lithium chemistry data base and component design of the components such as ; Cold Traps, Hot Traps, Impurity measurement, and Hydrogen isotope separation are planned. Some alternatives are considered for hydrogen isotope processing. Experiments are expected to provide the information on, system processing characteristics, scalable data for capacity of impurity processing, impurity behavior database, and suggested desirable system configuration, operation capability and limit for IFMIF relevant conditions. Data will also be utilized in the safety analysis and entire facility design. The results to be obtained until the end of 1995 will provide sufficient data to allow decision on the lithium chemical process and further testing of the integrated system.

3.2 Hydrogen sensor development

New type of hydrogen sensor is under fabrication and planned to be tested in stand alone experiments. Based on the results, a prototype of the sensor assembly will be tested in a lithium loop in 1996. Cold trap may also be tested to verify the performance.

3.3 Lithium loop test

The lithium loop in the Tokyo Institute of Technology is one of the few valuable resource to be available for IFMIF CDA. It originally was constructed for the study of the lithium-heliu two phase flow for liquid breeding blanket application, but is also capable to flow pure liquid lithium. It has almost all of the essential components required to operate lithium loop such as EMP, quench tank, cold trap, plugging indicator and instrumentations. In this year, the operation of the loop as it is, and possible to obtain some impurity analysis in actual loop will be attempted. Particularly the impurity concentration and species under practical condition will be valuable information. Some "grab" samples will be taken fro the operating loop and will be chemically analyzed offsites. In 1996, experiments on the purity control such as measurement of effectiveness of the cold trap, and some field tests of the hydrogen sensor will be planned. Currently, preparation for the operation of the loop, and sampling from working loop is performed.

4, . Results

Prelininary considerations and system analysis are made for the entire material flow and processing in the IFMIF target system. Followings are some of the results of the conceptual designs that will identify the technical issues to be further pursued by R&D efforts as well as design.

4.1 Lithium chemical loop design

The reference design of the lithium chemical loop is based on the ESNIT design, and no major problem or change is identified yet. In order to achieve the required impurity level, only a part of the lithium will be taken from the main target loop to the purification process. It is pointed out from the safety stand point that the total lithium inventory is desired to be minimized. Since the generation rate of the impurity in the loop is anticipated to be the same level, only the proportion of the lithium to be sent to the purification system will increase, without changing the capacity of the purification system.

Oxygen and nitrogen impurities are trapped respectively at cold and hot traps. These impurities are anticipated to come mainly from air in the occasions in itnitial loading and periodical maintenance. The hot trap for nitrogen removal is therefore planned to be used mainly such initial cleaning. Amounts of incoming these impurity elements in normal operation are unknown and the current design is not quite ready to handle if they are significant. Possible minor leaks in the beam line vacuum would be the one of the major source. Beryllium generated by the nuclear reaction will be one of the major source of activities in the lithium loop and trapped as nitride. It may be needed to induce some nitrogen on purpose for this purpose if the nitrogen is consumed and exhausted during the operation. Because the cold trap will accumulates the ^{7}Be and other impurity nuclides, radiation shields will be required.

4.2 Hydrogen trapping options

Control of hydrogen isotopes in the lithium is one of the issues to be solved during the CDA. Inventory limit of the tritium in the lithium loop must be considered in the selection of process. Currently both cold trap and hot trap are considered for hydrogen removal. Major source of hydrogen isotopes are, deuterium beam, hydrogen comes from moisture in the residual gas after the initial loading and maintenance, outgasseing in the beam transport, and tritium produced by nuclear reactions. Approximately 2×10^{14} atoms per mA/s of beam is estimated to generate by direct reaction. Reaction of lithium-6 with slower neutrons are not estimated, but could be significant and thus tritium production rate could be larger than the previous estimations. Trapping of D and T by yttrium is simple, and probably cost less than other options, but the regeneration will not be realistic. The traps will be relaced, and the trapped tritium and hydrogen isotopes are disposed as the form of yttlium hydrides in a metal container. Although the tritium will be immobilized at the trap, the total inventory will be in the order of several 10 grams in 9 month period of operation. It is concerned that the total tritium inventory in the loop may likely be limited, or the entire facility might be regarded to handle large amount of tritium, that requires special attention and regulations.

Cold trapping of lithium hydride and periodical regeneration for DT recovery is more complicated, but technically more desirable to extract tritium. In this option, multiple traps will be prepared in parallel, and while one is on line for trapping, the other is regenerated. During the regeneration cycle, the trap is heated and evacuation or carrier gas stream extracts the DT from decomposing lithium hydrides to out of the lithium loop. Other trapped species such as lighium oxide will remain in the trap until the disposal of the trap whenever appropriate. Hydrogen isotope mixture including tritium will be removed from the loop and disposed. This option will allow to control the tritium inventory in the loop, and thus limit the amount of tritium that could be released in the case of major leak of lithium. Due to the small difference of the operation temperatures between the loop and the trap, and relatively large solublity limit, it is concerned that the trapping efficiency of hydrogen may not be good.

In order to improve the efficiency to recover tritium, continuous addition of deuterium in the purification subloop, followed by the cold trapping and isotope can be considered. This option will minimize the tritium inventory in the loop. With a significantly reduced tritium concentration and inventory in the loop, it may be expected that the target system would not be regarded as a tritium system. For the increased amount of total hydrogen isotopes to be handled, isotope separation followed by the regeneration of the cold trap will be required to minimize the volume of waste. Thermal diffusion process is expected to be the best for this purpose.

4.3 Processing of vacuum exhaust

A processing system for the vacuum exhaust from the target, quench tank, beam line, cover gas for Li pretreatment or maintenance, and any other primary loop of the IFMIF is identified as a major part of the chemical process that needs a special attention in the aspect of the radiation control. One of the major path for the operational impurity removed from the IFMIF system is the solid waste. Radioactive beryllium, nitrogen, oxygen and other impurity elements are trapped/filterated in the form of solid lithium compounds. The other path of the material from the primary loop to outside is the exhaust system, and the performance of this would be the dominant factor in the estimation of the impact to the environment.

The target lithium that is exposed to the beam should always be evacuated to maintain the vacuum in the beam line in the range of 10^{-4} Pa. Anticipated species of the gas are, hydrogen isotopes, moisture, helium and other typical residual gases in a vacuum chaber. Beam transport will also be evacuated, and the exhaust will contain tritium as a product of reaction in the beam line. The exhaust of these vacuum pumps will therefore require special features for the tritium system. The pumps should be oil free to prevent contamination with tritiated oils. Organic materials are subject to the permeation of tritium, and possible radiation damage that would eventually cause unexpected leak. The exhaust should be treated for tritium removal. Possible options are, gettering with active metal such as titanium or uranium, or oxidation followed by adsorption, depending on the oxygen and moisture contents. Although significant amount of materials will be activated with neutron particularly in the test cell region, the airborne activity from the vacuum exhaust may be the major source of the release into the environment.

Particular technical difficulty is anticipated for the pumping of lithium vapor that should be handled as radioactive contaminant. Currently the only available technique is a kind of foreline trap backed with oil-free vacuum pump train. The traps will separate the lithium vapor from the exhaust as a deposit. If lithium makes aerosol or particulates, they may not be trapped, or a filter that will considerably reduces the conductance is needed. The trap should be periodically replaced or regenerated. None of the known oil-free vacuum pumps are known to work well with lithium deposites. Especially turbo molecular pumps are often sensitive for deposits that causes error on the movement of the rotor. Some concepts to capture and/or prevent the lithium vapor mixed with the vacuum exhaust aresuggested and considered as a part of a Japanese CDA tasks.

Secondary containment of the IFMIF system and exhaust process is also studied as a chemical system interfaces with lithium loop. Inert cover gas for lithium and secondary containment atmosphere may contain small amount of tritium and some other radioactive materials, and that should be processed before released to the environment.

4.4 Electrochemical hydrogen sensor

It is possible to monitor the chemical potential of hydrogen in liquid metal using solid protonic conductor. Attached figure 1 shows its principle. Solid protonic conductor cell with hydrogen permeable electrodes on both sides of the membrane generates an electromotive force corresponding to the difference of the chemical potential on both sides of the electrodes. This electromotive force is proportional with the ratio of logarithmic hydrogen partial pressure on both sides. When one side of the electrode is exposed to the known concentration of hydrogen standard, and the other dipped in the liquid lithium, the real time hydrogen concentration in the lithium can be monitored continuously. Some kinds of ceramics and other materials are considered as the electrolyte. Electrodes should be hydrogen permeable while compatible with liquid lithium. Vanadium, Niobium and Palladium or these clad materials are considered.

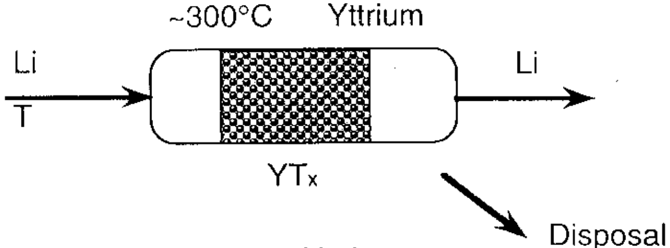
If the feasibility of this cell is verified, it may also be used for extraction of hydrogen isotopes from the liquid lithium. Since the principle of sensing is reversible, with a voltage across the electrode can theoretically transfer hydrogen from one side to another. Required voltage and compression is expressed by the same equation, and 100mV is sufficient to achieve several order of magnitude of hydrogen compression/extraction. Amount of hydrogen to be extracted is expected to obey Coulomb's law. Because the rate of hydrogen coming into the lithium loop is small, (less than 300mA equivalent including tritium), the technical difficulty to scale the cell to the desired capacity is expected to be small.

Preparation of the proof of principle experiments of above concepts is undergoing. If the results will be favourable, the results will be reflected in the process design.

5 Concluding Remarks

Although the experience of operation of liquid lithium is available from the achievements of FMIT, and many of the components and techniques of FBR would be helpful, maintaining impurity levels in the loop is technically quite premature. Particularly, real time monitoring of impurity species and concentration is not an available technique. Improvements in this field is highly desirable. When regarding the chemical system of the entire IFMIF system, it is suggested that the exhaust processing and integrated control of hazardous materials will require more intensive design study. Lithium chemical loop is only a part of such an total system.

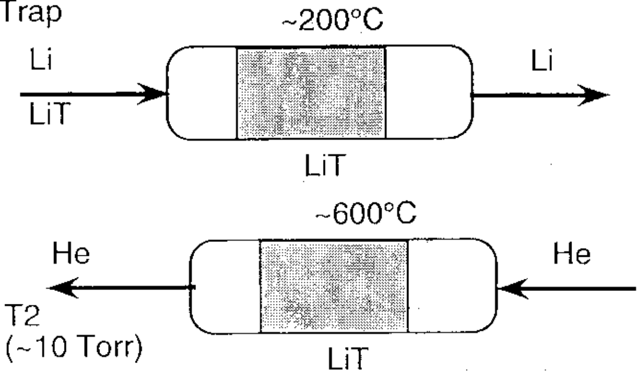
Hot trap



Hydrogen trapped at Yttrium
Hot trap is disposed as solid waste

Advantage: simple
Disadvantage: Large loop inventory
Waste Tritium

Cold Trap

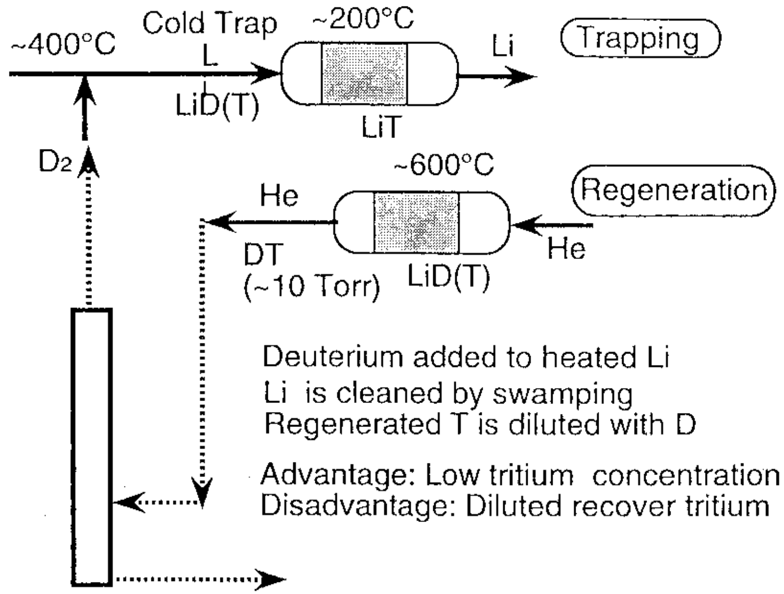


Hydrogen trapped as Li hydrides
Regeneration with carrier gas to recover hydrogen

Advantage: Recovery of DT
Disadvantage: Poor purification

Hydrogen Isotope Removal Concepts

Cold Trap + Swamping



Deuterium added to heated Li
Li is cleaned by swamping
Regenerated T is diluted with D

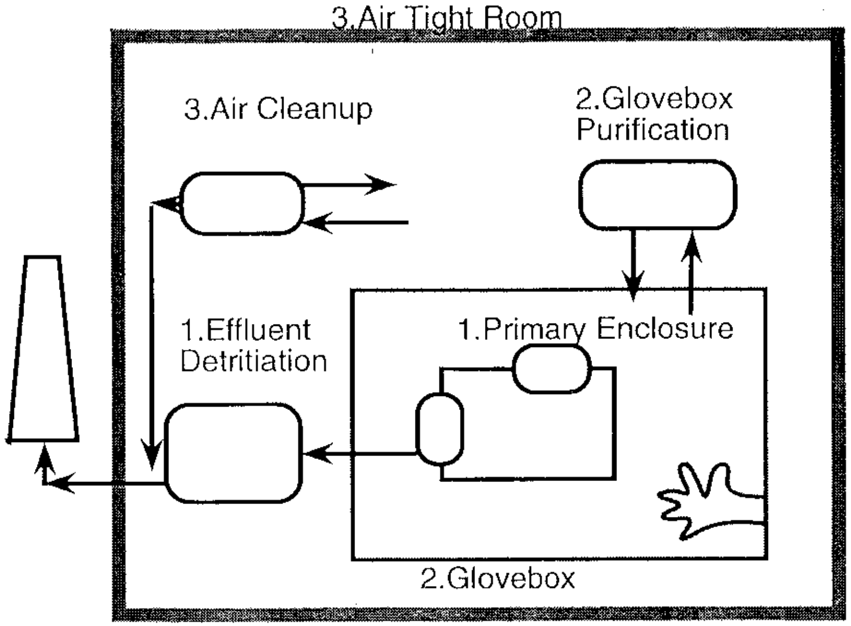
Advantage: Low tritium concentration
Disadvantage: Diluted recover tritium

\+ Isotope Separation

DT is separated by Thermal Diffusion
Deuterium is recirculated to loop
Enriched tritium extracted

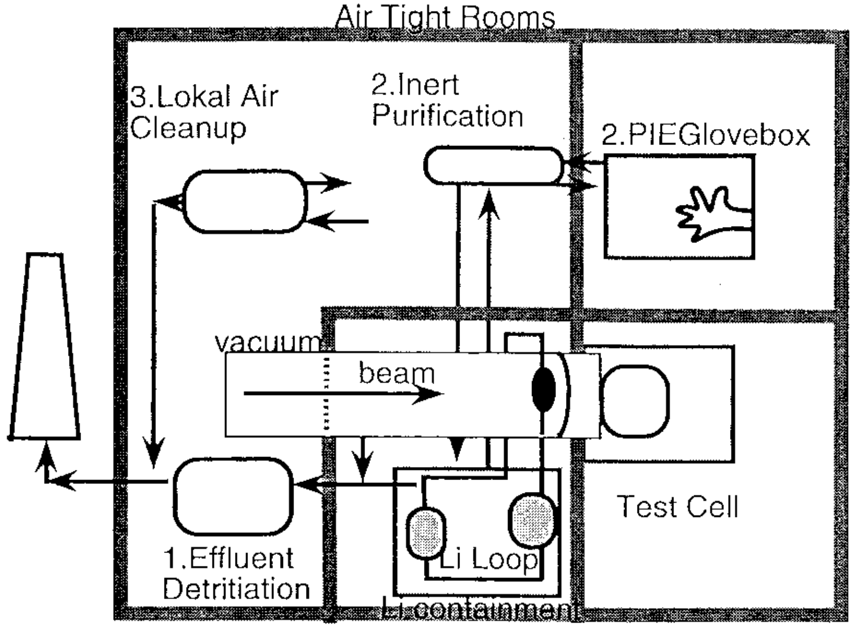
Advantage: Tritium as product
Disadvantage: complicated system

Hydrogen Isotope Removal Concepts



For large amount of tritium inventory
3rd containment costs

Typical Tritium Confinement System



Example of IFMIF Confinement

Li loop, beam line and test cell vacuum is primary confinement for airborne activity

Li loop, test cell and PIE is 2ndary contained

Room does not expect major tritium release

Major parameters of purification loop

Assumed Impurity

	O	H	N	Be
from surface	400	40	400	
total generation		3400		80
from maintenance	4000	3440	14400	80

Cold Trap

Ar gas coolant 70kW

Ar 765 l/s 30°C 150°C

Li 0.5 l/s 265°C 200°C

Capacity 300 l

Hot trap 1

Y sponge 180kg capacity 90 l

Operation temperature 265°C

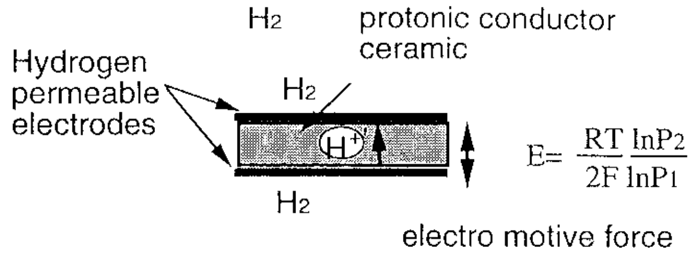
0.1 l/s Li

Hot trap 2

Ti sponge 70kg capacity 35 l

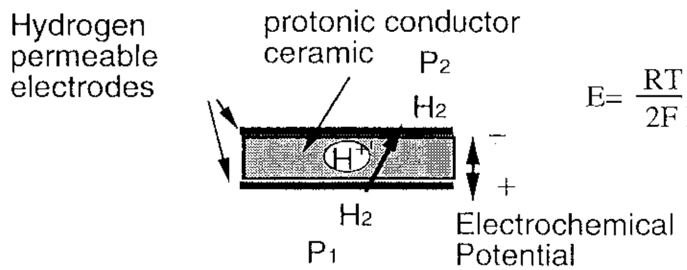
Operation temperature 600°C

0.2 l/s Li



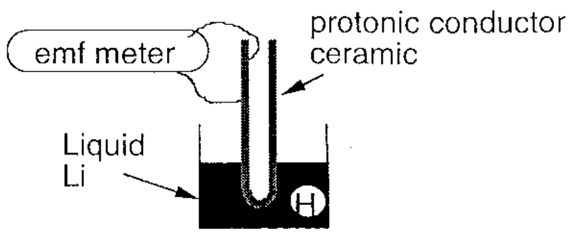
$$E=\frac{RT}{2F}\frac{\ln P_2}{\ln P_1}$$

PRINCIPLE OF ELECTROCHEMICAL H-METER

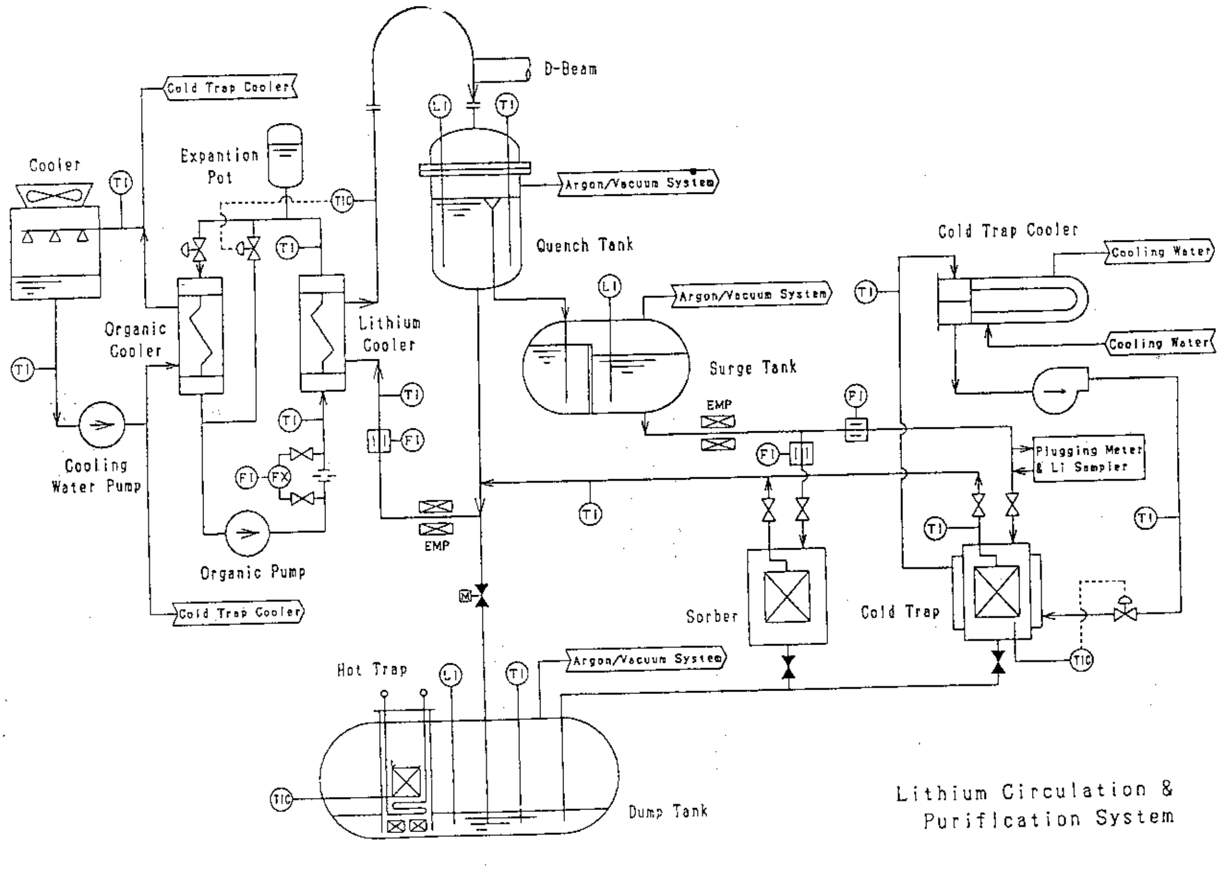


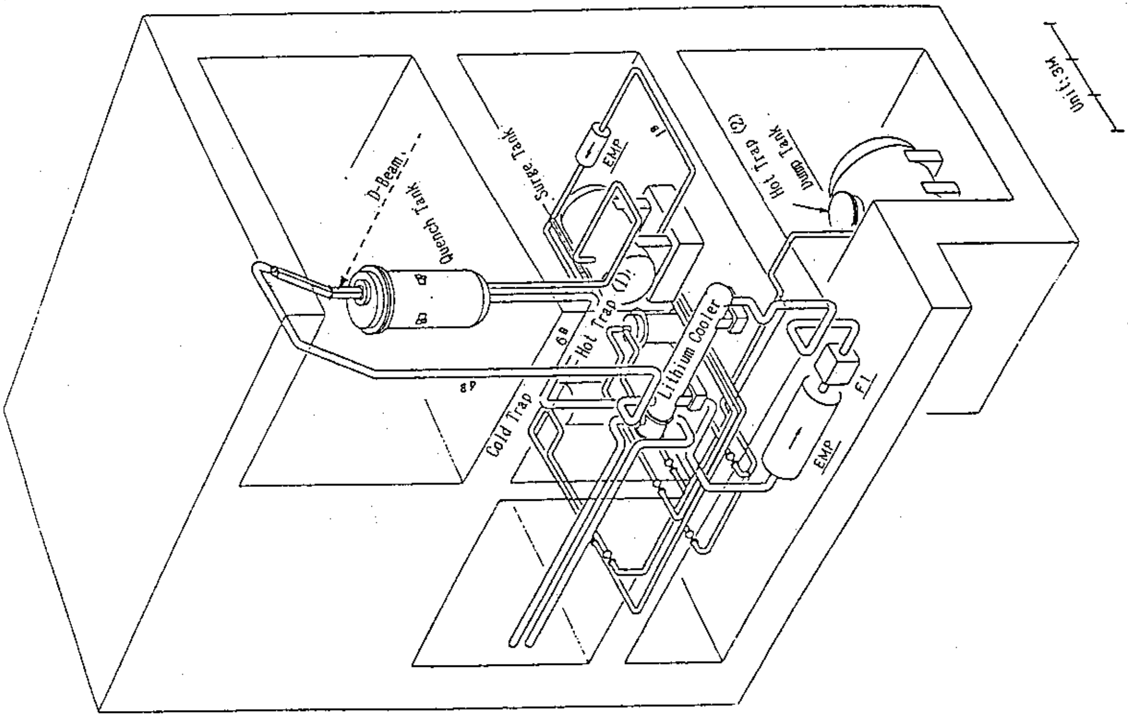
$$E=\frac{RT}{2F}\frac{\ln P_2}{\ln P_1}$$

PRINCIPLE OF ELECTROCHEMICAL H-PUMP



MONITORING H WITH CERAMIC CELL


D-Beam
Cold Trap Cooler
Cooler
Expantion Pot
Quench Tank
Argon/Vacuum System
Cold Trap Cooler
Cooling Water
Organic Cooler
Lithium Cooler
Surge Tank
Cooling Water Pump
Plugging Meter & Li Sampler
Organic Pump
EMP
Sorber
Cold Trap
Hot Trap
Dump Tank
Lithium Circulation & Purification System


D-Beam
Quench Tank
Surge Tank
EMP
Hot Trap (1)
Lithium Cooler
Cold Trap
Hot Trap (2)
Dump Tank
FL
EMP

4.2 Requirements and Preliminary Design for Li Chemistry Monitoring and Process System

L. Green, G. A. Bayles, R. E. Witkowski
Westingihouse Science & Technology Center

IFMIF-CDA Technical Workshop on Li-Target System
Tokai-Mura, Japan
July 18-21, 1995

LG Vg 1
July 18-21, 1995

Westinghouse
Science & Technology Center

SOME LITHIUM ISSUES REMAINING FROM ELS/FMIT EXPERIENCE

- Beam on target behavior not confirmed
- Limited experience with hot and cold traps. Additional development, esp with hot trap getter materials for nitrogen recommended
- Limited on-line monitoring experience (PTI, resistivity meter). Further development recommended
- No heat exchanger
- Development of sampling/analysis methods for O, C, radioisotopes identified
- Remote analysis in the presence of ^{7}Be impurity
- High vapor deposition rates near target in target beam tube - effect on instrumentation

LG Vg 2
July 18-21, 1995

Westinghouse
Science & Technology Center

BEAM ASSOCIATED IMPURITY BUILDUP (NO REMOVAL)

^{7}Be

Saturation: 0.2 appm (1.4 X 10^5 Ci)

Tritium

Saturation: 171 appm

20 years 116 appm

Deuterium

≅ 1 appm/day

LG Vg 3
July 18-21, 1995

Westinghouse
Science & Technology Center

IMPURITIES IN ELS LITHIUM (WPPM)

Impurity	Range	Typical
H	40-80	50
N	6-60	15
O	15-33	25
C	0.2-11	2
Si	300-450	350
Ca	400-30	*
Al	500-200	*

*Concentration decreased steadily during loop operation

LG Vg 20
July 18-21, 1995

Westinghouse
Science & Technology Center

CHEMISTRY LOOP COMPONENTS

- Cold Trap (^{7}Be,O)
  200°C
- Hot Trap (H,D,T)
  250°C
- Hot Trap (N,C)
  550°C
- EM Pump
- Flow Meters
- Valves
- Trace Heating
- Vacuum/Argon System

LG Vg 4
July 18-21, 1995

Westinghouse
Science & Technology Center

DESIGN & SIZE/VOLUME REQUIREMENTS FOR IFMIF CHEMISTRY LOOP COMPONENTS, & COMPARISONS TO OTHER SYSTEMS

	ELS	ESNIT	FMIT	IFMIF
Cold trap Material	SS	SS	SS	SS
Cold Trap Size (m)	0.6 OD, 2.2 H	0.78 OD, 2.2 H		TBD
Cold Trap Throughput (l/s)	0.19	0.5		TBD
Cold Trap Temp (°C)	194	200	200	200
Hot Trap #1 Material	Titanium	Yttrium Sponge		Yttrium Sponge
Hot Trap #1 Size (m)	0.41 OD, 1.34 H	0.56 OD, 1.0 H		TBD
Hot Trap #1 Throughput (l/s)	0.19	0.1		TBD
Hot Trap #1 Temp (°C)	550	243	550	243
Hot Trap #2 Material	NA	Ti Sponge	NA	Ti Sponge
Hot Trap #2 Size (m)	NA	0.56 OD, 2.2 H	NA	TBD
Hot Trap #2 Throughput (l/s)	NA	0.05	NA	TBD
Hot Trap #2 Temp (°C)	NA	550	NA	550
Piping Volume (l)	10			
Surge Tank Volume (l)	380			TBD

LG Vg 5
July 18-21, 1995

Westinghouse
Science & Technology Center

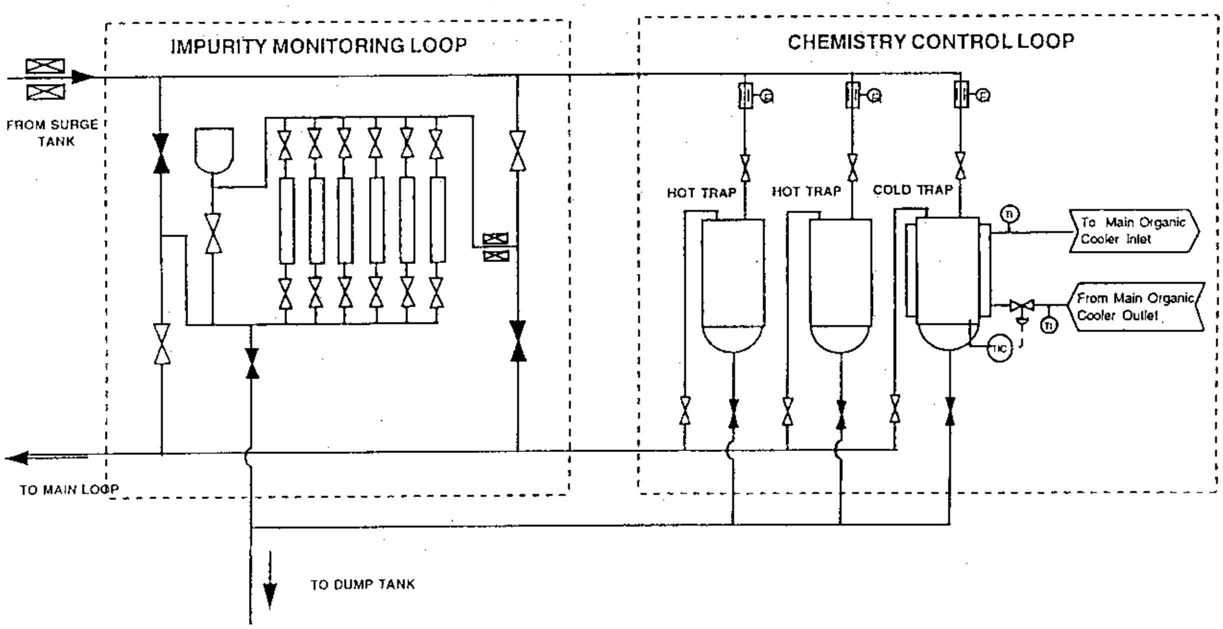
IMPURITY MONITORING LOOP COMPONENTS

- On-Line Meters
  - Hydrogen (+ QPMS)
  - Oxygen
  - Nitrogen
  - Resistivity
- Off-Line Monitoring
  - Flow through tube sampler (FTTS)
- EM Pump, Valves, Flowmeters
- Vacuum/Argon System

LG Vg 6
July 18-21, 1995

Westinghouse
Science & Technology Center

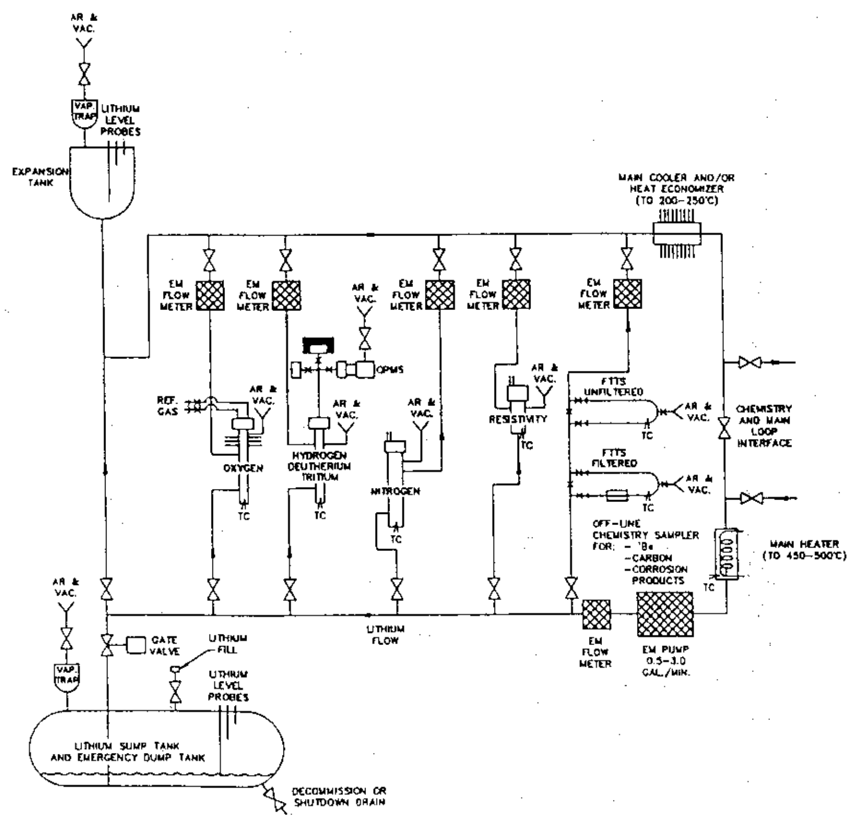
CHEMISTRY CONTROL AND IMPURITY MONITORING LOOP INTERFACE



LG Vg 6
June 27, 1995

Westinghouse
Science & Technology Center

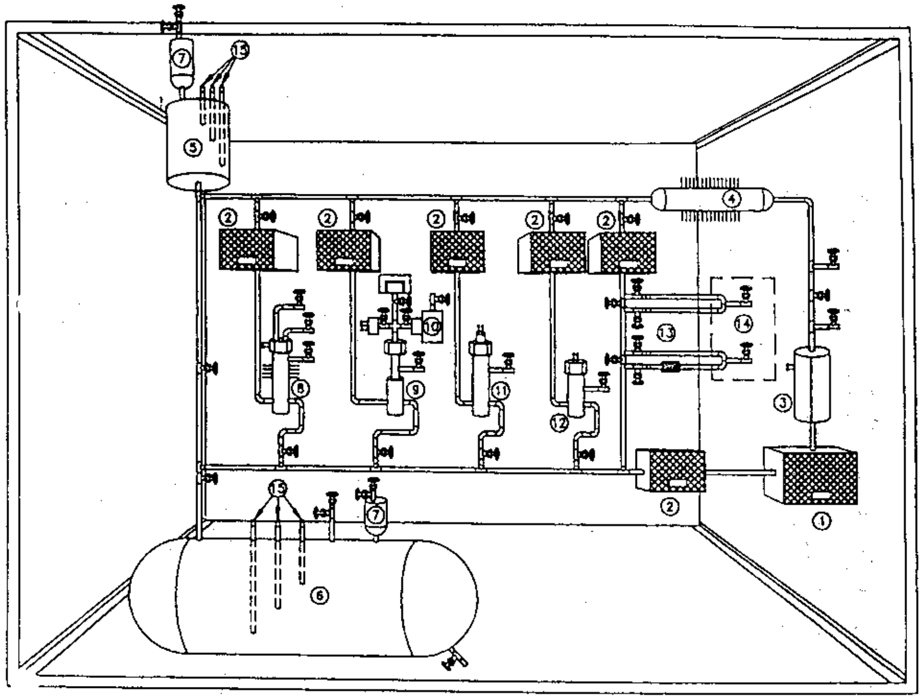
SCHEMATIC DIAGRAM OF IMPURITY MONITORING LOOP



LG Vg 8
July 18-21, 1995

Westinghouse
Science & Technology
Center

PERSPECTIVE PLAN, IMPURITY MONITORING LOOP



LEGEND

1. EM PUMP
2. FLOW METER
3. MAIN HEATER
4. MAIN COOLER OR ECONOMIZER (OPTIONAL)
5. EXPANSION TANK
6. SUMP, DUMP TANK (OPTIONAL)
7. VAPOR TRAP
8. OXYGEN METER
9. HYDROGEN METER
10. QUADRUPOLE MASS ANALYZER
11. NITROGEN METER
12. RESISTIVITY METER
13. FILTERED AND UNFILTERED FTTS
14. FTTS ACCESS PANEL
15. LITHIUM LEVEL PROBES

LG Vg 9
July 18-21, 1995

Westinghouse
Science & Technology
Center

ADVANTAGES OF ON-LINE NON-METALLIC IMPURITY MONITORING

- Safety
  - prompt indication of air in-leakage
  - prompt indication of HX leakage
  - prompt monitoring of trap performance
  - reduces probability of particulate formation
  - eliminate hazards of lithium handling
- Corrosion
  - reduces probability of rapid corrosion
  - longer life of components
- Handling
  - remote handling of highly radioactive samples
  - possibility of contamination
  - complexity of chemical analyses

LG Vg 10
July 18-21, 1995

Westinghouse
Science & Technology Center

LITHIUM RESISTIVITY MONITOR

- State of the Art
- Not impurity species specific
  - High sensitivity to nitrogen
  - Moderate sensitivity to hydrogen
  - Very low sensitivity to O, C
- Simple and robust, useful as monitor for large impurity excursions, e.g. air in-leakage
- Can provide approximate nitrogen concentrations in conjunction with hydrogen meter

LG Vg 11
July 18-21, 1995

Westinghouse
Science & Technology Center

ON-LINE HYDROGEN METER

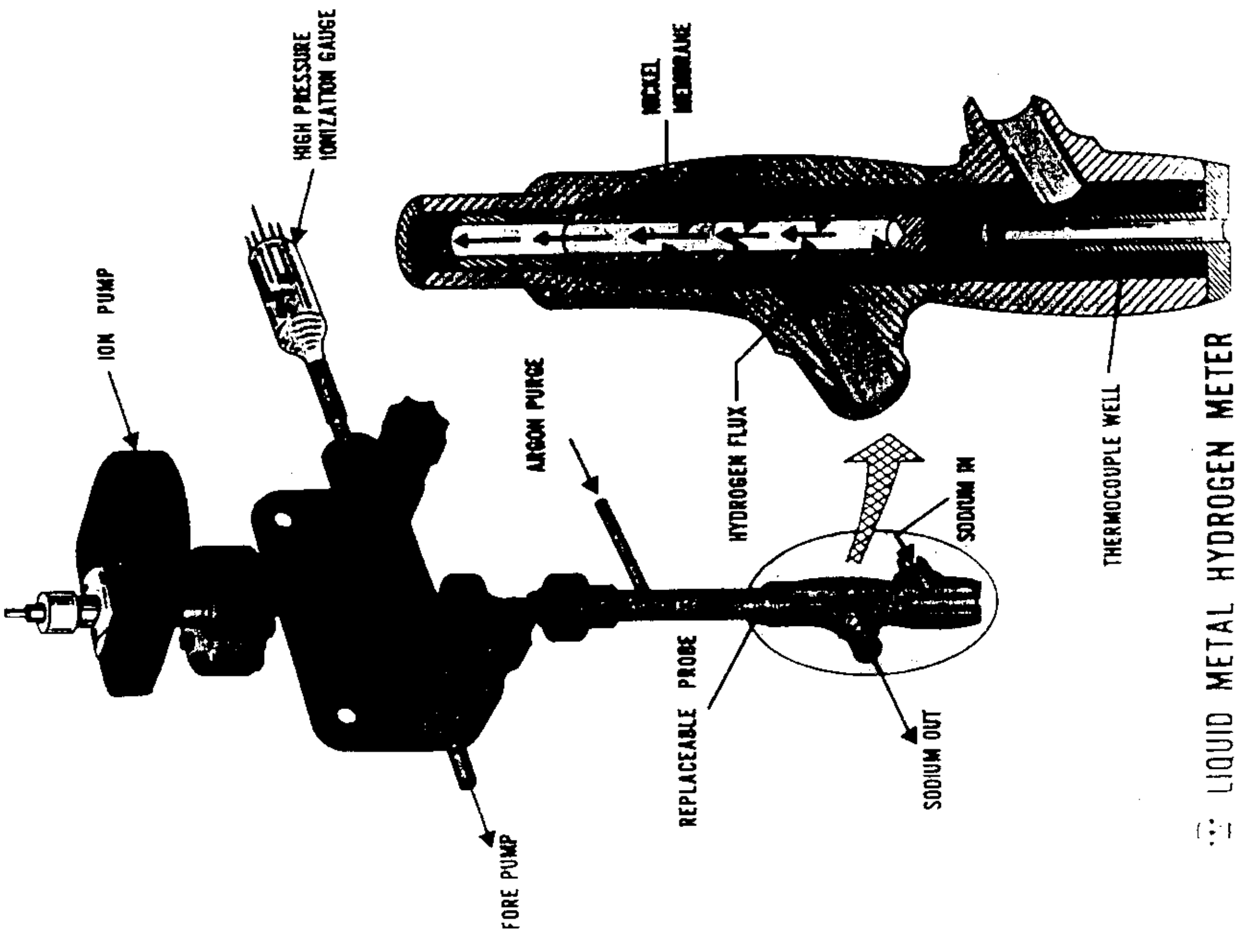
- Diffusion through a metal membrane
- Qualified in sodium and lithium systems
  - Nb, Nb-1Zr membrane for lithium
- Linear response demonstrated over a wide range of hydrogen concentrations
  - Sensitivity and stability enhanced at high temperature (~500°C)
- Quadrupole mass spectrometer (QPMS) added for isotopic information

ISSUES

- Concept feasibility fully demonstrated
- Additional loop testing under prototypical IFMIF conditions

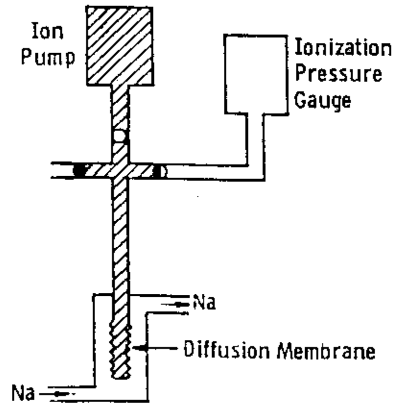
LG Vg 12
July 18-21, 1995

Westinghouse
Science & Technology Center

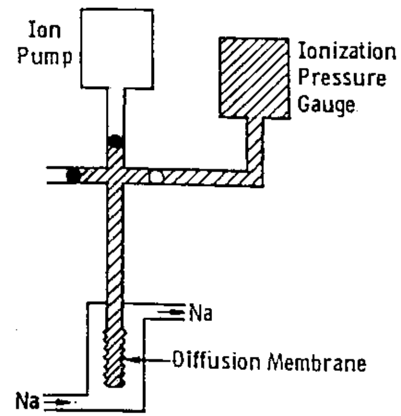


LIQUID METAL HYDROGEN METER

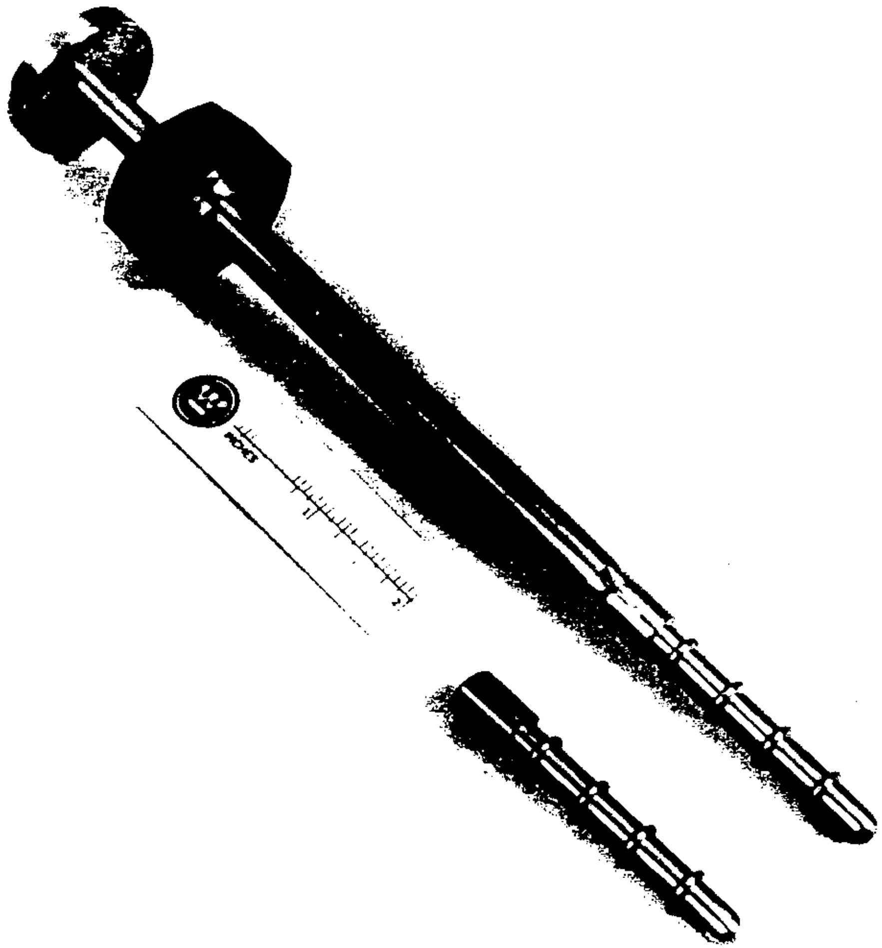
ALTERNATE MODES OF HYDROGEN METER OPERATION



DYNAMIC MODE

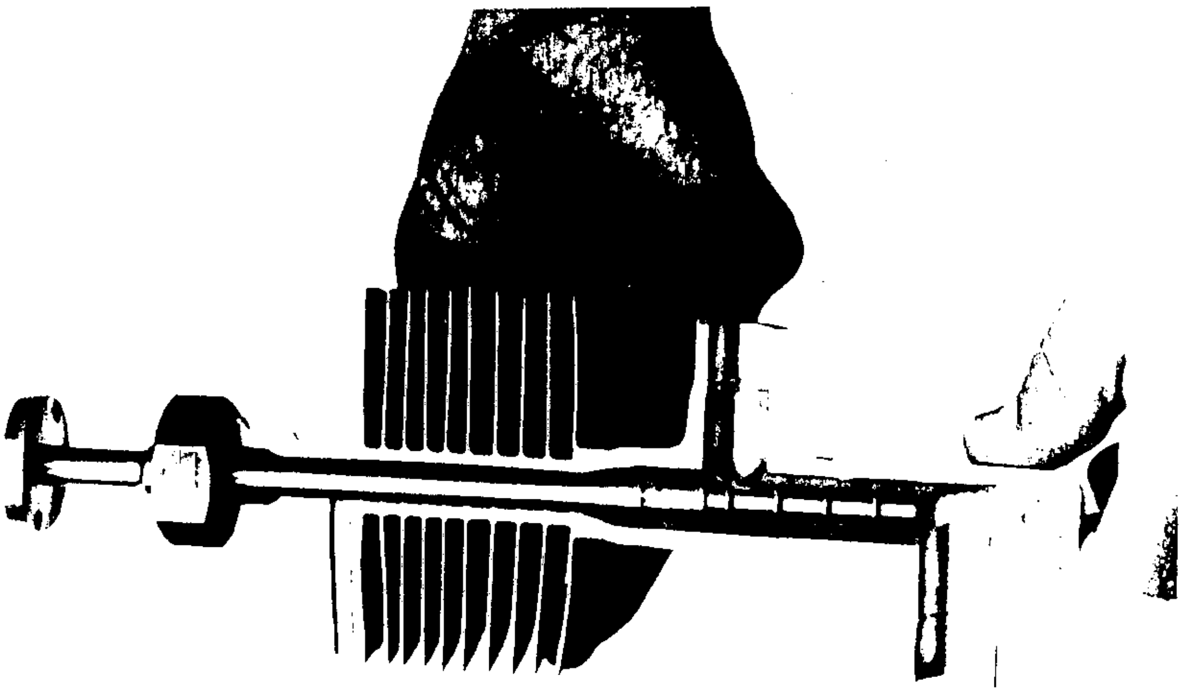


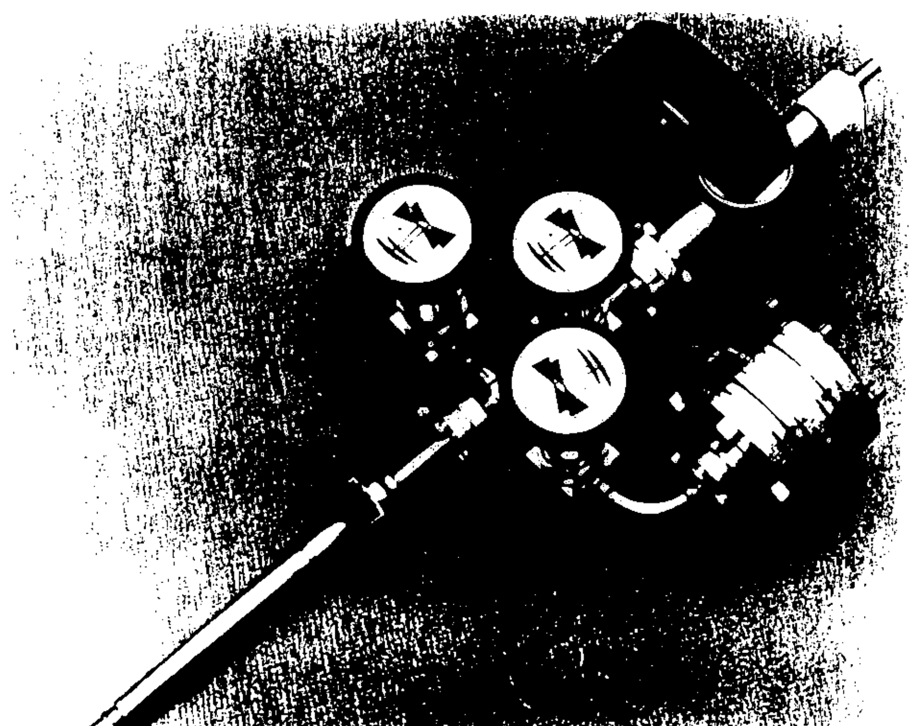
EQUILIBRIUM MODE



LG Vg 13
July 18-21, 1995

Westinghouse
Science & Technology
Center





ON-LINE OXYGEN METER

- Yttrium doped thoria (YDT) electrochemical concentration cell
- Requires low nitrogen impurity concentrations for acceptable electrolyte lifetime
- Limited tests in lithium at 480°C provided good results
- Small size, compatible with H meter housing

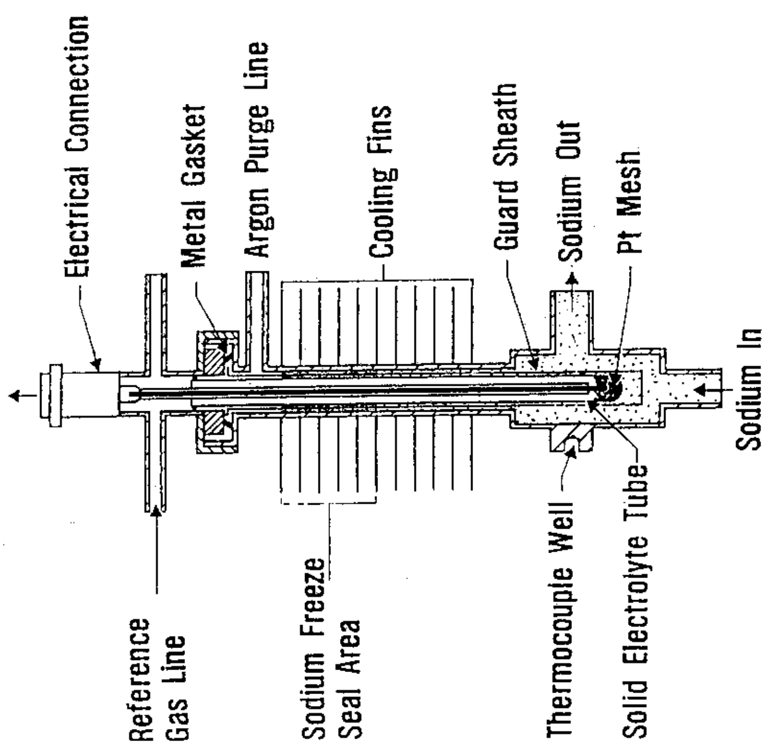
ISSUES

- Requires confirmatory testing of YDT electrolyte compatibility in the lithium

LG Vg 14
July 18-21, 1995

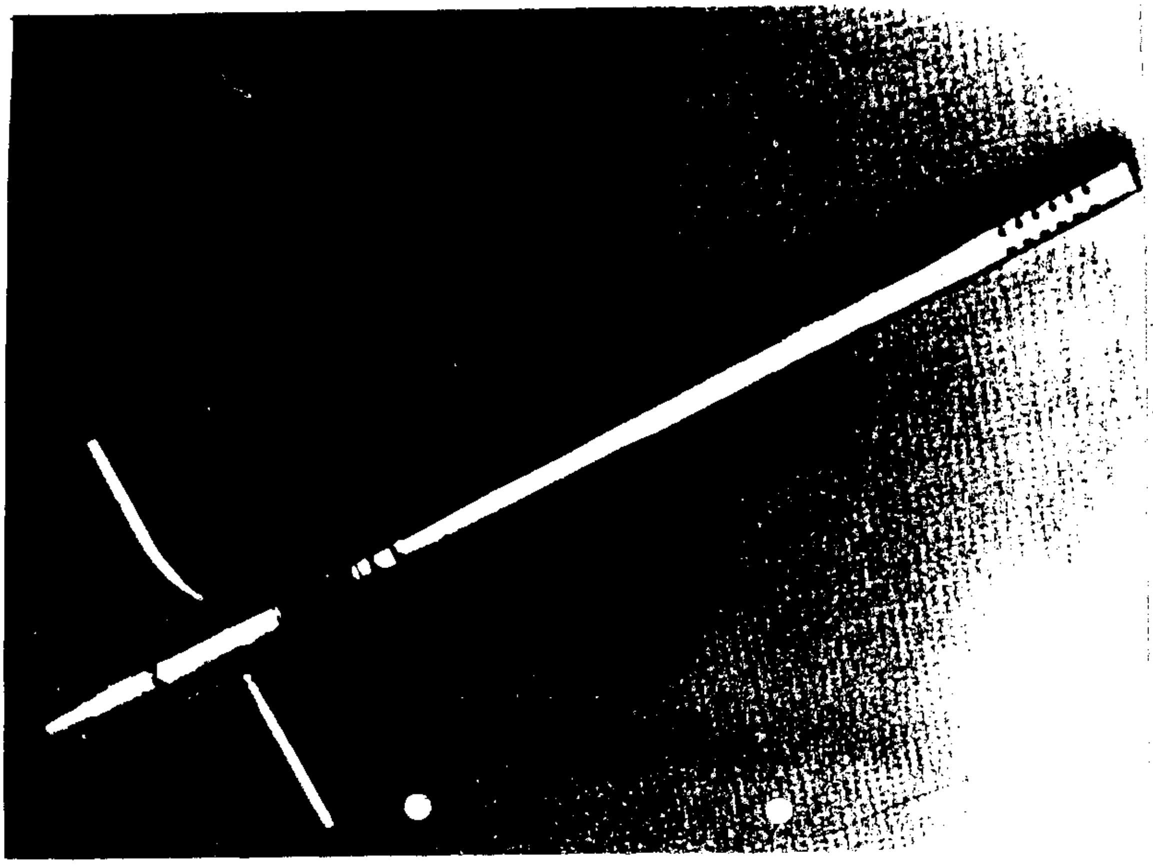
Westinghouse
Science & Technology Center

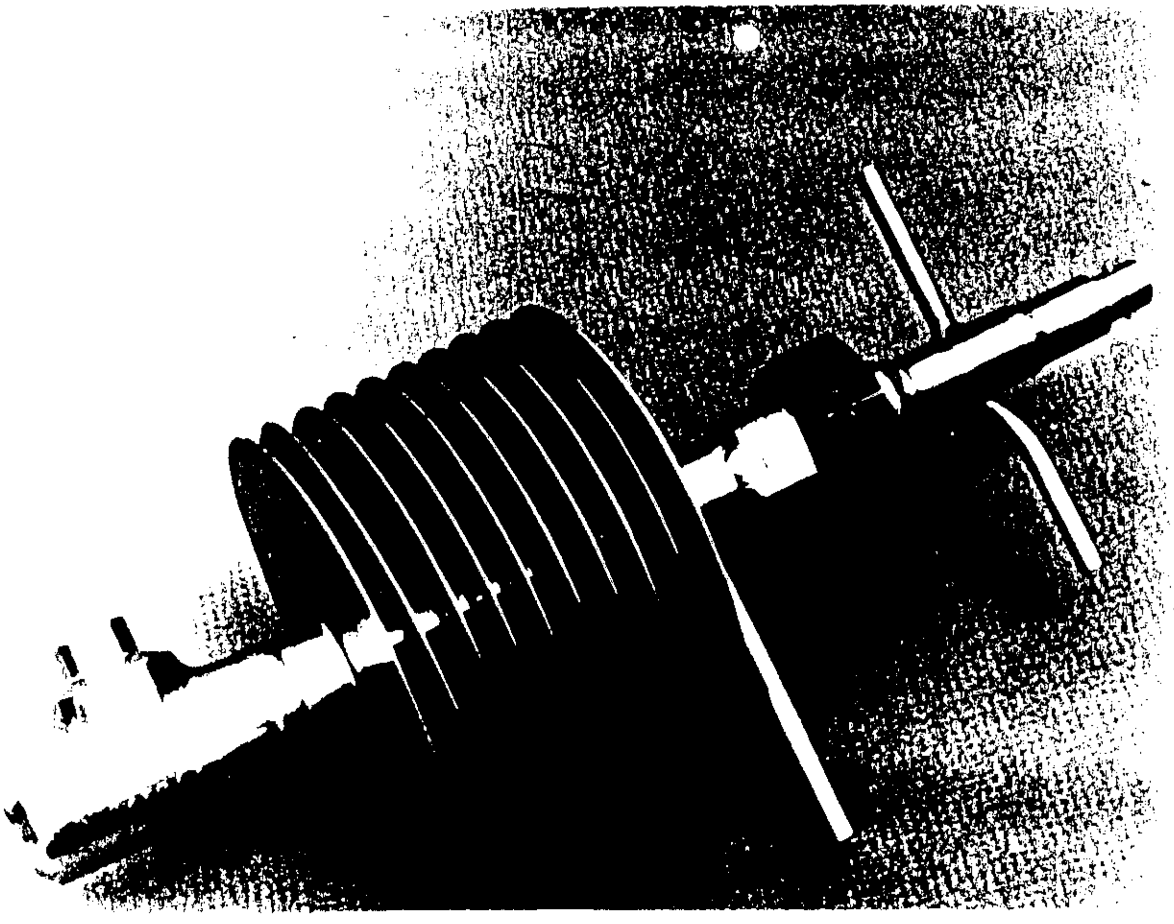
SCHEMATIC OF WESTINGHOUSE LIQUID METAL OXYGEN METER



Westinghouse
Science & Technology Center

LG Vg 15
July 18-21, 1995





ON-LINE NITROGEN METER

- Potentially, nitrogen is major impurity
- Lithium nitride highly corrosive
- No experience in on-line monitoring from sodium applications
- Large database on chemistry of the lithium-nitrogen system
- Molten salt (LiCl-LiF-Li_3N) electrolytic cell identified as a promising concept
- Iron membrane material for electrolyte containment

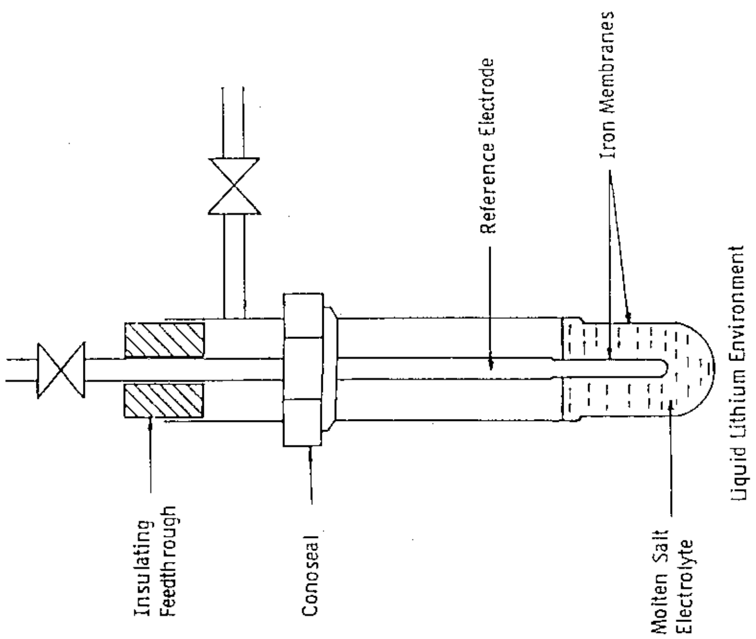
ISSUES

- Requires significant development program

LG Vg 16
July 18-21, 1995

Westinghouse
Science & Technology Center

MOLTEN SALT ELECTROCHEMICAL NITROGEN METER



Westinghouse
Science & Technology Center

LG Vg 17
July 18-21, 1995

STATUS SUMMARY OF ON-LINE IMPURITY METERS

Meter	Status	Development Requirements
Resistivity	Well developed	Minimal. Demonstration of use as N meter when coupled to a hydrogen meter
Hydrogen	Well developed & commerically available for Na. POP demonstrated for Li	Minimal. Long term confirmatory testing with attached QPMS desirable
Oxygen	Well developed and commercially available for Na, feasibility demonstrated for Li	Long term compatibility of solid electrolyte in Li
Nitrogen	Concept identified	Extensive. POP and long term testing required

LG Vg 18
July 18-21, 1995

Westinghouse
Science & Technology Center

FLOW THROUGH TUBE SAMPLER (FTTS)

- Proven state-of-the-art technique
- Removal of small bulk samples for off-line analysis
- Both filtered and un-filtered systems tested in ELS

LG Vg 19
July 18-21, 1995

Westinghouse
Science & Technology Center

4.3 Hydrogen/tritium Recovery System

Dai Kai Sze, Dale Smith
Argonne National Laboratory

Presented at

1st IFMIF-CDA Technical Workshop on
Li-Target System

Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

July 18-21, 1995

Goal of the Work

- To recover tritium produced in the lithium target with an acceptable tritium inventory
- To keep tritium concentration in the lithium to a level which allows unprotected access.

Target for Tritium Control

- For fusion reactor, the tritium recovery system is designed to keep the tritium concentration in the lithium to ~1 appm.
- This target is to keep tritium inventory in the lithium to about 200 g.
- For IFMIF, the lithium inventory is estimated to be 2 m^3. Thus, the tritium inventory is not a key concern.
- We will design the tritium system so that the tritium concentration in the air will be less than the MPC (maximum permissible concentration).

Maximum Permissible Concentration

- The MPC for the CANDU system is 10^{-5} Ci/m^3 in air.
- The CANDU system routinely operates with tritium concentration in the air higher (by a factor 2 to 1000) than the MPC.
- The concentration of tritium which will give a partial pressure of MPC is 40 appm.
- The total tritium inventory in the lithium for the 40 appm tritium concentration is 17 g.
- I will suggest that the tritium system will be designed to the MPC limit.

Tritium Recovery Methods

- Molten Salt Recovery
- Gettering Bed
- Permeation Window
- Distillation
- Cold Trap

Molten Salt Recovery System

Basic Principle:

- LiT will be preferentially distributed into the salt from Li.
- LiT can be decomposed by electrolysis.

Development stage:

- All steps have been developed in laboratory scale.

Good feature:

- Tritium can be recovered from lithium to ~ 1 appm.
- Steady State operation

Reason for not selection:

- Complicated system
- Salt will be carried back to lithium.
- SS operation is not required by this system.

Gettering Bed

Basic Principle:

- The solubility of tritium in the gettering bed is higher than in lithium.

Development stage:

- The gettering bed technology is well developed for tritium (hydrogen) control in lithium and Na.

Good feature:

- Simple operation
- Well developed chemistry

Reason for not selection:

- High temperature operation (400 to 500° C)
- Difficult regeneration
- Not reactor relevant

Permeation Window

Basic principle:

- Tritium can permeate across a permeation window for recovery.

Developed stage:

- Permeation window has been well developed in tritium processing facilities.

Good feature:

- Simple operation
- Separate impurities from tritium stream

Reason for not selection:

- Low tritium partial pressure over lithium requires a large permeation window.
- Need high temperature operation
- Not reactor relevant

Vacuum Distillation

Basic principle:

- Large separation factor of tritium from lithium can be obtained at high temperature (~ 1000 C).

Development stage:

- Some small laboratory scale experiments have been carried out.

Good feature:

- ?

Reason for not selection:

- Very high temperature operation (~ 1000 C)

Cold Trap

Basic principle:

- The Li (H+T) will be supersaturated at low temperature.

Development stage:

- Cold trap of hydrogen from lithium was demonstrated in a laboratory scale experiment.
- Cold trap of (T+H) from Na is an industry step.

Good feature:

- Well developed technology
- Can control tritium to very low level concentration
- Potential for SS operation
- Proposed as the reference method for ITER

Reason for selection:

- Low temperature operation
- Recovery both D and T
- Method may be developed by ITER.
- Key experiments has to be performed.

Tritium System Parameters

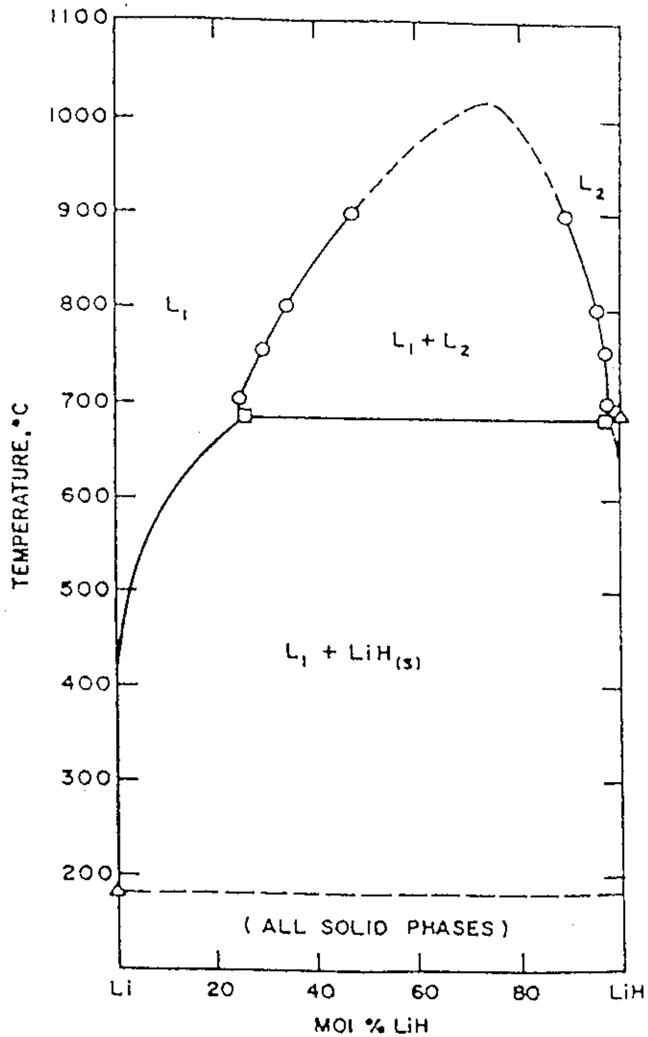
Lithium flow rate for the target	0.075 m^3/s
Lithium inlet temperature	250°C
Lithium outlet temperature	305°C
Tritium production rate	15 g/y
Deuterium deposition rate	157 g/y
Total power	8.5 MW
Allowable tritium concentration in lithium	40 appm
Lithium flow rate to the recovery system	0.1 cm^3/s
Total tritium inventory in lithium	17 g

Concept of Cold Trap

- The hydrogen concentration in the lithium can be reduced to 440 appm by cold trap.
- This concentration is too high if the only hydrogen isotope in the lithium is tritium.
- Deuterium is added to the lithium to about 1000 appm.
- Cold trap will reduce the total hydrogen concentration to about 440 appm, while reducing the tritium concentration proportionally.
- The basic concept is same as the one used for the sodium system.

Li-H Phase Diagram

- The Li-H phase diagram provides fundamental information for cold trap.
- The regime marked by L1 + LiH(s) is the two phase regime, within which LiH will precipitate out.
- The solid curve on the right of the phase diagram defines the regime under which cold trap will work.
- This solid curve were measured by Adams, et. al.



Schematic drawing of the lithium-lithium hydride phase diagram based on existing data. The dashed lines represent boundaries that have not been investigated experimentally.

Hydrogen, Deuterium Solubility in Lithium

- The solubilities of protium and deuterium in the lithium are given by the following equations:

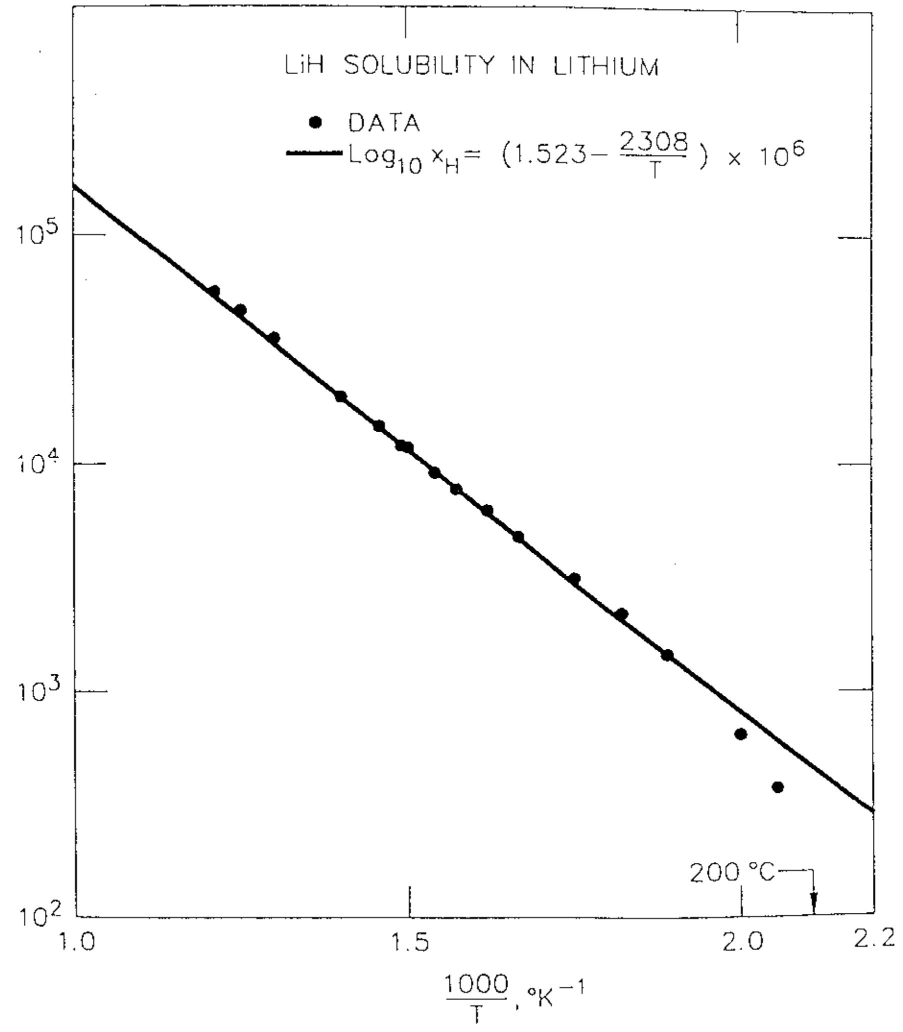
$$\log_{10} X_H = 1.523 - 2308/T$$

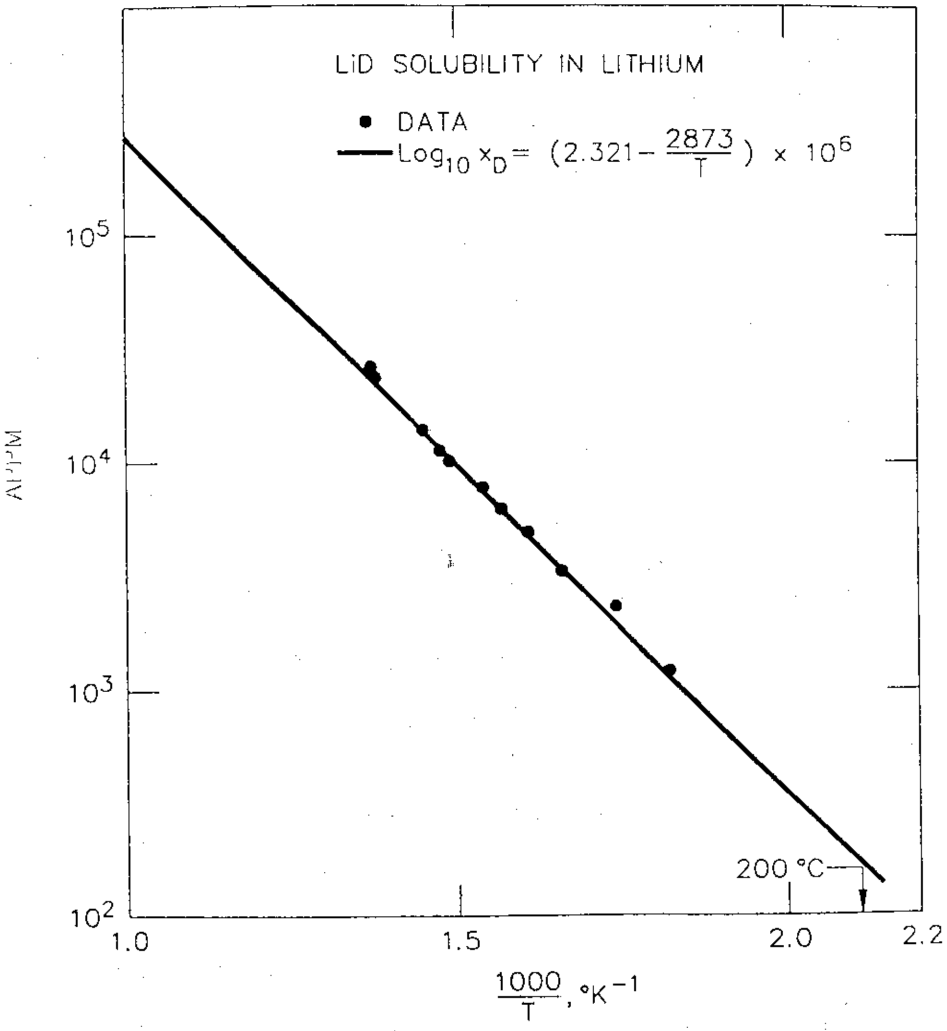
$$\log_{10} X_D = 2.321 - 2873/T$$

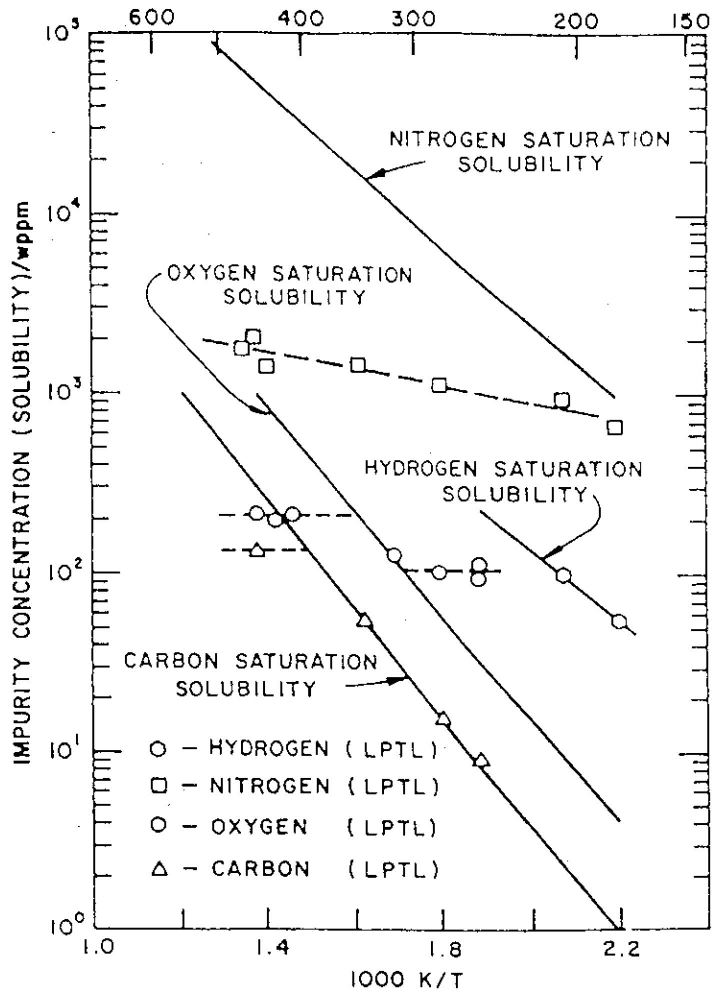
at 200°C, $X_H = 440$ appm

$X_D = 177$ appm

Thus, cold trap has potential to reduce the hydrogen concentration in the lithium to ~440 appm.







Summary of cold trap performance data obtained on the LPTL.

Cold Trap Information

- LiH (D) solubility in lithium near the cold trap temperature have been measured.
- Cold trap of LiH to the saturation concentration has been demonstrated.
- Co-precipitation of Na(H+T) has been demonstrated. No isotopic effect was observed.
- Meshless cold trap process to separate NaH from Na was demonstrated.

Cold Trap Regeneration

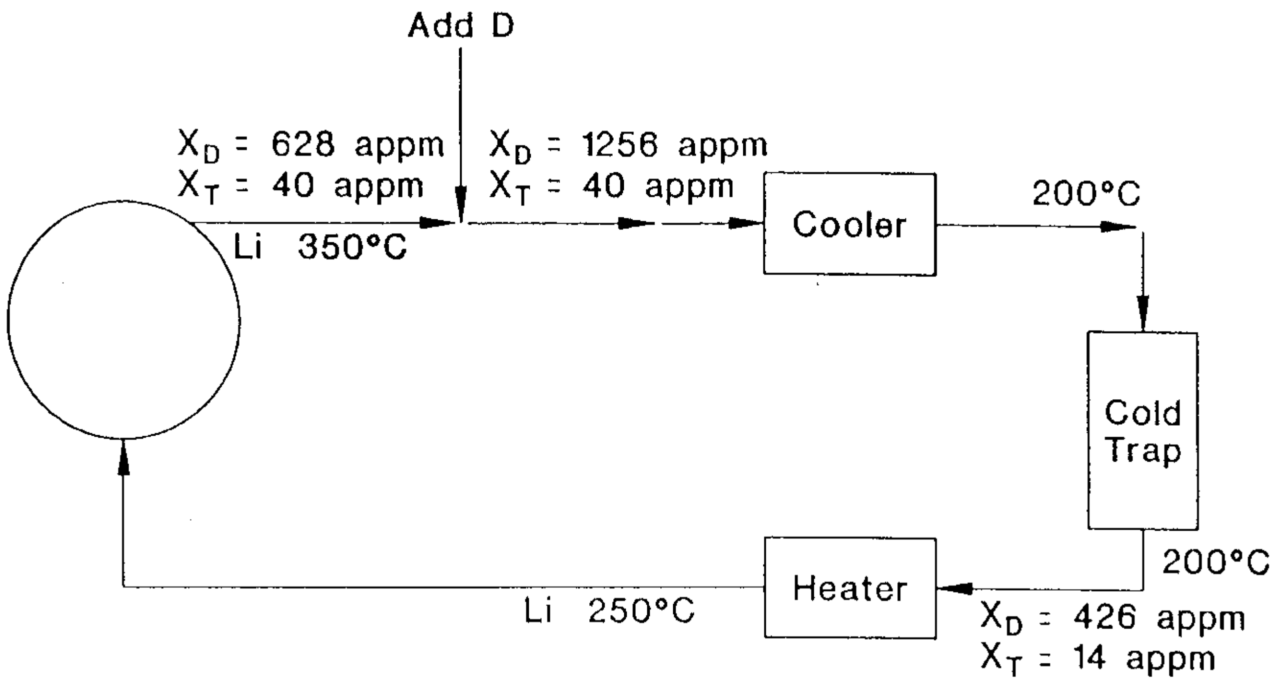
- Hydrogen decomposition pressure over LiH has been measured.
- Regeneration of (H+T) from Na(H+T) has been demonstrated. No isotopic effect was observed.
- Continues separation of NaH from Na by meshless cold trap was demonstrated.

Hydrogen Addition

- Protium addition to Na to assist tritium remove from Na was demonstrated.
- The hydrogen addition can be either in the form of H2, or NaH.

Isotope Separation

- The separation of hydrogen isotopes by ISS has been demonstrated by TSTA.
- Computer codes are available to calculate the ISS operation with multiple feed streams.
- The additional cost and tritium inventory due to this blanket stream over the ITER tritium plant are very modest.



Cold trap concepts.

5. Preliminary Safety Analysis for the Li-system/Design Items and Schedules

5.1 An Overview on Lithium Reactivity/Compatibility

G. BENAMATI ENEA-Energy Department- Fusion Branch
F. BIANCHI ENEA-Energy Department- Fission Branch

Tokai-mura (Japan), July 18-21, 1995

The purpose of this work is to review:

- lithium reactivity with atmospheres (air, N_2, O_2, ...);
- lithium reactivity with coolant (water);
- lithium reactivity/compatibility with structural materials (steels, concrete).

Some preliminary indications are underlined in the area of:

- possible use of coolants;
- methods able to reduce the consequences of lithium lekages;
- areas needing further investigations.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Lithium characteristics

Lithium melting point	453.5 K
Lithium boiling point	1615 K
Lithium density	502.2 kg/m3 (600 K)
Lithium conductivity	46.32 W/m K (600 K)
Lithium heat of vaporisation	21200 kJ/kg
Specific heat	1.02 kJ/kg (600 K)
Standard reduction potential	-3.024 V

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with oxygen

$$2Li + 0.5O_2 \rightarrow Li_2O \qquad \Delta G_{298} = -561.2\,kJ/mole \quad \Delta H_{298} = -595.1\,kJ/mole$$

$$2Li + O_2 \rightarrow Li_2O_2 \qquad \Delta G_{298} = -571.0\,kJ/mole \quad \Delta H_{298} = -636.0\,kJ/mole$$

Oxide	Heat of formation (500 K)		
	kJ/mole Li	kJ/g Li	kJ/dm^3 Li
Li_2O	-302.31	-43.57	-22320
Li_2O_2	-321.47	-46.32	-23728
Na_2O	-210.72	- 9.16	- 8226
Na_2O_2	-257.62	-11.21	-10060

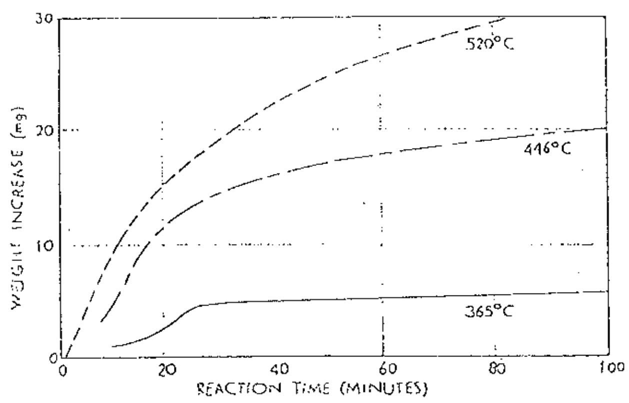
ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with oxygen

From a kinetic point of view anhydrous oxygen reacts slowly with lithium.

The reaction evolves from 523 K and ignition temperature is about 903 K.

Humidity in oxygen <u>increases strongly</u> the reaction rate.

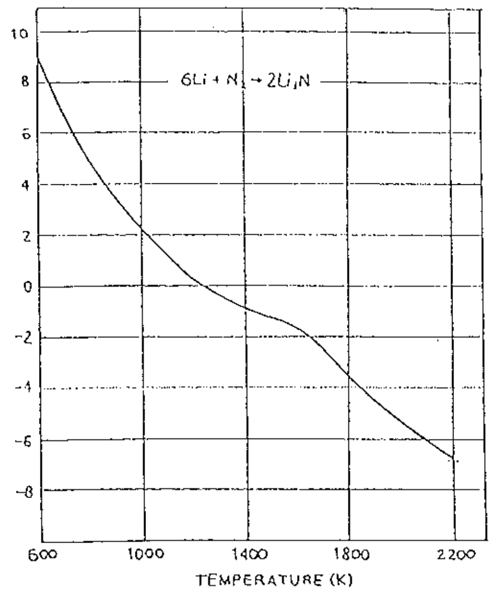


ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with nitrogen

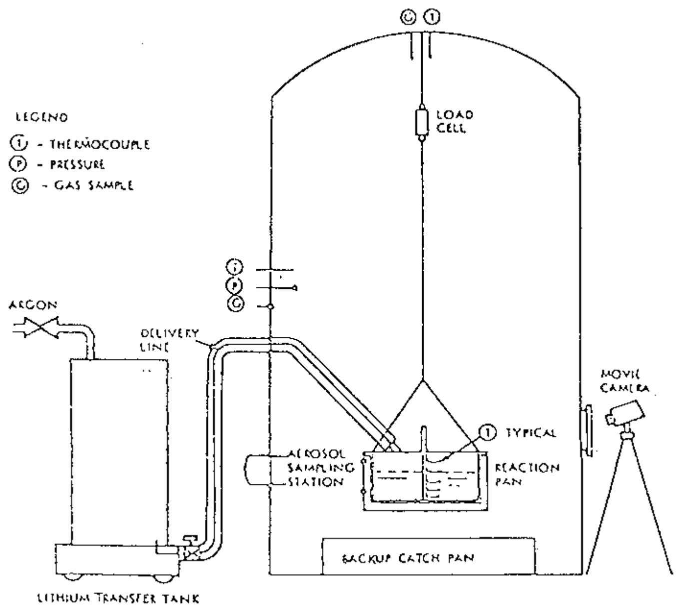
Lithium can react with nitrogen producing stable compounds; the best known is Li_3N, having the m.p. at 1092 K.

$$3Li + 0.5N_2 \rightarrow Li_3N \qquad \Delta G_{298} = -156.17 \text{kJ/mole} \qquad \Delta H_{298} = -198.88 \text{kJ/mole}$$



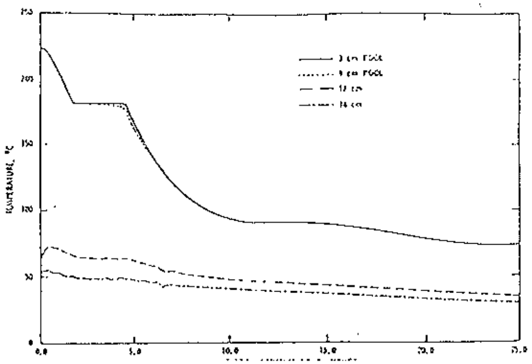
Li_3N equilibrium constant

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

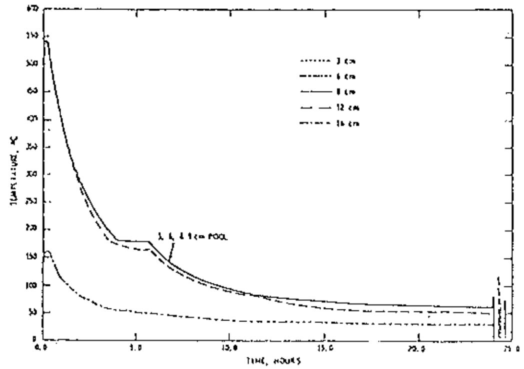


. Schematic of Lithium-Atmosphere Reaction Test Equipment Arrangement.

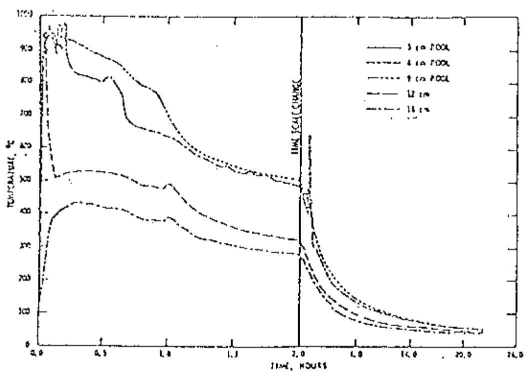
ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali



498 K



813K



1116 K

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with nitrogen

The following results came from the experiments carried out in Hanford labs:

- at low temperature (≤ 498 K) the reaction rate is low due to thermal losses (reaction is quickly extinguished);
- no problems of violent evolution arose up to 773-823 K;
- the maximum temperature reached, with high initial temperature of lithium, was 1223 K.

The reaction rate depends from :

- turbulence of the system,
- presence of humidity
- mass/area ratio.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with air

Nine lithium pool tests have been performed at Hanford labs.

The results indicate that reaction occurs spontaneously when the pool has a temperature higher than 516 K.

Maximum pool temperature : 1323 K
Maximum flame temperature : 1533 K

Parameter affecting the reaction rate:

- turbulence of the system,
- presence of humidity,
- mass/area ratio,
- rate of heat removal from the pool,
- mass of available air.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with air

Effect of mass/surface area in a pool fire:

mass/surf. [kg/m2]	max. pool temp. [K]	Δt/ΔT [K/s]
50	~1270	~.7
215	~1270	~0.17

initial temp. 870 K
hum. 10 %

Further data are needing on this item.

Effect of initial temperature in a pool fire:

No data from tests with large amount of lithium have been carried out.

Preliminary indications from small scale tests seem evidence that for a pool (50 kg/m2) an additional reaction time of 10 minutes is required to reach the maximum pool temperature if the initial temperature changes from 513-573 K to 723-873 K.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with air

Points wich need of further investigations:

- Suppression methods (powder like carbon microsphere, inert gas..),
- model for lithium combustion,
- experiences on large scale (≥ 50 kg) on the parameters affecting the reaction rate (mass/surface area, initial temperature, humidity...).

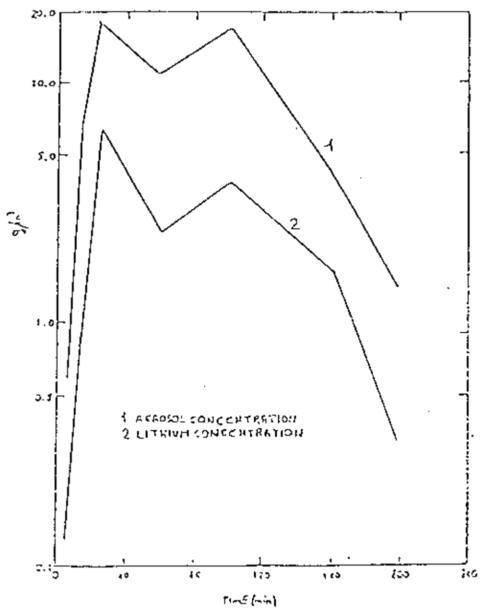
ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with air

Aerosol formation and composition.

The main products from lithium combustion in air are reported in the table

in. tem. K	Oxide	Nitride	Hydrox.	Carb./per.
516	45 %	44 %	9 %	1 %
783	49	47	3-4%	-



ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with water

$$Li + H_2O \rightarrow LiOH + 0.5H_2 . \Delta H_{298} = 204 kJ / mole Li$$

$$2Li + H_2O \rightarrow Li_2O + H_2 . \Delta H_{298} = 186 kJ / mole Li$$

	Li	Na	K	Ru	Cs
-ΔH(kJ/mol) for: $M+H_2O \rightarrow MOH+0.5 H_2$	508	469	481	475	478
Atoms ($*10^{14}$) exposed on immersion of 10 mm^3	26.1	36.1	18.2	18.5	15.7
Solubility of metal hydroxides in water(mol% at K)	53.6 (293)	105.0 (273)	190.7 (288)	175.6 (288)	263.8 (288)
Melting point of metals(K)	453.7	371.0	336.9	312.1	301.8

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with water

The hydrogen generation is about 0.5 mole of H_2 for 1 mole of Li; two are the problems related to water lithium interaction:

1) Thermal explosion
2) Cemical explosion (oxygen/hydrogen reaction).

main problems:

- high quantity of hydrogen produced,
- high quantity of heat released,
- high temperature reached during the reaction and over pressure ,
- pollution by the production of hydroxide.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

Reaction with concrete

Several experiences have demonstrated that molten lithium can chemically attack concrete.

A test programme has been performed at HEDL to characterise the reaction of lithium with magnetite and basalt concrete at temperatures between 507 K and 1143 K.

RESULTS

- The concrete to lithium maximum reaction ratios ranged from 6.5 kg concrete/kg Li for magnetite to 3.9 kg concrete/kg Li for basalt.
- Lithium concrete reaction rates were found to be dependent on type of concrete, initial lithium temperature, rate of lithium addition and atmosphere in which the reaction occurred.
- For initial lithium temperatures of ~ 670 K (or greater) penetration rates of up to 2.5 cm/min for magnetite and 2.3 cm/min for basalt were measured.

ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

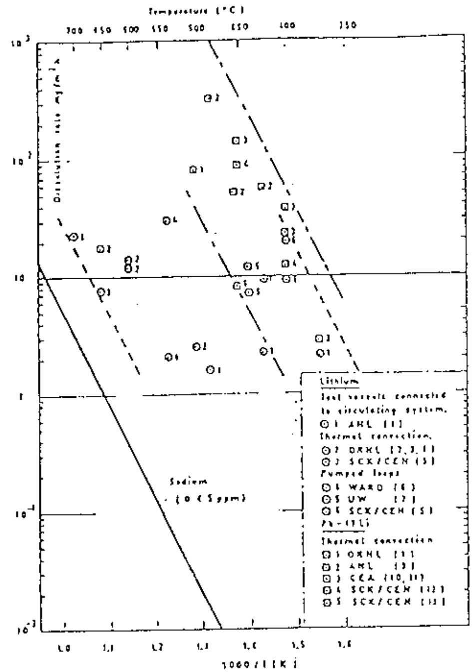
Reaction with concrete

- A maximum temperature of 1439 K in the Li pool has been observed in a reaction between magnetite and lithium (initial lithium temperature 533 K). The test has been carried out in Ar atmosphere.

- A maximum temperature of 1470 K in the Li pool has been observed in a reaction between basalt and lithium (initial lithium temperature 613 K).The test has been carried out in Ar atmosphere.

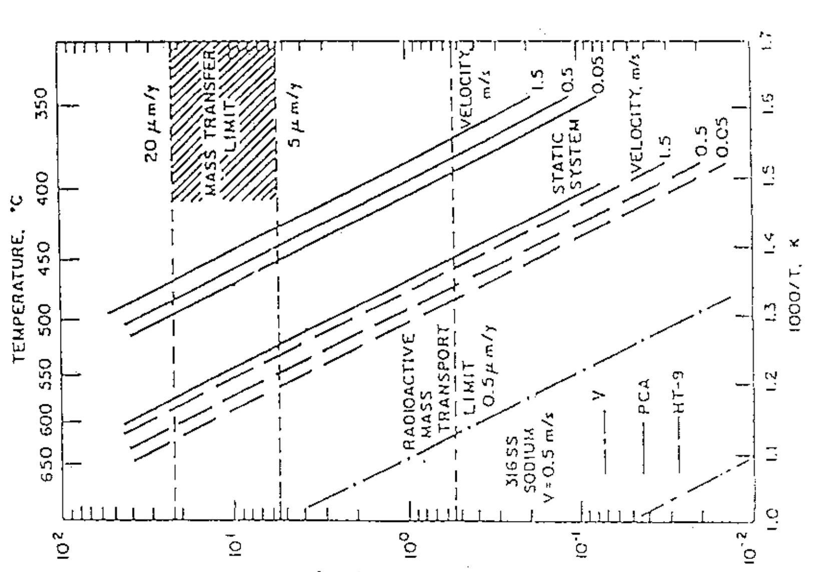
- Tests carried out in air evidence a considerable increase of the Li/concrete reaction rate and higher maximum temperatures.

REACTION WITH AUSTENITIC STAINLESS STEEL



ENEA Divisione Materiali Speciali per la Fusione Termonucleare
Progetto Compatibilità Materiali

REACTION WITH FERRITIC STAINLESS STEEL



5. 2 FMEA Approach and Safety Consideration on IFMIF

S. Konishi, Y. Kato
JAERI IFMIF Target System Group

1.Introduction

The Objective of this task is to provide a preliminary safety assessment of the lithium loop and entire target system of the IFMIF. The target system involves considerable amount of liquid lithium and activated impurities including tritium, and thus is the major chemical and radiological hazard in the entire facility. It is necessary in the early stage of the conceptual design to identify the possible hazards and reflect the safety assessments into the system design. The expected outcome of the task is a rough concept of the future safety analysis to be planned in the design directed to the immediate construction, and to provide some safety related aspects that may contribute in the design options. It is not an intention of this task to expand the safety analysis of the entire facility, or to provide any quantitative safety data base. Although there is no definite design available now, such an analysis is expected to provide an important aspects in the CDA. The result will also be reflected in the site determination and site specific preparation.

2.Technical outline of task

The activity in this task is focused on the Failure Mode and Effect Analysis of the entire target system design, and some related areas. This approach is expected to be most appropriate to provide the safety related information and consideration in this early design phase. Safety aspects will be given for comparison of technical options in the conceptual design. It is also suitable to provide common understanding and standardized measure among parties involved in the CDA. Assumable failures, accidents and problems in the system are being identified, and rated and classified for the seriousness, effects and probability. No quantitative analysis is attempted.

3. Plan and current status

FMEA are being made on the following hazards of the target.

Chemical hazard : Lithium fire
loss of vacuum of the target chamber
malfunction of chemical system

minor and major leak of lithium
interaction problem with beam line
Beryllium

Radiological hazard :Beryllium
Tritium
Other activated materials
neutron and radiation from test cell

Activity has started in this year, and some example FMEA were generated on generally accepted concepts of target and lithium loop, without considering any specific design that are not available in this phase of the CDA. This preliminary analysis is scheduled to be completed by October 1995, and will be revised by interaction with the ongoing target system design after that.

3. Results and findings

3.1 Lithium loop hazard

The most important events to be considered is a major leak of the liquid lithium and the resulting fire. Although the probability is very low, and the system will be designed to prevent such an event with highest priority, this hazard will remain as a most important accident to be considered. The largest impact is related to the release of radioactive materials to environments. Significant amount of the radioactivity in the target system could be airborne form such as lithium aerosol. From this aspect, to minimize the inventory of lithium is essential, because lithium is the only medium of the movable hazardous material, and its amount can only be controlled by the concentration in it. Propagation of the event to accelerator or test cell region is of major concern, and thus isolation between these subsystems should be considered in the design. Containment of the lithium loop and its major components have a significant impact on the potential safety of the lithium system. It is not difficult and thus lithium fire is not a serious issue.

3.2 Target stability and back wall

Instability of the target lithium film is a major concern. Bubbles, boiling, instability that generates thin part in the liquid film, and a sudden stop of loop flow are possible, and the overall probability of such an event cannot be estimated at this time. The risk and hazard of this event should be considered in conjunction with the thermal resistance of the back wall and the response of the interlock that should stop the beam. The result of the exposure of backwall to the beak is anticipated to be catastrophic and typical time constant of the phenomena when a material is exposed to 100 kW/cm^2 of power is in the range of milliseconds. It is strongly recommended to increase the reliability and tolerance of the back wall to maximum level to obtain a response time for interlock, however the speed of the detection of off-normal event on target is questionable. In the safety point of view, isolation of target from beam line and cell is difficult, and thus effect should be considered in these subsystems.

3.3 Confinement of radioactivity

Movable radioactive nuclides, particularly tritium is a major hazard for the environment in the case of accident. Site inventory of tritium is usually a good measure, however in the lithium target system, the mobility of tritium could be an important factor. Tritium trapped and immobilized on some solid media may need a different consideration.

Multiple confinement of tritium and other movable nuclides should be considered in the entire IFMIF system. Particularly vacuum exhaust that is anticipated to contain relatively high level of activity will need careful designing to be acceptable for any of the possible IFMIF sites. In the off-normal events, isolation of primary subsystems of beam, target and test cell is not reliably achieved. Containment in the test cell region to prevent mitigation of back wall rupture is needed. Secondary, and if needed, tertially confinement should be considered for inert cover gases for target and test cell.

Contamination and radiation control in the beam line is currently unknown. It is suggested for accelerator design to assess possible radiological hazards in both normal and accidental conditions.

3.4 Activation

Activation of the construction materials, equipments and solid materials in the IFMIF system induced by the scattered neutrons is not a hazards in the FMEA, because they are not specific in accidents. However, very high activity around the lithium target limits the access of workers for emergency operation or quick mending, and any other efforts to minimize the damage in the accidents. Interlock, remote handling and fail safe design is extremely important.

Although the effects of the neutron that strayed or is back-scattered from test cell are not estimated in the target system, activation and tritium production by thermal neutron may not be negligible.

3.5 Beryllium

Chemical hazard of beryllium is expected to be negligible when compared to the hazard resulted from any leak of lithium. However in the leaked lithium, the gamma activity of beryllium is anticipated to attribute a possible major dose of workers.

3.6 Beam line interface

Some of the events anticipate excess evaporation of lithium that would diffuse to beam line vacuum. Acute effect is a poor vacuum, that can be handled by pumps. Differential pumping will be effective to maintain a sufficient vacuum in the beam line, however no known pump can handle considerable amount of lithium vapor. Accumulation of lithium in downstream beam line may cause contamination and problem such as fire and chemical hazard in maintenance that needs exposure to air. Here, the needs for a vacuum pump that can handle lithium vapor and tritium is identified as a major technical issue.

4.Recommendations

Although it is too early to make any conclusions at this stage, several suggestions and recommendations can be drawn from this ongoing safety analysis. It is generally agreed that the IFMIF is technically feasible in near future, however some of the components, design and techniques require R&D activities to complete the entire facility to be safe and acceptable. As considered above, for instance, confinement and potential hazard of radioactivity is a major concern. In general, various technologies required for IFMIF as a nuclear facility are in the very early stage. Some from FBR technology will be applicable, but handling of tritium, vacuum, high energy beam and lithium are rather new.

Effects that mitigate from target to other subsystems are not considered here, but seems important. Further analysis is recommended.

The IFMIF as a whole, can be regarded as a new type of nuclear facility that has various features to be shared with fusion reactor and blankets. Many of the safety technology to be developed to complete the IFMIF facility may be expected to be applicable for fusion reactor. Moreover, it is suggested that not only for material irradiation study, IFMIF can actively be utilized as a major facility to study fusion nuclear technology.

Attachment: example of FMEA

The FMEA is being made for some of the target systems of IFMIF in accordance with a typical format. No quantitative analysis is made, and only possible causes and effects of off-normal events are identified and evaluated.

FMEA ratings

	Detection easiness	
A	easy	immediately detected and alarmed
B	limited	detected with delay or needs observation
C	difficult	no detection available

	Frequency	
A	operational events	more than once per year
B	likely events	$1/y \sim 10^{-2}/y$
C	unlikely events	$10^{-2} \sim 10^{-4}/y$
D	extremely unlikely events	less than 10-4/y

	Risk	
I	operational	caution required
II	danger	limited function
III	minor hazard	immediate halt and repair
IV	major hazard	accident, damage of facility
V	extreme	possible environmental effect

FAILURE MODES AND EFFECTS ANALYSIS FOR IFMIF TARGET SYSTEM

1. LITHIUM LOOP

COMPONENT	PURPOSE	FAILURE MODE	EFFECT	DETECTION	MITIGATION OR PREVENTION	FREQUENCY	RISK
EMP	Circulate liquid lithium	Process leak	lithium in 2ndary containment	B.Pressure flow	Leak check	C	IV
		stop	lost target flow	A Pressure flow	current check interlock	D	V
		insufficient flow	low target flow	A. Current flow	periodical check	C	IV
Li plumbing	Circulate liquid lithium	Process leak	lithium in 2ndary containment	B.Pressure flow	Leak check	C	IV
			lithium in air	B.Pressure flow	detect minor leak	D	V
		plugging	lost target flow	A Pressure flow	impurity control	D	V
heat exchanger	remove beam heat	internal leak	lithium in oil possible rad release	B.Pressuree	alarm, interlock	C	IV
		stopped oil	loss of cooling	A.temperature	alarm, interlock	C	III
		oil leak	minor contamination	B. pressure	leak check	B	III
cold trap hot trap	impurity control	Plugging t	loss of flow	A. flow	monitor DP	B	III
		malfunction breakthrough	impurity in Li	B.plugging meter	impurity monitor	B	III
			possible main loop plug			C	IV

2. TARGET ASSEMBLY

COMPONENT	PURPOSE	FAILURE MODE	EFFECT	DETECTION	MITIGATION OR PREVENTION	FREQUENCY	RISK
LI	absorb beam power	minor instability	excess backwall heat	B.flow monitor?	Interlock	**A**	**IV**
		major instability	excess backwall heat	B.flow monitor?	Interlock	B	IV
		excess evaporation	Li in beam line	A. pressure of vacuum	interlock	A	III
back wall	form Li film	swelling	improper Li film	C. ??	replacement	A	III
		rupture	Li in test cell	B. ??	replacement interlock	C	IV
target chamber	maintain vacuum	poor vacuum	Li in beam line	A. pressure of vacuum	interlock	A	III
		failure in exhaust process	possible radiation release	A rad monitor	interlock	B	IV V

Here, for instance, minor instability of the lithium flow is identified as frequent and serious. It is because a wave on the free surface or formation of bubble may allow deuterium beam to hit the backwall with near the maximum stopping power, and destroy it in some milli-seconds. Reflecting this result, the target design should either improve backwall, stability of the target, or change the logic so that the target and test cell design can experience such an event frequently without any mojor safety concern.

5.3 Requirements for Li-technology Test Loop and Beam-on-target Experiment

Y. Kato, T. Aruga, S. Konishi
IFMIF Target System Group of JAERI/JAPAN

1. Introduction

In the IFMIF-EDA activity we should make practical and final designs of lithium target system. Some critical issues will be still remained at the end of the IFMIF-CDA. To clear these issues before construction of real Li-target system , practical experiments in the EDA term will be required by use of :

i) Li technology test loop
ii) Beam-on target test facility

2. Concept and design requirements for the Li technology test loop

We think that main IFMIF Li-loop components are able to design and product on the base of sodium technology so that the R & D of them should not be made in this Li technology test loop except the issues concerning chemical behavior and/or some new proposal in IFMIF-CDA. The following experimental certifications should be made and its results will be made feed back to EDA design work.

a) Surface stability of target Li jet flow for reference IFMIF target.
b) Corrosion /Erosion of target assembly (nozzle, backwall, etc.)
c) Feasibility of large capacity EMP (or parallel operation of smaller size EMP) ,heat exchanger and some components or devices which are proposed in the CDA activity.
d) Calibration of EM Flowmeters
e) Calibration of on-line impurity monitors and the function of chemical processing system
f) Function of the exchangeable target assembly by remote operation.
g) Emergency counter operation for Li leak, EMP trouble and others.

The components or devices tested in this loop could be used again in the real Li target system if their features are proved. The draft of the Li technology test loop is shown in Fig. 1.

3. Beam-on target experiment

The main purposes of the beam on target experiment are:

A) Analysis of the boiling phenomena in the target Li jet flow
B) Evaluation of the vaporization rate of Li by thermal evaporation and by spattering
C) Stability confirmation of Li flow at the beam-on.

For the IFMIF reference target size (5 x 20 cm) and the beam conditions (250 mA), boiling margin and vaporization rate of Li are assumed to be not so severe. In the present status, there are no high current (>100 mA,35MeV, CW) deuteron or proton accelerator which could be used for IFMIF target study in Japan.

However the maximum current density and /or the maximum target size along with the vertical flow direction for evaluating the surface boiling phenomena could only be demonstrated by the beam-on target experiment. There seems to be two ways:

1. Beam-on target experiment should be done by use of real accelerator of IFMIF.
2. Even by the lower power accelerator, basic beam-on target experiments should be made by adjusting the target conditions such as the Li flow velocity. Some these accelerators which are now operating seem to be the candidate

If we take the second situation, we should take care for the energy deposition curves of lower deuteron (or proton) energy in the Li to analyze the surface (boiling) phenomena. Fig. 2 ~ Fig. 3 show the energy deposition of deuteron and proton beam in the Li of about 200 C (beam energy dispersion: σ=0.5MeV). From these figures it is clear that the beam energy lower than 2 MeV could not be used for the boiling simulation because the beam stop range is too short.

4. Plans to the next stage

1. Practical lithium technology test loop will be designed until March, 1996. The loop should fundamentally corresponds to the IFMIF lithium system and the feasibility test of its main components can be performed by it.

2. In regard to the beam on target experiment, the deuteron (or proton) accelerator which can practically be performed the lithium target experiment will be surveyed.

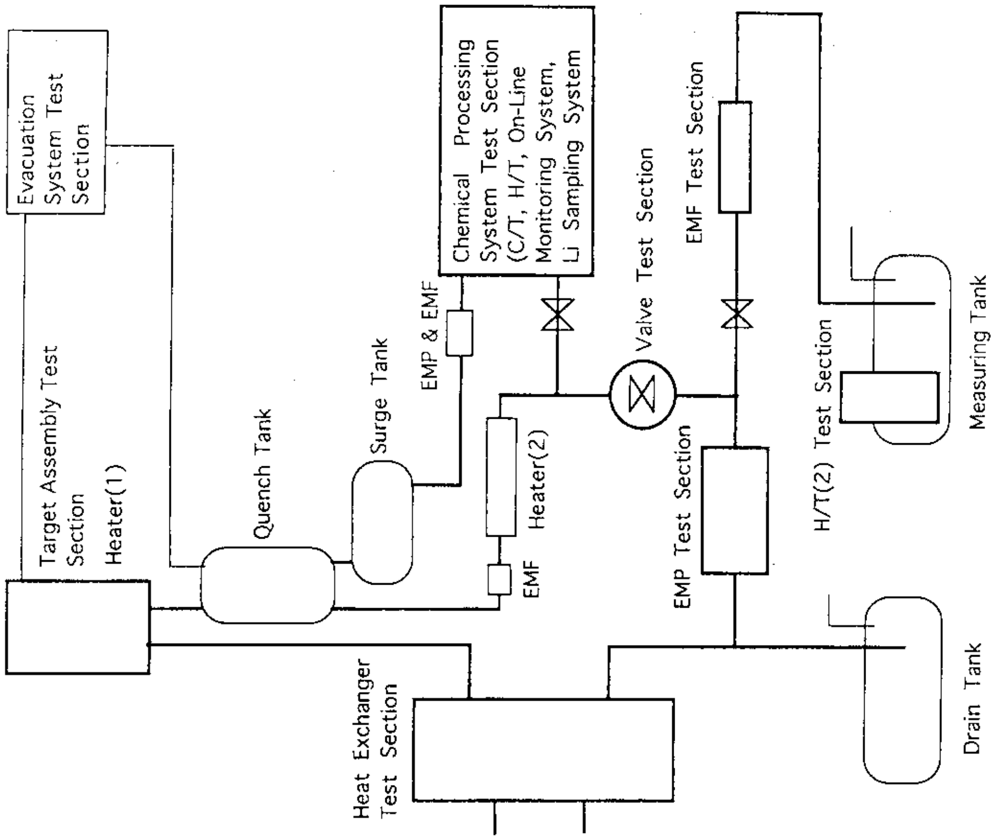


Fig. 1 Basic Concept of the Lithium Technology Test Loop

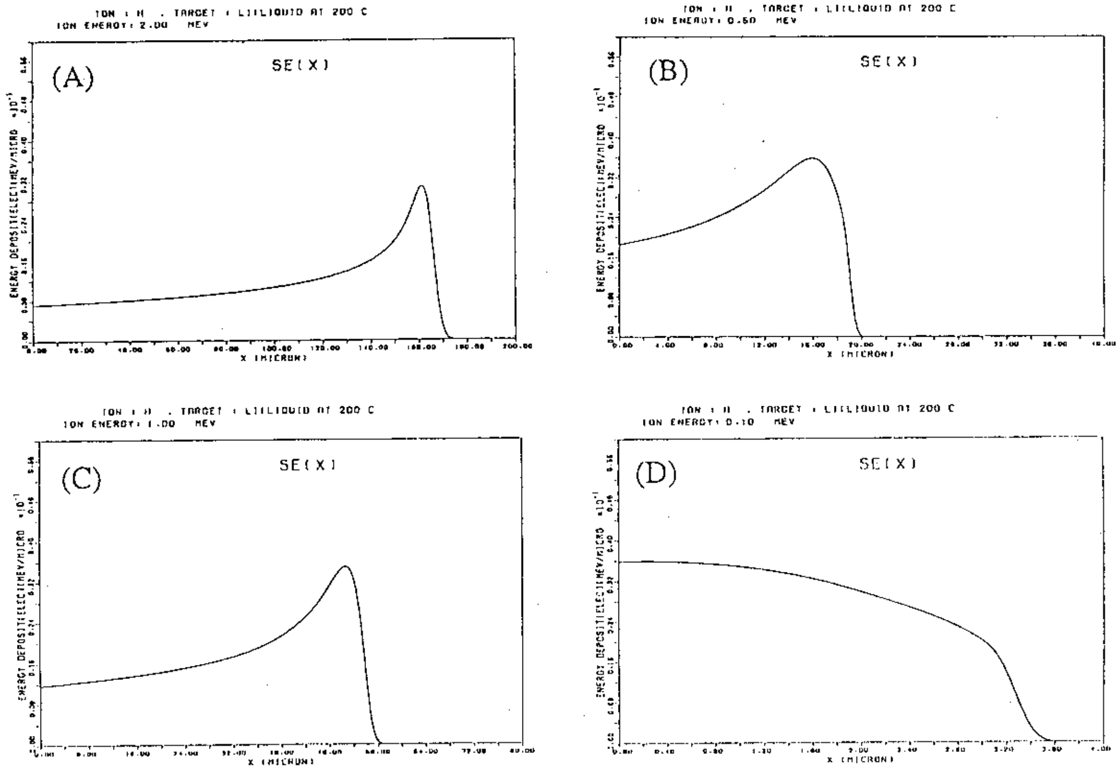
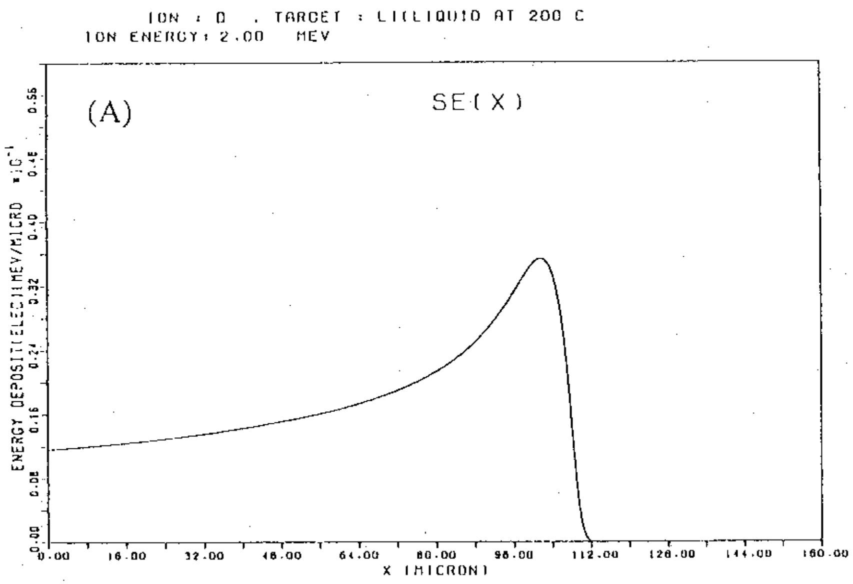


Fig. 3 Proton Energy Deposition In lithium (200 C)
(A) : H(E)= 2 MeV, σ = 0.5 MeV (B) : H(E)= 1.0 MeV σ = 0.5 MeV
(C) : H(E)= 0.5MeV, σ = 0.5 MeV (D) : H(E)= 0.1 MeV, σ = 0.5 MeV



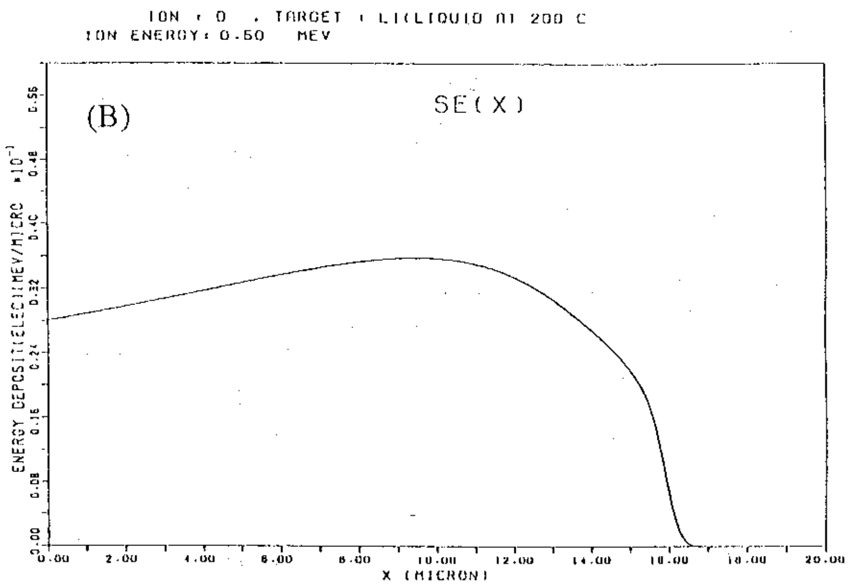


Fig. 2 Deuteron Energy Deposition In lithium (200 C)
(A) : D(E)= 2 MeV, σ = 0.5 MeV (B) : D(E)= 0.5 MeV σ = 0.5 MeV

5.4 IFMIF Facility Safety Requirements

G. BENAMATI ENEA-Energy Department- Fusion Branch
F. BIANCHI ENEA-Energy Department- Fission Branch

Tokai-mura (Japan), July 18-21, 1995

OBJECTIVES OF ACTIVITY

- REVIEW THE SAFETY REQUIREMENTS FOR DESIGN, CONSTRUCTION AND OPERATION;
- TO REPORT, WHERE NECESSARY, SOME RECOMMENDATIONS RELATIVE TO SAFETY REQUIREMENTS AND CRITERIA;
- TO MAKE A CHOICE AND INDICATE, WHERE NECESSARY, THE LIMITS OF SAFETY REQUIREMENTS AND CRITERIA.

BACKGROUND

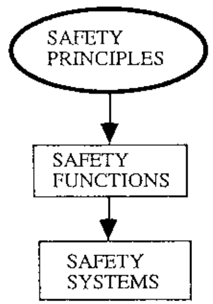
- KNOWLEDGE AND PROVEN TECHNOLOGY OF LMFBR;
- EXPERIENCE GAINED IN OPERATION OF EXPERIMENTAL METAL LIQUID SYSTEMS

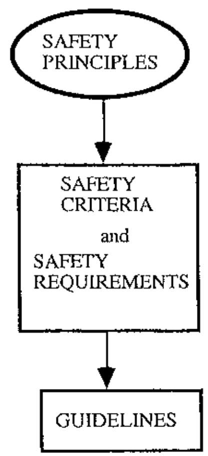
•END OF ACTIVITY: APRIL 30,1995

- DOCUMENT ISSUED:
" MAIN LIQUID-METAL-SYSTEM SAFETY REQUIREMENTS"

SAFETY PRINCIPLES

- TO ENSURE CONTAINMENT OF THE LIQUID METAL, THE RADIOACTIVE MATERIALS AND TOXIC ELEMENTS (e.g. BERYLLIUM);
- TO MAINTAIN COOLING (A COROLLARY OF THE FIRST);
- TO MINIMISE THE RELEASE OF RADIOACTIVE AND/OR TOXIC MATERIALS INTO THE ENVIRONMENT IN NORMAL AND ABNORMAL OPERATING CONDITIONS.





REQUIREMENTS AND CRITERIA HAVE BEEN DEFINED FOR THE FOLLOWING ITEMS:

1) SAFETY FUNCTIONS

   LITHIUM CONTAINMENT
   LITHIUM HEAT REMOVAL
   PURIFICATION
   DRAINING
   INERTIZATION AND SWEEPING
   COVER-GAS SUPPLY, PURIFICATION AND HANDLING
   LOOPS PREHEATING AND HEAT INSULATION
   LITHIUM STORAGE, MELTING AND FILLING
   LEAK DETECTION
   INSTRUMENTATION AND CONTROL
   CONTROL ROOM
   ELECTRIC POWER SUPPLY AND DISTRIBUTION
   ROOMS VENTILATION AND ATMOSPHERE TREATMENT
   CONFINEMENT OF SOURCE TERM

2) AREA EVENTS

3) EXTERNAL EVENTS

4) DESIGN

5) MATERIALS

6) CONSTRUCTION AND TESTING

LITHIUM CONTAINMENT

REQUIREMENT

• TO ASSURE THE INTEGRITY OF LITHIUM SYSTEM FOR:

- ALL NORMAL OR ABNORMAL OPERATING CONDITIONS, ENVIRONMENTAL CONDITIONS AND NATURAL PHENOMENA THAT COULD AFFECT THE SYSTEM INTEGRITY;

- THE SYSTEM DESIGN LIFE OR COMPONENT DESIGN LIFE (e.g. BACK WALL OF TARGET).

CRITERIA:

• GENERALLY RECOGNISED APPLICABLE CODES OR STANDARDS ON DESIGN, CONSTRUCTION, INSPECTION AND TESTING SHALL BE USED;

• STRUCTURAL FAILURE OF COMPONENTS (e.g. BACK WALL OF TARGET) DUE TO RADIATION DAMAGE AND LEADING A LOSS OF THE SYSTEM INTEGRITY MUST BE PREVENTED.

• CONSERVATIVE DESIGN AND AN EFFECTIVE QUALITY ASSURANCE PROGRAMME INCLUDING HIGH QUALITY MANUFACTURE, INSPECTION, TESTING AND DESIGN VALIDATION MUST BE MADE.

SOME GUIDELINES

• LITHIUM LEAKAGE FROM THE SYSTEM SHOULD BE LIMITED BY RELIABLE MEANS (e.g. DOUBLE WALL PIPE, JOINTS WELDED);

• SENSITIVE AND RELIABLE INSTRUMENTATION TO DETECT LITHIUM LEAKAGE FROM THE SYSTEM (LEAKAGE DETECTION AND LEVEL MONITORING) SHOULD BE PROVIDED;

• COMPONENTS SHOULD BE DESIGNED TO PERMIT PERIODIC INSPECTION AND TESTING OF IMPORTANT AREAS TO ASSESS THEIR STRUCTURAL AND LEAKTIGHT INTEGRITY;

LITHIUM HEAT REMOVAL

• TO ENSURE THE BARRIER INTEGRITY OF LITHIUM SYSTEM.

• FAILURE OF HEAT REMOVAL SYSTEM MUST BE DETECTED AND SUITABLE CORRECTIVE OR PROTECTIVE ACTIONS MUST BE TAKEN WITH RELIABILITY APPROPRIATE TO THE POTENTIAL CONSEQUENCES OF THE FAULT AND THE INITIATING EVENT FREQUENCY.

PURIFICATION

• PURIFICATION FUNCTION MUST BE ASSURED IN ALL OPERATING CONDITIONS; MAINLY:
- AT THE FIRST CHARGING OF THE SYSTEM;
- DURING THE NORMAL OPERATING CONDITIONS.

• THE IMPURITY CONCENTRATION MUST BE MONITORED FOR MAINTENANCE NEEDS AND CONTROLLED TO PREVENT DETRIMENTAL CHANGES IN THE PROPERTIES OF STRUCTURAL MATERIALS USED TO CONTAIN LITHIUM AND PLUGGING OF COMPONENTS.

• THE ARRANGEMENT OF COMPONENTS SHALL ALLOW:
- ACCESSIBILITY FOR INSPECTION AND MAINTENANCE,
- MAINTENANCE OF THE COMPONENTS (REPAIR OPERATIONS AND EQUIPMENT REMOVAL) WITHOUT INJURY TO PERSONNEL, PRINCIPALLY DURING THE TRAPS REMOVAL,
- DRAINING BY GRAVITY OF THE PIPING INTO THE DUMP TANK.

DRAINING

• THE DRAINING FUNCTION MUST ALWAYS BE ASSURED FOR ALL OPERATING CONDITIONS, INCLUDING ACCIDENTS.THE POSSIBILITY OF DRAINING IN AN EMERGENCY IS AIMED TO MINIMISE/LIMIT THE QUANTITY OF LITHIUM THAT CAN BE RELEASED IN THE EVENT OF A SYSTEM LEAKAGE, OR RUPTURE,OR TO PERMIT SUBSEQUENT REPAIRS.

• THE CONDITION THAT CAN INHIBIT THE DRAINING, FOR EXAMPLES VACUUM IN THE COVER-GAS, MUST BE PREVENT.

• DRAIN LINES MUST BE OF SUFFICIENT INSIDE DIAMETER AND MUST BE MAINTAINED AT AN ADEQUATE TEMPERATURE TO ENSURE FLUIDITY AT ALL TIMES.

• THE ARRANGEMENT OF THE SYSTEM DRAIN LINES AND SUMP OR DRAIN TANK SHALL ALWAYS BE SUCH THAT THE SYSTEM NEED NOT BE PRESSURISED FOR DRAINING: THE LIQUID SHALL FLOW BY GRAVITY FROM THE LOWEST POINT IN THE SYSTEM TO THE TOP OF THE DRAIN TANK BY OPENING A DRAIN VALVE.

INERTIZATION AND SWEEPING

+ NITROGEN CANNOT BE USED BECAUSE OF ITS REACTIVITY WITH LITHIUM, ITS ACTIVATION AND UNDESIRABLE EFFECTS ON STRUCTURAL MATERIALS.

+ HELIUM OR ARGON CAN BE USED AS COVER-GAS AND FOR CLEANING THE INSIDE COMPONENT SURFACES OF THE SYSTEM;

• INERT-GAS BLANKET SHALL BE PROVIDED FOR COMPONENTS CONTAINING LITHIUM WITH FREE SURFACE IN WHICH THERE IS THE RISK OF COMING INTO CONTACT WITH OXYGEN, MOISTURE, AND OTHER IMPURITIES THAT CAN LEAD TO POTENTIALLY HAZARDOUS CONDITIONS (e.g. ACCELERATED CORROSION, MASS TRANSFER, PLUGGING, FOULING, etc.).

• THE ACCEPTABLE OXYGEN/NITROGEN AND MOISTURE CONTENT SHALL BE FIXED IN FUNCTION OF THE OPERATING TEMPERATURE OF THE SYSTEM AND THE LITHIUM SYSTEM CAPABILITY TO REMOVE OXIDES/NITIDE FROM LITHIUM.

• THE PERMISSIBLE AMOUNT OF EACH CONTAMINANT IN THE COVER GAS WILL BE DETERMINED BY THE SYSTEM DESIGN AND THE QUANTITY OF GAS USED.

• AIR AND MOISTURE MUST BE REMOVED, BEFORE LITHIUM SYSTEM IS FILLED WITH LITHIUM. THIS OPERATION MUST BE REPEATED IF THERE IS A SIGNIFICANT INTERVAL OF TIME BETWEEN CLEANING AND FILLING OR IF THE SYSTEM IS TO BE REFILLED AND NO CLEANING IS REQUIRED.

COVER-GAS SUPPLY, PURIFICATION AND HANDLING

• A RELIABLE INERT-GAS SUPPLY AND A SUITABLY SIZED OFF-GAS HANDLING SYSTEM MUST BE PROVIDED

• IMPURITY LEVELS IN THE COVER-GAS (e.g. OXYGEN AND NITROGEN) SHALL ALWAYS BE CONTROLLED AND KEPT BELOW THOSE REPORTED IN THE TECHNICAL PRESCRIPTIONS.

• THE TRITIUM CONCENTRATION SHALL BE MONITORED AND SHIELDING AND WASTE HANDLING PROVISIONS MUST BE PROVIDED.

LOOPS PREHEATING AND HEAT INSULATION

• TO PERMIT CHARGING AND TO PREVENT SOLIDIFICATION OF LITHIUM IN THE PIPING AND COMPONENTS DURING CHARGING.

• TO ENSURE THE DUMPING FOR ALL OPERATING CONDITIONS INCLUDING ACCIDENTS

• DURING PREHEATING OPERATIONS COMPLETE HEATING TO PREVENT SOLIDIFICATION OF LITHIUM IN SMALL PIPING AND HEATING AT A CONTROLLED RATE TO AVOID THERMAL STRESSES IN COMPONENTS (e.g. PUMPS VALVES, etc.) MUST BE ASSURED.

LITHIUM STORAGE, MELTING AND FILLING

• LITHIUM STORAGE, MELTING AND FILLING IS A OPERATION FUNCTION; IT INDIRECTLY CONTRIBUTES TO THE FULFILMENT OF SAFETY REQUIREMENTS.

• DURING THE STORAGE, MELTING AND FILLING CARE MUST BE TAKEN TO ENSURE THAT THERE ARE NOT LITHIUM LEAKAGE TO AVOID DAMAGE OF COMPONENTS AND POTENTIAL INJURY TO OPERATING PERSONNEL AND ENVIRONMENT, AND TO PREVENT AIR IN-LEAKAGE INTO THE SYSTEM.

LEAK DETECTION

• TWO COMPLEMENTARY TYPES OF LITHIUM LEAK DETECTION MUST BE PROVIDED:
- ONE, ALLOWING THE DETECTION AND LOCATION OF LEAK BY ELECTRIC DEVICES (e.g. SPARK PLUGS TYPE LEAK DETECTORS)

- THE OTHER, ALLOWING LEAK DETECTION BY LITHIUM FUMES AND/OR AEROSOL (FLAME SPECTROPHOTOMETRY, IONIC DETECTORS).

• THE DETECTION DEVICES MUST BE PRECISE IN THE LOCATION OF LEAK, QUICK ENOUGH IN THE DETECTION AND RELIABLE.

INSTRUMENTATION AND CONTROL

• INSTRUMENTATION AND CONTROL SYSTEM MUST ALLOW ADEQUATE CONTROL AND MONITORING OF VARIABLES AND SYSTEMS OVER THEIR ANTICIPATED RANGES FOR OPERATING CONDITIONS.
APPROPRIATE MANUAL AND REMOTE CONTROLS SHALL BE PROVIDED TO MAINTAIN THESE VARIABLES AND SYSTEMS WITHIN PRESCRIBED OPERATING RANGES.

• DURING ACCIDENT CONDITIONS THE PARAMETERS MONITORED, SELECTED AND PRESENTED WITH UNAMBIGUOUS INFORMATION AT CONTROL ROOM MUST ALLOW THE OPERATING PERSONNEL TO:
- DIAGNOSE EVENTS THAT HAVE CAUSED OR CAN CAUSE THE INTEGRITY LOSS OF LITHIUM SYSTEM OR CONTAINMENT;
- VERIFY SYSTEMS OPERABILITY IN SUCH A WAY AS TO TAKE ADEQUATE DECISIONS AS REGARDS THEIR OPERATION;
- MAINTAIN THE RELEASE OF RADIOACTIVITY UNDER CONTROL AND ESTIMATE THE NECESSARY ACTIONS PROMPTLY.
MANUAL AND REMOTE CONTROLS THAT MAKE IT POSSIBLE TO BEGIN THE ACTIONS NECESSARY TO BRING THE LITHIUM SYSTEM TO A SAFE STATE SHALL BE PROVIDED.

- REDUNDANCY, INDEPENDENCE AND TESTABILITY OF INSTRUMENTATION AND CONTROL SYSTEM SHALL BE TAKEN INTO ACCOUNT IN THE DESIGN

CONTROL ROOM

• TO ALLOW TO OPERATING PERSONNEL TO REMOTELY CONTROL, MONITOR AND PERFORM OPERATIONS TO BRING AND TO MAINTAIN THE FACILITY IN A SAFE STATE AT ALL TIMES.

• IS IT NECESSARY FOR IFMIF FACILITY AN APPROPRIATE LOCATION OUTSIDE THE CONTROL ROOM SUFFICIENTLY ISOLATED AND INDEPENDENT WITH NECESSARY INSTRUMENTATION AND CONTROLS TO BRING TO AND MAINTAIN THE FACILITY IN A SAFE STATE?

• THE CONTROL ROOM DESIGN MUST BE BASED ON IDENTIFICATION OF BASIC FACILITY FUNCTIONS AND ON THEIR DISTRIBUTION IN AUTOMATIC AND MANUAL FUNCTIONS. THE DESIGN SHOULD BE ACCEPTABLE ON THE BASIS OF THE AVAILABLE TIMES AND OF THE RESULTS COMING FROM THE ANALYSIS OF MANUAL ACTION REQUIRED FOR THE POSTULATED EVENTS.

• THE CONTROL ROOM SHALL BE DESIGNED WITH ERGONOMIC GOALS CONCERNING, e.g., INSTRUMENTATION AND CONTROLS LAY-OUT, THEIR ACCESSIBILITY AND LIGHTING.

• PROVISIONS (e.g., CHROMATIC CODES, etc.) MUST BE PROVIDED TO MAKE THE OPERATING PERSONNEL'S OPERATIONS EASY AND TO MINIMISE THE PROBABILITY OF HUMAN ERROR.

• THE COMMUNICATION SYSTEM WITH THE INSIDE AND THE OUTSIDE OF THE FACILITY MUST BE PROVIDED.

• ENVIRONMENTAL CONDITIONS, SUCH AS ILLUMINATION, SOUND AND CLIMATE, MUST BE PROVIDED TO ASSURE PERSONNEL COMFORT.

• THE CONTROL ROOM SHOULD BE PROVIDED WITH ADEQUATE PROTECTION TO PERMIT OCCUPANCY AND ACCESS UNDER ACCIDENT CONDITIONS (e.g. LEAK, RUPTURE, FIRE), THAT IS WITHOUT DANGER OF INJURY OR EXPOSURE TO TOXIC OR/AND RADIOACTIVE MATERIAL.

ELECTRIC POWER SUPPLY AND DISTRIBUTION

• AN ONSITE AND OFFSITE ELECTRIC POWER SYSTEM SHALL BE PROVIDED

• EACH SYSTEM, ASSUMING THE OTHER SYSTEM IS NOT FUNCTIONING, MUST BE DESIGNED TO:
- ASSURE THAT SPECIFIED DESIGN CONDITIONS CONCERNING LITHIUM SYSTEM INTEGRITY ARE NOT EXCEEDED AS A RESULT OF ACCIDENTS OR OPERATING PERSONNEL'S ERRORS AND OTHER VITAL FUNCTION ARE MAINTAINED IN THE EVENT OF POSTULATED ACCIDENTS;
- BE AVAILABLE WITHIN A REASONABLE TIME.

• THE ONSITE ELECTRIC POWER SYSTEM SHALL HAVE SUFFICIENT INDEPENDENCE, REDUNDANCY AND TESTABILITY

• THE EQUIPMENT OF THE ONSITE ELECTRIC POWER SYSTEM SHALL BE:
- CAPABLE TO PERFORM ITS FUNCTION IN ALL THE RANGE OF THE SPECIFIED WORKING CONDITIONS.
- DESIGNED TO PERMIT APPROPRIATE PERIODIC INSPECTION AND TESTING OF PARTS OR COMPONENTS

• THE SYSTEM SHALL BE DESIGNED WITH A CAPABILITY TO TEST PERIODICALLY:
- THE OPERABILITY AND FUNCTIONAL PERFORMANCE OF THE COMPONENTS OF THE SYSTEM AND THEIR OPERABILITY,
- THE OPERABILITY OF THE SYSTEMS AS A WHOLE AND UNDER CONDITIONS AS CLOSE TO DESIGN AS POSSIBLE, THE FULL OPERATION SEQUENCE THAT BRINGS THE SYSTEM PARTS INTO OPERATION.

ROOMS VENTILATION AND ATMOSPHERE TREATMENT

• TO REDUCE, CONSISTENT WITH THE FUNCTIONING OF OTHER ASSOCIATED SYSTEMS, THE AMOUNT OF TOXIC AND RADIOACTIVE MATERIAL THAT COULD BE RELEASED INTO THE ENVIRONMENT,

• TO PREVENT EXPLOSIONS, THAT COULD DEGRADE CONTAINMENT INTEGRITY.

• THE CONTAINMENT ATMOSPHERE TREATMENT SYSTEM SHALL BE DESIGNED TO PERMIT PERIODIC INSPECTION OF IMPORTANT COMPONENTS AND PERIODIC PRESSURE AND FUNCTIONAL TESTING UNDER CONDITIONS AS CLOSE TO DESIGN

CONFINEMENT OF SOURCE TERM

• TO CONTROL AND TO MAINTAIN THE MATERIAL RELEASE INTO THE ENVIRONMENT LOWER THAN THE SPECIFIED ACCEPTABLE LIMITS FOR ANY OPERATING OR POSTULATED ACCIDENTS CONDITIONS.

• THE CONTAINMENT STRUCTURES, INCLUDING ACCESS OPENINGS AND PENETRATIONS, MUST BE DESIGNED SO THAT THEY CAN ACCOMMODATE WITH SUFFICIENT MARGIN THE CALCULATED PRESSURE AND TEMPERATURE CONDITIONS RESULTING FROM ANY ACCIDENTS, SPECIFIED BY SAFETY ANALYSIS.

• IN CASE OF LOSS OF ACTUATING POWER, AUTOMATIC ISOLATION VALVES SHALL TAKE THE POSITION THAT PROVIDES GREATER SAFETY.

• THE CONTAINMENT SYSTEM SHALL BE DESIGNED TO PERMIT PERIODIC FUNCTIONAL AND LEAKAGE VALVE TESTING.

• EACH LINE, WHICH PENETRATES THE CONTAINMENT AND CONNECTS DIRECTLY TO THE CONTAINMENT ATMOSPHERE, SHALL BE ABLE TO CLOSE AUTOMATICALLY AND RELIABLY IN ACCIDENT CONDITIONS, WHEN CONTAINMENT ISOLATION IS REQUIRED.
UNLESS THE ISOLATION CAPABILITY CAN BE DEMONSTRATED ON SOME OTHER BASIS, SUCH AS INSTRUMENT LINES, THIS LINE SHALL BE PROVIDED AT LEAST WITH TWO ISOLATION VALVES, ONE INSIDE AND ONE OUTSIDE THE CONTAINMENT. THESE VALVES, LOCATED AS CLOSE TO THE CONTAINMENT AS POSSIBLE, SHALL BE ACTUATED INDEPENDENTLY AND RELIABLY.
IF THE LINE PENETRATES THE CONTAINMENT AND IT IS NOT CONNECTED DIRECTLY TO THE INTERNAL ATMOSPHERE, IT SHALL BE PROVIDED WITH AT LEAST ONE ISOLATION VALVE, LOCATED OUTSIDE THE CONTAINMENT AS CLOSE AS POSSIBLE.

AREA EVENTS

EVENTS TAKEN INTO ACCOUNT:

- **LITHIUM WATER REACTIONS**
- **CONVENTIONAL FIRES**
- **LITHIUM FIRES**

-LITHIUM NITROGEN REACTION

-LITHIUM AIR REACTION

EVENTS EXCLUDED:

- INTERNAL MISSILES,

- DISCHARGING FLUIDS,

- PIPE WHIPPING,

LITHIUM WATER REACTIONS

• TO MINIMISE THE POSSIBILITY OF LITHIUM WATER REACTIONS.

CONVENTIONAL FIRES

• STRUCTURES AND COMPONENTS SHALL BE DESIGNED AND LOCATED IN ORDER TO:
- MINIMISE, CONSISTENTLY WITH OTHER SAFETY REQUIREMENTS, THE PROBABILITY OF FIRES AND EXPLOSIONS;
- LIMIT THEIR ADVERSE EFFECT SO THAT THE SYSTEM OPERABILITY IS NOT COMPROMISED;
- ENSURE THE SECURITY OF PERSONNEL AND MAINTAIN SAFETY FUNCTIONS;

• THE SAFETY SYSTEMS MUST BE PROTECTED AGAINST FIRE IN SUCH A WAY AS TO ALLOW THEM TO FULFIL THEIR FUNCTIONS.

• A SAFE ESCAPE ROUTE AND EXITS FOR PERSONNEL MUST BE PREPLANNED AND PROVIDED IN THE DESIGN TAKING INTO ACCOUNT ANY LOCATION WHERE FIRE IS POSSIBLE.

• IN THE DESIGN THE SIMULTANEOUS OR SUCCEEDING OCCURRENCE OF A FIRE WITH AN INTERNAL ACCIDENT OR EXTERNAL HAZARD SHALL BE CONSIDERED ON THE BASIS OF THE PROBABILITY OF THESE COMBINATIONS AND THEIR POTENTIAL CONSEQUENCES.

LITHIUM FIRES

• LITHIUM LEAKAGE AND FIRES SHALL BE DETECTED AND LOCATED WITH ADEQUATE RELIABILITY; THEIR EFFECTS ON STRUCTURES AND COMPONENTS ENSURING A SAFETY FUNCTION SHALL BE LIMITED TO A LEVEL APPROPRIATE TO THE POTENTIAL CONSEQUENCES OF THE FAULT AND ITS FREQUENCY.

• ARRANGEMENTS OF THE COMPONENTS SHALL BE MADE TO REDUCE TO AN ACCEPTABLE LEVEL THE RISK TO PERSONNEL WORKING IN PLACES THAT COULD BE AFFECTED BY LITHIUM FIRES AND COMBUSTION PRODUCTS.

•THE CONSEQUENCES OF RELEASE INTO THE ENVIRONMENT OF RADIOACTIVE AND TOXIC MATERIALS BY LITHIUM FIRES SHALL BE KEPT BELOW SPECIFIED LEVELS. ALSO THE RELEASE OF COMBUSTION PRODUCTS SHALL BE KEPT WITHIN APPROPRIATE LIMITS.

EXTERNAL EVENTS

EVENTS TAKEN INTO ACCOUNT:

- **EARTHQUAKES**
- **FLOODS**
- **ABNORMAL WINDS**

EVENTS TO EXCLUDE IF THE PROBABILITY OF THESE EVENTS IS VERY LOW:

- EXTERNAL MISSILES DUE TO EXPLOSIONS OUTSIDE THE SITE AND HAZARDOUS EFFECTS OF GASEOUS RELEASES OUTSIDE THE SITE RESULTING FROM ANY ACCIDENT IN MEANS OF TRANSPORTATION, PIPELINE OR INSTALLATION

- EXTERNAL MISSILES DUE TO EXPLOSIONS OR RUPTURE OF PRESSURISED COMPONENTS INSIDE THE SITE

EVENTS NEGLECTED:

- AIRCRAFT CRASH

- SABOTAGE

EARTHQUAKES

• THE SAFETY FUNCTIONS ARE MAINTAINED DURING AND AFTER AN EARTHQUAKE.

• THE DESIGN AND THE ANALYSIS OF THE RESPONSE OF COMPONENTS AND STRUCTURES SHALL BE PERFORMED IN ACCORDANCE WITH APPLICABLE CODES AND STANDARDS.

FLOODS

• TO PREVENT FLOODWATER THAT CAN CAUSE UNACCEPTABLE EFFECTS ON THE SAFETY OF THE SYSTEMS.

• THE MAXIMUM FLOOD LEVEL SHALL BE CHOSEN CONSISTENTLY WITH THE REQUIREMENTS OF THE APPLICABLE RULES AND STANDARDS OR DETERMINED WITH THE SAME CRITERIA AS FOR THE NUCLEAR POWER PLANTS CONSIDERING THE HEIGHT OF THE ASTRONOMICAL TIDES, RIVER FLOOD WATER, etc.;

ABNORMAL WINDS

THE BUILDINGS OF THE LITHIUM PLANT SHALL BE DESIGNED TO WITHSTAND THE EFFECTS OF ABNORMAL HIGH WIND LOADING.

DESIGN REQUIREMENTS

• STRUCTURES, PIPING AND COMPONENTS OF LITHIUM SYSTEM MUST COMPLY WITH THE REQUIREMENTS OF APPLICABLE AND RECOGNISED CODES AND STANDARDS.

• THE SYSTEM MUST BE DESIGNED IN ACCORDANCE WITH ADDITIONAL REQUIREMENTS SPECIFIED IN CODES AND STANDARDS APPLICABLE, THE RADIOACTIVITY BEING INVOLVED.

• STRUCTURES AND COMPONENTS OF LITHIUM PLANT MUST BE CLASSIFIED IN ACCORDANCE WITH IMPORTANCE OF THE SAFETY FUNCTION(S) TO BE PERFORMED.

STRUCTURAL, MECHANICAL, ELECTRICAL AND SEISMIC REQUIREMENTS MUST BE ASSOCIATED WITH EACH CLASS AND RELATED TO HOMOGENEOUS GROUPS OF PLANT PARTS.

THE CLASSIFICATION MUST TAKE INTO ACCOUNT THE CONSEQUENCES THAT STRUCTURES, SYSTEMS OR COMPONENTS FAILURE CAN CAUSE, THE FREQUENCY WITH WHICH THE SAFETY FUNCTIONS PERFORMED BY THEM ARE OR CAN BE REQUESTED AND THE OPERATING CONDITIONS

• A QUALITY ASSURANCE PROGRAMME MUST BE APPLIED IN ORDER TO PROVIDE ADEQUATE ASSURANCE THAT STRUCTURES AND COMPONENTS OF THE SYSTEMS PERFORM THEIR SAFETY FUNCTIONS SATISFACTORILY AND MINIMISE THE PROBABILITY AND SIZE OF ANY UNDETECTED DEFECTS IN ORDER TO EXCLUDE DEVELOPMENT OF UNSTABLE CRACK CONFIGURATIONS.

• THE DESIGN SHALL TAKE ACCOUNT OF COMBINATIONS OF THE EXTERNAL EVENTS WITH INTERNAL ACCIDENTS AND OPERATING CONDITIONS:

• STRUCTURES AND COMPONENTS MUST BE DESIGNED TO WORK IN ENVIRONMENTAL CONDITIONS ACCORDING TO NORMAL OPERATING CONDITIONS OF THE FACILITY AND TO PERFORM THEIR SAFETY FUNCTION IN ALL THE ACCIDENT CONDITIONS FOR WHICH THEIR OPERATION IS FORESEEN.

MATERIALS REQUIREMENTS

- THE INTERACTIONS OF MATERIALS WITH LITHIUM, LITHIUM REACTIVITY AND DEGRADATION OF MECHANICAL PROPERTIES DUE TO RADIATION MUST BE TAKEN INTO ACCOUNT IN THE DESIGN.

- MATERIALS SELECTED FOR THE SYSTEMS MUST BE COMPATIBLE WITH LITHIUM FOR ALL OPERATING CONDITIONS AND ENVIRONMENTAL CONDITIONS EXPECTED DURING THE FACILITY LIFE.

- THE MATERIAL MUST COMPLY WITH THE REQUIREMENTS OF APPLICABLE AND RECOGNISED CODES AND STANDARDS.

CONSTRUCTION AND TESTING REQUIREMENTS

- CURRENT ENGINEERING PROCEDURES AND PRACTICES APPLICABLE TO QUALITY CONTROL, FABRICATION, ASSEMBLY OF COMPONENTS PARTS, ERECTION, CLEANING, AND PRE-OPERATIONAL TESTING, INSPECTION AND MAINTENANCE OF LIQUID-METAL SYSTEMS MUST BE EMPLOYED.

- CONSTRUCTION AND TESTING SHOULD COMPLY WITH REQUIREMENTS OF APPLICABLE AND RECOGNISED CODES AND STANDARDS.

5.5 Lithium Jet Simulation

Presented by
Thanh Hua (ANL)
at the
IFMIF-CDA Technical Workshop
on Li-Target System
Tokai-mura, Japan
July 18-21, 1995

An IFMIF Target Simulation Study Has Been Selected as a PhD Dissertation Topic

- This presentation is being made on behalf of Karani Gulec, a PhD candidate in the Nuclear Engineering Department at the University of Tennessee
  - Committee members include: Art Ruggles
    John Haines
    Tom Shannon
    Paul Stevens
- Outline of PhD dissertation effort
  - Concentrating only on the hydraulic stability of the Li film target
    - No thermal effects
  - Perform linear stability analysis and compare with previous results (analysis and draft paper completed)
  - Define experimental apparatus and test conditions for Li jet simulation (nearly completed)
  - Construct experimental facility (complete by ~ Fall '95)
  - Perform experiments (~ during the next year)
  - Perform CFD analyses to compare with experimental results - TBD

There Are Three Nondimensional Numbers Which Define This Type of Flow

Reynolds No. = Re = ρ U δ / μ = inertia force / viscous force

Weber No. = ρ U^2 δ / γ = inertia force / surface tension

Modified Froude No. (based on centrifugal force)

= Fr_c = R / δ = inertia force / body force normal to flow direction

- For the Li target, the centrifugal force >> the gravitational force

  g_{cent} = U^2 / R ~ 1600 m/s² >> g

- Must select flow parameters (R, δ, U) to match these three numbers

A Water Flow Experiment Can Be Used to Simulate the Hydraulic Stability Conditions for the IFMIF Li-Target

- There are two hydrodynamic instability mechanisms for the Li-target case
  - Kelvin-Helmholtz Type -- Caused by interaction of inertia forces and surface tension (linear stability analysis for potential/inviscid flows)
  - Gortler Type -- Caused by interaction of the radial pressure gradient in the boundary layer and centrifugal forces
- By matching the Froude, Weber, and Reynolds numbers, water can simulate the stability features for the Li-target
- Air-shear and gravitational effects must be mitigated in the water simulation
  - Velocity matching at the water-air interface is planned
  - Lower velocities in water simulation lead to a concern about the relative importance of gravitational forces
  - Target orientation will be studied to determine the importance of gravitational effects

Linear Stability Analysis Results

- Centrifugal and gravitational forces are found to be second order effects
- Linear stability analysis establishes the balance between surface tension and inertia forces as the most important (first order) effect in stability

$$k \gtrless V_s R [(R \rho) / (R' T \delta)]^{1/2} \quad \text{required for stability}$$

k = wave number of perturbation
V_s = velocity at the boundary layer interface
R = radius of curvature for solid plate
δ = film thickness
R' = radius of curvature for free-surface ($R - \delta$)
T = surface tension
ρ = fluid density

Basis for Similarity Between Water Flow Simulation and Li-Target

- Ratio of boundary layer thickness to jet thickness is the same at angle θ for fixed Re, We, Fr_c

Kelvin-Helmholtz Instability -- For fixed values of Re, We, and Fr_c:

- Wave number depends only on the Froude number and Weber number
  $k = Fr_c \; We^{1/2}$
- Ratio of wavelength to jet thickness is the same
  $\lambda/\delta \propto We^{-1/2}$
- Ratio of wave velocity to velocity at free-surface is the same
  $v/U = We^{-1/8}$

Gortler Instability -- For fixed values of Re, We, and Fr_c:

- Gortler number at any value of θ is the same
  $Go(\theta) = \text{constant} \; (Re \; Fr_c \; \theta^3)^{1/2}$
  where θ is the angle traversed along the constant radius of curvature plate

Velocity and Length Scales for Li Target Simulation

Velocity Scale:

$$U' = (\gamma'/\gamma_{Li})\ (\mu_{Li}/\mu')\ U_{Li}$$

Length Scale:

$$L' = (\gamma_{Li}/\gamma')\ (\mu'/\mu_{Li})^2\ (\rho_{Li}/\rho')\ L_{Li}$$

Flow Parameters Required for Water Simulation at Various Temperatures

- Since some water properties vary greatly from 0 - 100°C, various scales are possible
- Reference Li flow conditions: T = 220°C, U = 17 m/s, R = 0.25 m, δ = 21 mm, Nozzle Width = 0.5 m

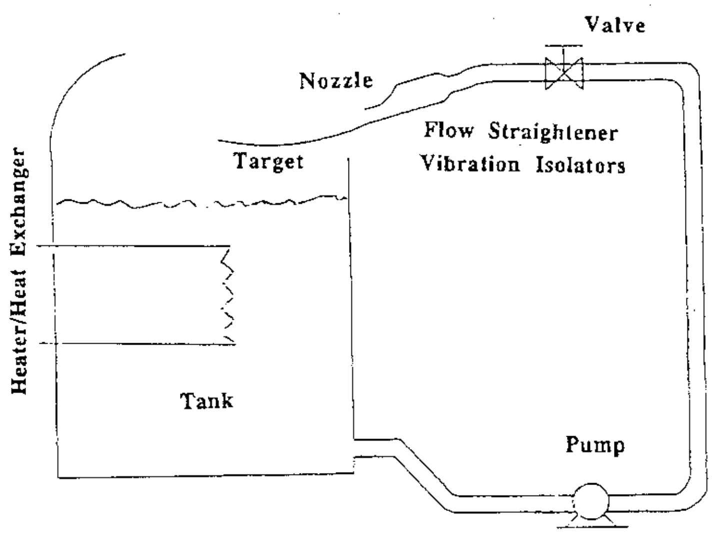
T_{water} (°C)	20	50	80
L_w/L_{Li}	9.2	2.96	1.37
U_w/U_{Li}	0.1	0.17	0.25
Vol Flow Rate (L/s)	1510	270	83
Pump Power (kW)	8.7	4.7	2.8

Conclusion: Water temperature of 80°C selected as the reference for simulations because of reasonable length scale and flow parameters

What Are the Differences Between This Work and Hassberger's FMIT Experiments?

- Analytically determined stability conditions are known
  - Tests over a range of parameters are needed to confirm or modify relationships
- Output from this study is different:
  - We seek a more fundamental understanding of flow stability, i.e. we plan to perform a systematic evaluation of stability, but will likely not have the final IFMIF target parameters (design is still evolving)
  - Hassburger's focus was on verification/validation of the FMIT design
- Also, we are going to develop a numerical model of this flow. The model is intended to be a flexible engineering tool for designing/evaluating the IFMIF target. The experimental data will be used to validate the model.

Experimental Setup



6. Data Base for Lithium and Its Compounds

6.1 Lithium Data Base: Status Report

by

S. Cevolani

Analysed Physical Properties of Liquid Lithium

1. Density
2. Dynamic Viscosity
3. Specific Heat
4. Thermal Expansion Coefficient
5. Thermal Conductivity
6. Vapour Pressure
7. Liquid Surface Tension
8. Electrical Resistivity
9. Velocity of sound

Main References

/1/ R. C. Weast, Editor
Handbook of Chemistry and Physiscs
CRC Press, 56th Edition (1975)

/2/ S. S. Kutateladze, V. M. Borishanskii, I. I. Novikov, O. S. Fedinskii
Liquid Metal Heat Transfer Media.
Chapman & Hall LTD, London (1959)

/3/ R. W. Ohse, Editor
Handbook of Thermodynamic and Transport Properties of Alkali Metals.
Blackwell Scientific Publications (1985)

/4/ T. Lyman, Editor
Metals Handbook, Vol. 1: *Properties and Selection of Metals.*
American Society for Metals, Metals Park-Novelity, Ohio, 8th Edition (1961)

/5/ C. A. Hampel, Editor
Rare Metals Handbook
2nd Edition, Reinhold Publishing Corporation, Chapman & Hall Ltd, London (1961)

/6/ J. G. Yevick, Editor
Fast Reactor Technology: Plant Design.
MIT Press, Cambridge (1966)

Status Report

1. Basing on the identified references, a complete set of relationships has been produced.

2. The data bases used by other participants to the CDA are to be collected.

3. From all the collected data a recommended data base will be produced.

6.2 Review of Lithium Physical and Thermal Properties

IFMIF Task CDA-T-VII:

Thanh Hua
Argonne National Laboratory

presented at

1st IFMIF-CDA Technical Workshop on
Li-Target System

Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

July 18-21, 1995

PURPOSES AND SCOPE OF WORK

- Provide Li physical and thermal properties data base for the ITER Material Handbook and IFMIF Task CDA-T-VII
- Data published through 1967 have been compiled by Cowles and Pasternak(1) (C&P). Data published through 1971 was compiled by Maroni, Cairns, and Cafasso(2) (M&C&C) and compared with work reviewed by C&P. Another review was published in 1978 by Jeppson, Ballif, Yuan, and Chow(3)
- This work included reviewing the various sources, particularly those cited in C&C&M 's compilation, checking for accuracy and converting the empirical equations into SI units

(1) USAEC Report, UCRL-50647 (1969)
(2) Argonne National Laboratory Report, ANL-8001 (1973)
(3) Handford Engineering Development Laboratory, HEDL-TME 78-15 (1978)

PROPERTIES REVIEWED

- Density
- Thermal conductivity
- Electrical resistivity
- Viscosity
- Vapor pressure
- Surface tension
- Specific heat
- Enthalpy

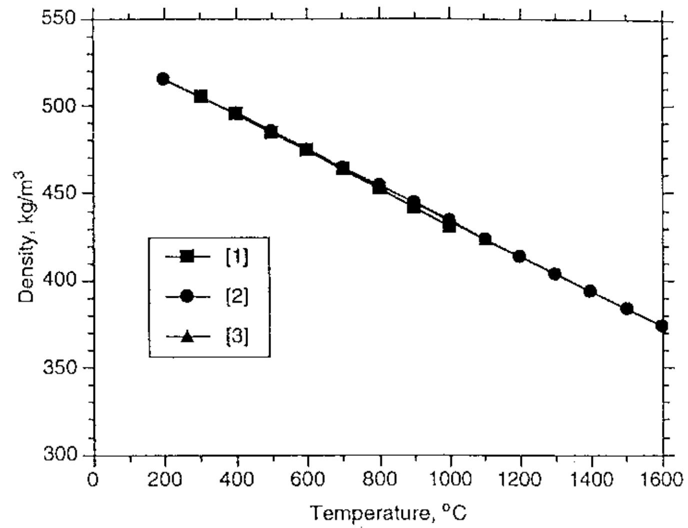
PROPERTIES OF LITHIUM

Feature	Value
Atomic number	3
Atomic weight	6.94 amu
Isotope	Li-6 Li-7
Melting point, °C	180.6
Boiling point, °C	1342
Heat of vaporization, cal/g	4680
Heat of fusion, cal/g	103.2
Volume change on melting	1.5%

SAFETY FEATURES

- Solid lithium at room temperature is not as dangerous as other alkali metals
- Liquid lithium is very reactive with air, water, concrete, carbon dioxide and nitrogen. Usually, these reactions go on until there is no lithium left
- In Li/water reaction, most of the hydrogen is bound to the liquid metal as LiH. The hydride is decomposed when temperature exceeds 1000°C
- Hydrogen liberation in air is of special concern because of the explosive mixture of the two gases

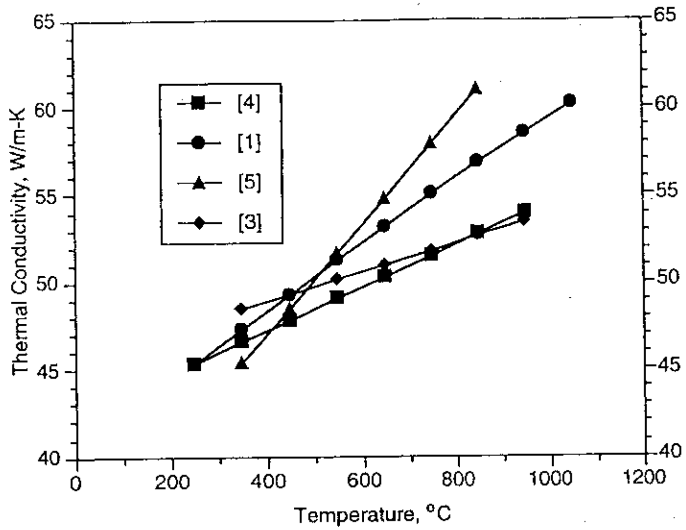
Density of Lithium vs. Temperature



t in °C:

$\rho = 508.2 - 0.10336\,(t-271.7) - 4.8279 \times 10^{-7}\,(t-271.7)^2 - 5.2853 \times 10^{-9}\,(t-271.7)^3$	300 - 1000 °C	[1]
$\rho = 515 - 0.101\,(t - 200)$	200 - 1600 °C	[2]
$\rho = 536.8 - 0.103\,t$	400 - 1125 °C	[3]

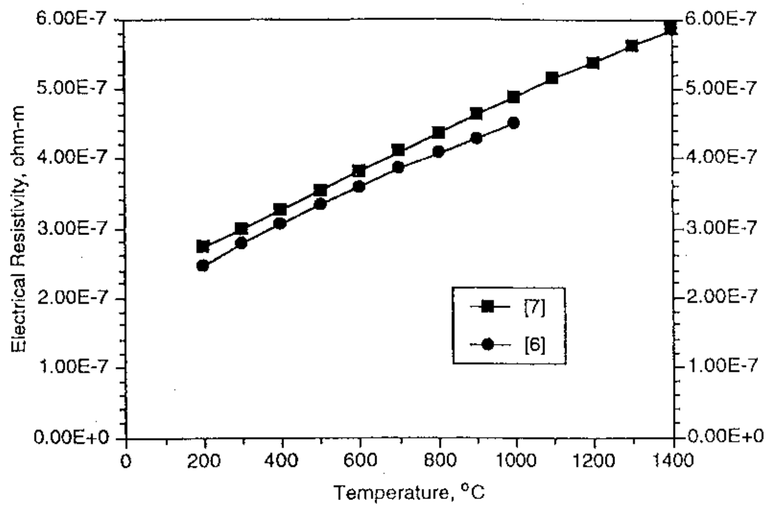
Thermal Conductivity of Li vs. Temperature



t in °C:

$k = 42.29 + 0.0123\,t$	250 – 950 °C	[4]
$k = 43.88 + 0.0209\,(t - 180.6) - 2.43 \times 10^{-6}\,(t - 180.6)^2$	300 – 1100 °C	[1]
$k = 34.50 + 0.0312\,t$	320 – 850 °C	[5]
$k = 45.6 + 8.29 \times 10^{-3}\,t$	300 – 900 °C	[3]

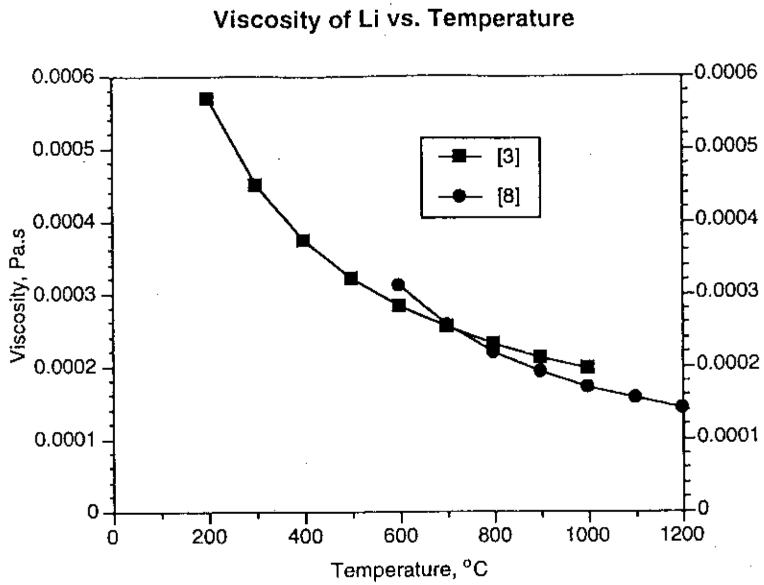
Electrical Resistivity of Li vs. Temperature



t in °C:

$\rho_e = 1.833 \times 10^{-7} + 3.34 \times 10^{-10}\,t - 6.80 \times 10^{-14}\,t^2$	200 – 1000 °C	[6]
$\rho_e = 2.193 \times 10^{-7} + 2.60 \times 10^{-10}\,t + 2.58 \times 10^{-14}\,t^2 - 1.82 \times 10^{-17}\,t^3$	200 – 1430 °C	[7]

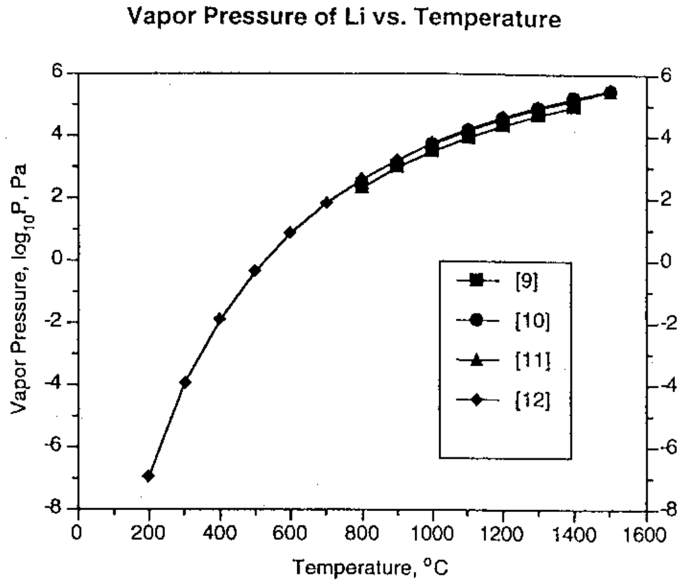
Viscosity of Li vs. Temperature



T in K:

$\log \eta = -1.5064 - 0.737 \log T + \frac{109.9}{T}$	200 – 1000 °C	[3]
$\log \eta = -4.338 + \frac{726.1}{T}$	600 – 1200 °C	[8]

Vapor Pressure of Li vs. Temperature

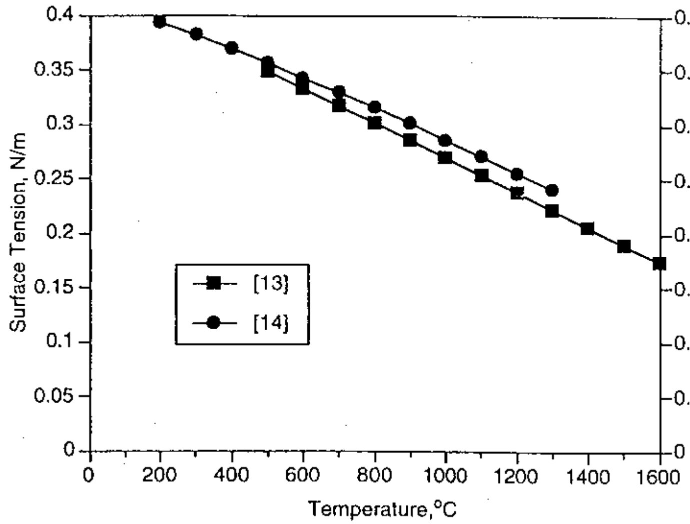


T in K:

$\log P = 12.404 - \frac{8283.1}{T} - 0.7081 \log T$	800 – 1400 °C	[9]
$\log P = 9.889 - \frac{7877.9}{T}$	1000 – 1500 °C	[10]
$\log P = 9.795 - \frac{7740}{T}$	1100 – 1700 °C	[11]

$\log P = 19.218 - \frac{8551.2}{T} - 3.80 \log T + 6.72 \times 10^{-3} T - 6.4 \times 10^{-6} T^2 + 2.684 \times 10^{-9} T^3$	0 – 181 °C (solid)	[12]
$\log P = 15.124 - \frac{8442.5}{T} - 1.640 \log T + 2.597 \times 10^{-4} T$	181 – 1077 °C (liquid)	[12]

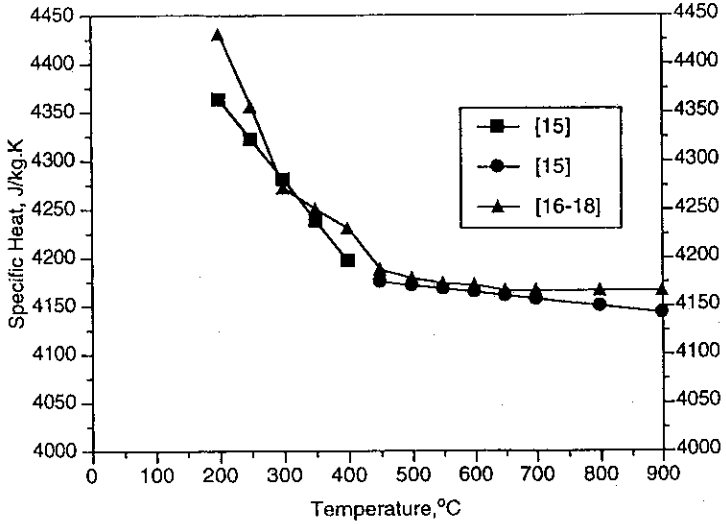
Surface Tension of Li vs. Temperature



T in K:

$\sigma_s = 1.6 \times 10^{-4} (3550 - T) - 9.5 \times 10^{-2}$	500 – 1600 °C	[13]
$\sigma_s = \frac{3.53 \times 10^6}{\rho^2} \exp - \frac{1815}{\rho}$	200 – 1300 °C; ρ is density in $\frac{kg}{m^3}$	[14]

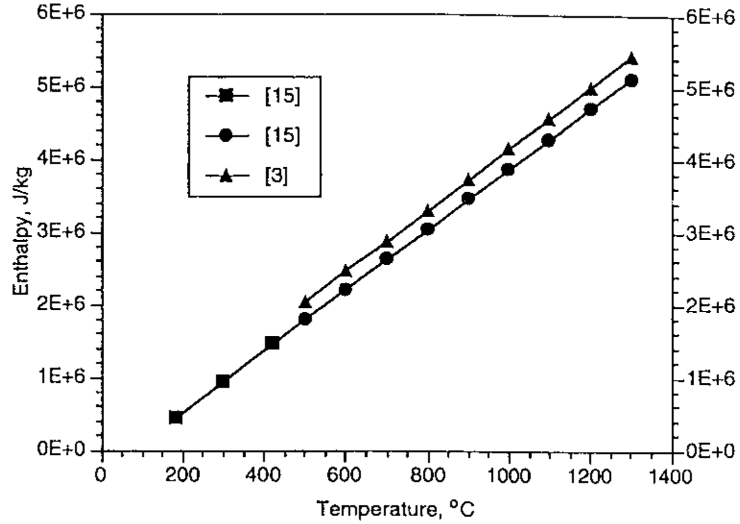
Specific Heat of Li vs. Temperature



t in °C:

$c_p = 4530.2 - 8.38 \times 10^{-1}\ t$	181 – 420 °C	[15]
$c_p = 4207.6 - 7.33 \times 10^{-2}\ t$	420 – 900 °C	[15]

Enthalpy of Li vs Temperature

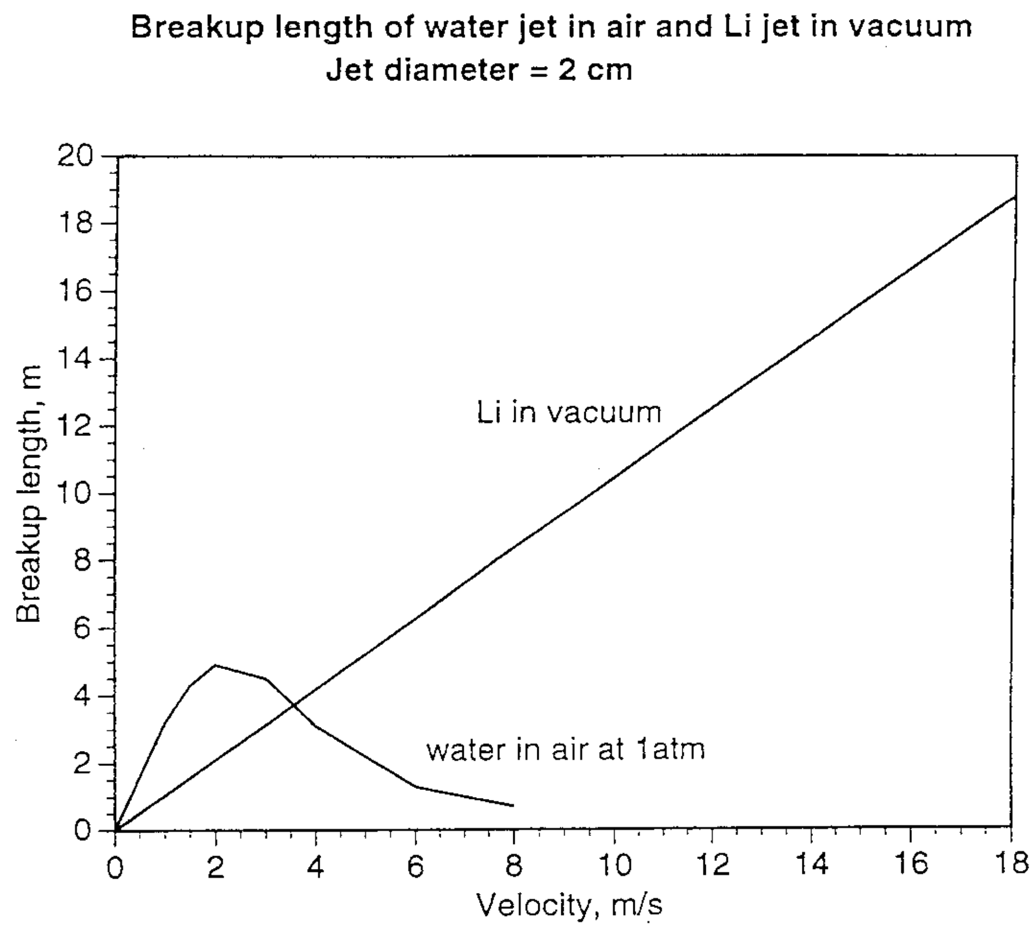


t in °C:

$H_T = -0.372 \times 10^6 + 4.53 \times 10^3\ t - 4.191 \times 10^{-1}\ t^2$	181 – 420 °C	[15]
$H_T = -0.304 \times 10^6 + 4.21 \times 10^3\ t - 3.615 \times 10^{-2}\ t^2$	420 – 900 °C	[15]
$H_T = -2.125 \times 10^4 + 4.19 \times 10^3\ t - \frac{2.166 \times 10^7}{t}$	500 – 1300 °C	[3]

REFERENCES:

1. I. I. Novikov, V. A. Gruzdev, O. A. Kraev, A. A. Odintsov, and V. V. Roshchupkin, *High Temperature,* 7, 65 (1969).
2. E. I. Gol'tsova, *High Temperature,* 4, 348 (1966).
3. E. E. Shpil'rain, Yu. A. Soldatenko, K. A. Yakimovich, V. A. Fomin, V. A. Savchenko, A. M. Belova, D. N. Kagan, and I. F. Dvaniova, *High Temperature,* 3, 870 (1965).
4. E. E. Shpil'rain and I. F. Krainova, *High Temperature,* 8, 1036 (1970).
5. J. W. Cooke, *J. Chem. Phys,* 40, 1902 (1964).
6. E. E. Shpil'rain and V. A. Savchenko, *High Temperature,* 6, 247 (1968).
7. D. V. Rigney, S. M. Kapelner, and R. E. Cleary, "The Electrical Resistivity of Lithium and Columbium–1 Zirconium Alloy to 1430 °C," CANEL Report TIM–854 (September 1965).
8. D. V. Rigney, S. M. Kapelner, and R. E. Cleary, "The Viscosity of Lithium," CANEL Report TIM–849 (July 1965).
9. V. M. Anisimov and L. D. Volyak, *High Temperature,* 7, 340 (1969).
10. D. V. Rigney, S. M. Kapelner, and R. E. Cleary, "The Vapor Pressure of Lithium Between 1307 and 1806 °K," CANEL Report TIM–844 (September 1965).
11. J. Bohdansky and H. E. J. Schins, *J. Phys. Chem.,* 71, 215 (1967).
12. An. N. Nesmeyanov, "Vapor Pressure of the Elements," translated from Russian and edited by J. I. Carasso, Academic Press, New York (1961).
13. J. Bohdansky and H. E. J. Schins, *J. Inorg. Nucl. Chem.,* 29, 2173 (1967).
14. L. D. Volyak and Yu. P. Os'minin, *Russ. J. Phys. Chem.,* 42, 524 (1968).
15. Quoted in "Blanket Comparison and Selection Study – Final Report" by D. L. Smith et al., Argonne National Laboratory Report ANL/FPP–84–1 (1984).
16. Atomic Energy Commisison, Dept. of Navy, Washington DC,"Liquid Meats Handbook," 2nd Edition, (1952).
17. P.E. Landolt and M. Sttig, "Lithium," Rare Metals Handbook, 2nd Edition, pp. 239-252 (1961).
18. T.B. Douglas, L.F. Epstein, J.L. Dever and W.H. Howland, "Lithium Heat Content from 0° to 900°, Triple Point and Heat of Fusion and Thermodynamic Properties of the Solid and *Liquid,*" *J. Am. Chem. Soc.,* 77, 2144 (1965)


Breakup length of water jet in air and Li jet in vacuum
Jet diameter = 2 cm
Breakup length, m
20
18
16
14
12
10
8
6
4
2
0
Li in vacuum
water in air at 1atm
0
2
4
6
8
10
12
14
16
18
Velocity, m/s

Ⅳ. Concluding Session

1. Improvement of the Work Breakdown Structure

H. Katsuta,Y.Kato
IFMIF Target System Group of JAERI

Confirmation and Discussion Items

1. Summary of the Task Description

2. Work Breakdown Structure

(1)Major technical issues and ploblems

(2)Critical path and prioritization

3. Technical Interface Items

4. Task Sharing

5. Home Tasks for the Design Integration Meeting

Li target

Initial work - packages
As agreed at KfK workshop

CDA-T-I-1	Preliminary analysis and concept design for Li target assembly
CDA-T-I-2	Evaluation and specification of target-beam-test cell interfaces
CDA-T-II-1	Preliminary conceptual design for Li loop system lay-out
CDA-T-II-2	Li loop component design: evaluation and specification of component design and performance
CDA-T-II-3	Li chemistry process system: define requirements and develop preliminary design
CDA-T-IV	Remote handling system (no effort during initial phase)
CDA-T-V	Preliminary safety analysis/evaluation
CDA-T-VI	Design of experimental facilities: preliminary evaluation of experimental facilities
CDA-T-VI	Review and evaluate existing data base on Li properties

IFMIF-CDA : Tasks of Lithium Target System*

	I-1	I-2	II-1	II-2	II-3	V	VI	VII	Other Items (Update)
E U	●	●				●	●	●	
U S	●	●	●	●	●			○	US-1 US-2
J P	●	●	●	●	●	○	●		JP-1 JP-2 JP-3

* Specified as Work Package in the IFMIF-CDA Workshop at Karlsruhe, Sept. 1994

JP : ○ : Tritium safety, JP-1 : Water Experiment, JP-2 : Basic Li purification experiment, JP-3 : Detailed WBS
US : ○ : Review of existing data base, US-1 & 2 : Neutronics analyses of the Li target and target system

→ Please confirm / update the dots ○ , and if necessary add the other items like JP column and its footnotes.

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-I-1
Task Title: Preliminary analysis and concept design for Li target assembly

	Task Responsible	Items of the Task Description
E U	ENEA/ S. Cevolani	a. Review of existing designs b. Setup of the computer model c. Thermal-hydraulic calculations d. Critical analyses d1 Critical analysis of the thermal hydraulic behavior of the Lithium jet d2 An assessment on the feasibility of a Li-target which fulfil the IFMIF requirement d3 Identification of critical issues
J P	JAERI/ Y. Kato	a. Evaluations of the deuteron stopping power with temp. dependence b. Analysis of the thermal and fluid dynamics and the optimized structure design of the target assembly c. Experimental analysis of the jet stability by water test loop d. Evaluation of the backwall swelling by neutron irradiation
U S	ANL/ Dale Smith	A. Dynamic stability of Lithium jet(T-I-1.1) Analysis of the effect of several conditions on the jet stability (no beam) B. Thermal hydraulic analysis of lithium jet with incident beam(T-I-1.2) Analysis of the flow stability, nucleate boiling, Li evaporation etc. C. Conceptual design of Lithium target assembly(T-I-1.3) Optimal design of straightener, nozzle and backwall configuration

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-I-2
Task Title: Evaluation and specification of target-beam-test cell interface

	Task Responsible	Items of the Task Description
E U	FZK/ W. Cherdoron	Investigation of the Li evaporation rate 1st stage: design under the normal atmospheric pressure 2nd stage: design under the target operating conditions
J P	JAERI/ Y. Kato	a. Experimental evaluation of the Li vaporization rate b. Estimation of 14C and 41Ar production rate in the test cell space
U S	ANL/ Dale Smith	a. Evaluation of the total vaporization rate integrated over the jet free surface b. Extent of the Li vapor interaction with the incoming deuteron beam c. Neutronics analysis of the Li target (T-I-2..2) d. Neutronics analysys of target system (T-I-2.3)

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-II-1
Task Title: Preliminary conceptual design for Li loop system lay-out

	Task Responsible	Items of the Task Description
E U		
J P	JAERI/ Y. Kato	Following system layout:: a. Li main loop with chemistry process(impurity control) system b. Secondary and ternary cooling systems c. Radiation shielding of the Li loop system Adequate work sharing with the parties is beneficial
U S	ANL/ Dale Smith	a. Scaling up and improving the Lithium system and its components of FMIT-ELS for IFMIF reference design b. Remote handling considerations will be included c. Scale drawing will be generated The parties will cooperate both to minimize duplication of effort if it is better

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-II-2
Task Title: Li loop component design

	Task Responsible	Items of the Task Description
E U		
J P	JAERI/ Y. Kato	Conceptual design of the : 1. Main EM pump 2. Heat Exchanger 3. Quench tank and Drain tank 4. Components of the Li purification system
U S	ANL/ Dale Smith	a. Design of the EM pump rated at 100 l/s flow rate based on the EM pump developed in the FMIT-ELS(Annular Linear Induction type) Some trade studies in design will be performed R &D requirements will also be identified b. Other components design with smaller effort than EMP

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-VII
Task Title: Review and evaluate existing data base on Li properties

	Task Responsible	Items of the Task Description
E U	ENEA/ S. Cevolani	a. Agreement with FZK on task sharing out b. Data collection c. Data elaboration d. List of recommended data and correlations
J P	JAERI/ Y. Kato	a. Compile the existing data b. Measurements of Li vaporization rate and specific heat
U S	ANL/ Dale Smith	a. Compile, review and evaluate the following properties of lithium as a function of temperature: density, enthalpy, vapor pressure, surface tension, viscosity, thermal conductivity, electrical resistivity and specific heat b. Empirical equations for the properties as a function of temperature will be adopted

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-II-3
Task Title: Li chemistry process system: define requirements and develop preliminary design

	Task Responsible	Items of the Task Description
E U		
J P	JAERI/ S. Konishi	a. Design : Evaluation of lithium chemistry data base Cold Traps, Hot Traps, Impurity measurement and Hydrogen isotope separation b. Experiments : Cold trap stand alone test Impurity sensor stand alone test Tests with a liquid lithium forced convection loop
U S	ANL/ Dale Smith	a. Design and specification of instrumentation and equipment to characterize impurities in the lithium Advances in on-line instrumentation for measurement of impurities developed since FMIT will be evaluated b. Design and specification of impurity removal system(hot and cold traps, filters) R & D requirements will be identified

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

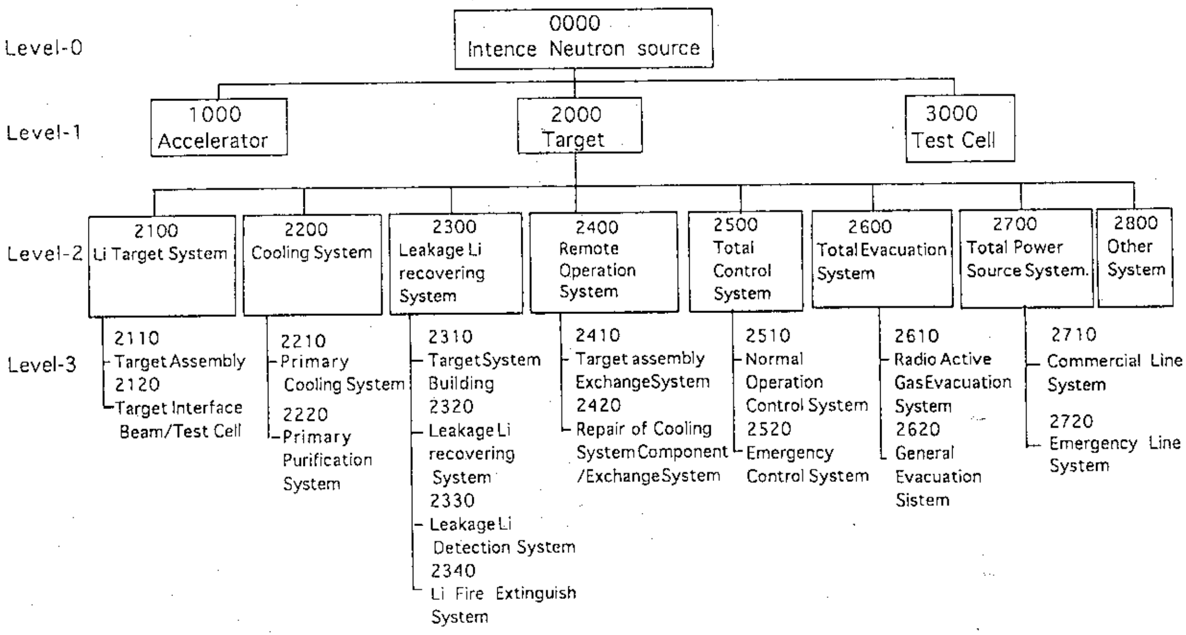
Task No.: CDA-T-V
Task Title: Preliminary safety analysis/ evaluation

	Task Responsible	Items of the Task Description
E U	ENEA/ G. Benamati	On the bases of the evaluation of safety analysis criteria(most critical accidents, their probability and consequences), following will be identified: a. High-risk accidents(in respect to the frequency and/or consequences) b. Possible solutions(in term of design, structural materials and technology) in order to prevent and/or protect against the occurrence of high-risk accidents
J P	JAERI/ S. Konishi	Following estimations will be made: a. Chemical hazard : Lithium fire loss of vacuum of the target chamber malfunction of chemical system Beryllium b. Radiological hazard : Beryllium, Tritium Other activated materials
U S		

Summary of the IFMIF-CDA Task Description
--Lithium Target System--

Task No.: CDA-T-VI
Task Title: Design of Experimental facilities : Preliminary evaluation of experimental facilities

	Task Responsible	Items of the Task Description
E U	FZK/ W. Cherdron	a. Summary of the existing knowledge b. Design and layout of the water test loop c. Design and layout of the Li test loop d. Elaboration of test matrix for experiments Typical R & D issues to be investigated by these facilities are: 1. Surface stability of the Li film 2. Backwall shape / nozzle shape 3. Pump design 4. Leak detection system 5. Li evaporation(together with I-2 and VII)
J P	JAERI/ Y. Kato	a. Design of the Li technology test loop for : 1. Test the target Li jet stability 2. Feasibility test of main components b. Design of the beam-on target test loop for : 1. Analyses the boiling and stability phenomena in the Li jet flow 2. Analyses the Li vaporization and spattering rate at target area
U S		



Position Structure (from Level 0 to Level 3)

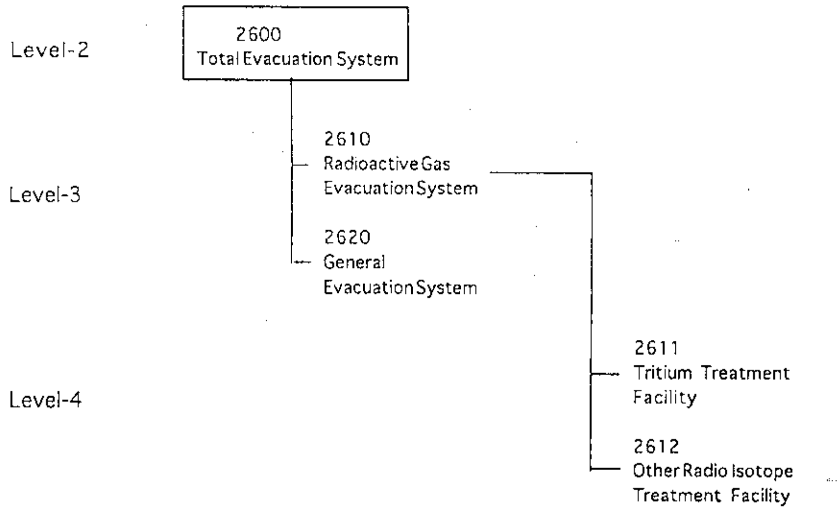
Level-2 / Level-3 / Level-4

- 2100 Li Target System (Level-2)
  - 2110 Target Assembly (Level-3)
    - 2111 Structure of Li Flow Rectifier (Level-4)
    - 2112 Structure of Nozzle
    - 2113 Backwall
    - 2114 Down Stream Guide
    - 2115 Measuring System
    - 2116 Interface of Target/Li System
  - 2120 Target Interface Beam/Test Cell
    - 2121 Interface Structure of Beam/Target
    - 2122 Evacuation System
    - 2123 Emergency Shutdown system
    - 2124 Interface Structure of Test Cell/Target

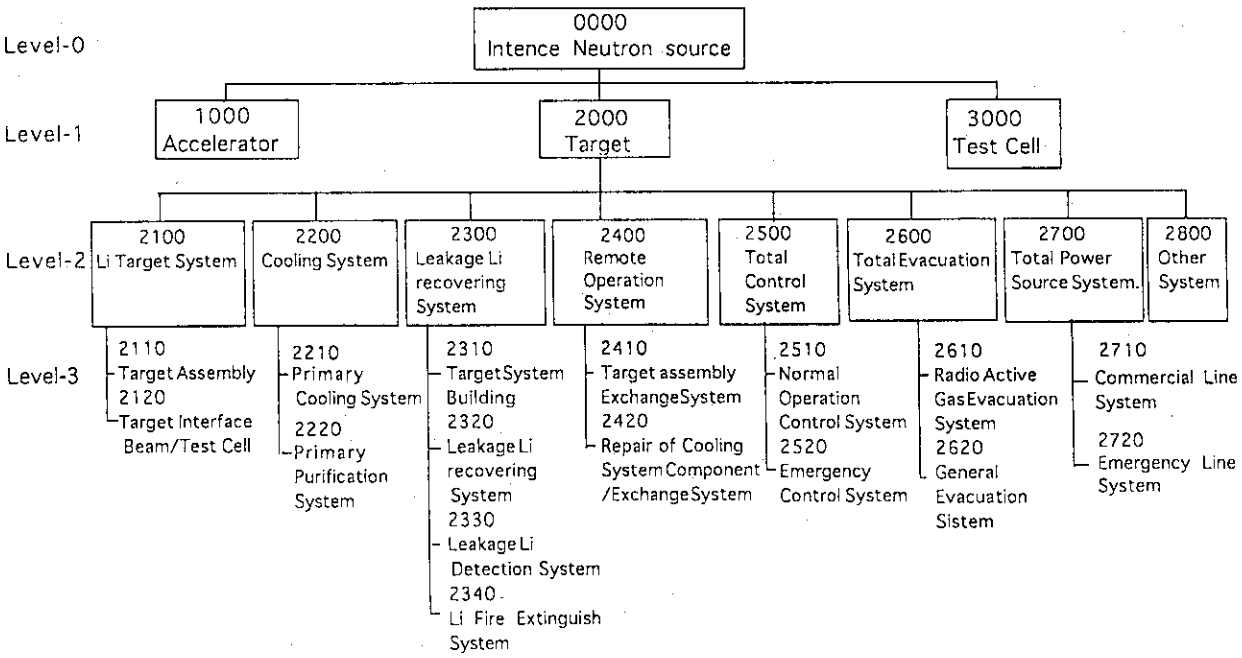
Position Structure (Partial-1)

- 2200 Cooling System (Level-2)
  - 2210 Primary Cooling System (Level-3)
    - 2211 EMP (Level-4)
    - 2212 Heat Exchanger
    - 2213 Valve
    - 2214 Piping
    - 2215 Quench Tank
    - 2216 Dump tank
    - 2217 Control System
    - 2218 Measuring Devices
    - 2219 Radiation Shielding
    - 2220 Gas System
  - 2220 Primary Purification System
    - 2221 Cold Trap
    - 2222 Hot Trap(1)
    - 2223 Hot Trap(2)
    - 2224 Surge Tank
    - 2225 Cooling Gas System
    - 2226 EMP
    - 2227 Piping
    - 2228 Valve
    - 2229 Impurity Monitoring System
    - 2230 Control System
    - 2231 Measuring Devices
    - 2232 Radiation Shielding
  - 2230 2ry Cooling System
  - 2240 Water Cooling System

Position Structure (Partial-2)



Position Structure (Partial-3)



Position Structure (from Level 0 to Level 3)

Main Work Items (Conceptual Design, R & D)

Position / Work	2110 (2111- 2116)	2120 (2121-2124)
Conceptual Design	(1) Stability of Li jet (flow velosity, shape, cause of instability, error estimation, upper and down flow system) (2) Analysis of boiling margin in Li jet (cause of uncertainty-gas containment rate, growth of void etc.-and error estimation) (3) Behavior of Li mist (4) Selection of backwall material and damage estimation (erosion/corrosion, swelling) (5) Estimation of reaction products	(1) Conseptual interface structure (with HEBT & test cell) (2) Estimation of Reaction products (ref. 2110(5)) (3) Estimation of the concept of emergency shutdown (4) Selection of vacuum pump (logic of repair and/or exchange) (5) Li vapor trapping device of low pressure drop
R & D CDA-EDA	(1) Jet stability test by water for reference IFMIF-Target size (2) Beam-on target test by Li loop for boiling and spattering analysis (3) Estimation of backwall life time (4) Li evaporation & deposition behavior	(1) Estimation of vacuum pump feasibility for metal vapor (2) Li vapor trapping device of low pressure drop
Correspond. IFMIF-Task	CDA-T-I-1	CDA-T-I-2

Main Work Items (Conceptual Design, R & D)

Position / Work	2210 (2211- 2220)	2220 (2221-2232)
Conceptual Design	(1) Selection of cooling system concept (Number of loop, flow rate, structural material, necessity of 2ry system) (2) Lithium data base (3) System design (4) Design conditions of components (5) Conceptual design of components (feature, size, structure, weight etc.) (6) Layout of components (concept)	(1) Evaluation of impurity production rate Acceptable level of impurities (2) Selection of cold trap outlet temp. (3) System design (4) Component design (5) Conceptual design of main components (feature, size, structure, weight etc.) Layout of components (6) (concept)
R & D CDA-EDA	(1) Certification test of Li components by Li-Technology test loop(2MW-8MW)	(1) Evaluation of features of C/T & H/T by Li loop (2) Test of impurity monitering system by Li loop
Correspond. IFMIF-Task	CDA-T-II-1, CDA-T-II-2, CDA-T-VI	CDA-T-II-2, CDA-T-II-3, CDA-T-VI

Main Work Items (Conceptual Design, R & D)

Position / Work	2300 (2320- 2330)	2600 (2611)
Conceptual Design	(1) Li detection system for Large , medium, small scale leakage and loop shutdown sequence (detector, leakage Li drain concept etc. are included) (2) preliminary safety analysis	(1) Preliminary estimation of tritium management facility (survey for safety criteria of release, release rate are included)
R & D CDA-EDA	(1) Development of Li detection system for Large , medium, small scale leakage and detectors (2) Li fire test and evaluation code for larger than medium scale leakage	
Correspond. IFMIF-Task	CDA-T-V	CDA-T-V,

IFMIF-CDA : Tasks of Lithium Target System*

	I-1	I-2	II-1	II-2	II-3	V	VI	VII	Other Items (Update)
E U	●	●				●	●	●	
U S	●	●	●	●	●			○	US-1 US-2
J P	●	●	●	●	●	○	●		JP-1 JP-2 JP-3

* Specified as Work Package in the IFMIF-CDA Workshop at Karlsruhe, Sept. 1994

JP : ○ : Tritium safety, JP-1 : Water Experiment, JP-2 : Basic Li purification experiment, JP-3 : Detailed WBS
US : ○ : Review of existing data base, US-1 & 2 : Neutronics analyses of the Li target and target system

→ Please confirm / update the dots ○ , and if necessary add the other items like JP column and its footnotes.

V. Workshop Summary

IFMIF-CDA Technical Workshop on Lithium Target System
JAERI Tokai, July 18 - 21, 1995

Summary

The Conceptual Design Activity (CDA) study on an International Fusion Materials Irradiation Facility (IFMIF) has been launched under the auspices of the IEA. The structure of working groups and relevant tasks have been defined and agreed in an IEA-workshop that was held September 26 - 29 1994 at FZK, Karlsruhe. For the Lithium-target System following seven tasks were identified:

CDA-T-I-1: Preliminary analysis and concept design for Li-target assembly,
CDA-T-I-2: Evaluation and specification of target-beam-test cell interfaces,
CDA-T-II-1: Preliminary conceptual design for Li-loop system lay-out,
CDA-T-II-2: Li-loop component design: evaluation and specification of component design and performance
CDA-T-II-3: Li-chemistry process system: define requirements and develop preliminary design
CDA-T-IV: Remote handling system (no effort during initial phase)
CDA-T-V: Preliminary safety analysis/evaluation
CDA-T-VI: Design of experimental facilities: Preliminary evaluation of experimental facilities
CDA-T-VII: Review and evaluate existing data base on Li properties.

In order to discuss on the results recently achieved and to coordinate necessary activities for an effective design integration, a technical workshop on the Lithium-target System was initiated. This workshop was on July 18-21 1995 at JAERI Tokai Japan and attended by 25 representatives from the research fields of lithium technology, mechanical engineering and fusion materials in the United States of America, the European Union and Japan.

The presentations and discussions made during this workshop were concentrated to extractions from FMIT/ESNIT experiences to IFMIF parameters. Concepts of free lithium jet (no backwall) and replaceable backwall for the IFMIF lithium target were presented. A water loop simulation test for the IFMIF lithium target design was proposed. For the safety analyses of the chemical hazard and radiological hazard, the concept of Failure Mode and Effects Analysis on IFMIF was presented.

The reference design concepts and major design parameters were considered. For the Design Integration workshop (in October at ORNL), design parameters, especially those for Target Assembly (Li-jet, velocity, inlet temperature; nozzle; interfaces), Li-loop System (1 or 2 loops), and Safety and

Support System were requested to be prepared. Dr. H. Maekawa was nominated to provide a first draft of these parameters and to distribute them for comments.

The followings were requested as the interface issues:

* Heat loading to the backplate and structure of the test assembly have to be defined by the test cell system group.
* Atmosphere in the test cell, particularly the option for maintaining a vacuum to minimize the impact of backplate rupture on the accelerator, will also be defined jointly with the test cell group and safety people.
* Specifications of the interface between HEBT and the lithium target including vacuum grade in the HEBT have to be defined by the accelerator system group.
* Access directions have to be discussed among the test cell and Li target groups for the maintenance and exchange of the target assembly and test samples.

CDA-T-I-1 (Preliminary analysis and conceptual design for target assembly)

Three Li-target design options were presented in **"Conceptual Design for Lithium Target Assembly" (US)**. The objectives were to develop an improved target design for IFMIF, specifically to

a) simplify/optimize maintenance,
b) enhance target lifetime,
c) improve reliability,
d) improve safety features, and
e) identify/prioritize major technical issues.

The three target design options evaluated were:

A) FMIT-type, Option A
(requires frequent replacement of entire target assembly),
B) Option B (replacement of backwall only),
C) Option C (free jet, no backwall replacement).

Option B and C appear to offer major advantages in terms of maintenance, lifetime, facility availability and cost. At the moment the reference target design was derived from extrapolation of the FMIT design. Further efforts were requested for the free jet type target design. It was agreed to conduct an independent assessment of the free jet concept as a possible alternative. Additional development work is also needed and requested for Option B.

The dynamic and thermodynamic stability of free jet was analyzed in **"Dynamic and thermodynamic stability of Li jet" (US)** The results were favorable (stable free jet and no nucleation) under IFMIF conditions mainly because of the larger beam spot (order of magnitude lower beam power deposition density) than that in FMIT. However, hydraulic stability testing is needed to confirm the analysis. Testing in low pressure environment (vacuum if possible) is important because the jet is significantly more stable in vacuum than in air due to the absence of aerodynamic interaction. For the same reason of lower beam power deposition density, jet velocity as low as 10 m/s may be sufficient provided the lithium evaporation rate from the surface is acceptable.

The thermal hydraulic code calculation (HIJET) and some analytical results at the IFMIF beam-on target conditions were introduced in **"Thermal hydraulic analysis of lithium jet with incident beam" (US)**. Velocity perturbations resulting from jet thermal expansion and beam deposited momentum were evaluated by this code and the results were shown to be small for targets with or without a backplate.

Present status on the analysis of target jet in JAERI/JAPAN was introduced in **"[1] Overview and relation with another task" (JA)**, and the results of thermal hydraulic analyses for reference IFMIF conditions were shown in **"[2] Thermal and Fluid dynamics of Li target flow" (JA)**. The maximum deuteron beam (35 MeV) current could be increased to 320 mA at least from the critical boiling margin near surface region when jet velocity is 20 m/s. If we consider the conditions of bubble growth in the jet and also the effect of lithium super heat , the maximum current may further be increased. The fluid analysis for double reducer/nozzle system were also shown in this presentation. This symmetric reducer could improve the surface jet stability and surface jet velocity. The results will be confirmed by JAERI water experiment.

Recent activity on this task in E.U. was presented in **"Thermal-hydraulic analysis of the lithium jet" (EU)**. Most of the analytical results for the reference IFMIF target conditions were consistent with that of JA. and U.S.

In **"Neutronic analysis and conceptual design for target assembly"** (US), preliminary neutronic analyses have been conducted in the following areas:

a) Impurity production in the lithium jet
b) Nuclear responses of target system
c) Interface with Target/Test Cell assembly
d) Effect of back plate curvature on Test volume

Typical conclusions were :

1) Tritium generation rate in jet is 15g/fpy
2) Be-7 production rate is $\sim$ 0.003 atms/d^+ion.
3) He production rate in Li is $\sim$ 0.09 atms/d^+ion.
4) Back plate damage rate is $\sim$70 dpa/fpy for 40MeV d^+ion.

More detailed analyses are needed for final design configuration.

It was pointed out in **"Some comments for backwall swelling" (JA)** that backwall would have limited life in the normal operation and would require periodic remote replacement. Backwall rupture or structural damage at off-normal events should also be considered. For the IFMIF conditions, 3 candidate backwall materials , Austenitic steel, Ferritic steel and Vanadium alloy were estimated with the properties of a) uniform elongation, b) yield strength, c) swelling (expected) and d) DBTT. Swelling will be small (< 1%) for the above candidates but possible rapid loss of ductility is an issue for austenitic steel and DBTT is a concern for the ferritic steel.

Boiling margin was evaluated in **"Target assembly design : some parametric evaluations" (EU)** for the parameters of beam energy distribution, jet/beam width, back plate curvature, chamber pressure and lithium velocity. The following typical result are reconfirmed :

a) Boiling margin at free surface region is the most critical issue and controlled by kinetics of evaporation.
b) The boiling margin is dependent mainly on chamber pressure and is not significantly affected by jet curvature.
c) Large internal boiling margin is calculated for IFMIF conditions.

The plan which is now going on to make the simulation test of IFMIF reference target was reported in **"Proposal for JAERI water loop test and target design" (JA)**. A well-defined stable lithium jet is essential for IFMIF, however there is a lack of detailed description (experimental conditions and results) for lithium target. JAERI now plans to perform water loop simulation tests being this fall, 1995. The main purposes are as follows:

a) Observe structure and stability of water jet along curved backwall of IFMIF reference design.
b) Partially confirm FMIT results.
c) Prepare the data base necessary for lithium loop tests.
d) Target design based on analysis and simulation parameters .

Some test parameters for IFMIF lithium loop system operation will be estimated in this 0experiments:
(Start-up/Shutdown, steady operation and optimum instrument setup).

Double reducer and diffuser proposed in this report are the new options of target assembly which will be expected to improve the surface jet stability /surface velocity and static pressure recovery of jet downflow.

CDA-T-I-2 (Evaluation and specification of target-beam-test cell)

A parametric analysis of the lithium evaporation from the jet free surface based on the reference design parameters was presented in **"Lithium vaporization from free surface" (US)**,. Such calculations showed that the surface evaporation was relatively small for the mentioned operating conditions. Also, it concluded that higher beam energies, lower beam current-densities and higher jet velocities reduce Li vaporization rate. Further analysis is needed for the evaluation of the impact of the vaporized lithium, its transport and condensation and its interaction with the beam.

Several issues related to the target and its facing vacuum system were considered in **"Some comments for the lithium vapor pressure control" (JA)**. Some methods to solve such issues were proposed:

- *Differential pumping
- *Liquid lithium flow in the target chamber
- *Li-diffusion pump.

A computational method (FIDAP code) for the determination of the lithium evaporation from the free surface was illustrated in **"Investigation of the Li evaporation rate" (EU)**.

CDA-T-II-1 (Preliminary conceptual design for Li-loop system lay-out)
CDA-T-II-2 (Li-loop component design : evaluation and specification of component design and performance)

The lithium system design was referred to a three loop scheme in **"IFMIF Li system layout and some components proposal" JA)**: the primary lithium loop, a secondary organic loop and a third water loop. A purification loop is also set in the primary loop. The design refers basically to the experience coming from the proven sodium technology; some uncertainties peculiar to the Li environment are to be investigated. A pressure recovering diffuser is foreseen for the recovery of the lithium pressure. Among the items to require great efforts, gas evacuation system, measures against lithium leak and remote handling system are the most important ones.

A preliminary conceptual design for the Li-loop system layout, component design and evaluation are presented in **"Preliminary conceptual Li-loop layout & component design and evaluation" (US)**. This layout refers again on a three loop system. In this case, the use of two pumps in parallel is foreseen. The design is based on the experience acquired with sodium technology.

CDA-T-II-3 (Li purification system design)

For this task, 3 papers were presented as follows:

1) **Design and test of lithium chemical loop (JA).**
2) **Requirements and preliminary design for Li chemistry monitoring and process system (US).**
3) **Hydrogen/tritium recovery system (US).**

All the items in these presentations were separated into following two categories.

(A) Li purification system design

Li purification and on-line impurity monitoring systems were proposed and discussed. Well established cold trap and hot trap technologies in sodium system can be applied and some promising on-line monitoring system were proposed. The feasibility for the process should be confirmed in the Li loop at IFMIF conditions.

Following concepts were being considered for the IFMIF reference design.

Impurity	Li Purification Method	Temperature
T, D, H	Cold Trap	~ 200 ^{o}C
	or	
	Yttrium Hot Trap	250 - 265 ^{o}C
O, C, Be	Cold Trap	~ 200 ^{o}C
	or	
	Ti Hot Trap	550 - 600 ^{o}C
N	Ti Hot Trap	550 - 600 ^{o}C

Impurity	Monitoring technique	Meter	Status
T, D, H	On-line	Diffusion Membrane & Electrolyte	Requires further development
O	Sampling or On-line	Solid Electrolyte	Requires further development
N	Sampling or On-line	Resistivity	Nonspecific Low sensitivity
		or Molten Salt Electrolyte	Requires extensive development

On-line monitoring of H and T is considered most important. Sampling monitoring of other impurities may be sufficient.

(B) Tritium system safety

The concentration of tritium which will give a partial pressure of MPC (Maximum Permissible Concentration in air) is 40 appm. The tritium system will be designed within the MPC limit. Tritium inventory in the Li-target system was suggested to be minimized. Basic tritium confinement system (zoning and multiple confinement) for IFMIF was discussed and agreed.

Processing of vacuum exhaust and active effluent was pointed out as an issue and thus further design effort will be made.

CDA-T-V (Preliminary safety analyses for the Li-system), CDA-T-VI (Design items and schedules of the experimental facilities for IFMIF-CDA)

For the first task (CDA-T-V), two papers were presented: In **"A review of liquid lithium reactivity" (EU)** , the reactions of Li with atmospheres (air, N_2, O_2, ...), Coolant (water) and structural materials (steels, concrete including the compatibility) were estimated. General conclusion is that at the maximum Li temperature which is expected about 300 C, the reactions tend to evolve relatively slowly rather than explosively. However for the reaction with water, two items such as high quantity of hydrogen produced, and also high quantity of heat released are the important issues in the safety design.

In the **"Safety analysis of the target" (JA)**, the activity is focused on the FMEA (Failure Mode and Effect Analysis) of the entire target system design and related areas. A number of chemical and radiological hazards were considered and classified according to risk. The basic concept of the confinement of radioactivity, particularly of tritium, was introduced.

For the second task (CDA-T-VI), three reports of

1) **"Requirements for Li-technological test loop and beam on target Åexperiment" (JA)**
2) **"IFMIF facility safety requirements" (EU)**
3) **"Requirement for water jet simulation test" (US)**

were presented.

In the first paper, it was emphasized that the basic technology of the Li loop components except the Li chemistry processing system have been established through the sodium technology. As well as the beam-on target experiment, their feasibility tests might be performed by the real IFMIF facility before normal operation of irradiation test. In the second paper, requirements and design criteria for about 14 items including Li containment, Li-heat removal, purification etc. were considered. In the last paper, the optimum conditions for the water simulation test were reported. One of the results shows that the water temperature of 80 C is desirable because of reasonable length scale and flow parameters. Some of the results will be available in JAERI water experiment.

CDA-T-VII (Data base for lithium and its compounds)

Present status of E.U. activity on this task was reported in **"Lithium data base: Status report" (EU)**. From the collected data used by each participants to the IFMIF-CDA , a recommended data base will be produced.

Some essential physical properties of lithium (density, thermal conductivity, electrical resistivity, viscosity, vapor pressure, surface tension, specific heat and enthalpy) were presented in **"Review of lithium physical and thermal properties" (US).** The graphs of the properties in SI units (temperature dependence) and corresponding empirical equations were shown with references. Data set of thermal diffusivity was requested to be included.

Acknowledgment

The authors are indebted to the concerning authorities of the each parties for the IFMIF-CDA activity. Particularly in Japan, the IFMIF-CDA coordinating group of JAERI; Drs. S. Saito, T. Funahashi, Y. Murao, S. Shimamoto, M. Shimada and T. Kondo, for the supports and encouragements.