MINUTES OF THE IFMIF TECHNICAL MEETINGS
MAY 17-20, 2005, TOKYO, JAPAN

IFMIF International Team

日本原子力研究所
Japan Atomic Energy Research Institute
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編集兼発行　日本原子力研究所
Minutes of the IFMIF Technical Meetings
May 17-20, 2005, Tokyo, Japan

IFMIF International Team

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(Received July 1, 2005)

The International Fusion Materials Irradiation Facility (IFMIF) Technical Meetings were held on May 17-20, 2005 at Japan Atomic Energy Research Institute (JAERI) Tokyo. The main objectives were 1) to review technical status of the subsystems; accelerator, target and test facilities, 2) to technically discuss interface issues between target and test facilities, 3) to review results of peer-reviews performed in the EU and Japan, 4) to harmonize design/experimental activities among the subsystems, 5) to review and discuss the Engineering Validation and Engineering Design Activity (EVEDA) tasks, and 6) to make a report of 1) - 5) to the IFMIF Executive Subcommittee. This report presents a brief summary of the Target Technical Meeting, Test Facilities Technical Meeting, Target/Test Facilities Interface Meeting, Accelerator Technical Meeting and the Technical Integration Meeting.

Keywords: IFMIF, Fusion Material, Neutron Source, Irradiation Facility, Transition Phase, EVEDA, Engineering Validation, Engineering Design, Peer Review

This report was edited by members of Office of Fusion Materials Research Promotion as follows; M. Ida, H. Nakamura, T. Yutani, S. Maebara, T. Umetsu and M. Sugimoto.
国際核融合材料照射施設(IFMIF)会合報告書
2005年5月17日〜20日に、日本原子力研究所計算科学技術推進センター

日本原子力研究所那珂研究所核融合工学部
IFMIF国際チーム

（2005年7月1日受理）

国際核融合材料照射施設(IFMIF)の技術会合および設計チームの各グループリーダーによる技術総合会合が2005年5月17日〜20日に、上野の計算科学技術推進センターで開催された。会合の主な目的は、1)サブシステムの技術検討の現状報告、2)ターゲット系とテストセル系とのインターフェイス事項の技術検討、3)総合設計報告書に対する日欧でのピアレビューの結果報告、4)サブシステムの設計・実験活動の間の調整、5)次期活動である工学実証・工学設計活動案の審議、および、6)それらのIFMIF執行小委員会への報告案作成である。本報告書は、ターゲット系技術会合、テストセル系技術会合、ターゲット系／テストセル系インターフェイス会合、加速器系技術会合、および、技術総合会合の要約を取り纏めたものである。

那珂研究所（東海駐在）：〒319-1195　茨城県那珂郡東海村白方白根2-4
本報告書は、核融合炉材料開発推進室の以下のメンバーにより、編集された。
井田瑞穂、中村博雄、湯谷順明、前原 直、梅津朋岳、杉本昌義
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Contributors

Major contributors in the meetings are as follows;

**Design Leader**
Shannon T. E. (University of Tennessee, US)

**Design Integration Group**
Sugimoto M.* (JAERI, JA), Chen J. (EFDA, EU), Chernov V. (VNIINM, RF), Lässer R. (EFDA, EU), Matsui H. (Tohoku Univ., JA), Umetsu T. (JAERI, JA)

**Accelerator Group**

**Target Group**

**Test Facilities Group**

*Group Leader
1. Introduction

The International Fusion Materials Irradiation Facility (IFMIF) is an intense neutron source for development of fusion materials. IFMIF activities have been carried out as international collaborations by the European Union (EU), Japan, the Russian Federation (RF) and the United States (US) in the framework of the Fusion Materials Implementing Agreement of the International Energy Agency (IEA). The IFMIF activities started as the Conceptual Design Activity (CDA) [1] during 1995-96, and a conceptual design and a cost estimate for IFMIF were performed in CDA. Viability of the IFMIF design was maintained through the Conceptual Design Evaluation (CDE) [2] during 1997-98. In 1999, on a request by the 28th IEA Fusion Power Coordinating Committee (FPCC), the IFMIF design was changed focusing on its cost reduction without changing the original mission. During 2000-2002, the activity of the Key Element Technology Phase (KEP) [3] was carried out to reduce key technology risk factors on long-time continuous operation of each subsystem of IFMIF; accelerator, target and test facilities.

To provide a basis for making a decision of IFMIF construction, the Engineering Validation and Engineering Design Activity (EVEDA) is being planned. The EVEDA consists of the detailed engineering design and the engineering validation including tests on components and parts of the subsystem. EVEDA is to be carried out under a new framework to responsibly perform all EVEDA tasks of design and validation, and to prepare an efficient transition to IFMIF construction.

For transition to the EVEDA, activities of Transition Phase have been carried out since 2003. The IFMIF reference design reported in the Comprehensive Design Report (CDR) [4] in January 2004 was peer-reviewed in the EU and the Japan Atomic Energy Research Institute (JAERI) respectively. Progress in the participant parties; the EU, Japan, the RF and the US has been reported and discussed at technical meetings of accelerator, target and test facilities, and technical integration meetings. Also a delegate of the People’s Republic of China (PRC) joined the meetings in this phase intending to join IFMIF activities.

This report presents a brief summary of the IFMIF meetings held in Tokyo, May 2005 as follows;

Target Technical Meeting, May 17th
Test Facilities Technical Meeting, May 18th
Target / Test Facilities Interface Meeting, May 18th
Accelerator Technical Meeting, May 18th
Technical Integration Meeting, May 19th-20th

The agendas and presentation materials are attached in the Appendixes.
2. Meeting Objectives

The purposes of the IFMIF Technical Meeting are
1) to review technical status of the subsystems; accelerator, target and test facilities,
2) to technically discuss interface issues between target and test facilities,
3) to review results of peer-reviews performed in the EU and Japan,
4) to harmonize design / experimental activities among the subsystems,
5) to review and discuss EVEDA tasks, and
6) to make a report of 1) - 5) to the IFMIF Executive Subcommittee.

3. Brief Summary of the IFMIF Technical Meetings

3.1 IFMIF Target Technical Meeting

In order to review transition tasks and discuss tasks of FY2005, an IFMIF target technical meeting was held at Tokyo, May 17, 2005 and attended by seventeen participants from EU, Japan and RF. Meeting has seven sessions (Overview, Li and Water experiments, Remote handling / Neutronics / Safety analyses, Design and Materials, Li purification / corrosion / monitors, Transition tasks and EVEDA, Summary). Meeting agenda and participants list are attached in Appendixes B and A, respectively. Presentations are attached also in Appendix B. A brief summary of this meeting is described below.

In session 1, an overview of EU activities was presented by B. Riccardi (ENEA). Transition activities on Li target and design integration tasks related to Li target were summarized. In addition, activities planned in 2005 were presented. IFMIF activities and fusion materials and technology R&D in Russia were presented by V. Chernov (VNIINM). A summary of Japanese activities performed by Universities and JAERI was presented by H. Nakamura (JAERI).

In session 2, N. Loginov (IPPE) presented the first results of the Li loop called as LTF-M. A. Mikharyev (IPPE) presented results of Li flow analysis and LTF-M experiment. N. Ishida (Osaka University) presented measurements of Li surface fluctuation by an electro-contact probe. B. Riccardi presented results of a water experiment at the joint of the replaceable backwall.

In session 3, B. Riccardi presented remote handling of the bayonet backwall and dose rate calculation due to neutron activation. M. Ida (JAERI) presented dose rate calculations due to beryllium-7 (Be-7).

In session 4, thermo-structural analysis of "cut and reweld" type backwall was presented by H. Nakamura. Thermo-structural analysis of "bayonet" type backwall was also presented by B. Riccardi.
In session 5, Li purification, corrosion and monitors in the LIFUS-III facility were presented. N. Loginov presented status of the rotating facility for corrosion and monitors. In addition, Li purification by soluble getter was presented. A. Suzuki (University of Tokyo) presented nitrogen gettering by Fe-Ti alloy performed in University of Tokyo and tritium gettering by Yttrium performed in Kyushu University.

In session 6, a proposed modification of EVEDA tasks was shown. Need of validation of thermo-structural characteristics of target assembly and backwall was pointed out by H. Nakamura. N. Loginov presented a new International Science Technology Center (ISTC) proposal on IFMIF Lithium Target Long-Term Performance.

In session 7, agreed action items were summarized by H. Nakamura.

3.2 IFMIF Test Facilities Technical Meeting

In order to review transition tasks and discuss tasks of FY2005, IFMIF test facilities technical meeting was held on May 18, 2005 and attended by eighteen participants from EU, Japan and RF. The meeting had four sessions (Overview, High & Medium Flux Test Modules (HFT&MFTM), User performance & Test Cell design). Following these sessions, an interface meeting on target / test facilities was held. The meeting agenda and participants list are attached in Appendixes C and A, respectively. The summary presentations of all contributors are attached also in Appendix C. A very brief summary of this meeting is described below.

In session 1, overview of EU tasks in 2004-2005 on accelerator, test facilities, target and design integration and proposals of 2006 work plan were presented by R. Lässer. An overview of Japanese tasks, especially on an alternative concept of HFTM with ceramic printed heater was presented by A. Shimizu.

In session 2, design activities on IFMIF HFTM in Kyushu University were presented by A. Shimizu and S. Ebara. HFTM&MFTM activities in EU on design progress, stress analysis, manufacturing, thermal hydraulic analysis were presented by V. Heinzel.

In session 3, User performance and test cell design were presented by A. Mößlang. These included nuclear libraries, entire nuclear response, activation&safety calculation, X-ray tomography, and HFTM test matrix. T. Yutani presented progress in JAERI on HFTM design and irradiation effect on thermocouple.

3.3 IFMIF Target / Test Facilities Interface Meeting

To clarify interface issues between Li target system and test module, an interface meeting was held on May 18 afternoon following the test facilities technical meeting. V. Heinzel presented various considerations on test cell atmosphere, startup procedure of Li circuit and test modules, horse shoe type shielding of test modules and adjustment of target
and test modules. Thermal analysis of Li target compatible with He environment were presented by M. Ida. Discussion on material selection of test module and target backwall has been done. Reference material of the test module canister is recommended to be stainless steel 316, because the operation temperature is below 150 °C. However, in case of the target backwall, stainless steel 316 is not recommended because the operation temperature is in a range of 300 °C to 400 °C due to low ductility after irradiation of several dpa. Use of ferritic low activation material is recommended. On gap between the backwall and the test module, present value of 2 mm is kept as a reference value. Action items in 2005 were defined.

3.4 IFMIF Accelerator Technical Meeting

The meeting was held at Tokyo, on May 18, 2005, with six attendees from US (R. Jameson as a group leader and T. Shannon), China (H. Zhao) and Japan (S. Suzuki, I. Watanabe and M. Sugimoto). The objective of the meeting was to summarize the status of activity on each accelerator tasks in the period of Oct. 2004 – May 2005, and to discuss the future activity related to accelerator subsystem. The information on EU was transferred through network communication after the accelerator sub-group meeting held at Knoxville, on May 16, 2005, with eleven attendees from EU (H. Klein, A. Schempp, H. Podlech, H. Liebermann, C. Gabor, G. Clemente and E. Margoto), US (J. Haines and T. Favale) and Japan (K. Nakayama and S. Maebara), in association with the Particle Accelerator Conference 2005.

The reported EU contributions were: a short review of past presentations performed by Saclay; an rf power system analysis performed by IBA; development of superconducting and normal conducting CH structures. Some archival material was received from Saclay on their previous work, and it will be abstracted to the IFMIF server database.

The contribution of US was to provide the information of DTL cost estimate in CDR by AES, for supporting the EFEDA independent IFMIF accelerator cost assessment.

The Japan contributions were focused on the examination of RFQ design using multi-drive loop and effects of tuners performed by JAERI. The technical comments given by a JAERI domestic peer review in 2004 were discussed.

From China it was expressed that the contribution to the IFMIF activity was an observer to track the IFMIF progress at the moment, and later a possible cost reduction of some components by manufacturing in China.

The following future activities were planned: in EU development of the CH structure is continued by IAP and beam raster scanning and beam monitoring will be started by UKAEA; in Japan examination of engineering model of RFQ including coupling plate and beam dynamics simulation in RFQ and optimization of HEBT are performed by JAERI; in China IMP is interested in raster scanning system for beam footprint generation and nondestructive beam monitor using Mg jet.
There was a comment from TED that it is necessary to develop an adapted 175MHz cavity for 1MW Diacrodre and to examine possible higher VSWR operations. The study of failure mechanisms and sub-assemblies testing are useful to guarantee a long lifetime.

3.5 IFMIF Technical Integration Meeting

The meeting was held at Tokyo, on May 19-20, 2005, with thirteen attendees from EU (R. Lässer, A. Möslang, V. Heinzel and B. Riccardi), US (T. Shannon as a team leader and R. Jameson), RF (V. Chernov and N. Loginov), China (H. Zhao) and Japan (H. Matsui, M. Sugimoto, H. Nakamura and M. Id). The objective of the meeting was to summarize the status of activity in each subsystem groups based on the technical meetings and information exchange during Sep. 2004 – May 2005. The status of technical reviews for CDR performed by EFDA and JAERI was also reported and the future activity including EVEDA task contents was discussed.

In the status report from the Test Facilities group leader, A. Möslang, EU tasks performed by FZK, TEKES, MEC in 2004 and contributions from Kyusyu Univ. and JAERI were reviewed, and future task plans were presented. The IFMIF Target/Test Module Interface Meeting was also addressed and several interface issues were identified, such as atmosphere and pressure in Test Cell, gap between backwall and test cell module, guiding structure for test modules, material data & selection of both backwall test modules.

In the status report from the Target group leader, H. Nakamura, results of three transition tasks were summarized: Li and water experiments carried out in IPPE and Osaka Univ. with a cavitation experiment under collaboration between ENEA and Osaka Univ.; purification/ monitors/corrosion & erosion experiments in progress at ENEA, IPPE, Univ. Tokyo and Kyusyu Univ.; engineering design including remote handling. The contents of EVEDA task were confirmed and action items were identified.

In the status report from the Accelerator group leader, R. Jameson, contributions in the period Oct. 2004 – May 2005 from EU, US, Japan and China were overviewed, and a technical meeting of the IFMIF Accelerator sub group held in Knoxville on May 16, 2005 was summarized. A priority list of transition phase tasks was presented.

In the status report from the Design Integration group leader, M. Sugimoto, contributions from EU, US and Japan were summarized, and future activity plan in the next period was presented, including the preliminary safety assessment document as a supplement to CDR.

The information about domestic reviews performed by EFDA and JAERI was presented and discussed. They did not find any major areas of concern or “showstopper”. The comments provided by each reviewer will be considered to add the new transition tasks or to include into detailed task contents in EVEDA.
It was agreed that the EVEDA task list presented in CDR is unchanged in this stage. The detailed description will be tracked by adding the notes to the original one through IFMIF web site.

The next meeting will be held at Santa Barbara on Nov. 30 – Dec. 1, 2005, just before the IFMIF Executive Subcommittee meeting.

Acknowledgement

The IFMIF Executive Subcommittee has been highly impressed with the dedication and enthusiasm of the IFMIF international team. Appreciation is also given to the FPCC for its continued interest in the IFMIF.

References


### Appendix A. Participants List at Each Meeting

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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Appendix B

Agenda and Documents of Target Technical Meeting
May 17, 2005, Tokyo, Japan
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IFMIF Target Technical Meeting
May 17, 2005, Tokyo, Japan

9:30 - 9:45  Welcome, Meeting Objectives
and review of agenda
M. Sugimoto (JAERI)
H. Nakamura (JAERI)

Session 1. (Overview)
9:45-10:00  Overview of Japan
Chairman: R. Lässer
H. Nakamura (JAERI)
10:00-10:15  Overview of EU
B. Riccardi (ENEA)
10:15-10:30  Overview of RF
V. Chernov (VNIINM)
10:30-10:45  Coffee break

Session 2. (Li and Water experiments)
10:45-11:05  Presentation on Lithium Test Facility (LTF-M)
Chairman: M. Ida
N. Loginov (IPPE)
11:05-11:55  Li loop & water experiment in IPPE
A. Mikheev (IPPE)
11:55-12:25  Li loop experiment in Osaka University
N. Ishida (Osaka Univ.)
12:25-12:45  Water experiment at the joint of the replaceable back wall
B. Riccardi (ENEA)
12:45-13:45  Lunch

Session 3. (Remote handling, Neutronics & safety analysis)
13:45-14:05  Presentation from ENEA
Chairman: H. Kondo
B. Riccardi (ENEA)
14:05-14:25  Accessibility of the IFMIF Li Loop
M. Ida (JAERI)

Session 4. (Design of target system, Material)
14:25-14:50  Thermal Stress analyses of Target Backwall in IFMIF
Chairman: V. Chernov
H. Nakamura (JAERI)
14:50-15:15  Presentation from EU
B. Riccardi (ENEA)
15:15-15:30  Coffee break

Session 5. (Li purification, corrosion and monitors)
15:30-15:55  Presentation from EU
Chairman: A. Suzuki
B. Riccardi (ENEA)
15:55-16:20  Presentation from RF
N. Loginov (IPPE)
16:20-16:50  Presentation from JA University
A. Suzuki (Univ. Tokyo)

Session 6 (Transition Phase and EVEDA)
16:50-17:00  Comments from Japan
Chairman: M. Sugimoto
H. Nakamura (JAERI)
17:00-17:10  Comments from EU
B. Riccardi (ENEA)
17:10-17:20  Comments from RF
N. Loginov (IPPE)

Session 7 (Summary)
17:20-17:30  Summary and Miscellaneous
H. Nakamura (JAERI)

Adjourn
Meeting Objectives

Hiroo Nakamura
JAERI

IFMIF Target & Test Facilities Technical Meetings
May. 17-18, 2005, Tokyo, Japan

Meeting Objectives

- Review Transition tasks
- Discuss issues and 2005 tasks
- Interface issues with test facilities
- EVEDA tasks
## Transition Tasks

### Target Tasks in Transition Phase

<table>
<thead>
<tr>
<th>Task ID</th>
<th>Task Title</th>
<th>Overview of Task Content</th>
<th>Justification</th>
<th>Contributing Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG-1</td>
<td>Flow stability in Li and water experiment</td>
<td>- Long term Li loop experiment</td>
<td>Obtain additional data for EVEDA to reduce uncertainty</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Water exp at different curvature</td>
<td>margins</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Diagnostics for Li/Water exp.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>TG-2</td>
<td>Li purification/monitors/corrosion/erosion</td>
<td>- Characteristics of impurity trap systems</td>
<td>Obtain additional data for EVEDA to improve reliability</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Material selection of monitors</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>TG-3</td>
<td>Engineering Design (include RH test)</td>
<td>- Examination of interface items</td>
<td>Establish base design for EVEDA phase</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- EVEDA Li test loop</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Remote handling system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(IFMIF Ex.subcommittee, EFDA CSU-Garching, Nov. 2002)
Summary of Japanese Activities on Target in 2004/2005

Hiroo Nakamura
JAERI

IFMIF Target& Test Facilities Technical Meetings
May. 17-18, 2005, Tokyo, Japan

Tasks in transition phase

<table>
<thead>
<tr>
<th>Task ID</th>
<th>Task Title</th>
<th>Overview of Task Content</th>
<th>Justification</th>
<th>Contributing Party</th>
</tr>
</thead>
</table>
| TG-1    | Flow stability in Li and water experiment | - Long term Li loop experiment  
- Water exp at different curvature  
| TG-2    | Li purification/ monitors/ corrosion/ erosion | - Characteristics of impurity trap systems  
- Material selection of monitors | Obtain additional data for EVEDA to improve reliability | EU: X, JA: X, RF: X |
| TG-3    | Engineering Design (include RH test) | - Examination of interface items  
- EVEDA Li test loop  
- Remote handling system | Establish base design for EVEDA phase | EU: X, RF: X |

(IFMIF Ex.subcommittee, EFDA CSU-Garching, Nov. 2002)
### Summary of TG-1

- **Li Experiment**
  - Osaka University: Wave amplitude was successfully measured by an electro-contact probe. Further analysis is in progress. Li sampling, evaporation study, ultra-sonic sensor are also planned.
  - JAERI: Collaborations with Osaka Univ. and IPPE are on going.

### Summary of TG-2

- **Li Purification**
  - Univ of Tokyo: Nitrogen gettering effect of Fe-Ti alloy were investigated. Evaluation of the effect is in progress.
  - Kyushu Univ: Reconsideration of tritium recovery by Y bed under dynamic flow-through operation has been done.
  - JAERI: Conceptual study of the purification system is on going. Collaborations with Japanese Universities and IPPE are on going.

- **Monitors**
  - Osaka Univ: Off line Li sampling device were attached to the Li loop. Measurement by contact sensor has been done.
Summary of TG-3
- Engineering Design (include RH test) -

Target Assembly&Back Wall:
- JAERI: Thermal analysis of TG assembly&backwall compatible with He condition has been done. Thermo-structural analysis of the back wall and preliminary evaluation of permissible stress have been done.

Activation:
- JAERI: Dose rate analysis on Be7 around Li loop has been done.

Remote handling:
-JAERI: Evaluation of Lip seal welding on material and structure are on going.

Design Description Document, EVEDA task Description Document:
-JAERI: Preparation of the DDD and EVEDA task DD are slow due to manpower limit.

Summary

In transition phase, the following target tasks are being conducted by Universities and JAERI/JNC.

- Li and Water Experiments
- Li Purification, Monitors, Corrosion/Erosion
- Design of Li target system

These activities in 2004/2005 will contribute smooth start of the EVEDA tasks.

Oct. 2005;
JAER+JNC → JAEA (Japan Atomic Energy Agency)
Overview of EU Li target tasks

B. Riccardi (ENEA Frascati)


IFMIF Target Technical Meeting
Tokyo 17 May 2005

TRANSITION ACTIVITIES

EU Li Target Tasks

EU Design Integration Tasks related to Li target

2005 ACTIVITIES
EU Li Target Tasks

➢ Water experiments
➢ Lithium corrosion and chemistry
➢ Design, construction and remote handling test of the removable back plate

Water experiments (ENEA Brasimone)

Task objectives

➢ evaluation of the stability of the IFMIF Lithium jet flow on the target by water experiments on HY-JET a simulacrum of double reduced nozzle with a concave replaceable back plate;

➢ monitoring of the cavitation occurrence near the nozzle, the flow straightener and the orificed pressure drop control device of the HY-JET mock-up.
Cavitation noises on both the flow straightener-orificed plates and at the outlet the nozzle detected at 5 m/s and 10 m/s.

Back plate central flow pattern at nozzle water velocity 1.7 m/s

Back plate lateral flow pattern at 3.2 m/s nozzle water velocity

Back plate lateral flow pattern at 10 m/s nozzle water velocity

Back plate central flow pattern at nozzle water velocity 10 m/s
Li corrosion and chemistry (ENEA Brasimone)

Impurity purification

200°C cold trapping stainless steel mesh to reduce impurity content to:
- 7 wppm (oxygen)
- 2 wppm (carbon)
- 63 wppm (hydrogen)

500°C Ti sponge hot trap for nitrogen to reduce N content to 7 ppm

250°C yttrium sponge hot trap for hydrogen to reduce H content to 7 ppm

Detail of test rig

LIFUS 3 loop at ENEA Brasimone
- Liquid metal inventory: 0.029 m³
- Mass flow rate: 0.162 kg/s
- Maximum T: 450°C
- Minimum T: 250°C
- Maximum Li velocity: 12 m/s
- Minimum Li velocity: 2 m/s

Remote handling of the removable back-plate (ENEA/Brasimone)

Design, manufacture and validation of the bayonet back-plate mock-up;
Definition and validation of the remote handling procedures.

Reference requirements
- Vacuum of 10⁻³ Pa (accelerator side);
- Vacuum of 10⁻¹ Pa (test cell side);
- Leak rate 10⁻⁸ - 10⁻¹⁰ mbar l/s (10⁻⁸ - 10⁻¹¹ Pa m³/s);
- Li inlet-outlet temperatures: 250°C, 300°C;
- Temperature peaks up to ~400°C;
- Metal gasket seal.

Back-plate mock up:
- Width: ~550 mm
- Height: ~550 mm
- Weight: 60 Kg
- Material: Aisi 316L
**RH test**
Back-plate installation and removal sequences have been optimized.
Reliability test of the remote handling and test failure simulation and rescue procedure have been completed

First step of the bolting procedure
![First step of the bolting procedure](image1)

Completion of bolting procedure on the back-plate
![Completion of bolting procedure](image2)

---

**EU Design Integration Tasks related to Li target**

<table>
<thead>
<tr>
<th>N</th>
<th>Deliverable description</th>
<th>Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Worker &amp; Public safety assessment. Reference Accidental Sequences analysis for IFMIF-KEP design.</td>
<td>ENEA</td>
</tr>
</tbody>
</table>
| 2 | Worker and public safety analyses  
   (i) **Worker safety: Estimation of neutron activation of impurities and corrosion products and contact dose in the Lithium loop**                                                      | ENEA        |
| 3 | Worker, public and environment safety analyses  
   (i) **worker safety: estimation of neutron activation of corrosion products and other impurities and estimation of contact dose in the lithium loop**; estimation of occupational radiation exposure to maintain lithium loop and accelerator vacuum pumping system; | UKAEA       |
Worker & Public safety assessment. Reference Accidental Sequences analysis for IFMIF-KEP design (ENEA Frascati)

The sequences analyzed involve Li target and accelerator interaction

1st accident: 10%, 20 s beam power excursion above the nominal 10 MW power (Relap 5)

2nd accident: water release from the accelerator cooling loop through beam line to the Li target (steam lithium reaction) (CONSEN code)

Results:

1st accident. The Li loop stabilizes rapidly and the system doesn’t go in a dangerous state.

2nd accident. No safety concern because even in the case that a significant part of water (up to 5%) turns in to steam and react with Li, pressure and temperature do not increase significantly and the H inventory is not enough for an explosion.

Worker safety: Estimation of neutron activation of impurities, corrosion products and contact dose in the Li loop (ENEA-F)

Preliminary assessment of the impact of corrosion products in Li loop for the worker dose considering the effect of neutron activation (no d)

Activation inventories and the decay gamma source has been estimated via code ANITA IEAF

The contact dose rates have been estimated by deterministic VITENEAL-IEF/SCALENEA-1 and MCNP-4C2 codes

Basic assumptions

- Loop wetted surface 572 m²
- Corrosion rate 0.16 mg/m²h *
- 200 wppm concentration of AISI 304 solution
- 11 months continuous irradiation with no purification of corrosion products

* Sharafat,Ghoniem (APEX)

<table>
<thead>
<tr>
<th></th>
<th>Li</th>
<th>Ti</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>99.973</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>0.002</td>
<td>Cr</td>
<td>0.0038</td>
</tr>
<tr>
<td>C</td>
<td>0.001</td>
<td>Mn</td>
<td>0.0004</td>
</tr>
<tr>
<td>N</td>
<td>0.001</td>
<td>Fe</td>
<td>0.01375</td>
</tr>
<tr>
<td>O</td>
<td>0.003</td>
<td>Co</td>
<td>0.00001</td>
</tr>
<tr>
<td>Al</td>
<td>0.00001</td>
<td>Ni</td>
<td>0.00181</td>
</tr>
<tr>
<td>Si</td>
<td>0.00015</td>
<td>Cu</td>
<td>0.00002</td>
</tr>
</tbody>
</table>

Li impurity concentration
Results

Due to the 4 weeks annual maintenance and EU regulatory limit for "Radiation worker" of 20 mSv/year, the zone with dose rates exceeding 125 μSv/h are "Restricted Access Areas".

The calculated dose rates at 1 day after shutdown exceed this limit (50 cm distance)

*All Li loop areas have to be declared "Restricted zone"

The worker radiation protection could be a concern for the Li loop if an efficient purification system is not provided

To maintain Li loop specific RH procedures and worker protection equipment and shielding could be necessary.

Investigation of IFMIF lithium loop activation and associated operator dose rates (UKAEA) *Preliminary data*

**Aim is estimation of a conservative upper bound on potential operator dose rates**

Nuclide inventory from TRACT was the input to FISPACT for calculation of resulting gamma spectra

Gamma spectra input to MCNP/4C model for computation of gamma dose rate

*two geometries* represented

- 20 m length of 20 cm-diameter pipe
- entire Li inventory in spherical volume (≈ to dump tank)

doses evaluated: contact dose and 1 m distance dose

**Estimation of Dose Rate as a Function of Decay Time** (Of interest for maintenance) Calculated by FISPATC code
Based on the initial results of this analysis:

- Maximum personnel dose rates due to ACPs, **during operation (at the instant of shutdown)**, in the vicinity of a large Li tank, are high
  - 11 Sv/hr in contact, 2.2 Sv/hr at 1 m.
- Maximum doses from pipework carrying Li, **1 hour after** shutdown
  - < 100 μSv/hr in contact, < 10 μSv/hr at 1 m.

---

### NEW ACTIVITIES

<table>
<thead>
<tr>
<th>N</th>
<th>Deliverable description</th>
<th>Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Theoretical study on the conditions for cavitations generation in various parts of the IFMIF Li-loop</td>
<td>ENEA</td>
</tr>
<tr>
<td>2</td>
<td>Thermomechanical analysis of the Li-loop structures to identify the probable deformation of the backplate during normal operation</td>
<td>ENEA</td>
</tr>
<tr>
<td>3</td>
<td>Verification of the backplate sealing performance against Li-infiltration and corrosion-induced damage based on the bayonet back-plate concept</td>
<td>VR-Studsvik</td>
</tr>
<tr>
<td>4</td>
<td>Development of a dedicated clean-up system for massive precipitated/activated corrosion products in Li-loop (literature study and experimental verification of magnetic trapping technology)</td>
<td>VR-Studsvik</td>
</tr>
<tr>
<td>5</td>
<td>Deuteron induced activation of corrosion products and other species in the Li-loop: identification of important reactions and analysis of the reaction cross-section data</td>
<td>UKAEA</td>
</tr>
</tbody>
</table>
V.M.Chernov
A.A.Bochvar Research Institute of Inorganic Materials (VNIINM), Moscow, Russia

IFMIF and Fusion Materials and Technology R&D in Russia

N.A.Obysov, ROSATOM, Moscow, Russia,
N.I.Budylin, VNIINM, Moscow, Russia,
A.G.Ioltukhovskiy, VNIINM, Moscow, Russia,
M.V.Leonteva-Smirnova, VNIINM. Moscow, Russia,
E.G.Mironova, VNIINM, Moscow, Russia,
M.M.Potapenko, VNIINM, Moscow, Russia,
V.N.Golovanov, RIAR, Dimitrovgrad, Russia>
M.N.Arnol'dov, IPPE. Obninsk, Russia>
A.I.Blokhin, IPPE, Obninsk, Russia,
N.I.Loginov, IPPE, Obninsk, Russia,
I.R.Kirillov, NIIEFA, St.Petersburg, Russia,
A.N.Tyumentsev, IPMS, Tomsk, Russia

<table>
<thead>
<tr>
<th>IFMIF</th>
<th>Fusion Materials&amp;Technology R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>technological investigation for validation of the project of</td>
<td>2. TBM DEMO (self-cooling and ceramic blankets).</td>
</tr>
<tr>
<td>lithium circulation loop and neutron lithium target for IFMIF.</td>
<td>3. Plasma Neutron Source (GDT).</td>
</tr>
<tr>
<td>2005-2007. ISTC Project (IPPE, VNIINM), under discussion:</td>
<td>4. Structure Materials for Fission (FBR BN-600, BN-800, cosmic) and</td>
</tr>
<tr>
<td>Target and Lithium Technology. Target Resources and Materials.</td>
<td>Fusion Reactors Applications (TBM, DEMO). Radiation damage:</td>
</tr>
<tr>
<td></td>
<td>fission-NS-fusion correlation.</td>
</tr>
<tr>
<td></td>
<td>5. Lithium Technology (BN-600, TBM, TOKAMAK).</td>
</tr>
<tr>
<td>Structure Materials:</td>
<td></td>
</tr>
<tr>
<td>V-(4-10)Ti-(4-5)Cr (300 – 750 °C). 40-50 kg heats</td>
<td></td>
</tr>
<tr>
<td>(2000), 100-300 kg heats (2006-2007). RAFMS Fe-12Cr-2W-V-Ta-B</td>
<td></td>
</tr>
<tr>
<td>Initial technology and Functional Properties. SSTT. Neutron Spectra</td>
<td></td>
</tr>
<tr>
<td>(IFMIF-FBR-DEMO). Libraries and codes. Nuclear Transmutations and</td>
<td></td>
</tr>
<tr>
<td>Properties. Radiation properties and Reactor Tests:</td>
<td></td>
</tr>
<tr>
<td>FBR: BOR-60 (5-20 dpa), BN-600 (50-150 dpa, 400-750 °C, 2006-2008).</td>
<td></td>
</tr>
</tbody>
</table>
LAMA MATERIALS R&D IN RUSSIA

R&D of LAMAs are based on the fabrication and high dose operation experience of Russian ferritic-martensitic 12% chromium steels for core components of the fast breeder power reactors BN-350 and BN-600 and vanadium alloys (early ITER, space power reactors).

The main goal:

- obtain industrial materials and articles based on their highly competitive in quality and engineering properties with corresponding materials of Japan, EC, USA.

- provide with such materials Russian power reactors BN-600 and BN-800 (under construction), TBM-DEMO and space reactors.

- ensure competitive participation of Russia in realization of international projects of fusion power reactors (DEMO, others) and TBM-DEMO.

### Li/V TBM (project). Materials

<table>
<thead>
<tr>
<th>Structural Materials</th>
<th>V-4Ti-4Cr:</th>
<th>315 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breeding material and coolant</td>
<td>Liquid Li (&lt;0.5 MPa, 350-550 °C)</td>
<td>11 kg</td>
</tr>
<tr>
<td></td>
<td>Temperature 250 – 550 °C Natural</td>
<td></td>
</tr>
<tr>
<td>Multiplier</td>
<td>Be</td>
<td>20 kg</td>
</tr>
<tr>
<td>Shielding materials</td>
<td>WC</td>
<td>150 kg</td>
</tr>
<tr>
<td>Primary shield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>structural materials (40%)</td>
<td>SS 316LN-IG</td>
<td>1600 kg</td>
</tr>
<tr>
<td>coolant (60%)</td>
<td>water (100/150 °C, 3 MPa)</td>
<td>300 kg</td>
</tr>
<tr>
<td>Support Frame and Shield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural material</td>
<td>SS 316LN-IG</td>
<td>TBD</td>
</tr>
<tr>
<td>Coolant</td>
<td>water (100/150 °C, 3 MPa)</td>
<td>TBD</td>
</tr>
<tr>
<td>Plumbing</td>
<td>Li coolant/Water/diagnostics</td>
<td></td>
</tr>
<tr>
<td>Structural material</td>
<td>V-4Ti-4Cr/316LN-IG/316LN-IG</td>
<td>15/35/30 kg</td>
</tr>
</tbody>
</table>
V-4Ti-4Cr. Yield Strength.

\[ \sigma_{0.1}, \text{ MPa} \]

- Russia
- USA
- Japan

T, °C

RUSFER-EK-181. Tensile strength, Yield strength

TS, YS, x 10 MPa

Temperature, °C
RUSFER-EK-181. Stress - Fracture time. 650 °C

Stress, MPa

1 - EP900 (0.14N)
2 - EP900 (0.10N)
3 - EP900 (0.08N)
4 - EK-181
5 - EP450

Fracture time, hrs

RUSFER-EK-181.

Dependence of stationary creep rate of specimens in 16Cr2W2NTaB - type steel of different ingots at 650 and 700 °C

- ingot 1, normalization 1100 °C, tempering 720 °C, 3 h
- ingot 1, normalization 1050 °C, tempering 720 °C, 3 h
- ingot 2, normalization 1050 °C, tempering 720 °C, 3 h

Stress, MPa

stationary creep rate, % / h
RAFMS Fe-12Cr-2W-V-Ta-B (RUSFER-EK-181).
IMPACT PROPERTIES.
IRRADIATION: BOR-60, 6-8 dpa

EUROFER, EUROFER-ODS and RUSFER-EK-181 (Fe-12Cr-2W-V-Ta-B)

Stress (MPa) and Fracture time (hrs), 650 °C

Larson-Miller curves, 650 °C
Neutron Spectrum

- BN-600
- IVV-2M, col 7-8
- IFMIF
- DEMO-RF
- BOR-60
- GDT-NS

Neutron flux (n/cm²/s, E > 0):
ITER: 3.88*10¹⁴, DEMO-RF: 9.00*10¹⁴, GDT: 5.18*10¹⁴, IFMIF: 6.71*10¹⁴, BN-600: 6.50*10¹⁵, BOR-60: 3.00*10¹⁵, IVV-2M: 5.29*10¹⁴

RUSFER-EK-181: dpa/fluence

Tᵣ = 1 year for Fe-12% Cr

- ITER
- DEMO-RF
- GDT-NS
- IFMIF
- BN-600
IRRADIAION VOLUMES: GDT, BN-600.

\[ \Delta R_n = R_{n+1} - R_n = 0.1 R_n \]

\[ V = 0.66 R_n^2 L \]

(\(R_0\) – source radius, \(R_n\) – neutron field radius, \(L\) – source length.

Irradiation volumes – between the nearest circumferences

**IFMIF Target System**

Li technologies. Li loop at IPPE, Obninsk.

Achievements

ISTC Programme

<table>
<thead>
<tr>
<th>Soluble getter</th>
<th>Impurity</th>
<th>Li Temperature</th>
<th>Initial Concentr.</th>
<th>Final Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Oxygen</td>
<td>350 °C</td>
<td>10-20 wppm</td>
<td>1-2 wppm</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Nitrogen</td>
<td>350 °C</td>
<td>50-100 wppm</td>
<td>2-5 wppm</td>
</tr>
</tbody>
</table>

IFMIF specifications (≤10 wppm) has been achieved experimentally
IPPE Lithium Loop.

Target mock-up (1:3)  Lithium jet.

Li volume: 270 liters, Flow rate: up to 50 m³/hr
Li Velocity: 4.6 m/s

The additional activation of the lithium jet and the back wall induced by neutrons generated by the deuteron beam inside of the lithium jet

Neutron energy spectra averaged over the volumes of the lithium jet and quench tank [S.P. Simakov, U. Fisher, U. von Molendorff]
The total dose rate induced in the lithium and the back wall by neutrons generated by the deuteron beam (40 MeV & 250 mA, fpy) inside of the lithium jet versus cooling time.

Industrial Li (wt.%: 97.0803),
SS316 (wt%: Fe-66.19, Ti-0.10, Cr-17, Mn-1.6, Ni-12, Mo-2.3, Co-0.1, Nb-0.005, C-0.015, N-0.006, P-0.025, S-0.005)

Problem: How to change the irradiated back wall from SS316?

RUSFER-EK-181. Radiation Damage. H, He, DPA.

<table>
<thead>
<tr>
<th></th>
<th>dpa/fpy</th>
<th>H/fpy, appm</th>
<th>He/fpy, appm</th>
<th>H/dpa</th>
<th>He/dpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITER</td>
<td>10.1</td>
<td>482</td>
<td>116</td>
<td>47.8</td>
<td>11.5</td>
</tr>
<tr>
<td>DEMO-RF</td>
<td>14.3</td>
<td>676.3</td>
<td>161.6</td>
<td>47.3</td>
<td>11.3</td>
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<tr>
<td>GDT-NS</td>
<td>14.4</td>
<td>707</td>
<td>167</td>
<td>49.1</td>
<td>11.6</td>
</tr>
<tr>
<td>IFMIF</td>
<td>33.6</td>
<td>1256</td>
<td>322</td>
<td>37.4</td>
<td>9.6</td>
</tr>
<tr>
<td>BN-600</td>
<td>60.9</td>
<td>151.6</td>
<td>8.14</td>
<td>2.5</td>
<td>0.13</td>
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</table>
## V-4Ti-4Cr. Radiation Damage. H, He, dpa

<table>
<thead>
<tr>
<th></th>
<th>dpa/fpy</th>
<th>H/fpy, appm</th>
<th>He/fpy, appm</th>
<th>H/dpa</th>
<th>He/dpa</th>
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<tbody>
<tr>
<td>ITER</td>
<td>11.3</td>
<td>386.5</td>
<td>98.7</td>
<td>34.2</td>
<td>8.73</td>
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<tr>
<td>DEMO-RF</td>
<td>15.28</td>
<td>438.6</td>
<td>115.3</td>
<td>28.7</td>
<td>7.55</td>
</tr>
<tr>
<td>GDT-NS</td>
<td>15.10</td>
<td>443.2</td>
<td>117.2</td>
<td>29.4</td>
<td>7.76</td>
</tr>
<tr>
<td>IFMIF</td>
<td>32.4</td>
<td>910.3</td>
<td>330.6</td>
<td>28.1</td>
<td>10.2</td>
</tr>
<tr>
<td>BN-600</td>
<td>79.8</td>
<td>22.8</td>
<td>5.83</td>
<td>0.29</td>
<td>0.07</td>
</tr>
</tbody>
</table>

The total dose rate induced in the back wall by neutrons generated by the deuteron beam (40 MeV & 250mA) inside of the lithium jet versus irradiation time.

SS316 (wt%: Fe-66.19, Ti-0.10, Cr-17, Mn-1.6, Ni-12, Mo-2.3, Co-0.1, Nb-0.005, C-0.015, N-0.006, P-0.025, S-0.005)
Lithium Test Facility (LTF-M)

Yu.Aksenov, N.Loginov
IPPE, Obninsk, Russia

IFMIF Target & Test Facilities Technical Meetings
May 17-18 2005, Tokyo, Japan

Contents

- Li experimental base of IPPE
- LTF-M specifications
- State-of-the-art LTF-M
- Future experiments
Li experimental base of IPPE

- LTF
- LTF-M
- Rotating disk facility
- Supporting possibilities:
  - Experimental Manufactory
  - Design department
  - Chemical laboratory, Na laboratory, Pb-Bi laboratory

### LTF-M parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant</td>
<td>Lithium</td>
</tr>
<tr>
<td>Coolant volume</td>
<td>0.27 m$^3$</td>
</tr>
<tr>
<td>Maximum of flow rate</td>
<td>Up to 50 m$^3$/h</td>
</tr>
<tr>
<td>Maximum of temperature</td>
<td>400 °C</td>
</tr>
<tr>
<td>Pressure</td>
<td>1.2-10$^{-3}$ - 1.6-10$^5$ Pa</td>
</tr>
<tr>
<td>Facility height</td>
<td>15.6 m</td>
</tr>
<tr>
<td>Electric installed capacity</td>
<td>200 kW</td>
</tr>
<tr>
<td>Pressure pipe diameter</td>
<td>70×5 mm</td>
</tr>
<tr>
<td>Down pipe diameter</td>
<td>89×5 mm</td>
</tr>
<tr>
<td>Structural material</td>
<td>Steel 12X18H10T*</td>
</tr>
<tr>
<td>State</td>
<td>Started in April 2005</td>
</tr>
</tbody>
</table>

*Similar to 304 SS*
LTF-M facility

1st floor

LTF-M facility

2nd floor

3rd floor
LTF-M facility
4th floor

Front view
Right-side view

Target assembly mock-up
LTF-M Equipment

Dump tank

MHD pump

LTF-M Equipment

Quench tank
### LTF-M Equipment

<table>
<thead>
<tr>
<th>Expansion compensator 1</th>
<th>Expansion compensator 2</th>
</tr>
</thead>
</table>

### LTF-M Equipment

<table>
<thead>
<tr>
<th>Magnetic flow meter</th>
<th>Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. operation temperature – 700°C</td>
<td>Electromechanical drive</td>
</tr>
</tbody>
</table>
LTF-M Equipment

Evaporation section  On-line level meter

Investigation methods

- Visualization of Li flow
- Electro contact probe
- Level meter
- Vacuum meter
- Li pressure measuring
- Electrochemical cell
- Mass-spectrometry
- Tube sampler
## Visualization

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Progressive</th>
<th>Digital video camera pco.1200 hs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>2560×1920 pixel</td>
<td>1280×1024 pixel</td>
</tr>
<tr>
<td>Minimal exposure</td>
<td>1/18000 s</td>
<td>Exposure time From 1.0 µs</td>
</tr>
<tr>
<td>Lens</td>
<td>9.36 mm, f/2.0-f/2.4</td>
<td>Image recording 1.0 GB/s</td>
</tr>
<tr>
<td>Shooting range</td>
<td>0.6 - ∞ m</td>
<td>Interframing time From 70 ns</td>
</tr>
</tbody>
</table>

## Electro contact measuring

<table>
<thead>
<tr>
<th>Number of probes</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of needles in probe</td>
<td>3</td>
</tr>
<tr>
<td>Material of needle</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>Drive of probe</td>
<td>Step motor IMS</td>
</tr>
<tr>
<td>Positioning accuracy, µm</td>
<td>±10</td>
</tr>
</tbody>
</table>
State-of-the-art LTF-M

- LTF-M starts to operate April 2005
- The main equipment is able to work
- Start-up of circulation was registered
- Li jet surface was observed and registered at 4 flow rates (up to 6 m/s) under vacuum
- Gassing from steel and cavitation took place
- Insufficient of Li quantity was filled in dump and quench tanks. As a result Li splashes were observed at inner surfaces of the target and it's glass windows

State-of-the-art LTF-M

- Li jet surface was observed and registered at 4 flow rates (up to 6 m/s) under vacuum
Future experiments

- Elimination of gassing
- Detailed observation of Li jet at velocities up to 15-20m/s
- Investigations of Li jet parameters with electric probes
- Testing of oxygen electrochemical cell
- Investigations of Li evaporation from jet surface
- Purification of Li in dump tank
## Li loop & water experiments in IPPE

A. Mikheyev, N. Loginov  
IPPE, Russia

### IFMIF Target & Test Facilities Technical Meetings  
May 17-18, 2005, Tokyo, Japan

---

### Comparison of target assembly mock-ups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FMIT</th>
<th>JAERI Phase 1</th>
<th>JAERI Phase 2</th>
<th>Osaka</th>
<th>IPPE</th>
<th>Prototype</th>
<th>IFMIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant</td>
<td>Lithium</td>
<td>Water</td>
<td>Water</td>
<td>Lithium</td>
<td>Lithium</td>
<td>Lithium</td>
<td></td>
</tr>
<tr>
<td>Nozzle geometry</td>
<td>1 stage</td>
<td>2 stages</td>
<td>2 stages</td>
<td>2 stages</td>
<td>2 stages</td>
<td>2 stages</td>
<td></td>
</tr>
<tr>
<td>Back-wall</td>
<td>Concave R=100mm R=269mm</td>
<td>Concave R=250mm</td>
<td>Straight</td>
<td>Straight</td>
<td>Concave R=250 mm</td>
<td>Concave R=250 mm</td>
<td>Concave R=250 mm</td>
</tr>
<tr>
<td>Jet thickness, mm</td>
<td>19</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Jet width, mm</td>
<td>100</td>
<td>240</td>
<td>100</td>
<td>70</td>
<td>70</td>
<td>100</td>
<td>260</td>
</tr>
<tr>
<td>Jet speed, m/s</td>
<td>17</td>
<td>1.2-17</td>
<td>2.5-20</td>
<td>Up to 15</td>
<td>Up to 20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Flow rate, l/s</td>
<td>40</td>
<td>102</td>
<td>20</td>
<td>13</td>
<td>13</td>
<td>50</td>
<td>133</td>
</tr>
<tr>
<td>Vacuum conditions, Pa</td>
<td>$10^3$</td>
<td>$10^5$</td>
<td>$10^4-10^5$</td>
<td>$10^3-10^5$</td>
<td>$10^3$</td>
<td>$10^3$</td>
<td></td>
</tr>
<tr>
<td>Working temperature°C</td>
<td>250</td>
<td>20</td>
<td>20-30</td>
<td>300-550</td>
<td>250-400</td>
<td>250-280</td>
<td>250-280</td>
</tr>
<tr>
<td>Nozzle material</td>
<td>304 SS</td>
<td>Acrylic resin</td>
<td>Acrylic resin</td>
<td>304 SS</td>
<td>304 SS</td>
<td>RAS</td>
<td>RAS</td>
</tr>
<tr>
<td>Lifetime, hours</td>
<td>9000</td>
<td>-</td>
<td>-</td>
<td>500</td>
<td>&gt;1000*</td>
<td>&gt;5000*</td>
<td>175200*</td>
</tr>
</tbody>
</table>

---

---
Design

Side view  Front view  Back view

Nozzle geometry

The nozzle is based on Shima model:

1st stage  \( t \in [3.07, 0.035] \)
\[
\begin{align*}
  x(t) &= \frac{1}{2\pi} \left[ 2\pi t \ln \left( \frac{\pi}{2} \right) - 2\pi t \ln \left( \frac{\pi}{2} \right) + \left( \sqrt{3M(a + b)} - (a + b) \ln(t) \right) \right] + 62.956 \\
  y(t) &= \frac{b}{\pi} \left[ (a - b) \pm \left( \sqrt{3M(a + b)} - (a + b) \ln(t) \right) \right] \\
  \text{where} \ a &= 100, \ b = 25
\end{align*}
\]

2nd stage  \( t \in [3.123, 0.035] \)
\[
\begin{align*}
  x(t) &= \frac{1}{2\pi} \left[ 2\pi t \ln \left( \frac{\pi}{2} \right) - 2\pi t \ln \left( \frac{\pi}{2} \right) + \left( \sqrt{3M(a + b)} - (a + b) \ln(t) \right) \right] + 161.687 \\
  y(t) &= \frac{b}{2} \left[ (a - b) \pm \left( \sqrt{3M(a + b)} - (a + b) \ln(t) \right) \right] \\
  \text{where} \ a &= 25, \ b = 10
\end{align*}
\]
Elements of design

Elements of target assembly mock-up

Straightener

Calculation of Li flow in mock-up

Computational code – FIDAP 8.7.2, Fluent Inc.

Initial and boundary conditions

Shima nozzle

U_{x=1.847 \text{ m/s}}
U_{y=0.765 \text{ m/s}}
G_{x=9.8 \text{ m/s}^2}
G_{y=0.0 \text{ m/s}^2}
F(0)=1.0
F(3)=0.0
P=0.001 \text{ Pa}

Vacuum
Back wall

Fragment of calculation mesh, angle of nozzle edge – 62°30’
Lithium velocity

Velocity vector plot inside and at outlet of nozzle

Velocity field in the area of nozzle edge (zooming).

Speed and pressure distributions
Turbulent kinetic energy contour plot

Angle of nozzle edge – 62°30’

Li jet flow

Function F distribution in nozzle and chute, angle of nozzle edge - 62°30’

Deformation of jet velocity field
Water experiment

Water test facility

Initial state
(no water)

Flow visualization

Digital photo camera Olympus E-20P

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Progressive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution, pixel</td>
<td>2560×1920</td>
</tr>
<tr>
<td>Minimal exposure, s</td>
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</tr>
<tr>
<td>Lens</td>
<td>9-36 mm, f/2.0-f/2.4</td>
</tr>
<tr>
<td>Shooting range, m</td>
<td>0.6 - ∞</td>
</tr>
</tbody>
</table>

Digital video camera pco.1200 hs

| Frame rate, fps | 636-32576 |
| Resolution, pixel | 1280×1024 |
| Exposure time, μs | From 1.0 |
| Image recording, GB/s | 1.0 |
| Interframing time, ns | From 70 |
Water experiment – 8 m/s

With straightener

No straightener

Water experiment – 12 m/s

With straightener

No straightener
Water experiment – 16 m/s

With straightener

No straightener

Flowing film of water at side walls
Target assembly mock-up

Places for electro-contact probes

Optical ports

Bellow

Quench tank

LTF-M facility

4th floor

Front view

Side view
Wall wettability with Li

Initial surface

Wetted surface

Li flow (vacuum)

Vacuum – 0.02 Torr

5.8 m³/h
(2.3 m/s)

10.7 m³/h
(4.2 m/s)

15 m³/h
(6 m/s)
Li flow (argon)

Ar pressure = 7 kPa
Li flow rate = 17 m³/h
Li speed = 6.7 m/s

Usual camera
High-speed camera

Cavitation phenomenon

Li speed = 6 m/s
Electro contact measuring (construction scheme)

Electro contact measuring

<table>
<thead>
<tr>
<th>Number of probes</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of needles in probe</td>
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<td>Material of needle</td>
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</tr>
<tr>
<td>Drive of probe</td>
<td>Step motor IMS</td>
</tr>
<tr>
<td>Positioning accuracy, $\mu$m</td>
<td>$\pm 10$</td>
</tr>
</tbody>
</table>
Scheme of measurements
Li loop experiment in Osaka Univ.

N. Ishida¹, H. Kondo¹, N. Yamaoka¹, S. Miyamoto¹, M. Ida², H. Nakamura², I. Matsushita³, T. Muroga⁴ and H. Horiike¹

¹ Osaka Univ.
² Japan Atomic Energy Research Institute
³ Shinryo High Technologies, Ltd.
⁴ National Institute for Fusion Science

Contents

- Introduction
- Experimental Facility
- Visual Observations
- Probe system
- Results
- Summary
Introduction
IFMIF Lithium Target

Lithium flows along a concave wall
Velocity : 15m/s
Deuteron beams : 40MeV, 125mA * 2
Irradiated region : 175mm downstream

Design issues
Stability of the lithium flow
Target thickness or amplitude of waves,
(These affect uniformity of neutron field directly.)

Experimental Facility
Lithium Loop at Osaka Univ.

- ALIP type electromagnetic pump (EMP) <700 l/min,
- Test section and void separation tank,
- Air cooler module,
- Electromagnetic flow meter
- Total tube length : 40m (SS304), Inventory : 420 litter.
Free Surface Test Section

- Honeycomb, perforated plates (Flow strainer)
- Nozzle (consists of two contractions section )
- Open flow channel (70 mm width )
- Viewing ports

Visual Observation of Free Surface by Micro-Flash Strobe

Velocity

< 3.0 m/s → Almost smooth, no wave.

5 ~ 9 m/s → Periodic 2 dimensional waves with wavelengths of 1.0~1.5 mm for the 1 cm region from the nozzle

> 10 m/s → Irregular 3 dimensional waves Transition to turbulence

These observations agree well with water experiments simulated IFMIF target by Itoh [2] and FMIT target experiments by Hassberger [3], [4]
**Electro-contact probe measurements**

To measure the surface fluctuation, Electro-contact probe was prepared.

The device detects contacts between a needle and Li surface

The probe is scanned in vertical direction with an accuracy of 0.1 mm.

At present the prove can not be scanned horizontally.

---

**Electro-contact probe device**

- **Two needles**
  - mechanically fixed
  - electrically independent

- **Electric motor cylinder**
  - to move the needles
  - resolution : 2\(\mu\)m

**set on second viewing port (on the beam axis)**

- 175 mm from the nozzle
- needle 1 : 16 mm from the side wall
- needle 2 : 35 mm (at the center of flow)
Electro-contact probe device

- **Two needles**
  - mechanically fixed
  - electrically independent
- **Electric motor cylinder**
  - to move the needles
  - resolution: 2μm

**set on second viewing port**
**on the beam axis**

- 175 mm from the nozzle
- needle 1: 16 mm from the side wall
- needle 2: 35 mm (at the center of flow)

Detection circuit

When a needle touches the lithium, the circuit is closed and a voltage drop occurs.

The two needles each have a circuit independently

Detection circuit

Example of voltage signal
**Block Diagram of Measurement System**

The position of the needles controlled by control unit step: 0.1 mm (can be 2 μm)

Contact signals recorded by PCM recorder through the detection circuit
- Sampling rate: 48kHz
- Sampling time: 20s

**Experimental conditions**
- Li temperature: 573 K
- Pressure: 0.119 MPa

---

**Voltage variation over time**

The signal is summarized statistically as below*

Contact frequency $f_c$

$$f_c = \frac{\text{(number of contact times)}}{\text{(total measurement time)}}$$

<table>
<thead>
<tr>
<th>Non-contact</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td></td>
</tr>
<tr>
<td>Height: 11.64 mm</td>
<td>Height: 10.94 mm</td>
</tr>
</tbody>
</table>

Contact signal in the case of 10 m/s (center)

*The summarization is the same as a water experiment by Loginov, Fedotovski et al.
Results of contact frequency

10 m/s

14 m/s

15 m/s

Black: 16 mm from side wall
Red: 35 mm (center of the channel)

Average thickness and surface fluctuation

Average liquid thickness
the height when the contact frequency is at its maximum

Amplitude of surface fluctuation
the half height between non-contact and full contact

Schematic of surface wave
Average thickness and surface fluctuation

Average thickness on velocity are not similar in the case of 16mm and 35 mm from the side wall.

Amplitude of the fluctuation increases when velocity increases
Approx. 2mm at the center of flow in the case of 15 m/s.
2.8mm at the 16mm from the side wall.

Movies of Surface flow

The varying of average thickness on velocity depends on surface wake

surface wake → generated from
    • nozzle corner
    • edge (not smooth)

Flow patterns recorded at the probe installed port

16 mm from the side wall
35 mm (center of channel)
Non-dimensional amplitude

The amplitude is summarized in non-dimensional form of $A/\delta_2$ against square of the Weber number based on $\delta_2$.

**Non-dimensional amplitude is found to be in proportion to $We\delta_2^2$**

![Graphs showing non-dimensional amplitude vs. $We\delta_2$](image)

$16$ mm from the side wall $35$ mm (center of flow)

$\delta_2$: Momentum thickness of the shear layer at the nozzle exit

---

Summary

- The electro-contact probe was prepared and the contact frequency was successfully measured. It was $\pm 2 \sim 3$ mm at $15$m/s of the velocity.

- In the case of $16$mm from the side wall, the amplitude behavior may be affected by surface wakes from side wall.

- The wave amplitude is found to increase in proportional with the square of Weber number. This means the wave is strongly dominated by Weber number (Surface tension)
Further Investigation

**Electro-contact probe**
- Reconstruction of wave pattern
- Re-experiment with cleaner nozzle

**Other**
- Measurement of thickness or surface shape by an ultrasonic or optical method (non-contact method)
- Measurement of evaporation behaviors.
- **Sampling of lithium and analysis of the components.**
Water experiment at the joint of the replaceable back wall

Giovanni Dell'Orco (ENEA Brasimone)
Presented by B.Riccardi (ENEA Frascati)

IFMIF Target Technical Meeting
Tokyo 17 May 2005

Test for the cavitation investigation

Objectives

➢ Monitoring of the cavitation occurrence near the nozzle and the orificed flow straightener of the HY-JET mock-up at ENEA Brasimone.

➢ Monitoring of the cavitation occurrence on the OSAKA University lithium loop (at the EM pump and the orificed flow straightener pressure drop control device).
Cavitation detection in the HY-JET experiment (ENEA Brasimone).

- The CASBA-2000 signal was always easily distinguishable from pedestal noises;
- the onset of the first cavitation noise was recorded close to the third multi-hole diaphragm when the nozzle velocity was $> 5$ m/s;
- At nozzle velocity $> 10$ m/s the cavitation noise was recorded at the nozzle outlet;
- the CASBA-2000 signal in dB was nearly linear versus the nozzle velocity below 13 m/s.
Cavitation noises on both the flow straightener-orificed plates and at the outlet nozzle detected at 5 m/s and 10 m/s.
CASBA-2000 - Li loop at OSAKA

CASBA at nozzle inlet

CASBA at EMP inlet

Tests at the OSAKA University lithium loop

The loop hydraulic performances calculated at the Li temperature of 310°C
The onset of cavitation noise was detected at EMP inlet in 3 conditions:
\[ p = 0.05 \text{ MPa} \quad v = 12.0 \text{ m/s}, \quad p = 0.065 \text{ MPa} \quad v = 13.3 \text{ m/s}, \quad p = 0.09 \text{ MPa} \quad v = 15.0 \text{ m/s} \]

No cavitation at EMP inlet detected at the Ar pressure of 0.11 Pa up to the max. \( v = 15 \text{ m/s} \)

No cavitation at flow straightener detected at \( Ar \ p > 0.05 \text{ Pa} \) up to the max. \( v = 15 \text{ m/s} \)

Li flow at the nozzle outlet during cavitation at EMP
Onset of cavitation noise:
P 0.05 MPa - v 12.0 m/s, P 0.065 MPa - v 13.3 m/s, P 0.09 MPa - v 15.0 m/s
Flow stability in water: experimental assessment of the effect of curvature radius (250 and 450 mm) and surface roughness on water jet stability

HY-JET MOCK-UP

The ENEA HY-JET mock-up is a simulacrum of the IFMIF Lithium jet flow with a double reduced nozzle and a concave target back plate. HY-JET was also subdivided in flanged components to assure some experimental flexibilities in the selection and change of the main parameters as the:

i) straightener;
ii) multi-holes diaphragm pressure reducer;
iii) double reduced nozzle;
iv) concave back-plate.

The nozzle was designed by the correlations derived from the Shima's model.
DOUBLE REDUCED HY-JET NOZZLE

Comparison among IFMIF, Osaka and ENEA Brasimone mock-ups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IFMIF Li loop</th>
<th>Water Exp. JAERI</th>
<th>Osaka Li loop</th>
<th>Water Exp. ENEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle Geometry</td>
<td>Double Reducer</td>
<td>Double Reducer</td>
<td>Double Reducer</td>
<td>Double Reducer</td>
</tr>
<tr>
<td>Stack wall Geometry</td>
<td>Conca`ve (R=250 mm)</td>
<td>Straight</td>
<td>Straight</td>
<td>Concave (R=250 mm)</td>
</tr>
<tr>
<td>Jet Thickness (mm)</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Jet Width (mm)</td>
<td>260</td>
<td>100</td>
<td>70</td>
<td>250</td>
</tr>
<tr>
<td>Li Speed (m/s)</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>10-20</td>
</tr>
<tr>
<td>Flow Rate (l/s)</td>
<td>133</td>
<td>TBC</td>
<td>13</td>
<td>30-80</td>
</tr>
<tr>
<td>Vacuum Condition (Pa)</td>
<td>$10^{3}$</td>
<td>$10^{4}$ - $10^{5}$</td>
<td>100-1000 (TBC)</td>
<td>Pressure $10^{5}$ (Pa)</td>
</tr>
<tr>
<td>Nozzle Material</td>
<td>RAP</td>
<td>acrylic resin</td>
<td>304 SS</td>
<td>304L SS</td>
</tr>
</tbody>
</table>
Test conditions

The first test campaign on HY-JET water experiments was carried-out with the following configuration:

- double SHIMA nozzle with 200 mm x 20 mm of jet thickness;
- concave removable back plate curvature with radius 450 and 250 mm;
- concave removable back plat surface roughness of 1 μm;
- full precision at the joint between the nozzle and the back plate (no stair).

Status

The tests on the target back plate with curvature of 250 mm and surface roughness of 1μm were concluded at the end of Nov 04.

The remaining tests (10μm) are going to be performed.
Hydraulic characterization (R=450mm)
The hydraulic characterization of the HY-JET mock-up flow straightener and the multiholes orificed plates pressure reducer has given the following best-fit correlations:

\[
\begin{align*}
\text{DP} &= 7.751 \times 10^{-3} \text{ Vn}^2 \times 2.069; \quad \text{flow straightener + two orificed plates} \\
\text{DP} &= 6.190 \times 10^{-3} \text{ Vn}^2 \times 2.073; \quad \text{flow straightener + one orificed plate;} \\
\text{DP} &= 4.455 \times 10^{-3} \text{ Vn}^2 \times 2.094; \quad \text{flow straightener;} \\
\text{Pn} &= 2.922 \times 10^{-3} \text{ Vn}^2 \times 2.223; \quad \text{pressure upstream the nozzle.}
\end{align*}
\]

Where: \( \text{DP} = \) pressure drop (bar); \( \text{Pn} = \) relative pressure (bar); \( \text{Vn} = \) nozzle water velocity (m/s).

At a nozzle velocity of 10 m/s the flow straightener and three orificed plates pressure drop is 0.09 MPa with an extrapolated value of 0.38 MPa at 20 m/s.

Hydraulic Instabilities (R=450mm)
The first tests have demonstrated that in laminar flow regime, with a Reynolds lower 2500 and a nozzle velocity lower 2.5 m/s, some diagonal waves with an angle of about 12° from the flow direction, arisen from the lateral tray walls.

These waves disappear above the transition to turbulent flow regime.

The water splashing on the lateral walls appears after the transition regime with large initial increasing versus the nozzle velocity in the turbulent regimes.

The discharge flow in the water tank procured large oscillations of free level (200-300 mm) with consequent fluctuation on the pump flow rate.

In the full turbulence flow regime, when the nozzle velocity approaches 10 m/s, the flow assumed the fully developed turbulence pattern with sparkling bubbles on the bulk, remaining well attached to the back plate central part.

The water jet waves were in the range of +/- 2 mm.

The lateral instabilities and the flow overcoming beyond the lateral tray walls seemed to be mitigated by the centrifugal forces on the jet.

The Göttler vortexes are not clearly observed due to the both turbulence in main flow and the superimposition with the lateral instabilities.
Hydraulic characterization (R=250mm)

The hydraulic characterization of the HY-JET mock-up flow straightener and the multiholes orificed plates pressure reducer has given the following best-fit correlations:

\[
\begin{align*}
DP &= 1.48 \times 10^{-2} \times V_n^{1.7284}; \quad \text{flow straightener + two orificed plates} \\
DP &= 1.21 \times 10^{-2} \times V_n^{1.7154}; \quad \text{flow straightener + one orificed plate;} \\
DP &= 0.82 \times 10^{-2} \times V_n^{1.7566}; \quad \text{flow straightener;} \\
P_n &= 7.49 \times 10^{-2} \times V_n^{1.0931}; \quad \text{pressure upstream the nozzle.}
\end{align*}
\]

Where: 
- \(DP\) = pressure drop (bar);
- \(P_n\) = relative pressure (bar);
- \(V_n\) = nozzle water velocity (m/s).

Hydraulic characteristic of the flow straightener and three orificed plates
Hydraulic Instabilities (R=250mm)

V-shaped pattern waves at 12° in laminar flow arisen from the lateral tray walls. These waves disappear above the transition to turbulent flow regime.

The water splashing on the lateral walls appears after the transition regime with large initial increasing versus the nozzle velocity in the turbulent regimes.

In the full turbulence flow regime (v>10 m/s), the flow assumed the fully developed turbulence pattern with sparking bubbles on the bulk still remaining well attached to the back plate.

The lateral instabilities and the flow overcoming beyond the lateral tray walls seemed to be mitigated at higher velocities by the centrifugal forces.

The Görtler vortexes are not clearly observed (turbulence effect)

The flow waves were in the range of +/- 2 mm.

Cavitation noises on both the flow straightener-orificed plates and at the outlet the nozzle detected at ab.10 m/s.

(R=250mm)

V-shaped pattern waves at 12° in laminar flow
Laminar flow at nozzle exit
Water rises at the lateral tray walls in transition laminar–turbulent flow
Water jet free surface oscillation in turbulent flow.
Turbulent flow at nozzle exit
Lateral effects in turbulent flow
RH of the replaceable backplate: 
*Reliability trials and rescue procedures*

Presented by B.Riccardi (ENEA Frascati)

*Contributors:* G. Collina, L. Muro, G. Miccichè (ENEA Brasimone)

IFMIF Target Technical Meeting
Tokyo 17 May 2005

**Objectives**

- Reliability assessment of the backplate prototype
- Development of the rescue procedures
Removable back-plate bayonet concept (Background)

Reference requirements
✓ Vacuum of $10^{-3}$ Pa (accelerator side);
✓ Vacuum of $10^{-1}$ Pa (test cell side);
✓ Leak rate $10^{-8} - 10^{-10}$ mbar l/s ($10^{-8} - 10^{-11}$ Pa m$^3$/s);
✓ Li inlet-outlet temperatures: 250°C, 300°C;
✓ Temperature peaks up to ~ 400°C;
✓ Metal gasket seal.

Back-plate mock up:
✓ Width: ~550 mm
✓ Height: ~550 mm
✓ Weight: 60 Kg
✓ Material: Aisi 316L

Verification test
Determination of the working parameters: torque, force transmitted to the plate)
The test carried out at RT and 270 °C.

Vacuum test
The parameters for these trials are:
✓ Leak rate $10^{-8}$ mbar*l/s
✓ Vacuum of $10^{-3}$ Pa in the target chamber;
✓ Vacuum of $10^{-1}$ Pa in the test cell outside the target chamber;

Tests carried out successfully at RT and at 270°C
Remote handling
The remote handling activity at DRP facility at ENEA Brasimone.

Tools
- Interface and tools for bolting the upper, lower and lateral skates
- Dedicated bolting tool to complete the back-plate bolting sequence to the specified torque and initial loosening.

Experimental Reliability Trials

To assess the reliability of the backplate prototype a test campaign, consisting in a number of remote backplate replacement operations, was planned.

A total of 100 trials were executed (50 installations and 50 removals).

At the end of each trial the status of the following components were checked:
- the dowel pins between the back-plate and the frame;
- the skate systems and the bearings;
- the threaded drive shafts of the skate systems
Reliability Trials cont'd

- the **grub screw** that ensures a tight connection between the threaded drive and the skate mechanism;

- the **four clips** which hold the gasket firmly in place during the insertion/removal operations.

Finally, an additional test to assess the effectiveness of the system to achieve and maintain the vacuum and the leak rate conditions was executed (over hundred **trials- November 2004**).

---

Reliability Trials cont'd

**Prototype Status After The Trials**

- General view of the upper part of the frame
- Status of the inclined planes and of the skate for the lateral part
Reliability Trials cont'd
Prototype Status After The Trials

Lower part of the frame
General view of the frame front backplate face

Prototype Status After The Trials (cont'd)

Status of the backplate
Reliability trials cont'd

Major Results

The trials confirmed the main results already obtained during the remote handling test campaign.

- the prototype is well suited to remote handling (i.e. backplate replacement operations were always completed successfully);
- the replacement repeatability time has been assessed (< 2 days). The replacement time was reduced after the improvement of the prototype and the modification of the replacement procedure (back-plate replacement is presently carried out using only a Tool);
- in general on the parts checked no failures were found, except for the hole in the lower part of the frame that was damaged even though not meaningfully (see next picture);

The trials carried out have demonstrated that damage has not affected the success of the replacement operations, as well as the backplate positioning was always within the range already measured.
Reliability trials cont’d

- the vacuum test confirmed the results obtained during the RH test campaign ( ~20 Nm of torque).
In addition, the backplate positioning repeatability was measured
( $\xi < \pm 0.1 \text{ mm}$ from the average backplate position) and so the repeatability of this operation should stay within this range.

The trials were carried out applying to the screws a torque value within the range 24+27.5 Nm (20+40% overloaded from the torque lower limit to reach the vacuum conditions).

Finally, was noted that reducing the range of the torque applied (24 ÷ 25 Nm) the accuracy of the backplate positioning is increased.
Rescue Procedures

These trials are aimed to assess the behaviour of the prototype under possible failure conditions.

To identify the weaknesses of the prototype FMEA has not been carried out. The idea was to use the results of the reliability trials and the experience gained during the manufacturing and testing.

The following rescue procedures have been selected:
- **Substitution of skate mechanisms** (lower, upper and lateral skate);
- **Renew of the skate drive systems**;
- **The sealing gasket**;
- **The dowel pins** between the backplate and the frame.

---

Rescue Procedures

The most critical components are the skate systems, and of these a failure in the lateral skate appears to be the worst case scenario.

Simulation of a failure disconnecting the skate body from its drive system is ongoing.
Rescue Procedures

A set of tools able to renew the correct working condition on the lateral skate has been designed.

Two tools are required to perform this operation:

• A tool to initially raise the skate. This tool has already been designed and manufactured;
• A tool to complete the operation.
Rescue Procedures

The lifting tool consists of a threaded shaft that allows the plate to be lifted. This tool uses two pins on the plate which are linked below the bolts connected to the body of the skate.

Rescue Procedures

The **second tool** integrates many features:

- A 3 degree of freedom positioning system for the bolting tool;
- A bolting tool;
- A micro camera capable of operation in a low light environment (lighting is expected to be < 1 lux);
- A miniature gripper.
- The control system.
**Rescue Procedures**

The system **has been thought to work laterally to the target.** Despite that all the major failure procedures require the accessibility of the front face of the prototype.

**As example, lateral skate replacement procedure** are here below briefly presented:
- Assuming the front face of the prototype is accessible;
- Disconnect the skate from its drive system using the system already presented (the tool might be used to connect or disconnect the skate);

**1st operation.** Unbolt the screws on the frame as shown in the next Figure;
Rescue Procedures

2nd operation the lateral cover of the skate is removed;

Rescue Procedures

2nd operation. The skate is replaced with a new one.
Finally The assembling procedure is the reverse of the disassembling procedure.
In parallel: Additional activities on the remote handling of a fully bolted bayonet backplate
Methodology approach

The study was performed through the following phases:

1. Radiation transport analysis for neutron spectra evaluations performed via both MCNP-4C2 and VITENEA-IEF/SCALENEA-1 systems for the Test Cell Target zone. Various D-Li neutron source modeling

2. Inventories calculations and decay gamma sources production with ANITA-IEAF activation code package. Neutron activation library based on IEAF-2001 data file.

3. Decay gamma transport analysis for dose rate evaluations performed via both VITENEA-IEF/SCALENEA-1 and MCNP-4C2 systems for the Longest Pipe of the Lithium loop.
Hypothesis

➢ eleven months per year of continuous operation;
➢ no purification of corrosion products for eleven months of operations;

Activation of impurities dissolved in liquid lithium occurs during the passage through the target.

➢ corrosion products generated in eleven months of operations are present in the loop from the beginning of the operation and of the irradiation phase;
➢ uniform distribution of corrosion products in the Li;
➢ all elements included in steel composition are dissolved in the lithium in the same proportions as those in the solid steel;
➢ Only neutron activation considered up to now.

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Activation calculations conditions/parameters

➢ Calculation code: ANITA-IEAF with neutron activation cross section library based on IEAF-2001 up to 150 MeV

➢ Neutron spectrum: calculated by MCNP-4C2 with McEnea source model based on the measurements of neutron emission spectra in Li(d,n) reactions for 40 MeV deuterons performed at the “Cyclotron and Radioisotope Center (CYRIC)”, Tohoku University, Japan

➢ Lithium mix composition: lithium impurities and corrosion products referred to 200 wppm of Steel SS-304 (a corrosion rate 0.16mg/m² · h and a SS-304 surface wetted from Li equals to 572 m²)

➢ Irradiation scenario: burn phase of 1523 s followed by a pulsed phase (910 steps of 4.5 ms burn and 910 steps of 84 s dwell)
➢ Cooling times after shutdown: 1s, 1h, 1d, 7d, 30d, 180d, 1y, 3y

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Decay gamma transport and dose rate calculations

The gamma transport calculations and dose rate evaluations were performed via both VITENEA-IEF/SCALENEA-1 and MCNP-4C2 code systems, as a comparison, using the decay gamma sources from ANITA-IEAF, in the 42-groups Vitamin-J energy structure.

The Sn SCALENEA-1 systems consists of: BONAMI-NITAWL II- XSDRNPM-XSDOSE modules of the Scale 4.4a system with the multi-group cross-section library VITENEA-IEF.

VITENEA-IEF is an intermediate energy coupled 256-neutron (up to 150 MeV) and 49-gamma-ray multi-group (up to 100 MeV) cross-section library in Ampx format, suitable for Sn radiation transport codes. The library was produced by ENEA via the processing of the LANL evaluated files of ENDF/B-VI release 6 and of FZK/INPE files using the NJOY-AMPX-SCALE code systems. The dose rate calculations performed via neutron and gamma fluence to ambient dose equivalent conversion factors, available in literature (ICRP-74 and Ferrari-Pelliccioni evaluation).

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| LI  | 99.973 |
| H  | 0.002  |
| C  | 0.001  |
| N  | 0.001  |
| O  | 0.003  |
| AL | 0.00001|
| SI | 0.00015|
| TI | 0.00001|
| CR | 0.0038 |
| MN | 0.0004 |
| FE | 0.01375|
| CO | 0.00001|
| NI | 0.00181|
| CU | 0.00002|

The results referred to the Longest Pipe are presented.

Longest Pipe:
- Lithium mix composition, radius 10 cm
- Clad SS-304, thickness 8.25 mm
- Length 660cm

Ø 200 mm
Thickness 8.25 mm

6600 mm
Longest pipe - horizontal position
The dose rates (\(\mu\text{Sv/h}\)) referred to the Longest Pipe, calculated on the external surface and at distances of 50 cm, 1m and 5m for the cooling times 1s, 1h, 1day, 1 week, 1 month, 6 months, 1 year and 3 years are given in the following table.

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Detector position</th>
<th></th>
<th></th>
<th></th>
<th>Detector position</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface</td>
<td>50cm</td>
<td>1m</td>
<td>5m</td>
<td>Surface</td>
<td>50cm</td>
<td>1m</td>
<td>5m</td>
</tr>
<tr>
<td>1s</td>
<td>3952</td>
<td>575</td>
<td>307</td>
<td>36</td>
<td>3932</td>
<td>574</td>
<td>304</td>
<td>36</td>
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<td>1h</td>
<td>2844</td>
<td>412</td>
<td>220</td>
<td>26</td>
<td>2823</td>
<td>411</td>
<td>219</td>
<td>26</td>
</tr>
<tr>
<td>1 day</td>
<td>1370</td>
<td>198</td>
<td>106</td>
<td>13</td>
<td>1360</td>
<td>198</td>
<td>105</td>
<td>13</td>
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<tr>
<td>1 week</td>
<td>585</td>
<td>85</td>
<td>46</td>
<td>6</td>
<td>589</td>
<td>86</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>1 month</td>
<td>338</td>
<td>49</td>
<td>26</td>
<td>3</td>
<td>335</td>
<td>49</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>6 months</td>
<td>102</td>
<td>15</td>
<td>8</td>
<td>1</td>
<td>101</td>
<td>15</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>1 year</td>
<td>38</td>
<td>6</td>
<td>3</td>
<td>0.4</td>
<td>38</td>
<td>5</td>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>3 years</td>
<td>7</td>
<td>1</td>
<td>0.05</td>
<td>0.06</td>
<td>6</td>
<td>0.9</td>
<td>0.6</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Dose rates- Longest Pipe (\(\mu\text{Sv/h}\))

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New calculations

The activation results (contact dose rate and decay gamma sources) are strictly dependent on the choice of the boundary conditions.

The main parameters that can influence the study of the activation of Li loop corrosion products are:

- Neutron spectrum
- Corrosion rate
- Irradiation scenario

To assess the impact of the changes of these parameters on the activation response functions, several new calculations have been performed all referred to the Longest Pipe.

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Impact of the neutron spectrum

Up to now we have available the following neutron source models to perform the corrosion products activation calculations:

- McEnea (new neutron source modelling)
- SCALENEA-1 (Sn target modelling-Oyama energy dependent only)
- McDeli (provided by FZK)
- McDelicious (provided by Simakov)
- MCNPX-2.5b internal model

New calculations have been performed with the neutron spectra obtained with the different neutron source models.

<table>
<thead>
<tr>
<th>Neutron spectrum</th>
<th>Dose rates ($\mu$Sv/h)</th>
<th>Contact Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling time</td>
<td>Detector position</td>
</tr>
<tr>
<td>McEnea</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>SCALENEA-1</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>McDeli</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>McDelicious</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>MCNPX-2.5b</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td></td>
</tr>
</tbody>
</table>
Impact of the irradiation scenario

The results related to two different irradiation scenarios were compared (SCALENEA-1 neutron spectrum – 200 wppm corrosion products in Li):

1. burn phase of 1523 s followed by a pulsed phase: 910 steps of 4.5 ms burn and 910 steps of 84 s dwell (the corrosion products pass through the target every 84s, where they will be irradiated for 4.5ms, in total 1527s of beam-on phase in eleven months of operation)

2. eleven months of continuous beam-on operation phase plus 4s of pulsed operation (910 steps of 4.5 ms burn and 910 steps of 84 s dwell)

Dose rates (µSv/h) – Irradiation scenario 1.

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Detector position</th>
<th>Contact Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface 50cm 1m 5m</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>1376 199 107</td>
<td>13 8.40E+03</td>
</tr>
<tr>
<td>1 week</td>
<td>593 86 46</td>
<td>6 3.60E+03</td>
</tr>
</tbody>
</table>

Dose rates (µSv/h) – Irradiation scenario 2.

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Detector position</th>
<th>Contact Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface 50cm 1m 5m 10m</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>3.20E+05 4.75E+05 2.55E+05 3.12E+04 8.90E+03 2.00E+07</td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td>3.00E+06 4.40E+05 2.34E+05 2.87E+04 8.16E+03 1.84E+07</td>
<td></td>
</tr>
</tbody>
</table>

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Impact of the corrosion rate

The results related to two different corrosion rates were compared (SCALENEA-1 neutron spectrum – Irradiation scenario 1.):

1. 0.16mg/m² h (corresponding to 0.2 µ m/y)

1. 1 µ m/y

Dose rates (µSv/h) – 0.2 µ m/y

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Detector position</th>
<th>Contact Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface 50cm 1m 5m</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>1376 199 107</td>
<td>13 8.40E+03</td>
</tr>
<tr>
<td>1 week</td>
<td>593 86 46</td>
<td>6 3.60E+03</td>
</tr>
</tbody>
</table>

Dose rates (µSv/h) – 1 µ m/y

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Detector position</th>
<th>Contact Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface 50cm 1m 5m 10m</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>6.88E+03 9.95E+02 5.30E+02 6.50E+01 1.80E+01 4.20E+04</td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td>2.97E+05 4.28E+02 2.30E+02 2.80E+01 8.00E+00 1.70E+04</td>
<td></td>
</tr>
</tbody>
</table>

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Conclusions

The calculations performed show how relevant are the choices of the activation conditions, neutron spectrum, corrosion rate and irradiation scenario, on the response functions as the dose rates.

Different neutron source models give almost same results for response functions inside the target.

Dose Rates around piping at 50 cm are 200 μSv/h 1 day after shutdown and 85 μSv/h after 1 week cooling time.

Considering the average 20mSv/y regulatory limit in Europe for “Radiation Worker” and the four-week period annual maintenance activities in Li loop these zones, exceeding 125 μSv/h, have to be declared “Restricted Access Areas”.

Evaluation of deuteron induced activation in the IFMIF lithium loop is required.
IFMIF Safety Analyses in UKAEA

Analysis of neutron activation of corrosion products in Li loop, and occupational dose rates: preliminary results

Neill Taylor, Panos Karditsas, Winston Han, Michael Loughlin, Robin Forrest
UKAEA (GB)

Presented by B.Riccardi (ENEA/Frascati)

IFMIF Target Technical Meeting
Tokyo 17 May 2005

Aim of the activity

• Preliminary assessment of Activated Corrosion Products (2004) with TRACT code for prediction of maximum dose rates

• 2005 activity: analysis of direct deuteron activation of Li impurities and corrosion products
Modelling with the TRACT code

- TRACT: UKAEA in-house code
- Models of Activated Corrosion Products in a coolant loop, including representations of
  - corrosion
  - transport of corrosion products around loop
  - activation of corrosion products but no model of multi-step reaction (trans. product from daughter nuclides)
  - re-deposition (plating out)
  - subsequent re-release, etc.
- Originally developed for water coolant loops
  - applied to ITER, fusion power plant assessments
  - also applied to Li loop in a fusion blanket

Assumptions of TRACT analysis

Beam deposition area on Li jet: 0.2 m W x 0.05 m H
Backplate and loop material: AISI 316 (SEAFP)
Loop surface area: 530 m² (without purification loop)
Initial lithium composition: natural isotopic ratio with no impurities
7Be not accounted for (i.e. trapping up to 1appb)
Corrosion rate of SS is $G_c = 1.433 \times 10^{-7} \, t^{-0.3} \, (\text{mum/yr})$
Elements of steel (and impurities) released into lithium in proportion to composition in solid (by TRACT)
Deposition rate of crud particles calculated by using Beal method (by TRACT)
Diffusion in solid calculated by Arrhenius equation (by TRACT)
Assumptions of TRACT analysis (Cont-d)

Geometry of IFMIF Li loop modelled explicitly
- particular attention to Li cooler
- temperature profile around loop represented
- Sixteen nuclides selected for activation calculations
  - based on importance for dose in preliminary calculations
- 2.5 year operation period computed
- FZK neutron spectrum combined with cross section data with FISPACT n activation code using Europ. Activ. System EASY–2004 ➔ results formatted for TRACT
- Activation analysis carried out by TRACT

Results: corrosion products activation

- Results for Li heat exchanger (dominates surface area of loop and representative of average behaviour around loop)
- Three components:
  - coolant: corrosion products in the coolant
  - deposit: ACPs deposited on walls
  - base: atoms migrated back into wall material matrix
- Variation around loop is small. The activity decreases when moving from the quench tank to the Li/jet feed pipe
- The maximum activity is the coolant intermediate in deposit negligible in the base material
- Saturation of dissolved corrosion products reached in ~1 week
- Overall activation equilibrium reached after ~ 300 days
- The effect of backplate direct neutron activation is negligible
Calculation of dose rates from ACPs

- Nuclide inventory from TRACT was the input to FISPACT for calculation of resulting gamma spectra
- Gamma spectra input to MCNP/4C model as source
  - computation of gamma dose rate
  - **two geometries** represented
    - 20 m length of 20 cm-diameter pipe
    - entire Li inventory in spherical volume (≈ to dump tank)
  - doses evaluated: **contact dose** and **1 m distance dose**
  - two source representations used:
    - source distributed in Li volume
      (equivalent to no plating-out of ACPs)
    - source distributed over surface
      (equivalent of complete plating-out of ACPs)

Dose rates at t=0  (no SS shielding)

- Shielding by pipe/tank wall not accounted for
- These are mid-range values - but there is only ±20% variation around loop

<table>
<thead>
<tr>
<th>20 cm diameter pipe</th>
<th>Contact Dose Rate (Sv/hr)</th>
<th>1m Dose Rate (Sv/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform volume</td>
<td>0.35</td>
<td>0.024</td>
</tr>
<tr>
<td>Plated out</td>
<td>1.12</td>
<td>0.025</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Full Li inventory in sphere</th>
<th>Contact Dose Rate (Sv/hr)</th>
<th>1m Dose Rate (Sv/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform volume</td>
<td>11.2</td>
<td>2.23</td>
</tr>
<tr>
<td>Plated out</td>
<td>63.4</td>
<td>3.86</td>
</tr>
</tbody>
</table>

Plating out on 20 cm diam. tube affects the contact dose rate by a factor 3 and has no effect on 1 m dose rate

Plating out on sphere affects the contact dose rate by a factor 6 (due change in contact flux + and gamma energy spectrum) and has some effect on 1m dose rate
Effect of shielding by SS316

20cm pipe calculations with the inclusion of an 8.2 mm SS316

The dose rate in such a case is insensitive to assumptions about
the distribution of the source, provided it remains axially
symmetric. (the scattering in the pipe wall destroys the
directional information of the photons)

Negligible effect of plating out.

<table>
<thead>
<tr>
<th>CYLINDRICAL GEOMETRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Distribution</td>
</tr>
<tr>
<td>Uniform volume</td>
</tr>
<tr>
<td>Plated out</td>
</tr>
</tbody>
</table>

Dose Rate as a Function of Decay Time
Calculated by FISPATC code
Relevant for maintenance

Contact and 1 m dose rates for 20 cm piping with 8.2 mm SS316 walls
Conclusions

Based on the initial results of this analysis:

- Maximum personnel dose rates due to ACPs, during operation (at the instant of shutdown), in the vicinity of a large Li tank, are high
  - 11 Sv/hr in contact, 2.2 Sv/hr at 1 m.
- Maximum doses from pipework carrying Li, 1 hour after shutdown
  - < 100 μSv/hr in contact, < 10 μSv/hr at 1 m.

- There are considerable uncertainties in this analysis, e.g.
  - corrosion rates
  - solubility data
- Dose rates could, of course, be substantially reduced by filtering of corrosion products and impurities
Accessibility of the IFMIF Liquid Lithium Loop


IFMIF Target Technical Meeting
JAERI Tokyo
May 17, 2005

CONTENTS

1. Objectives
2. Accessibility to the Li Loop
3. Properties of Be-7 deposition
4. Measures for hands-on maintenance
5. Summary
1. Objectives

To examine worker safety and maintenance scenario worker dose around Li loop was estimated.

Estimated radiation sources:
Erosion and corrosion of BW:
1 \mu m/year x 1 year
Equilibrium Be-7: 4.21 \times 10^{15} \text{ Bq}

2. Accessibility to the Li Loop

The analyses were done for two types of sources.

<table>
<thead>
<tr>
<th>Code: ACT-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activation of Backwall</td>
</tr>
<tr>
<td>n-316LN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code: QAD-CGQP2R</th>
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</thead>
<tbody>
<tr>
<td>Production of Be-7</td>
</tr>
<tr>
<td>\tau_{1/2}=53d</td>
</tr>
</tbody>
</table>

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<tr>
<th>Code: QAD-CGQP2R</th>
</tr>
</thead>
<tbody>
<tr>
<td>\tau_{1/2}=53d</td>
</tr>
</tbody>
</table>

Production = Decay
= 4.21 \times 10^{15} \text{ Bq}
0.33 g (0.072 wppm in 4.5 t-Li)
E_p = 0.48 \text{ MeV}
3.1 Activation Calculation of Backwall

Calculation Procedure and Conditions:
- Calculation code:
  ACT-4 of THIDA-2 system
- Cross section:
  ACT-4 (< 15 MeV)
  IEAF-2001 (>15 MeV)
- Back wall material:
  Stainless steel 316LN
- Neutron flux:
  data by McDelicious
- Neutron irradiation:
  1 year with 250 mA operation

Neutron Flux on Back Wall
(D-Beam: 40MeV, 250mA, 50 mm x 200 mm)

Decay of radioactivities of main RIs in the IFMIF back wall

Total activation:
3.1x10^{14} Bq/kg (1 day after beam stop)
7.5x10^{13} Bq/kg (1 year).

Dominant Nuclides:
Co-58 ($\tau_{1/2} = 2.3$ month)
Co-56 ($\tau_{1/2} = 2.5$ month)
Mn-54 ($\tau_{1/2} = 10$ month)
Co-57 ($\tau_{1/2} = 8.9$ month)
3.2 Corrosion rate evaluation

Based on existing data, corrosion rate of the 316LN has been preliminary selected to be 1 μm/year at 300 °C.

For 316SS, 1 mg/m²·hr=1.1 μm/year

At 300 °C (1000/T(K)=1.745), the corrosion rate in the existing data is 0.06 μm/year.

Considering Li speed effect on the corrosion rate and safety margin, the corrosion rate of 316SS for dose rate calculation is selected to be 1 μm/year.

3.3 Dose Rate Calculation

Calculation Conditions;
- Calculation code: QAD-CGGP2R code
- Source-1: 100 cm² for back wall foot print, with corrosion: 1 μm/year x 1 year
- Source-2: Equilibrium Be-7 of 4.21 x 10¹⁵ Bq
- Inner surface area of Li loop: 572 m²
- Criteria of hands-on maintenance: 10 μSv/hr
- Model: Piping with 10 m in length and 0.25 m in diameter
Result

Dose equivalent rate is dominated by Be-7. The value is several orders higher than the criteria at beam stop, and still high in the maintenance duration of 1 month.

![Graph showing dose equivalent rate as a function of distance from Li pipe (m).](image)

Effect by activated BW

![Graph showing dose equivalent rate as a function of distance from Li pipe (m).](image)

Effect by Be-7

---

3. Properties of Be-7 deposition

Be-7 deposition was examined by Beryllium-7 Experimental Lithium Loop (7BELL) in FMIT project. (H. Katsuta et. al, Transport of Beryllium-7 in a Lithium Loop)

**Test Condition**

- $T_{Li}: 230, 250, 270 \, ^\circ C$
- $U_{AV}: 1.2, 1.5 \, m/s$
- $C_N: 130 \, \text{wppm}$
- 3700 hr Operation

**Materials of Coupon in Legs:**

Y, Zr, Ti, 304, ...

![Schematic of 7BELL](image)
Be-7 deposition on pipes depending on temperature

Deposition remarkably depends on temperature.

Deposition ratio was 10 : 4 : 2 for 230, 250 and 270 °C

→ Recommend Cold Trap

(Typical temperature is 250/285 °C at main loop, 200 °C at C.T. in IFMIF)

Be-7 deposition on coupons depending on material

Deposition significantly depends on material.

Y was most effective, with increasing surface area due to crack.

Al-coated was second.
The others were same.
Temp. gave some effect.
Discussion on deposition material

There are types of deposition;

- Most Be as Be$_3$N$_2$ at Cold region, or under High C$_{Be}$
  In spite of $d_{Be3N2} = 2.7$ g/cc, there was no effect of gravity.
  Solubility of Be$_3$N$_2$ in Li is 0.0005 appm (~0.0035 wppm) at 227 °C
  (C$_{7Be}$ is 0.072 wppm in IFMIF loop under equilibrium condition)

- Remainder as unbound Be at Hot region, or under Low C$_{Be}$
  Diffusion into austenitic steel was estimated.
  Depth of penetration: 5.5 μm at 270 °C after 4000 hr operation.
  Calculated diffusion coefficient was $5.3 \times 10^{-15}$ cm$^2$/s
  (R. P. Anantatmula et. al, Control of Beryllium-7 in Liquid Lithium)

4. Measures for hands-on maintenance

Limit of worker dose: 100mSv/5years (ICRP recommendation) should be achieved by measures as follows;

- Radiation shielding
  to reduce γ-ray with a energy of 0.48 MeV by Pb shield

- Scenario of maintenance
  Employment of remote-handling device
  Control of access area and working time
5. Summary

- Radioactivity of the back wall calculated by the ACT-4 is $3.1 \times 10^{14}$ (1 day after beam stop) and $7.5 \times 10^{13}$ Bq/kg (1 year).

- Most of dose equivalent rate calculated by QAD-CGGR2R is that by Be-7. The rate is $10^5 - 10^6 \, \mu \text{Sv}/\text{h}$ on a pipe after 1 month, which is several orders higher than the criteria $10 \, \mu \text{Sv}/\text{h}$.

- Most of Be-7 would deposit as Be$_3$N$_2$ at Cold region.

- Besides cold trap, radiation shielding and maintenance scenario should be examined to control worker dose below 100 mSv/5years.

Future Works

- Activation calculation of RAF (F82H etc.) materials.
- Radiation dose rate around major components in the Li loop (EMP, Heat exchanger, Traps)
- Activation of Li impurities by deuteron beams
- Design of shielding / remote-handling for Li component
- Examination of maintenance scenario of Li loop
Thermo-Structural Analysis of Target Backwall in IFMIF

H. Nakamura¹, M. Ida¹, K. Shiba¹, K. Shimizu²

1 Japan Atomic Energy Research Institute
2 Mitsubishi Heavy Industries, Ltd.

IFMIF Target & Test Facilities Technical Meetings
May. 17-18, 2005, Tokyo, Japan

CONTENTS

1. General Design requirements
2. Background
3. Thermo-structural analysis
4. Summary and Future Plan
1. General Design Requirements

-Curved configuration to avoid Li boiling.
- Smooth surface compatible with high speed Li flow.
- Reliability under neutron irradiation of 50 dpa/y.
- Replaceable attachment structure by remote maintenance.

Target Assembly in 2004/2005 design (welding&cutting option)

2. Background

Previous results in 2004

• High heat transfer coefficient \( (\alpha) \) between BW and TG assembly reduces significantly induced stress and deformation.
• In case of \( \alpha = 15.8 \text{ W/m}^2\text{K} \) (contact pressure: 0.1 MPa) and \( t_{BW} = 1.8 \text{ mm} \), stress and deformation are 504 MPa and 2.2 mm, respectively.
• In case of \( \alpha = 150 \text{ W/m}^2\text{K} \) (contact pressure: 1 MPa ) and \( t_{BW} = 1.8 \text{ mm} \), stress and deformation are 270 MPa and 0.3 mm, respectively.

FY2005 task -> Effects of BW thickness, material and configuration on stress and deformation
3. Thermo structural analysis

- Calculation Code : ABAQUS v6.4.1
- Material : 316L Stainless Steel
  (Alternative material : RAF-F82H)
- Material data : un-irradiated value
- Minimum thickness of BW : 1.8 mm (ref), 3 mm, 5 mm
- Heat transfer coefficient between BW and TG assembly:
  15.8 W/m²K @ contact pressure, 0.1MPa
- Heat transfer coefficient between BW and Li:
  34 kW/m²K @ Li flow speed, 20m/s
- Constraint conditions:
  Free in azimuthal & radial directions
  Rigid in rotation
Model and Nuclear Heating Rate

- **25 W/cm\(^3\) at center**

- **Constraint Position**
  - \(0.715 \text{ m}, 15 \text{ mm}\)
  - \(0.25 \text{ m}\)

- **Contact Face**
  - \(X = 0 \text{ m}\)

- **Target Assembly Side**
- **Test Assembly Side**

**Backwall model**

Nuclear Heat in Backwall
(MCNP calculation by I. C. Gomes)

Calculation model of ABAQUS

- **Model**: 1/4 section of backwall
- **Number of elements**: 35170
- **Number of nodes**: 40338
- **Constraint conditions**
  - Free in azimuthal and radial directions
  - Rigid in rotation
Deformation Length
(dependence of BW thickness and thermal contact coefficient)

Reduction of deformation length is not significant by increasing backwall thickness. Improvement of thermal contact is a key issue.

![Graph showing deformation length vs. minimum thickness of backwall]

\[ \alpha = 15.8 \text{ or } 150 \text{ W/m}^2\text{-K} \]

Deformation of backwall

FY2005: Dependence of BW thickness under good thermal contact condition.

---

Temperature and von Mises stress (t=5 mm, \( \alpha = 15.8 \text{ W/m}^2\text{-K} \))

- Max. temperature: 445 °C (t=1.8mm) -> 451 °C (t=5mm)
- von Mises stress: 504 MPa (t=1.8mm) -> 487 MPa (t=5 mm)

![Temperature contour (TF side) and von Mises stress contour (Beam side)]

(Free in Y, Z directions)
von Mises Stress
(dependence of BW thickness and thermal contact coefficient)

Similar to deformation, reduction of the Mises stress is also not significant as increasing BW thickness.

3D contour of von Mises stress (t=5 mm, α=15.8 W/m/K)

Stress Category and Limits

Stress Category
Primary Stress : General Membrane ($P_m$)
Local Membrane ($P_L$)
Bending ($P_b$)

Secondary Stress :
Secondary Membrane+Bending ($Q$)
Peak Stress ($F$)

Stress Limits

\[
\begin{align*}
&P_m < S_m \\
&P_L + P_b < 1.5 S_m \\
&P_L + P_b + Q < 3 S_m \\
&P_L + P_b + Q + F < S_a
\end{align*}
\]

$S_m = \min \{1/3 S_T, 2/3 S_Y\}$

In present design, the stress limit is tentatively defined as follows;
$Q < 1.5 S_m$ where $P_L, P_b, P_m = 0$
According to present data base, neutron irradiation increase tensile and yield strength by a factor of 3.

At 330 °C, $1.5S_m$ values are
250 MPa (unirradiated)
~750 MPa (7 - 16 dpa)
(Material data base; K. Shiba)

Considering early stage of IFMIF operation, unirradiated value is selected as a permissible value (250 Mpa@330°C). Further evaluation on peak stress, fatigue, creep, He effect, etc. are needed.

---

4. Summary and Future Plan

Summary

- By increasing BW thickness from 1.8 mm to 5 mm, reductions of deformation and induced stress are not significant.
- In case of 5 mm thick BW with $\alpha = 15.8$ W/m²·K, von Mises stress and deformation of BW are 487 MPa and 1.7 mm, respectively.
- Considering early stage of IFMIF operation, unirradiated value is selected as a permissible value.
- More efforts to reduce induced thermal stress and deformation are needed.
Future plan

- Thermal-structural analyses
  (thermal contact coefficient, peak stress, RAF material, irradiated material data, etc.)

- Update of backwall design
  (configuration, clamp mechanism, cooling method)

- Hydrodynamic effect of backwall deformation

- In EVEDA, experimental validation of thermo-structural behavior of the backwall and target assembly is needed.
- In conjunction with Users group, evaluation of fatigue, creep, He effect is needed.
INTERNATIONAL FUSION MATERIALS IRRADIATION FACILITY (IFMIF)

Thermomechanical analysis of the Li-target backplate: preliminary results

B. Riccardi, S. Roccella (ENEA Frascati)

IFMIF Target Technical Meeting
Tokyo 17 May 2005

Objectives

**Design integration study** of the backplate in the target load assembly in order to have an accurate geometry for the Finite Element Modelling.

**Thermal analysis**
2D nuclear heat generation distribution calculated by Simakov during TW4 IFMIF activities.

The heat exchange thermal convection with Li lithium, thermal contact between backplate and target assembly and no radiation for the other surfaces.

**Mechanical analysis** to estimate the stress-strain field for a backwall material reliability analysis and to estimate the deformed shape which is of great importance for the Li flow stability.
Design integration

Option 1: massive backplate

Option 2: thin backplate
Bayonet Backplate integration

Option 1: massive backplate
FEM model

- Nodes: 46096
- Elements: 36445
- Element types: DC3D8
- Analysis type: Sequential Thermal-Stress Analysis.
- Elastic analysis

Thermal analysis

Neutron heat generation
(S. Simakov 2005)

Boundary conditions

Case 1
- Li heat transfer coefficient 34000 W/m²K
- Contact heat transfer coeff. 2000 W/m²K
- Full contact Backplate-TG assembly
- Boundary Temperature 300 °C
- Radiation not considered

Case 2
- Li heat transfer coefficient 34000 W/m²
- Contact heat transfer coeff. 2000 W/m²K
- Partial contact Backplate-TG assembly
- Boundary Temperature 300 °C
- Radiation not considered
Results Case 1

Full thermal contact Backplate-TG assembly
Backplate clamped on TG assembly (u3=0) + bolts
Material: AISI-316 LN

Temperature (°C)

Max Mises 420 MPa

Results - Case 1 Cont'd

Deformed shape

\( U_{\max} = -0.05 \text{mm} \quad U_{\min} = 0.23 \text{mm} \)

\( U_{\max} = 0.17 \text{mm} \quad U_{\min} = -0.09 \text{mm} \)

\( U_{\max} = -0.21 \text{mm} \quad U_{\min} = 0.09 \text{mm} \)
Results Case 2

Partial thermal contact Backplate-TG assembly
Backplate partially clamped on TG ass. + bolts
Material: AISI 316 LN

Temperature (°C)

Results of mechanical analysis - Case 2 Cont'd

Deformed shape

$U_{\text{max}} = -0.11\text{mm}$
$U_{\text{max}} = 0.36\text{mm}$

$U_{\text{min}} = 0.29\text{mm}$
$U_{\text{min}} = -0.03\text{mm}$

$U_{\text{min}} = -0.27\text{mm}$
$U_{\text{min}} = 0.41\text{mm}$
Option 2: thin backplate

FEM model

Nodes: 25688
Elements: 19879
Element types: C3D8
Analysis type: Sequential Thermal-Stress Analysis
Elastic analysis
Results Case 1

Full thermal contact Backplate-TG assembly
Backplate clamped on TG assembly (u3=0) + bolts
Material: AISI 346 LN

Max Mises 81 MPa

Temperature (°C)

Results - Case 1 Cont’d

Deformed shape

$U_{\text{max}} = 0.05$ mm $U_{\text{min}} = -0.04$ mm

$U_{\text{max}} = 0.06$ mm $U_{\text{min}} = -0.01$ mm

$U_{\text{max}} = 0.23$ mm $U_{\text{min}} = -0.01$ mm
Results: Case 2

Partial thermal contact Backplate-TG assembly
Backplate partially clamped on TG ass. (u3=0) +
bolts
Material: AISI 316 LN

Temperature (°C)

Max Mises 230 MPa

Results Case 2 Cont'd

Deformed shape

\[ U_{\text{max}} = 0.24 \text{ mm} \quad U_{\text{min}} = -0.02 \text{ mm} \]

\[ U_{\text{max}} = 0.14 \text{ mm} \quad U_{\text{min}} = -0.003 \text{ mm} \]

\[ U_{\text{max}} = 0.18 \text{ mm} \quad U_{\text{min}} = -0.17 \text{ mm} \]
### Results: Case 2

Partial thermal contact Backplate-TG assembly
Backplate partially clamped on TG ass. (u3=0) + bolts

**Material:** F82H

Max Mises 98 MPa

Temperature 364°C

---

### Option 1: Massive Backplate

<table>
<thead>
<tr>
<th>Boundary conditions</th>
<th>$T_{max}$ (°C)</th>
<th>$\sigma_{M}$ (300°C)</th>
<th>Mises max (MPa)</th>
<th>Max. displ. U3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li heat transfer coefficient Contact heat transfer coeff. Boundary Temperature 300°C Full contact Backplate-TG assembly</td>
<td>34000 W/m²K 2000 W/m²K</td>
<td>Uninf.</td>
<td>470</td>
<td>135</td>
</tr>
<tr>
<td>Li heat transfer coefficient Contact heat transfer coeff. Boundary Temperature 300°C Partial contact Backplate-TG assembly</td>
<td>34000 W/m²K 2000 W/m²K</td>
<td>Uninf.</td>
<td>470</td>
<td>135</td>
</tr>
</tbody>
</table>

### Option 2: Thin Backplate

<table>
<thead>
<tr>
<th>Boundary conditions</th>
<th>$T_{max}$ (°C)</th>
<th>$\sigma_{M}$ (300°C)</th>
<th>Mises max (MPa)</th>
<th>Max. displ. U3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li heat transfer coefficient Contact heat transfer coeff. Boundary Temperature 300°C Full contact Backplate-TG assembly</td>
<td>34000 W/m²K 2000 W/m²K</td>
<td>Uninf.</td>
<td>408</td>
<td>120</td>
</tr>
<tr>
<td>Li heat transfer coefficient Contact heat transfer coeff. Boundary Temperature 300°C Partial contact Backplate-TG assembly</td>
<td>34000 W/m²K 2000 W/m²K</td>
<td>Uninf.</td>
<td>418</td>
<td>120</td>
</tr>
</tbody>
</table>

### F82H

| Li heat transfer coefficient Contact heat transfer coeff. Boundary Temperature 300°C Partial contact Backplate-TG assembly | 34000 W/m²K 2000 W/m²K | Uninf. | 364 | 452 | 98 | n.a. |
Conclusions

Design integration of bayonet backplate on to target assembly has been carried out

Integration is feasible but interaction with VTA is an issue

Preliminary results of thermal-mechanical analysis of bayonet backplate concept (massive and thin option) indicate that:

when the backplate is made of AISI316L the maximum stress generally exceed the elastic limit therefore the use of RAFM steel is required.

the thermal displacements produce a limited deviation of liquid lithium-backplate wall profile.
INTERNATIONAL FUSION MATERIALS IRRADIATION FACILITY (IFMIF)

Lithium purification, corrosion and monitors

Presented by B.Riccardi (ENEA Frascati)

Contributors: A.Aiello, A.Gessi (ENEA Brasimone) A.Lind (SV-Studsvik)

IFMIF Target Technical Meeting
Tokyo 17 May 2005

Operating parameters
- Liquid metal inventory: about 20 kg
- Mass flow rate: 0.162 kg/s
- Maximum T: 450°C
- Minimum T: 250°C
- Maximum Li velocity: 12 m/s
- Minimum Li velocity: 2 m/s

Detail of test rig
Lifus 3 commissioning

- Before starting the loop safety authorities asked a series of tests in water to fully qualify the loop;
- During those tests a series of needed modification were evidenced → the manufacturer was asked to readapt the loop to respect safety and quality rules
- Some lines have been substituted and some welds have been redone;
- The magnetic mass flow rate was replaced with a Vortex type one;
- A new water qualification test was performed using the final specimens.
- The final approval of the safety authorities was in mid October.
- Li was charged in mid December 04
- A system for lithium sampling in vacuum was installed on the auxiliary loop to perform off line measurement of impurities.

Lifus 3 experiment

- The LIFUS 3 loop work is focussed on corrosion tests over EUROFER 97 and AISI 316L steels, as well as on lithium monitoring experiments.
- The tests started in March 2005.
- Each experimental run is of 1000 hours and coupled with sampling and analyses techniques for the liquid Li.
- The total duration of the tests is 3000 hours.
- The corrosion tests at a temperature of 350°C with a liquid metal velocity of about 19-20 m/s (in the test section).
- Activity stopped due to the pump failure after about 30 hour of discontinuous working.
Impurity monitoring & purification

- In the first step the Lithium will be characterized by means of an offline sampling.
- In the second step, cold traps and hot traps will be coupled with this sampling technique. The sampling and the traps will test each other.
- In the third phase, sensors for dissolved impurities, developed together with the School of Chemistry, Nottingham, (N$_2$, O$_2$, C, H$_2$) will be added to the facility, thus improving the Li characterization.

Lithium offline sampling

- Liquid Li will be sampled at definite intervals by means of a swagelock vacuum container.
- The sampling will check the dissolved impurities concentration
- Preliminary Li data (expected with no trapping) at 350°C:
  - Hydrogen: below 1000 ppm
  - Nitrogen: below 10000 ppm
  - Oxygen and Carbon: up to 50 ppm

![Graph of solubility of non-metal impurities in Lithium as a function of temperature.](image-url)
Li off line analysis (first step)

Hydrogen determination:
A Li sample will be sealed in a iron capsule ➔ heating at 700°C ➔ Hydrogen diffusion into a sweeping gas ➔ H2 oxidized to water by hot copper oxide. The resulting water will be measured with a commercial sensor. Sensitivity: 5 wppm.

Nitrogen determined by dissolving the sample in hot water thus giving ammonia, then measured potentiometrically. Sensitivity 1 wppm.

Electrical resistivity methods (1 wppm sensitivity) by means of a steel capillary. Sensitivity is 1 wppm (Kreffield et al., JCM Dalton, 1974)

Carbon will be measured also by water dissolution ➔ via acetylene. The hydrocarbons will be separated cryogenically and flushed and measured by a flame ionization detector. Sensitivity 0.01 wppm.

Oxygen still represent a difficult task. Activation analyses seem to be the best approach, as well as spectroscopic techniques.

The equipment at ENEA labs, is a simultaneous oxygen and nitrogen analyser for the analysis of metals, ores, carbides, minerals. The analyser consists of a high power electrode furnace where a pre-weighted sample is combusted in a helium atmosphere. The resulting CO₂ is measured by solid state infrared detectors and N₂ is measured by thermal conductivity detectors. The sensitivity is < 10 wppm.

---

Hot and Cold traps design principles

STATUS Getter material selected; traps designed and going manufactured

- Aim is to reduce C, H, N, O concentration below 10 wppm

- Traps system:
  - Cold Trap
    - Aisi 304 mesh
  - Yttrium intermediate Trap (H)
    - Yttrium (getter) mesh
  - Hot (Titanium) Trap (N)
    - Titanium (getter) mesh

- Residence time: 300 s
- The 3 traps will be placed inside a glove box
Cold Trap (CT)

- Mass flow rate: 0.44 g/s = 0.87 cm³/s
- Temperature: 200 °C
- Heat Exchanger:
  - Lithium-Air
  - 189 W exchange
- Total CT Volume: 272 cm³
  - Aisi 316 Mesh: ≈ 12 cm³
- Aim is to get to:
  - H → 63 wppm
  - C → 2 wppm
  - N → 1447 wppm
  - O → 7 wppm

Yttrium intermediate Trap
(YP)*

- Mass flow rate: 0.44 g/s = 0.88 cm³/s
- Temperature: 280 °C
- Heater
  - 150 W requested
- Total YT volume: 300 cm³
  - Yttrium mesh = 36 cm³
- Aim is to get to:
  - H concentration below 10 wppm

* System will be equipped with a by-pass to avoid contamination of the Yttrium grid with Nitrogen
Hot Trap (HT)

- Mass flow rate: 0.44 g/s = 0.92 cm³/s
- Temperature: 550 °C
- Heater
  - 646 W requested
- Total HT volume: 341.75 cm³
  - Titanium mesh ≈ 41 cm³
- Aim is to get to:
  - N concentration below 10 ppm

Offline analytical methods: preliminary data

The resistivity metering for dissolved Nitrogen

The measured specific resistivity is proportional to the dissolved Nitrogen concentration, according to the equation:

\[ \rho/\Omega m = 16.476 \times 10^{-8} + 4.303 \times 10^{-10} T_C - 2.297 \times 10^{-13} T_C^2 \]

A first batch of as-received Lithium is being tested. It comes saturated in all dissolved impurities, thus allowing a validation of the analytical methods.

Correlation between resistivity and Nitrogen concentration (Kreffield et al., JCS Dalton, 1974, 2325-2329). This calibration correspond to saturated Li in Nitrogen.
Equilibrium foils method

The equilibrium foil method, coupled with spectroscopic techniques, can be effective in revealing Nitrogen and Oxygen, but still the technique is under development.

The tests are being performed in a small glove box. A sample of Li is put in an alumina crucible, insulated and warmed.

Test temperature is set at 450°C. Ar atmosphere is kept by means of external gas inlet.

The measurement itself is performed by means of a small AISI steel foil (0.10mm thickness; 10mmx30mmm dimensions) that must be kept inside the liquid Li sample for at least 500 hours. A 30 Angstrom ca. surface layer is then in equilibrium with the Li itself, having formed Cr hydrides and Fe and Cr oxides.

The foils will then be carefully cleaned and analyzed by means of X-ray fluorescence and diffractometry.

X-ray diffractogram of an equilibrium foil.

Peak list selection for Austenite and Iron Nitride.

X-ray Fluorescence spectrum, with Nitrogen signal enhanced.
Proof of concept is provided by the determination of resistivity data for solutions of nitrogen in liquid lithium as a function of time, composition and temperature.

The dominant feature of the resistivity-composition isotherms is a linear increase in resistivity with nitrogen composition.

The minimum nitrogen concentration which can be measured at that temperature is 0.007 mol % N (140 wppm N).

Resistivity-composition isotherms for solutions of nitrogen in liquid lithium at 400°C
Examples of the use of the meter to monitor nitrogen composition

The changes in resistivity observed on addition of nitrogen to liquid lithium in the presence of chromium and vanadium show the viability of the meter as a method of monitoring N composition.

It is shown that chromium and vanadium are very effective in removing nitrogen from liquid lithium. Experiments with titanium are on-going.

For both metals, the amount remaining in solution is less than the minimum, which can be measured by the meter [0.007 atom % N (140 wppm N)].

N introduced in small aliquots obtaining non-equilibrium resistivity-time data

When getter is exhausted the resistivity remains constant.

**Non-equilibrium resistivity-time data for addition of nitrogen to lithium containing 0.72 mol % chromium (pellets) at 475°C**

**Equilibrium resistivity-composition for the addition of N to liquid lithium containing 0.72 mol % chromium at 475°C**

Verification of back-plate sealing performance against Li-infiltration and corrosion-induced damage based on the bayonet back-plate concept (SV-Studsvik–Sweden)

**Objectives:**

Study the interaction of liquid lithium with Helicoflex HNV 200 and stainless steel.

Expose the sealing in Li environment for one month at 200, 250 and 300 C in a He atmosphere

Exposure duration : 1 month

Characterise by SEM and another advanced instrument, the Li-corrosion damage of Helicoflex HNV 200

Propose a preventive approach against the back plate sealing leakage
Development of a dedicated clean-up system for dissolved and magnetic species in the liquid Li (VR-Studsvik-Sweden)

Objectives:
To make a literature study to better understand the interaction between lithium and other metals and how to characterise the dissolved Li-Metal corrosion products (useful analytical techniques), and possibly exiting methods for separation of the corrosion products from the lithium.
To use the magnet approach to separate magnetic corrosion products from the liquid lithium.
Osaka University Li loop experiment shown severe SUS304 corrosion at grain boundaries and large dissolution of chromium at surface. Dissolution of iron, chromium and nickel resulted in the formation of a thin spongy ferrite layer.
The purification must include both the dissolved non-metallic impurities and metallic species (Ni, Cr, Fe).
From experience on LiPb system, magnets can be effectively used to seize/remove a large fraction of dissolved corrosion products from the loop system piping. ➔ Interest in examining the efficiency of the magnet approach for liquid lithium.

Experimental set-up
A stainless steel piece is introduced into a container made of stainless steel.
One container in each set up is then filled with liquid lithium which is kept for one month at 300 °C.
The hot Li is then poured into another container passing a magnet with possibility to regulate the magnetic force ➔ The magnetic species in the Li will be caught.
Two experiment/magnetic field will be performed. Two different magnetic field levels will be used starting with 1 T.
The collection efficiency is then calculated using the caught amount of metallic species on the magnet and the analysed amount of the dissolved metal.
The dissolved amount of Ni and Fe in the Li metal will be analysed by ICP or another suitable instrument.

![Diagram of the experimental set-up](image-url)
Li purification, corrosion and monitors

N. Loginov, M. Arnoldov, V. Morozov
IPPE, Obninsk, Russia

Basic problems

- Analysis of the impurity sources in IFMIF circulation loop
- Selection of optimal methods for determination of impurity concentration and for purification of lithium
- Development and manufacture of devices for impurity concentration monitoring and for purification of lithium
- Experimental study of devices for monitoring and purification
Lithium Test Facility (LTF)

Lithium volume - 0.06 m³
Flow rate - up to 10 m³/h
Temperature - up to 450⁰C
Electrical power - 200 kW

Facility include:
- electromagnetic pump,
- cold trap,
- plug indicator,
- sampler-distiller,
- tube sampler etc.

LTF is a part of the LTF-M
Results obtained on LTF

Residual gases after degassing (%)

<table>
<thead>
<tr>
<th>°C</th>
<th>Pa</th>
<th>Ar</th>
<th>H₂O</th>
<th>CO⁺</th>
<th>CO₂</th>
<th>N₂</th>
<th>O₂</th>
<th>OH</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.10⁻⁴</td>
<td>0.0</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>4.10⁻³</td>
<td>0.5</td>
<td>6.0</td>
<td>51</td>
<td>7.0</td>
<td>0.1</td>
<td>1.8</td>
<td>1.8</td>
<td></td>
</tr>
</tbody>
</table>
Basic results

- Two cycles purification of lithium by means of cold trap have been performed
- Chemical analysis of lithium samples from the tube sampler after each cycle was carried out
- Metallic impurities contents in Li was small
- The combined method (cold trap + chemical method) of the nitrogen removal from lithium was investigated

<table>
<thead>
<tr>
<th>Impurity</th>
<th>№ 1</th>
<th>№ 2</th>
<th>№ 3</th>
<th>№ 4</th>
<th>№ 5</th>
<th>№ 6</th>
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<tr>
<td>Fe</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
<td>50</td>
<td>&lt; 30</td>
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<td>340</td>
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<tr>
<td>Cr</td>
<td>60</td>
<td>70</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>540</td>
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<tr>
<td>Ni</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
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<tr>
<td>Mn</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
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<tr>
<td>Ca</td>
<td>80</td>
<td>60</td>
<td>80</td>
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<td>Mg</td>
<td>&lt; 10</td>
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<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>200</td>
<td>350</td>
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<tr>
<td>Be</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
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<td>&lt; 30</td>
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<td>&lt; 30</td>
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<tr>
<td>Na</td>
<td>8.5</td>
<td>8.8</td>
<td>9.2</td>
<td>9.0</td>
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<td>K</td>
<td>3</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td>N</td>
<td>483</td>
<td>452</td>
<td>424</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Basic results

Sampler distiller was tested

- Temperature of distillation: 700°C
- Distillation time: 5 h
- Min. Oxygen concentration: 1-2 ppm
- Max. Oxygen concentration: 2000 ppm
- Accuracy: ± 20%

Basic results

Tube sampler for Nitrogen, Carbon and metallic impurity monitoring was tested

- Range of operation temperature: 200-350°C
- Min. concentration (Nitrogen, Carbon): 1-2 ppm
- Max. concentration (Nitrogen, Carbon): 2000 ppm
- Accuracy: ± 20%
- Method: chemical analysis
Basic results

Plug indicator was tested
- Primarily for Hydrogen
- Range of operation temperature 200-350°C
- Min. concentration 100 ppm
- Max. concentration 1000 ppm
- Accuracy indicator

Basic results

Purification of motionless Li by means of soluble getters was investigated
Lithium volume 5 l
Temperature up to 400°C
Installation include:
- Container for initial lithium
- Container for chemical purification
- Filter
- Container for filtered lithium
- Sampler
Basic results

Purification of Lithium. Soluble getters

<table>
<thead>
<tr>
<th>Getter</th>
<th>Impurity</th>
<th>Temperature, °C</th>
<th>Initial concentration, ppm</th>
<th>Final concentration, ppm</th>
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</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Oxygen</td>
<td>350</td>
<td>10-20</td>
<td>1-2</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Nitrogen</td>
<td>350</td>
<td>50-100</td>
<td>2-5</td>
</tr>
</tbody>
</table>

Rotating disk facility

Modernized facility includes
- Rotating assembly
- Pool with liquid Li
- Loop for purification of Li in the pool and impurity monitoring
- Oxygen electrochemical cell
- Plug indicator
- Cold and hot traps
Rotating disk facility

Test section, rotary actuator, and transmission were modernized

Rotating disk facility equipment

Sampler
Rotating disk facility equipment

Electrochemical cell test section

Rotating disk facility

Program:

1. Startup investigation
   (end of May – middle of July)
   - Calibration of loop volume
   - Vacuum testing
   - Degassing
   - Filling loop with Li
   - Research of wettability period
   - Li purification by cold and hot traps
   - Determination of Li impurity state
Program:
2. Investigation of corrosion/erosion interaction of Li with stainless steels (July – September)
   - Testing samples of X18H10T steel at 300°C during 100 hours
   - Testing samples of 316SS at 270°C during 500 hours
   - Metallography of samples

Testing regimes

<table>
<thead>
<tr>
<th>Rotation speed, rpm</th>
<th>Centrifugal force, g</th>
<th>Velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>2184</td>
<td>160</td>
<td>6.86</td>
</tr>
<tr>
<td>2760</td>
<td>255</td>
<td>8.67</td>
</tr>
<tr>
<td>6366</td>
<td>1359</td>
<td>20.00</td>
</tr>
<tr>
<td>7400</td>
<td>1836</td>
<td>23.25</td>
</tr>
</tbody>
</table>
Conclusions

The main preliminary conclusions are:

- Be-7 precipitate in Lithium in the form of Be$_3$N$_2$, which is poorly soluble in Lithium
- Expected time of LTF-M degassing is 500-1000h
- Purification of Li by means of cold traps (O, H-isotopes, C, Me) and soluble Al getter (N, O) can be recommended for IFMIF
- As a monitors can be used:
  - sampler-distiller (similar BN-600 reactor) and electrochemical sell for Oxygen
  - plug indicator for Hydrogen
  - tube sampler for Nitrogen, Carbon and metallic impurities
Activities at Japanese Univ.
on Lithium Purification

Satoru Tanaka, Akihiro Suzuki
University of Tokyo
Fukada Satoshi
Kyusyu University

**O, N, C, H(T) in Li**

- Generation of tritium at 7.4 g/year
  - Safe removal of tritium
  - Nitriding, carbonizing, hydrogenation of structural material
  - Embrittlement of material
  - Li$_2$O, Li$_3$N, Li$_2$C$_2$, LiH (precipitation)
  - Pile up and erosion of material
Method to control impurities

1. Cold trap

Solubility of impurities in molten lithium

at 500K
oxygen, carbon < 10 ppm (good)
nitrogen, hydrogen > 1000 ppm (poor)

For nitrogen and hydrogen, another method is needed

Reduction of N and O is necessary for usage of Y trap

Series of
(1) Cold Trap reduction of O, C
(2) Ti Hot Trap reduction of N
(3) Y Hot Trap reduction of T(H,D)
N trap experiment

Sample N getter: Fe-Ti(5at%,10at%) alloy

Ti: high affinity but short life
Fe: large diffusion coefficient but low affinity

=> Fe-Ti alloy: long life(=efficient) N getter

Ti-N: surface reaction
Fe-Ti alloy-N
Fe-N: solid solution

N trap experiment

Measurement of Fe-Ti gettering effect for N

1. Soak specimen and kept at 873 K
   Fe-Ti plate (10×40×1mm×3)

2. Sample Li in Glove box and weigh it

3. change N to NH₃ and calculate N concentration in Li

Pure water
NH₃ sensor
HCl

Heater
Li 25g (N 250ppm)
Sampling tube
Ar
-873K
Result of measurement

Fe-10at.%Ti successfully reduce N concentration to >20ppm. In case of starting with high N concentration, limit of N reduction were around 100ppm-N. -> capacity of N gettering looks low

Result of XRD and EPMA

- peaks from αFe and Fe₂Ti phase were found before immersion.
- After immersion, these peaks disappeared and new peaks of TiN appeared.

Understand the mechanism of the loss of the gettering effect. investigate the Fe-Ti alloy at lower Ti composition
Diffusivity of H (T) in Li

\[ D_{Li-H} = 1.3 \times 10^{-3} \exp(-105 [kJ/mol]/R_g T) \]

H trap experiment

Experimental apparatus for H recovery by Y plate in static Li

<table>
<thead>
<tr>
<th>Element</th>
<th>Impurity level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>3000ppm</td>
</tr>
<tr>
<td>Ca</td>
<td>400ppm</td>
</tr>
<tr>
<td>K</td>
<td>300ppm</td>
</tr>
<tr>
<td>Fe</td>
<td>50ppm</td>
</tr>
<tr>
<td>S</td>
<td>60ppm</td>
</tr>
<tr>
<td>N</td>
<td>105ppm</td>
</tr>
<tr>
<td>O</td>
<td>Not determined</td>
</tr>
</tbody>
</table>
**H₂ recovery from Li was successful at 400-500°C**

- **H₂ recovery from Li at 500°C**
- **H₂ recovery from Li at 400°C**

---

**H₂ removal rate as a function of temperature**

- H₂ removal rate came down at temperatures lower than 350°C

**H₂ absorption rate**

\[
\frac{pV}{R_g T} \frac{dy_{H_2}}{dt} = W \left( y_{H_2, in} - y_{H_2} \right) - j_{H_2}
\]

---

**Comparison of hydrogen absorption rate between Li-Y-H₂ and Y-H₂ systems in 573-773K**
Pretreatment of Y by HF to remove oxide

- Pretreatment of Y by HF
  - Immersion of Y in HF solution
  - $\text{Y}_2\text{O}_3 \rightarrow \text{YF}_3$
  - $\text{Y}_2\text{O}_3 + 6\text{HF} \rightarrow 2\text{YF}_3 + 3\text{H}_2\text{O}$
  - $\Delta G = -172.84\text{kcal/mol}$

Experiment is under way.

H$_2$ concentration changes

Observation of surface after immersion of Y in Li for 50 days

No corrosion by Li was observed.
Tentative conclusions

- Hydrogen diffusivity in Li was correlated to:

\[ D_{Li-H} = 1.3 \times 10^{-3} \exp(-105[kJ/mol]/R_g T) \]

- \( H_2 \) in Li was recovered by an Y plate at 400 and 500°C

- Corrosion layer of ~10um scale was not observed at Li-Y interface after 50 days immersion in Li at 400°C.

Reconsideration of recovery of tritium by Y bed under dynamic flow-through operation

Equilibrium operation (previous evaluation)

Dynamic operation (new evaluation)

Breakthrough curve

Tritium concentration in Li and Y
Tritium concentration at outlet of Y bed under dynamic flow-through condition

- When an Y bed is heated at $10^{-3}$ Pa and 800°C, the bed is desorbed until $YT_{0.006}$.

$$\frac{C}{\sqrt{P_{Ti}}} = 2.92 \times 10^{-6} \exp\left(\frac{23200}{R_yT}\right)$$

T solubility in Y

- Li in equilibrium with $YT_{0.006}$ at 500°C is $LiT_x$ (x=1 wppm)
  (equilibrium pressure $10^{-6}$ Pa).

$$\frac{C}{\sqrt{P_{Ti}}} = 8.5 \times 10^{-6} \exp\left(\frac{42300}{R_yT}\right)$$

T solubility in Li

*Absorption condition is relieved to 500°C (from 250°C) under dynamic operation. The total tritium capacity is not changed so much.

It was predicted that Y bed at 500°C under dynamic flow-through condition can remove T down to 1 ppm in IFMIF Li loop.

---

Future plan

1. Develop a method to activate Y surface in Li
   Development of YF$_3$ method
   V(Ti)-Y or Fe(Ti)-Y clad
2. Investigation on T(H) trap by Y trap
   Development on detection method of hydrogen at low concentration.
   - Hydrogen permeation method.
   - Tritium tracer
3. Design of mockups.
EVEDA Tasks
- Target Facility -

H. Nakamura
JAERI

IFMIF Target & Test Facilities Technical Meetings
Tokyo, May 17-18, 2005

General requirements

1) Li target facility is most critical facility among IFMIF since the Li loop contains liquid Li, radioactive reaction elements (tritium, Be-7) and radioactive corrosion product.

2) During commissioning, the Li target facility needs smooth start-up and reliable operation since full power beam-on target is planned to satisfy IFMIF schedule.

Therefore, prior to construction, engineering validation to confirm and establish the IFMIF target facility is essential.
Purposes of EVEDA (1)

1) Validation of stable Li flow under long term operation up to 10,000 hrs level and transient operation of Li flow simulating start-up and shut-down of the Li loop with a IFMIF type nozzle and a concave back wall.
2) Validation of a height of the Li loop layout which realize high speed Li flow up to a Li flow velocity of 20 m/s without cavitation under a vacuum condition of $10^{-3}$ Pa.
3) Validation of compatibility of Li loop materials with liquid Li under low impurity level in a long term operation up to 10,000 hrs level.
4) Validation of characteristics of the Li purification system and the monitors to control the impurities concentration below permissible levels in the main Li loop.

Purposes of EVEDA (2)

5) Validation of various diagnostics characteristics on Li free surface behavior, Li thickness, Li temperature, deformation of the target assembly/back wall.
6) Validation of Li handling technologies on Li leak, combustion and extinction and validation of safety operation of the IFMIF Li loop.
7) Validation of remote handling technology.
8) Preparation of preliminary operation manual of the IFMIF Li loop and training of operation team of the Li loop.
9) Engineering design of the components enough levels to prepare procurements of the target system for construction.
Engineering validation tasks

To establish reliable design of target assembly and backwall, update of EV tasks is proposed as follows.

TG-1a : EVEDA Li test loop
TG-1b : Target assembly and backwall
TG-1c : Erosion/Corrosion
TG-1d : Diagnostics
TG-1e : Li purification system
TG-1f : Remote handling system
TG-1g : Li safety handling

Task sharing (draft for discussion)

TG-1a : JA,EU,RF
EVEDA Li loop

TG-1b : JA,EU
TG assembly&BW

TG-1c : EU,RF
Erosion/corrosion

TG-1d : JA,RF,EU
Diagnostics

TG-1e : EU,RF,JA
Li purification

TG-1f : EU,JA
Remote handling

TG-1g : JA,EU,RF
Li safety handling

TG-2a -TG-2d: JA,EU,RF
Eng. design
TG-1a : EVEDA Li test loop

- EVEDA Li test loop with Li inventory about 1/2.6 of IFMIF
- Demonstration tests of Li flow stability, impurity control (<10 wppm) and long time (10,000 hrs level) operation

Nozzle exit shape: 10 cm\(^4\) x 2.5 cm\(^3\)
(26 cm\(^4\) x 2.5 cm\(^3\) : IFMIF TG)
Li velocity: 10 to 22 m/s
Li flow rate: 50 l/s (133: IFMIF TG)
Impurity content: <10 wppm
Li purification: Cold trap, Hot traps
Diagnostics: High speed camera, Ultra-sonic sensor, Imp. monitors

TG-1b : TG assembly and Backwall

- To establish reliable design of target assembly and backwall, thermo-structural testing simulating IFMIF condition is needed.

Target assembly: Full size
Temperature: RT to 400 °C
Vessel pressure: 0.1 Pa vacuum 0.1MPa He/Ar
Backwall: Replaceable
Diagnostics: Temperature, Deformation
Engineering design tasks

In EVEDA, engineering design shall be done to enough levels to prepare procurement for construction.

TG-2a : Target assembly, Main loop, Li purification Loop and Monitors

TG-2b : Diagnostics

TG-2c : Remote Handling System

TG-2d : Safety, Vacuum, Control

---

**EVEDA Tasks - Target -**

<table>
<thead>
<tr>
<th>No.</th>
<th>Task</th>
<th>Contents</th>
<th>Cost (M$CE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG-1a</td>
<td>EVEDA Li test loop</td>
<td>Construction, operation and testing of EVEDA Li test loop.</td>
<td>9.0</td>
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<tr>
<td>TG-1b</td>
<td>Target assembly and backwall</td>
<td>Thermo-structural testing of target assembly and backwall.</td>
<td>1.5</td>
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<tr>
<td>TG-1c</td>
<td>Emission/Corrosion</td>
<td>Emission/corrosion measurements in material loop and Li test loop.</td>
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<tr>
<td>TG-1d</td>
<td>Diagnostics</td>
<td>Li jet free surface and thickness monitor in Li test loop.</td>
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<tr>
<td>TG-1e</td>
<td>Li purification system</td>
<td>Validation of removal and measure of tritium, Th, C, N and O.</td>
<td>1.6</td>
</tr>
<tr>
<td>TG-1f</td>
<td>Remote handling system</td>
<td>Development and verification of remote handling systems of the back wall and target assembly.</td>
<td>1.7</td>
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<tr>
<td>TG-1g</td>
<td>Li safety handling</td>
<td>For safety operation, additional tests on Li leak, contamination, extraction and radioactive materials behavior at annuals.</td>
<td>1.1</td>
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<tr>
<td></td>
<td>sub-total</td>
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<table>
<thead>
<tr>
<th>No.</th>
<th>Task</th>
<th>Contents</th>
<th>Cost (M$CE)</th>
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<tbody>
<tr>
<td>TG-2a</td>
<td>Target assembly, Main and Purification Loops</td>
<td>Design of the target assembly, the Li main loop, the Li purification loop.</td>
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<tr>
<td>TG-2b</td>
<td>Diagnostics</td>
<td>Design of various diagnostics and arrangements</td>
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<td>TG-2c</td>
<td>Remote Handling System</td>
<td>Design of the remote handling system for the target assembly and/or the back wall.</td>
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<tr>
<td>TG-2d</td>
<td>Safety, Vacuum, Control System</td>
<td>Safety analysis and design of vacuum system and control system.</td>
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<td>sub-total</td>
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Summary

- Update of EVEDA tasks on target facility has been proposed.
  ⇒ More detailed task contents need to be defined.
  ⇒ Technical discussion of EVEDA initial tasks needs to be started.
Proposal of update of EVEDA Tasks

H. Nakamura
JAERI

IFMIF Target & Test Facilities Technical Meetings
Tokyo, May. 17-18, 2005

Engineering validation tasks

To establish reliable design of target assembly and backwall, update of EV tasks is proposed as follows.

TG-1a : EVEDA Li test loop
TG-1b : Target assembly and backwall
TG-1c : Erosion/Corrosion
TG-1d : Diagnostics
TG-1e : Li purification system
TG-1f : Remote handling system
TG-1g : Li safety handling

- 171 -
TG-1b : TG assembly and Backwall

To establish reliable design of target assembly and backwall, thermo-structural testing simulating IFMIF condition is needed.

Target assembly: Full size
Temperature: RT to 400 °C
Vessel pressure: 0.1 Pa vacuum, 0.1MPa He/Ar
Backwall: Weld&cut or Rayonet
Diagnostics: Temperature, Deformation

---

Task sharing (draft for discussion)

TG-1a : JA, EU, RF
EVEDA Li loop

TG-1b : JA, EU
TG assembly&BW

TG-1c : EU, RF
Erosion/corrosion

TG-1d : JA, RF, EU
Diagnostics

TG-1e : EU, RF, JA
Li purification

TG-1f : EU, JA
Remote handling

TG-1g : JA, EU, RF
Li safety handling

TG-2a - TG-2d: JA, EU, RF
Eng. design
Summary

- Update of EVEDA tasks on target facility is proposed.
  ⇒ More detailed task contents need to be defined.
Action Items
- Compilation of purification system information sheet
  end May to mid June Nakamura
- EVEDA task description, DDD early July Nakamura
- Coordination of analyses on calculation conditions
  (Neutronics, Thermal stress) ASAP Ida, Riccardi
- Publication of presentation mid Aug. Ida

Next meeting Dec. 2005 in conjunction with ICFRM-12
- Discussion on Transition activities, EVEDA tasks
Appendix C

Agenda and Documents of Test Facilities Technical Meeting
May 18, 2005, Tokyo, Japan
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IFMIF Test Facilities Technical Meeting  
May 18, 2005, Tokyo, Japan

Session 1. (Overview)  
9:30 - 9:40 Welcome  
   Meeting objectives and review of agenda  
9:40-10:00 Overview EU tasks 2004-2005  
10:00-10:10 Overview JA tasks 2004-2005  

Chairman: T. E. Shannon  
M. Sugimoto (JAERI)  
A. Möslang (FZK)  
R. Lässer (EFDA)  
A. Shimizu (Kyushu Univ.)

Session 2. (High & Medium Flux Test Module)  
10:20-11:00 HFTM: concept & code calculations  
11:00-12:15 HFTM & MFTM: Design progress, stress analysis; manufacturing, thermal hydraulic codes & validation  
   (6 EFDA tasks)  
12:15-13:15 Lunch  

Chairman: R. Lässer  
A. Shimizu (Kyushu Univ.)  
V. Heinzel (FZK)

Session 3. (User performance & Test Cell design)  
13:15-13:55 Nuclear libraries, entire nuclear response (3D), activation & safety calculations, X-ray tomography, HFTM test matrix (7 EFDA tasks, EU summary)  
15:00 Miscellaneous  

Chairman: A. Shimizu  
T. Yutani (JAERI)  
all
OVERVIEW EU TASKS 2004 and 2005

R. Lässer

Test Facilities Technical Meeting

18 May 2005

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium Association</td>
<td>Completion of the updated reference design of the entire accelerator system (a) RF source calculation and specifications definitions (closed). (b) Review of updated reference design of the entire accelerator system (closed).</td>
</tr>
<tr>
<td>IBA</td>
<td></td>
</tr>
<tr>
<td>CEA</td>
<td></td>
</tr>
<tr>
<td>FZK (University Frankfurt)</td>
<td>Development of an optional technology for the 5-40 MeV IFMIF accelerator, based on the normal conducting Interdigital H (IH) structure from 5-9 MeV and the superconducting Crossbar-H (CH) accelerator structure from 9-40 MeV, with engineering study specific to IFMIF application. (open)</td>
</tr>
</tbody>
</table>
EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

Accelerator Facility: R. Fediand (CEA)

PRESENT
EVEDA

Complete system

1MW

RF coupler

140 mA D²⁺
Build or re-used

Injection of 140mA in RFQ

RFQ manufacturing process, Cooling process, 3D extremity

* H²⁺ source

Minimum to be done during EVEDA

Low Level

DTL hot model and test

diagnostics

Recommendation: to study also raster scanning for possible use in IFMIF

Test Facilities Technical Meeting 18-May-05 R. Lässer

Page 3

---

EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

A 175 MHz IH-CH-Linac for IFMIF

Not to scale

Room temperature

Superconducting temperature

ECR-source

A-vane-RFQ

IH-structure

CH

CH

CH

CH

CH

Transverse focusing

<table>
<thead>
<tr>
<th>Parameter CH-tank 1</th>
<th>Values</th>
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<tbody>
<tr>
<td>E_acc (MV/m)</td>
<td>3.5</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1.2</td>
</tr>
<tr>
<td>Gaps</td>
<td>12</td>
</tr>
<tr>
<td>E_peak (MV/m)</td>
<td>18.2</td>
</tr>
<tr>
<td>B_peak (mT)</td>
<td>33</td>
</tr>
<tr>
<td>G (Ω)</td>
<td>55</td>
</tr>
<tr>
<td>E_peak/E_acc</td>
<td>5.2</td>
</tr>
<tr>
<td>B_peak/E_acc (mT/(MV/m))</td>
<td>9.3</td>
</tr>
</tbody>
</table>

H. Podlech, IAP, Universität Frankfurt

Test Facilities Technical Meeting 18-May-05 R. Lässer

Page 4
Industrial study with ACCEL showed feasibility

H. Podlech, IAP, Universität Frankfurt

OVERVIEW EU TASKS 2004 2/8

EU 2004 Tasks for Lithium Target (1/1)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEA</td>
<td>Replaceable backplate. Reliability of the remote handling. Tests in a relevant number of failure simulation and rescue procedure. (open)</td>
</tr>
</tbody>
</table>
EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

Replaceable backplate: European concept: metallic seal (no cutting, no welding required)

G. Micciche: ENEA-Brasimone

Test Facilities Technical Meeting 18-May-05 R. Lässer

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### OVERVIEW EU TASKS 2004 3/8

**EU 2004 Tasks for Test Facility (1/3)**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>HFTM: Experimental validation of the thermohydraulic code used for the design of the IFMIF-HFTM thermal heat coefficients to be used in the design of test module. Stress analysis of the HFTM reference design at stationary conditions; Analysis of the suitability of STAR-CD or a comparable code for simulating the natural convection in the test cell. (open)</td>
</tr>
<tr>
<td>FZK</td>
<td>HFTM: Implementation of suitable software package to link thermal hydraulics codes with stress analysis codes; exemplary application to HFTM reference design. (open)</td>
</tr>
<tr>
<td>FZK</td>
<td>MFTM: Optimization of the design outline of the in situ creep-fatigue test module; stress analysis and calculation of the temperature distribution of the entire module. (open)</td>
</tr>
</tbody>
</table>

Test Facilities Technical Meeting 18-May-05 R. Lässer

Page 8
EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

OPERATION OF THE HELIUM LOOP FOR THE IFMIF THERMAL HYDRAULIC EXPERIMENTS (ITHEX):

 gap 0.5mm
 gap 1.0mm

V. Heinzel, FZK

He-flow: laminar, turbulent or transition.
Heat transfer coefficient,
Removal of nuclear heat

Test Facilities Technical Meeting 18-May-05 R. Lässer

EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

In situ creep fatigue test module

Medium flux volume

3 independent creep-fatigue tests within beam footprint

FZK design

Test Facilities Technical Meeting 18-May-05 R. Lässer
## Overview EU Tasks 2004 4/8

**EU 2004 Tasks for Test Facility (2/3)**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>Neutronics application and users tasks: Development of reference test matrix. (closed)</td>
</tr>
<tr>
<td>(a)</td>
<td>Neutronics application and users tasks: (a) Update global geometry model for entire test module assembling. (closed)</td>
</tr>
<tr>
<td>TEKES</td>
<td>(b) Neutronics application and users tasks: (b) 3D calculation of entire nuclear response. (closed)</td>
</tr>
<tr>
<td>FZK</td>
<td>HFTM: Implementation of suitable NDT inspection methods for the structural integrity assessment of instrumented capsules and rigs by micro-tomography. Experimental validation of real time micro-radiography of miniaturized samples under mechanical stress. (closed)</td>
</tr>
</tbody>
</table>

---

**Compressed Pebble Bed**

3-D tomography reconstruction:
Insert: frontal cross-sections of the bottom zone showing pebbles in contact with the steel plate

Frontal cross-section (top) axial cross-sections through contact area between steel plate and aluminum pebbles (bottom-left) and through middle of bottom layer of aluminum pebbles (bottom-right)
### OVERVIEW EU TASKS 2004 5/8

**EU 2004 Tasks for Test Facility (3/3)**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
</table>
| FZK    | HFTM: Manufacturing of  
a) an instrumented capsule with 3-fold heater  
b) one rig and three dummies with heaters  
c) an extended container length  
d) one compartment  
Up-grading the helium-loop |
| MEC    | Evaluation and validation of D-Li cross-section data:  
- Up-dated evaluations of $d + ^{6,7}\text{Li}$ data up to 50 MeV (closed) |
| FZK    | Evaluation and validation of D-Li cross-section data:  
- Preparation and processing of ENDF data files for $d + ^{6,7}\text{Li}$  
- Validation analyses and neutron yield uncertainty assessment (open) |

---

**EFDA**

**Manufacturing**  
V. Heinzel, FZK  
- Manufacturing of instrumented capsule with 3-fold heater  
- Manufacturing of one rig and three dummies with heaters  
- Manufacturing test of extended container length  
- Manufacturing of one compartment  
- Up-grading the helium-loop

I. Tiseanu, MEC  
- The capsule with specimens will be provided for X-ray tomography
## OVERVIEW EU TASKS 2004 6/8

### EU 2004 Tasks for Design Integration (1/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
</table>
| ENEA   | Worker and public safety analyses  
(i) Worker safety: Estimation of neutron activation of impurities and corrosion products and contact dose in the Lithium loop;  
(ii) Public safety: Deterministic analysis of representative accident sequence in order to evaluate the effectiveness of containment and the risk of radioactive release to the environment. (closed) |
| UKAEA  | Worker, public and environment safety analyses  
(i) worker safety: estimation of neutron activation of corrosion products and other impurities and estimation of contact dose in the lithium loop; estimation of occupational radiation exposure to maintain lithium loop and accelerator vacuum pumping system;  
(ii) public safety: deterministic analysis of representative accident sequence in order to evaluate the effectiveness of containment and the risk of radioactive release to the environment;  
(iii) environment safety analysis: evaluation of operational releases of radioactive and toxic materials and evaluation of radioactive waste generation. (open) |

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## OVERVIEW EU TASKS 2004 7/8

### EU 2004 Tasks for Design Integration (2/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEA</td>
<td>Completion of the analysis of the test cell shielding performance. Comparison with results obtained with different methods. (closed)</td>
</tr>
<tr>
<td>FZK</td>
<td>Full 3D analysis of the shielding performance of the IFMIF test cell by making use of a computational scheme coupling 3D Monte Carlo and deterministic (SN) transport calculations. (closed)</td>
</tr>
</tbody>
</table>

Test Facilities Technical Meeting 18-May-05  R. Lässer  Page 16
### OVERVIEW EU TASKS 2004 8/8

**Further EU 2004 Tasks (5.1b) for IFMIF**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEA</td>
<td>Independent cost assessment of the IFMIF conventional facilities, central control and common instrumentation. (open)</td>
</tr>
</tbody>
</table>
| UKAEA  | Independent cost assessment of the entire IFMIF accelerator facilities:  
|        | a. Evaluation of the accelerator and power supply design from the point of view of cost effectiveness:  
|        | b. Evaluation of the methodology of the costing, to determine if it represents the optimum approach;  
|        | c. Evaluation of the itemised results of the costing, to assess if they appear reasonable by comparison with other recent accelerator construction projects. (open) |
| UKAEA, VR, ENEA, CIEMAT | IFMIF Preliminary Safety Report (PSAR) for a Generic Site (open) |

---

### OVERVIEW EU TASKS 2005 1/5

**EU 2005 Tasks for Accelerator Facility (1/1)**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>Evaluation on whether or not the beam raster scanning method is generally applicable to the IFMIF design. Calculation of beam profile shape, as well as temporal and spatial stability of flat top and edges. Safety consideration. Cost estimate of a complete beam profile assembly</td>
</tr>
<tr>
<td>UKAEA</td>
<td>System study and adaption of a beam monitoring system that combines sensitivity, fast interlock capability and long term reliability under 10 MW beam power operation.</td>
</tr>
</tbody>
</table>
### OVERVIEW EU TASKS 2005 2/5

#### EU 2005 Tasks for Lithium Target (1/1)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEA</td>
<td>Theoretical study on the conditions for cavitations generation in various parts of the IFMIF Li-loop</td>
</tr>
<tr>
<td>ENEA</td>
<td>Thermo-mechanical analysis of the Li-loop structures to identify the probable deformation of the backplate during normal operation</td>
</tr>
<tr>
<td>VR</td>
<td>Verification of the backplate sealing performance against Li-infiltration and corrosion-induced damage based on the bayonet back-plate concept</td>
</tr>
<tr>
<td>VR</td>
<td>Development of a dedicated clean-up system for massive precipitated/activated corrosion products in Li-loop (literature study and experimental verification of magnetic trapping technology)</td>
</tr>
</tbody>
</table>

### OVERVIEW EU TASKS 2005 3/5

#### EU 2005 Tasks for Test Facilities (1/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
</tr>
<tr>
<td>HAS</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
</tr>
<tr>
<td>FZK</td>
<td>Design of a horseshoe type neutron shielding block enveloping all test modules to reduce further the nuclear inventory and the gamma dose rate in the rooms surrounding the test cell</td>
</tr>
</tbody>
</table>
**OVERVIEW EU TASKS 2005 4/5**

EU 2005 Tasks for **Test Facilities** (2/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
</table>
| FZK    | **Calculation of complete nuclear response through the entire test cell with consideration of an additional neutron shielding block:**  
(i) 3D distribution of nuclear responses using McDeLicious and MCNP codes.  
(ii) 3D distribution of the activity inventory using suitable activation codes and activation data (IEAF-2001/EAF-2005) |
| MEC    | **X-ray microtomography for HFTM capsules and rigs:**  
(i) influence of the sample radioactivity on the tomographic reconstruction quality and practical procedures to mitigate its effects, and  
(ii) experimental determination of resolution limits of specimens, capsules and rigs for complete rig assemblies. |

**OVERVIEW EU TASKS 2005 5/5**

EU 2005 Tasks for **Design Integration** (1/1)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td><strong>3D radiation shielding analysis of all rooms surrounding the test cell using state-of-the-art computational tools:</strong> Assessment of the effect of an additional horseshoe-type neutron shielding block inside the test cell.</td>
</tr>
<tr>
<td>TEKES</td>
<td><strong>3D radiation shielding analysis of the test cell cover and the access cell in the presence of an additional horseshoe-type neutron shielding block inside the test cell.</strong></td>
</tr>
<tr>
<td>UKAEA</td>
<td>Deuteron induced activation of corrosion products and other species in the Li-loop: identification of important reactions and analysis of the reaction cross-section data</td>
</tr>
</tbody>
</table>
Proposed EU tasks for WP2006 1/4

Proposed EU Tasks for Accelerator Facilities (TW6-TTMI-001):

- More detailed end-to-end simulation of the deuteron beam to determine the loads on the walls and possible activation under consideration of all possible errors and fluctuations in the accelerator components.
- Development of diagnostics for beam observation in the HEBT and its possible use for independent fast interlock strategy to stop the deuteron beam.

Proposed EU tasks for WP2006 2/4

Proposed EU Tasks for Li Target (TW6-TTMI-002):

- Li corrosion and chemistry:
  monitoring of metallic corrosion products and their removal from the Li-loop.
- Development/improvement of neutron detection diagnostics and its possible use for independent fast interlock strategy to stop the deuteron beam.
- Production of the Remote Handling Handbook for IFMIF.
Proposed EU tasks for WP2006 3/4

Proposed EU Tasks for Test Facilities (*TW6-TDMI-003*):

- Further studies of He-flow and cooling conditions in the test facility for removal of the nuclear heat.
- Development of miniature instrumentation to measure the irradiation conditions, e.g. the important neutron parameters required for characterisation of the material specimen.
- Continuation of the production of a Materials Handbook for IFMIF (activity started in WP2005).
- Preliminary version of DDD for the test facilities.

Proposed EU tasks for WP2006 4/4

Proposed EU Tasks for Design Integration (*TW6-TDMI-004*):

- Shielding calculations of the Li-loop including the issue of deuteron activation of corrosion products.
- Validation experiments for the cross-section data calculated for the activation of corrosion- and gaseous products by deuterons of the IFMIF beam if required.
- Activities to promote
  - the decision on EVEDA,
  - an agreement on the location and composition of the central team,
  - an agreement between the participating countries on the financial sharing of the tasks to be performed during EVEDA.
Alternative design for HFTM

- Specimens are housed in cast-type capsules.
- Capsules are made of the same material as specimens to make nuclear heating in the capsules the same as specimens.
- Capsules elongated in the spanwise direction promote uniform temperature profile in themselves.
- Temperature of a capsule is measured to identify that of specimens housed in it.

Lateral design/He bonding is superior to upright config./NaK bonding.

- Realizing uniform temp. throughout each capsule and its easy control.
- Direct temp. measurement of specimens by use of dummy specimen.
- Minimizing lead wires (T.C. and heaters)
- Avoid troublesome liquid metal treatment and its chemical/nucleate activity.
- Quick temp. response by minimizing gap layers.
PROPOSAL

- Irradiation test scenario should be planned not based on material classification but on temperature level classification.

so that

- One irradiation set may be composed of several candidate materials but excessive temperature difference should be avoided over one irradiation set.

<table>
<thead>
<tr>
<th>TEMP</th>
<th>MATER.</th>
<th>LAFS</th>
<th>VANADIAL</th>
<th>SiC</th>
<th>BREEDER A</th>
<th>BREEDER B</th>
<th>MULTIPLA</th>
<th>MULTIPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>250~400</td>
<td>L A F S</td>
<td></td>
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<tr>
<td>400~550</td>
<td>V A N A D I A L</td>
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<tr>
<td>550~650</td>
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<tr>
<td>650~800</td>
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<tr>
<td>800~1000</td>
<td>B R E E D E R B</td>
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<tr>
<td>1000~</td>
<td>M U L T I P L A</td>
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<tr>
<td></td>
<td>M U L T I P L E</td>
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</tr>
</tbody>
</table>
Use of atmospheric pressure in irradiation room and target back wall as pressure boundary will,

- increase the danger of injuring accelerator assembly, but,
- not attenuate the neutron flux seriously,
- liberate us from vacuum keeping in irradiation room,
- make cooling of nozzle and back wall assembly easy,
- make cooling of channel wall of HFTM from outside possible, which is attractive for high temperature irradiation test.
- mitigate pressure difference between inside and outside of flat plate channel wall, which reduces its deformation.
Development of ceramic printed heater/capsule wall

- Minimizing gap number and uncertainty.
- Design simplicity.
- Avoid additional gas formation due to deformation of wounded heaters.
- High temperature stability.
- Loose formation of capsule assembly. \(\Rightarrow\) stress free design and easy treatment for material test stage.
Capsule wall heater

printed heater    coated SiC

[mm]

1.0
Design Activity on IFMIF HFTM in Kyushu University

IFMIF Target & Test Facilities Technical Meetings
May 17-18, 2005, Tokyo

A. Shimizu, S. Ebara
Kyushu University

HFTM design of Kyushu Univ.

- Capsules elongated in the spanwise direction promote uniform temperature profile in themselves.
- Specimens are housed in cast-type capsules.
- Capsules are made of the same material as specimens to make nuclear heating in the capsules the same as specimens.
- Temperature of a capsule is measured to identify that of specimens housed in it.

coolant flow (He)
neutron flux
T.C. specimens
<capsule inside>
Capsule design

- specimens
- thermocouple
- cast-type capsule (the same material with specimens is preferred)
- Can be unified?
- plate heater (for temperature control)

Design activity considering spatial distribution of nuclear heating

- Spatial distribution of nuclear heating
  - Previous activity has been proceeded with on the assumption of a constant nuclear heating of 5W/g.
- Neutron flux attenuates by about 1% as it travels for 1 mm toward the beam direction.
  - Nuclear heating has similar distribution to the neutron flux

Experimental & numerical studies considering non-uniform profile of nuclear heating were conducted.
Spatial distribution of nuclear heating

Mock-up experiment using gas loop

- Only one capsule corresponding to the reference position is installed in the test section.
- The capsule includes 2 kinds of heaters
  - mica heaters that simulate nuclear heating and make a non-uniform temperature distribution.
  - ceramic heaters for temperature control to even the non-uniform temperature distribution.
Mica heater for non-uniform heating

Ceramic heater for temperature control

In the present run, custom-made heaters could not be prepared and ready-made ones were used.
**Experimental loop & test section**

**Experimental Loop System**
- Compressor
- Surge tank
- Flow control valve
- Bypass
- Vacuum pump
- N₂ gas bomb

**Test section detail**
- Coolant Flow
- [Front view]
- [Side view]
- Capsule
- Insulator
- Al
- Dimensions:
  - 203 [mm]
  - 183
  - 12.6
  - 34.6
  - 426.5

---

**Improvement of temperature profile -a half power-**

Temperature profiles for the case of a half power of mica heaters (simulating nuclear heating) (Re=17,000)

- Temperature profile is surely improved by ceramic heaters although temperature level is raised as the power of ceramic heaters becomes large.
- The power of 100 W is so excessively large that the ΔT oppositely becomes large.

---

**Graph:**
- End vs. Center temperature profiles
- Power levels: 100 W, 61 W, 31 W, 9 W
- ΔT values: 9.5, 8.6, 10.7, 17.0
- Thermocouple position (mm): 0, 20, 40, 60, 80
- Nuclear heating only
- Max. ΔT [deg.C] in the specimen
- Power of a ceramic heater
**Improvement of temperature profile -a full power-**

Temperature control for the case of a full power of mica heaters (Re=17,000)

- The effect of ceramic heaters on the temperature profile is limiting.
- It is considered because of the relatively small power of ceramic heaters to mica heaters.

→ **Heater with higher power density is needed.**
- Temperature in the end region could not be raised by heating of ceramic heaters.

→ **For more fine temperature control, heaters with high power density had better be located on the end region.**

---

**Numerical simulation**

Conjugate solid/fluid heat transfer with turbulent flow

low Reynolds number k-ε model for flow field (Abe et al., 1993)

\[ \bar{\tau} - \bar{\nu} - \varepsilon_T \] model for temperature field (Abe et al., 1995)

Additional heater is introduced on the end of capsule.

**<Numerical conditions>**

\[ Re = 939.3 \ (U_{in} = 43.7 \text{ m/s}) \]
\[ 1691 \ (78.9 \text{ m/s}) \]
\[ 1880 \ (87.6 \text{ m/s}) \]
\[ 5636 \ (263 \text{ m/s}) \]

\[ T_{in} = 50 \text{ deg.C, } P_{in} = 0.3 \text{MPa} \]
Temperature distribution for each capsule location
-Re_m=1880, nuclear heating only-

- Re_m=939.3, nuclear heating only -

The difference between the most highest and the most lowest of the maximum temperature is 275 deg.C.
Temperature profile in beam direction

- Temperature profiles are almost symmetric against the geometrical center in spite of the nuclear heating profile.

Temperature profile in spanwise direction

- Temperature distributions are quite improved by heaters for temperature control.
- The use of the end heater is effective.
Required heater power for each temperature level

The role of the temperature control heaters is to make uniform temperature & to raise temperature level.

- Capsule temperature doesn't rise so much for large Re cases even if a huge power is supplied.
  → In order to raise the temperature level, small Re is preferable.

Temperature level and temperature difference

- High capsule temperature causes a large ΔT.
- Small Re leads to a small ΔT in the capsule compared with large Re case at the same temperature level.
  → Small Re is preferable.
Summary

- Thermal-hydraulic experiment & simulation were done taking account of the non-uniform nuclear heating in the HFTM.
- From experiment
  - Uniformity of temperature profile in the capsule could be improved to some extent by heaters for temperature control.
  - It is necessary for more fine temperature control to use smaller heaters with higher power density.
- From simulation
  - Introduction of the end heater was effective to the temperature uniformity.
  - In order to maintain a high temperature level in capsule, we should select a coolant flow with low Re not so as to require too excessive heater power of heaters for temperature control.

Near Future Tasks

- Demonstration of heater-printed capsule
  - Heat conductivity of conventional heater is poor, which leads to excessive pumping power for coolant.
  - Unexpected occurrence of gap between heater and capsule under operation makes temperature of capsule uncontrollable.
  - The higher the heater power is, the bigger a required size of electric terminal.
- Accurate distribution of coolant flow rate
  - Accuracy of coolant flow rate effects on cooling performance severely.
  - Large eddy motion before manifold makes unsteady change of coolant flow rate at each channel.
• Outer mounted heaters may become thermal barrier for cooling control. (Excess pumping power)

• Small gap between heater and capsule wall should cause large non-uniformity of inner temperature distribution of capsule. (Uncontrollable situation)

• Multi-layer coating technique has been already developed in the industrial world.

• Possible combination of ceramic and heater materials is Magnesia-Alumina Spinel ($\text{MgAl}_2\text{O}_4$) and Mo.
Summary

- Thermal-hydraulic experiment & simulation were done taking account of the non-uniform nuclear heating in the HFTM.
- From experiment
  - Uniformity of temperature profile in the capsule could be improved to some extent by heaters for temperature control.
  - It is necessary for more fine temperature control to use smaller heaters with higher power density.
- From simulation
  - Introduction of the end heater was effective to the temperature uniformity.
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Near Future Tasks

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- Accurate distribution of coolant flow rate
  - Accuracy of coolant flow rate effects on cooling performance severely.
  - Large eddy motion before manifold makes unsteady change of coolant flow rate at each channel.
The use of ceramic heaters with high thermal conductivity leads to such good cooling performance as 250 deg. C can be attained by comparably small Re of 20,000.
### Materials & thermal properties

<table>
<thead>
<tr>
<th>material</th>
<th>density [kg/m³]</th>
<th>heat capacity [J/kg/K]</th>
<th>thermal conductivity [W/m/K]</th>
</tr>
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<tbody>
<tr>
<td>capsule</td>
<td>SS316</td>
<td>8018</td>
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<tr>
<td>coolant</td>
<td>He</td>
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<td>5193</td>
</tr>
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<td>heater</td>
<td>Ceramics (Kyocera corp.)</td>
<td>4000</td>
<td>750</td>
</tr>
<tr>
<td>insulation</td>
<td>Hemisal (Nichias corp.)</td>
<td>1700</td>
<td>1000</td>
</tr>
<tr>
<td>vessel</td>
<td>F82H</td>
<td>787.1</td>
<td>1052</td>
</tr>
</tbody>
</table>

### Improvement of temperature distribution

- $Re_m=1880$ -

Without Heater

+heater (40W+20W)
Natural convection in the Target and Test Cell

O. Ekechukwu
S. Gordeev,
V. Heinzel,
A. Möslang,
T. Kurz
V. Slobodtchouk,
E. Stratmanns,

The lithium containing components have temperatures between 250 and 300 °C.

The test modules have temperatures between 50 and 150 °C.

The temperature allowance for the shielding concrete is below around 100 °C.
Target and Test Cell pressure and atmosphere

- Natural convection with an argon atmosphere vanishes at $p < 10^{-3}$ Pa
- between the back plate and the HFTM container natural convection with an argon atmosphere vanishes at $p < 1$ Pa
- with an argon atmosphere at about normal pressure the Ra-number is $Ra < 10^7$
- Argon is activated (see calculations of S. Simakov)

- Helium at a slight suppressure is suggested
Natural convection

Suitability of STAR-CD for calculating natural convection
Validation

- 3D at Low Rayleigh numbers
- 2D at high Reynolds numbers

Demonstration of
- 2D/3D at high Rayleigh numbers in symmetric cavity
- 3D at high Rayleigh numbers but unsymmetrical cavity
  and buoyancy driven flow

Natural convection in a tilted rectangular box heated from below;
tilt angle 15°, Ra = 2.6x10^4

The simulation calculations with STAR-CD and the High-Reynolds k-e
model provide in some cases reasonable results
Simulation of natural convection with STAR-CD

As a conclusion, one can say that the low Re number turbulence models give velocity profile in near the wall region close to the laminar one, i.e. over-predict the experimental data. The use of the high Re number turbulence models with a strong restriction on $y^+$ ($y^+ \geq 30$) can result in the fact that it is difficult to describe correctly the narrow boundary layer zone (at a low velocity of the fluid flow, which it typical for the natural convection). In this connection it should be mentioned that $k$-omega high Re number turbulence models are more “flexible”, because they are applied up to $y^+ = 5$. Moreover, at industrial applications for cases, where the natural convection plays a significant role and a cavity has several differently heated elements, the flow can be considered as combined natural-and-forced convection flow. The low Re number turbulence models require very fine mesh of the near wall region and also require much computing time and resources. In this case the use of the high Re number turbulence models (particularly, $k$-omega) for the flow simulation can be reasonable.

Buoyancy driven convection through a box (1x1x1 m) with symmetric inlet and exit structures

The simulations with 2D and 3D showed no significant differences; STAR-CD 2 layer model
3D at high Rayleigh numbers but unsymmetrical cavity and buoyancy driven flow

The simulations with the 2 Layer model in STAR-CD describes the fluctuations at the chimney inlet

Geometric Model for the Target and Test Cell:
The lithium containing components have 250/300°C and the walls have 50°C; the target and test cell is filled with helium at normal pressure
Temperature and Velocity distribution in the test cell due to natural convection. The calculations were done with STAT-CD by applying the k-omega high Reynolds model.
Target and Test Facilities: Recent Developments:

- **HFTM Design:**
  - Container adaptation to neighboring components: --- Short container with internal flanges
  - Stress analyses: --- reflector cooling improved
  - Stress analyses --- thicker wall and corner radius and symmetric rig
  - Stress analyses of rig and capsule: --- symmetric rig
  - Gap influence: --- MFTM design
  - Power density following rig density variation --- uniform rig

- Helium channel tolerance --- 10% allowances maximum

- **Helium Cooling --- validation with IDAHO**

- **Helium Cooling validation with IDAHO Experiment and ITHEX**
  - single channel --- annular --- rectangular
  - Double channel with 1 rig

- **MFTM Design:**
  - Once through cooling
  - Jet cooling --- validation

- **Target and Test Cell atmosphere --- natural convection**
  - Validation of STAR-CD
  - First Assessment of the convection in the Target and Test Cell

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**Horizontal cut of the HFTM container with integrated lateral reflector; Container with four compartments each with three rigs;**

- **Main Helium channels with a width of 1mm between the rigs and 0.5 mm between the rig and compartment walls**

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V. Heinzel, A. Möslang, Forschungszentrum Karlsruhe, IFMIF – Meeting, Tokyo, May 18th 2005
Specimens and the space between filled with sodium and thermocouples in
• capsules with electric jacket heaters
• Specimen stack height 81 mm
• Inserted in rigs
• Weld seams out of high flux field

Elevation cut off of the capsule with the Specimens

• The triple heater system is wound around the capsule
• The power of each heater can be adjusted independently
The electric heaters have to compensate:

a) The vertical temperature increase of the helium

b) Local heat transfer coefficient variations due to boundary development in flow direction

c) Local heat transfer coefficient variations in rectangular channels

HFTM: –
Recent Design Work
Design integration: spatial interaction of the container angle with the back plate – requires an extension of the container to 600 mm

Design integration – manufacturing technology: container manufacturing

- No machine for the spark erosion of the container with a height of 600 mm and a sufficient tolerance is available;

- The development of an appropriate machine is mandatory!
Design integration: originally a streaming effect through the gaps in the HFTM on the flux distribution in the MFTM was analyzed. It elucidated the reflector repercussion of the MFTM on the HFTM.

As consequence the design of the MFTM was initiated.

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Design Integration – MFTM design:
all MFTM sub units are available in CATIA V5 drawings

Creep-Fatigue Module  Tritium breeding module  Tungsten neutron spectrum shifter

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Design integration:

- Test modules in irradiation position

Design integration:

- Spatial interaction of the HFTM and MFTM independent of the container height
Design integration: container design changes: the new container is welded to an inner flange which provide the necessary stiffening. It has a height of 400 mm which can be spark eroded by an existing machine.

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HFTM - Design iterations

Stress analyses ↔ Thermo-hydraulics

Design amendments

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Stress analyses started with the first container and thermo-hydraulic analyses:

Temperature distribution

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Stress analyses: yield strength of stainless steel

316 L Stainless steel

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- Presentation by A. Möslang at the Target Technical Meeting at Brassimone
  - 1. October 2004

Conclusion: for start-up the container is made from austenitic steel 316L

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Stress analyses of the container

- The exceeding stresses in case of 316L caused:
  - the make up of a finer model for the thermo-hydraulic
  - the implementation of a new version of STAR-CD - the comparison was acceptable
  - Amendments of the reflector cooling
  - old / new – lateral reflector

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New Model for the thermo-hydraulic calculations

- The inlet sections and axial reflectors were modeled and the nuclear power distribution over all container components inserted.

Amended reflector cooling

Case 0 “old”

He inlet

The maximum temperature was reduced and redistributed in addition the inlet “orifice” was varied.
### Cooling Channel Variation

<table>
<thead>
<tr>
<th>Case</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
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<tbody>
<tr>
<td>Case 0</td>
<td>7</td>
<td>20</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>Case 1</td>
<td>7</td>
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<td>50</td>
<td>80</td>
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<tr>
<td>Case 2</td>
<td>7</td>
<td>30</td>
<td>-</td>
<td>80</td>
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<td>Case 3</td>
<td>7</td>
<td>20</td>
<td>50</td>
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<td>65</td>
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<td>35</td>
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<td>75</td>
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<td>Case 6</td>
<td>7</td>
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<td>Case 7</td>
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<td>80</td>
</tr>
<tr>
<td>Case 8</td>
<td>7</td>
<td>20</td>
<td>45</td>
<td>80</td>
</tr>
</tbody>
</table>

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Reflector with 3 cooling slit channels

Reflector with 4 cooling slit channels

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Max. von Mises Stresses 486.6MPa

Deformation factor = 100

254.6MPa

The container with the better reflector cooling is less sensitive to the lower end restraint; further stress reduction possible

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Stress analyses

The central container region is less deformed

Compression in the centre (e) presses the container wall on to the rigs

---

Gap (+) and Contact (-) between Rig and Capsule

<table>
<thead>
<tr>
<th>Direction of Beam</th>
<th>High temp. (mm)</th>
<th>Low temp. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-0.124</td>
<td>+0.004</td>
</tr>
<tr>
<td>b</td>
<td>+0.376</td>
<td>+0.060</td>
</tr>
<tr>
<td>c</td>
<td>+0.040</td>
<td>+0.016</td>
</tr>
<tr>
<td>d</td>
<td>+0.222</td>
<td>+0.222</td>
</tr>
<tr>
<td>e</td>
<td>-0.461</td>
<td>-0.401</td>
</tr>
<tr>
<td>f</td>
<td>+0.203</td>
<td>+0.203</td>
</tr>
</tbody>
</table>
Container Wall Stress and Strain due to internal over pressure of 0.3 MPa:
--- transition stiffening plate and container wall ---

CPS4i - c0afR - Dicke
=1.0mm, Radius = 0.5 mm, inner pressure = 3 bar (R.T.)

Mises stresses max. 429 MPa

Tensile stresses max. 417 MPa
deflection max. 0.288 mm
CPS4i – c0afR20 -
Dicke = 1.0mm, Radius
= 2.0 mm, Innendruck =
3 bar (R.T.)

Mises stresses max.
327 MPa

Deflection max.
0.248 mm

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CPS4i – c0bfR -
Dicke = 1.0mm,
Radien = 0.5 mm,
Innendruck = 3 bar
(R.T.)

Mises stresses
max. 356 MPa

Deflection
0.242 mm

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CPS4i – c0cfR160L6 –
Dicke = 1.0 mm, Radius
= 16.0 mm auf 6.0 mm
Länge, Innendruck = 3
bar (R.T.)

Mises stresses
max 201 MPa

Deflection
max. 0.183 mm

CPS4i – c0a15fR –
Dicke = 1.5 mm,
Radius = 0.5 mm,
Innendruck = 3 bar
(R.T.)

Mises stresses
max. 208 MPa

Deflection
max. 0.088 mm
CPS4i – c0a15fR20 -
Dicke = 1.5mm,
Radius = 2.0 mm,
Innendruck = 3 bar
(R.T.)

Mises stresses max.
154 MPa

Deflection max.
0.078 mm

CPS4i – c0b15fR -
Dicke = 1.5mm,
Radian = 0.5 mm,
Innendruck = 3 bar
(R.T.)

Mises stresses max.
172 MPa

Deflection max
0.077 mm
CPS4i – c0c15fR160L6
− Dicke = 1.5mm,
Radius = 16.0 mm auf
6.0 mm Länge,
Innendruck = 3 bar
(R.T.)

Mises stresses
max. 92 MPa

Deflection max.
0.061 mm

• Rig

high / low - temperature
• Capsule

high / low - temperature
The smaller channels at the shorter rig side create hot helium plumes:

- Nuclear heat is released in the stiffening plates and the lateral rips and the rips reduce the helium through put
- As consequence hot spots occur at the upper part of the stiffening plates
The lateral rips were removed or reduced

Reduction of hot spots at the stiffening plates

Without rip       3x10mm rip       1x20mm rip       Without rip

$G_{He} = 0.11 \text{ kg/s}$  $G_{He} = 0.11 \text{ kg/s}$  $G_{He} = 0.11 \text{ kg/s}$  $G_{He} = 0.121 \text{ kg/s}$
Implementation of MpCCI
exemplary thermo-hydraulic analyses of deformed channels

- The implementation of the MpCCI coupling interface was delayed for
  the following reason:
- the software for the coupling the CFD Code Star-CD with a structural
  code ABAQUS (Permas) was only available at the end of July 2004.
- in the two way MpCCI coupling between structural and fluid dynamic
  codes Star-CD sends the temperature distribution and get back
  displacements from the ABAQUS. In the case where the deformations
  in the structure are large and cause a significant change of the flow
  geometry the fluid meshes can be strongly deformed. If the CFD grid is
  very fine (the case of the low Re number models) it can lead to the
  formation of the defective fluid cells and to the breaking of the
  calculation.
- In order to save time we started to calculate the influence of exemplary
  variations of the cooling channel

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Exemplary thermo-hydraulic analyses of deformed channels

- The simulation carried out shows the following.
- The decrease in the cooling channels cross section by 20% may be
  dangerous because of increased hydrodynamics and mechanical loads
  to the structure.
- The decrease in the cooling channel cross section by 10% may be
  considered as acceptable. The deviation of the gas gap thickness
  inside the rig from the reference value affects the temperature
  distribution in the model more significant than cooling channel
  deformation.
- The heat of the target back wall results in a rise of the maximum
  temperature of the HFTM front wall by 19.20C and the maximum flow
  temperature in the first line of the cooling channels by 17.10C. The
  temperature distribution in other elements of the HFTM is practically
  the same as without the heat of the target back wall. There is some
  reserve to reduce the effect of the heat of the target back wall on the
  HFTM – gas gap thickness between the back wall and the HFTM can
  be increased to 2 mm.

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Variation of the lateral rig spacer pads

- **Case 1.** Reference design.
- **Case 2.** The width of the cooling channel on the long side of the rig is reduced by 10\%, i.e. 0.9 mm instead of 1 mm. The width of the cooling channel on the short side of the rig is unchanged.
- **Case 3.** The width of the cooling channel on the long and short sides of the rig is reduced by 10\% (1mm → 0.9mm, 0.5mm → 0.45mm) compared with the reference design of the rig.
- **Case 4.** The same as in case 2, but without ribs on the short side of the rig.
- **Case 5.** The width of the cooling channel on the long side of the rig is reduced by 20\%, i.e. 0.8 mm instead of 1 mm. The width of the cooling channel on the short side of the rig is unchanged.
- **Case 6.** The width of the cooling channel on the long and short sides of the rig is reduced by 20\% (1mm → 0.8mm, 0.5mm → 0.4mm) compared with the reference design of the rig.
- **Case 7.** The same as in case 5, but without ribs on the short side of the rig.

---

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---

deformation for all channels: results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Case 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{\text{max}}$, m/s</td>
<td>402.5</td>
<td>404.6</td>
<td>409.8</td>
<td>405.6</td>
<td>441.1</td>
<td>483.8</td>
<td>478</td>
</tr>
<tr>
<td>$W_{\text{ref}}$, m/s</td>
<td>332.8</td>
<td>385.3</td>
<td>392</td>
<td>390.6</td>
<td>458.1</td>
<td>510.9</td>
<td>505</td>
</tr>
<tr>
<td>$\Delta P$, bar</td>
<td>0.745</td>
<td>0.9</td>
<td>0.928</td>
<td>0.918</td>
<td>1.08</td>
<td>1.25</td>
<td>1.24</td>
</tr>
<tr>
<td>$T_{\text{max}, \circ C}$</td>
<td>386.2</td>
<td>376.9</td>
<td>375.5</td>
<td>375.2</td>
<td>380.3</td>
<td>382.3</td>
<td>383.6</td>
</tr>
<tr>
<td>$T_{\text{max}, \circ C}$</td>
<td>380.4</td>
<td>369.3</td>
<td>367.9</td>
<td>367.6</td>
<td>372.8</td>
<td>374.6</td>
<td>376</td>
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<tr>
<td>$T_{\text{max}, \circ C}$</td>
<td>372.4</td>
<td>360.9</td>
<td>359.6</td>
<td>359.3</td>
<td>364.5</td>
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<td>367.5</td>
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<td>149.9</td>
<td>150.6</td>
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<td>148.0</td>
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<td>154.1</td>
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<tr>
<td>$T_{\text{max}, \circ C}$</td>
<td>152.5</td>
<td>147.5</td>
<td>147.4</td>
<td>137.1</td>
<td>149.3</td>
<td>162.9</td>
<td>159.2</td>
</tr>
</tbody>
</table>

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Exemplary thermo-hydraulic analyses of deformed channels
deformation of individual channels

- Case 8. The cooling channels of rig 2 on long sides are decreased by 10% (1 mm → 0.9 mm) and isolation gas gap between the rig vessel and the capsule with samples is increased accordingly by 0.1 mm. The nuclear heating only is operation condition.
- Case 9. The cooling channel width is equal to the reference design value, but the insulation gas gap between the rig vessel and the capsule with samples is increased by 10% under nuclear heating only.
- Case 10. The same as the case 9, only the isolation gas gap between the rig vessel and the capsule with samples is decreased by 10%.
- Cases 11 – 13 are the same as the cases 8-10, but electric heating is added to the nuclear one (all three section of the electrical heater are into operation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 8</th>
<th>Case 9</th>
<th>Case 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>W, m/s</td>
<td>344.6</td>
<td>348.2</td>
<td>344.7</td>
</tr>
<tr>
<td>ΔP, bar</td>
<td>0.696</td>
<td>0.707</td>
<td>0.696</td>
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<tr>
<td>T, °C</td>
<td>388.5</td>
<td>389.9</td>
<td>400</td>
</tr>
<tr>
<td>T, °C</td>
<td>377</td>
<td>382.5</td>
<td>393</td>
</tr>
<tr>
<td>T, °C</td>
<td>368.1</td>
<td>374.4</td>
<td>384.9</td>
</tr>
<tr>
<td>T, °C</td>
<td>142.1</td>
<td>141.8</td>
<td>142.4</td>
</tr>
<tr>
<td>T, °C</td>
<td>130.8</td>
<td>130.2</td>
<td>130.9</td>
</tr>
</tbody>
</table>

V. Heinzel, A. Moesling, Forschungszentrum Karlsruhe, IFMIF – Meeting, Tokyo, May 18th 2005
deformation of individual channels

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case Ref. design</th>
<th>Case 11</th>
<th>Case 12</th>
<th>Case 13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>value</td>
<td>Rel. to ref. design, %</td>
<td>value</td>
<td>Rel. to ref. design, %</td>
</tr>
<tr>
<td>$W_{\text{max}}$, m/s</td>
<td>397</td>
<td>400.3</td>
<td>0.83</td>
<td>396.5</td>
</tr>
<tr>
<td>$\Delta P$, bar</td>
<td>0.77</td>
<td>0.78</td>
<td>1.29</td>
<td>0.77</td>
</tr>
<tr>
<td>$T_{\text{in}}, ^\circ\text{C}$</td>
<td>655.2</td>
<td>679.5</td>
<td>3.71</td>
<td>699.8</td>
</tr>
<tr>
<td>$T_{\text{in}}, ^\circ\text{C}$</td>
<td>650.2</td>
<td>674.9</td>
<td>3.8</td>
<td>693.6</td>
</tr>
<tr>
<td>$T_{\text{in1}}, ^\circ\text{C}$</td>
<td>648.4</td>
<td>673.4</td>
<td>3.86</td>
<td>691.9</td>
</tr>
<tr>
<td>$T_{\text{in2}}, ^\circ\text{C}$</td>
<td>175</td>
<td>174.9</td>
<td>-0.1</td>
<td>174.9</td>
</tr>
<tr>
<td>$T_{\text{in3}}, ^\circ\text{C}$</td>
<td>217.4</td>
<td>219.3</td>
<td>0.87</td>
<td>218.4</td>
</tr>
</tbody>
</table>

Comparison of the main thermal-hydraulic characteristics of the HFTM without and with the heat of the target back wall

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Without a heat of the back wall</th>
<th>With a heat of the back wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{\text{max}}$, m/s</td>
<td>344.6</td>
<td>349.8</td>
</tr>
<tr>
<td>$\Delta P$, bar</td>
<td>0.696</td>
<td>0.706</td>
</tr>
<tr>
<td>$T_{\text{in}}, ^\circ\text{C}$</td>
<td>385.5</td>
<td>384.1</td>
</tr>
<tr>
<td>$T_{\text{in}}, ^\circ\text{C}$</td>
<td>368.1</td>
<td>366.9</td>
</tr>
<tr>
<td>$T_{\text{in1}}, ^\circ\text{C}$</td>
<td>377</td>
<td>376</td>
</tr>
<tr>
<td>$T_{\text{in2}}, ^\circ\text{C}$</td>
<td>142.1</td>
<td>160.4</td>
</tr>
<tr>
<td>$T_{\text{in3}}, ^\circ\text{C}$</td>
<td>118.3</td>
<td>137.5</td>
</tr>
<tr>
<td>$T_{\text{b1}}, ^\circ\text{C}$</td>
<td>90.82</td>
<td>107.9</td>
</tr>
</tbody>
</table>

The effective thickness of the gas gap inside the rigs is equal to 0.5 mm in the process of the calculation carried out.

The calculations are done with the high Reynolds number k-ε turbulence model (Chen modification of the standard k-ε turbulence model is used). It is desirable to repeat these calculations for individual rig with a low Reynolds number turbulence model and with more fine and more detailed simulation of the rig design.
Rigs are self reflecting:

All rigs are filled with the same selection of specimen

Spaces between specimens are filled up with filler pieces for enhancing the neutron flux and dpa/ppy (and providing addition test material)
Arguements for a horse shoe shielding

V. Heinzel, A. Möslang, K. H. Lang, V. Simakov, E. Stratmanns

Target and Test Cell Model for the nuclear calculation
Contact $\gamma$-dose rates from gases at 1 atm after 1 year irradiation in the IFMIF test cell.

To study a possible measure of reducing the liner radioactivity, a shielding block was inserted between the carbon reflector and the test cell front wall (Fig. 1). The block consisted of a 30 cm layer of steel and a 10 cm boron-cadmium mixture, the material density being reduced by 20% to account for heat removal channels. As Fig. 4 shows such a shielding block would reduce the dose rate for both steel liner variants by a factor 2 to 3. It reduces nuclear heating in liner from 1.5 to 0.5 mW/g.
Contact dose rates from the Eurofer and SS-316 liner of the test cell front wall after 1 y irradiation (dash curves show shielding block effect).
UPGRADING AND OPERATION OF THE HELIUM LOOP FOR THE IFMIF THERMAL HYDRAULIC EXPERIMENTS (ITHEX)

- Integration of new components in the ITHEX helium loop
- Experiments with the ITHEX annular testsection
- Laser Doppler Anemometer facility
- Fabrication of adjustable flat duct testsection

Upgraded ITHEX experimental facility

- 2x side-channel compressor
- Tightness in overpressure and vacuum
- Oxygen probe to determine dilution by ambient air.
- Coriolis Massflowmeter
- 3x Plate heat exchangers
- (1)-(4): measuring \(p, T\)
Sidechannel compressors

- relatively high pressure ratio per stage
- no instabilities at low/high end of volume flow rate
- low in oscillations

Performance of 2 modified two-stage SV 6.250/2
(industrial laser gas circulators):

- Helium tight in vacuum and overpressure conditions
- Control with frequency inverter possible for 10%-100% massflow
- Pressure rise: 700hPa (limited by motor torque)
  Helium: \( Re = 5500 \)
  Nitrogen: \( Re = 14000 \)

Oxygen sensor

Dilution air severely alters the gas properties when working with helium. Note: \( M_{air} / M_{He} = 7 \)!

Air content is detected via the oxygen partial pressure.

The oxygen probe used is a commercial ZrO2 probe adapted for the use with ITHEX:

- Working pressures up to 0.6MPa
- Retrofitted with an additional heater jacket for helium atmospheres
- Cell temperature controlled
Results of adiabatic pressure loss measurements

Onset of transition to turbulent regime for Re > 4 000

Fully turbulent level not reached for Re = 10 000

V. Heinzell, A. Moeslang, Forschungszentrum Karlsruhe, IFMIF Meeting Tokyo, 18th of Mai
Results of heated experiments

Deteriorated heat transfer for $3000 < Re < 10000$

LDA velocity measurements in plenum/entrance

Measured data on plenum/duct centerline

V. Heinzel, A. Moesling, Forschungszentrum Karlsruhe, IFMIF Meeting Tokyo, 18th of Mai
Planned investigations

- More experiments will be conducted with the annular testsection using several gases at the entrance pressures 0.2-0.3MPa and strong heating rates $q^+$ up to 0.004

- The flat duct testsection will be integrated in the loop, experiments will be conducted for gapwidths $s=0.5\text{mm}$ and $s=1\text{mm}$

- The pressure scanner will be used to measure local friction factors in both testsections as indicator for turbulence development.

- Laser-Doppler Anemometer measurements in the plenum/entrance region of facility will assess velocity and turbulence profiles which can be used as entrance conditions for CFD calculations and as validation data for turbulence models.
Results of heated experiments

IFMIF High Flux Test Module thermal-hydraulic design

- Maximum entry pressure is 0.3MPa.
- Small cross section of the coolant ducts effects high helium velocities. Mach numbers of 0.5 can be reached at the exit.
- Only low Reynolds numbers $Re < 10000$ are reached in the narrow channel.
- High pressure drop and heating accelerates the flow. This reduces turbulence.
- The thermal boundary layer is still in development along the cooled surface.
- The shape of the entrance is significant for the flow in the relevant section.
- Wall roughness must be considered.

Design process relies on tools validated for gas flows in the described conditions.

⇒ IFMIF Thermal Hydraulic Experiment (ITHEX) provides validation data
Outline

- Upgrade of helium loop for ITHEX
- Experiments with annular testsection
- First results with LDA facility
- Fabrication of adjustable flat duct testsection

Flanges

Connection of piping and loop components:

- DIN 2631 flanges (flat gasket ring)
- COMPAC flanges (annular gasket)
- KF flanges (system for rapid mounting)

Experience favours the COMPAC flange for the use in future low pressure / low temperature Helium loops
ITHEX annular testsection photographs

V. Heinzel, A. Mooslang, Forschungszentrum Karlsruhe, IFMIF Meeting Tokyo, 18th of Mai

ITHEX variable flat duct testsection

V. Heinzel, A. Mooslang, Forschungszentrum Karlsruhe, IFMIF Meeting Tokyo, 18th of Mai
Manufacturing technologies

Crucial technologies tested with intermediate design solutions

Contributions from the production of test sections for experiments

S. Gordeev,
V. Heinzel,
A. Möslang,
K.-H. Lang,
E. Stratmanns,
Manufacturing the grooves for the electric heaters

The grooves for the electric heaters are fine milled with a finger milling

Milling time 100 h

The corners are crucial for the insertion of the heaters

The bent technology at the the corners is not yet tested
Winding up the electric heaters for ITHEX

Fill in of the specimens

Samples of technology tests from former design solutions are used for further tests
Fill in of specimens

„Specimens“ for fill in tests

The capsule with specimens will be provided for X-ray tomography

Specimens Fill-up
Brazing the electric heaters

Brazing the ITHEX test section:

7 h 20 $\Rightarrow$ 600 °C
12 h arrest temperature at 600 °C with gas release
5 h 600 °C $\Rightarrow$ 1000 °C with three shorted arrest point with gas release
24 h cooling down under vacuum

The whole procedure took 1 week.

We are looking for an other braze furnace

Brazing the electric heaters

Heat up of the brazed inner cylinder revealed braze failures
Brazing the electric heaters

Heat up of the brazed inner cylinder revealed braze failures

Only minor failures remained
Brazing the electric heaters

Braze test with reduced size
The grooves and bent radii in original dimensions
A outer box for the guidance of the filler material was applied.
The solution looks promising and may cause a design change.
Target and Test Facilities
- Design Progress

International-Fusion-Material-Irradiation-Facility

U. Fischer
S. Gordeev,
V. Heinzel,
A. Möslang,
K. H. Lang ,
S. Simakov,
V. Slobodtchouk,
E. Stratmanns,
P. Vladimirov,
IFMIF - In-Situ-Experiments
Preliminary design of rod drive

Inlet conditions:
P = 0.2 Mpa
V = 77.7 m/s
T = 50° C

Temperature distribution in the structure with nuclear and electrical heating
Temperature distribution in the structure with electrical heating only

Reference concept

Title: Heinzl, A. Mondel, S. Godlev, et al. IFMIF Meeting, Tokyo, 18th of May 2005
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Temperature distribution in the structure with nuclear and electrical heating (adapter of ceramic)

Temperature distribution in the structure with nuclear and electrical heating (additional heating in the screw cap)

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Creep-fatigue specimen arrangement with
Temperature distribution in the structure with nuclear and electrical heating (with interior pipe)

<table>
<thead>
<tr>
<th>Fall</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_{\text{Inj,Prot}}$ (W/cm²)</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>$q_{\text{cool}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapter-Mat.</td>
<td>SS</td>
<td>SS</td>
<td>Cer</td>
<td>SS</td>
<td>SS</td>
<td>Cer</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>$q_{\text{DAM}}$ (W/cm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$q_{\text{Dewatt}}$ (W/cm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He-Führungsgrohr</td>
<td>ohne</td>
<td>ohne</td>
<td>ohne</td>
<td>ohne</td>
<td>ohne</td>
<td>ohne</td>
<td>mit</td>
<td>mit</td>
</tr>
<tr>
<td>$T_{\text{max,Prot}}$ (°C)</td>
<td>549</td>
<td>442</td>
<td>540</td>
<td>562</td>
<td>483</td>
<td>586</td>
<td>499</td>
<td>440</td>
</tr>
<tr>
<td>$L_{\text{sp}}/L_{\text{tota}}$</td>
<td>0.46</td>
<td>0.38</td>
<td>0.43</td>
<td>0.48</td>
<td>0.37</td>
<td>0.83</td>
<td>0.5</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Jet Flow

Validation of turbulence models

Test case 1. Single jet.

axisymmetric turbulent air jet impinging on a heated flat plate

Computational Domain:

- \( D = 25 \, \text{mm} \)
- \( R = 150 \, \text{mm} \)
- \( L / D = 2, 4 \)
- \( Re = 5000, 10000, 15000 \)

grid resolution:
- \( 150 \times 150 \) (Low Re)
- \( 120 \times 120 \) (High Re)
Test case 1. Single jet
Local Nusselt number $Re = 5000, 10000, 15000, LD = 2$

Distribution of turbulent kinetic energy for the impinging jet on the flat plate at $LD = 4$ and $Re = 5000$

- $k$-$\varepsilon$ Low Re model (Lien et al.)
- $k$-$\varepsilon$ Low Re model
- V2F model
- $k$-$\varepsilon$ RNG Two Layer model
- $k$-$\varepsilon$ cubic model (Suga et al.)
Test case 1. Single jet.
Local Nusselt number $Re = 5000, 10000, 15000$ $L/D = 4$

Distribution of turbulent kinetic energy for the impinging jet on the flat plate at $L/D = 2$ and $Re = 5000$
Test case 2. Jet Array

Jet array heat transfer distribution under an array of orthogonal impinging jets

- Air in
- Office Plate
- Pressure chamber
- Impingement Channel
- Computational Domain

- 4 x 12 jets
- Dj = 6.35 mm
- Jet to jet distance 4 x Dj
- Jet to plate distance 3 x Dj
- Re = 4850, 9550, 18300

The mass flow ratio of crossflow-to-total-jet flow for the case Re = 18300.
Test case 2. Jet Array

Span averaged Nusselt number distribution

Re = 4850

Re = 9550

Re = 18300

Test case 2. Jet Array

Turbulent kinetic energy distribution in the symmetry plane of the jet array

Re = 9550

RNG TL turbulence model

V2F turbulence model

k-ε LRN nonlinear turbulence model
REVIEW    EU TASKS 2004 (Cutout)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Test Facilities Tasks (Cutout)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>Neutronics application and users tasks: Development of reference test matrix.</td>
</tr>
<tr>
<td>(a) TEKES</td>
<td>Neutronics application and users tasks: (a) Update global geometry model for entire test module assembling.</td>
</tr>
<tr>
<td>(b) FZK</td>
<td>Neutronics application and users tasks: (b) 3D calculation of entire nuclear response.</td>
</tr>
<tr>
<td>MEC</td>
<td>Evaluation and validation of D-Li cross-section data: - Updated evaluations of $d + ^6\text{Li}$ data up to 50 MeV</td>
</tr>
<tr>
<td>FZK</td>
<td>Evaluation and validation of D-Li cross-section data: - Preparation and processing of ENDF data files for $d + ^6,7\text{Li}$ - Validation analyses and neutron yield uncertainty assessment</td>
</tr>
</tbody>
</table>

IFMIF
Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo A Möslang

---

REVIEW    EU TEST Facilities TASKS 2004 (Cutout)

Contributors


IFMIF
Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo A Möslang
Reference Test Matrix  EU Task 2004 003 D4

Mission:  
- Qualification of candidate materials up to about full lifetime of anticipated use in a fusion DEMO reactor \(\rightarrow \sim 150 \text{ dpa}\)
- Advanced material development for commercial reactors
- Calibration and validation of data generated from fission reactors and particle accelerators

Small Scale Specimens

- Quasi Standards
- Further R&D required

Fixing tool for capsule assembling

capsule
Reference Test Matrix

EU Task 2004 003 D4

Specimen Density Variations

Nuclear Responses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EF-39% (3.53)</th>
<th>EF-39% (3.53)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacements per Fe atom [dpa/fpy]</td>
<td>16.4</td>
<td>16.3</td>
</tr>
<tr>
<td>H production per Fe atom [ppm/fpy]</td>
<td>810</td>
<td>810</td>
</tr>
<tr>
<td>H2 production per Fe atom [ppm/fpy]</td>
<td>189</td>
<td>189</td>
</tr>
<tr>
<td>Nuclear heating [W/kg] [W/cm²]</td>
<td>1.24 (6.6)</td>
<td>1.24 (6.6)</td>
</tr>
<tr>
<td>2004-2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packet-2 Packet-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE Report 2003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High Flux Volume

Suggested Specimen Loading

IFMIF

- 279 -
Reference Test Matrix

IFMIF

High flux test module (20-50 dpa/fpy)

- Thermo couples
- Ohmic heating
- Capsule
- 4x3 Rigs
- 700-1150 Specimens
- Reflector RAFM Steel

Reference Test Matrix

IFMIF

High Flux Volume

Suggested Specimen Loading

- 2 packets per capsule
- 1 Temperature per capsule
- Each capsule contains packets with the same alloy class (or otherwise compatible materials)
- Total number of packets = 2x12 = 24
- Additional space for
  - Spacers (TEM, Modeling evaluation,...)
  - Online neutron/γ Monitors, 3-4 Thermocouples
### Reference Test Matrix

**EU Task 2004 003 D4**

#### Proposed loading matrix for each material/irradiation condition

<table>
<thead>
<tr>
<th>Property</th>
<th>Multiplicity at each irradiation condition</th>
<th>Volume / Specimen (cm³)</th>
<th>Specimen package density (%)</th>
<th>Tot. Vol. * occupied in capsule (cm³)</th>
<th>% of total volume* per material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstructure swelling</td>
<td>≥ 6</td>
<td>0.0014</td>
<td>66</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Tensile</td>
<td>12</td>
<td>0.075</td>
<td>76</td>
<td>0.57</td>
<td>4.1</td>
</tr>
<tr>
<td>Fatigue</td>
<td>6</td>
<td>0.249</td>
<td>51</td>
<td>4.65</td>
<td>33.3</td>
</tr>
<tr>
<td>Fracture toughness</td>
<td>2</td>
<td>0.560</td>
<td>92</td>
<td>1.83</td>
<td>13.2</td>
</tr>
<tr>
<td>Crack growth</td>
<td>3</td>
<td>0.280</td>
<td>92</td>
<td>0.61</td>
<td>4.4</td>
</tr>
<tr>
<td>Bend bar/dynamic frac. tough.</td>
<td>12</td>
<td>0.291</td>
<td>99</td>
<td>3.53</td>
<td>25.2</td>
</tr>
<tr>
<td>Creep</td>
<td>8</td>
<td>0.133</td>
<td>79</td>
<td>1.35</td>
<td>9.7</td>
</tr>
<tr>
<td>Thermocoupl., n/y-monitors</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>10.1</td>
<td></td>
</tr>
</tbody>
</table>

* *includes space occupied by NaK

24 Packages in 12 Rigs → 1032 Specimens

---

### Summary Test Matrix

- The present roadmap allows about 5-6 years of IFMIF irradiation for 80 dpa input to DEMO pre-design → broad data base only for few alloy classes

- Suggestions for revised loading matrix
  - 1x125 mA operation: 2017-2019 - data base for alloys A,B (10,15,20 dpa) - 3-4 rigs for fundamental studies, etc.
  - 2x125 mA operation: 2020-2023 - data base for alloys A,B (40,60,80 dpa) - few rigs for fundamental studies, etc.
  - 2024-2039+ - engineering data base for DEMO/PROTO for various other materials - few rigs for fundamental studies

- Beam footprint variations are NOT taken into account
Why updating the IFMIF test cell model?

4 major changes:

1) changes in the materials

2) putting each test module in its own universe ("universization")
   → Easily possible to move and remove them

3) remodeling the cover and VIT

4) remodeling the walls

---

1. Materials

Which materials lack cross section data above 20 MeV?

**Importance: moderately high**

<table>
<thead>
<tr>
<th>ID</th>
<th>element</th>
<th>where?</th>
<th>Density (unweighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12000</td>
<td>Mg</td>
<td>concrete</td>
<td>0.000787</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermocoax (heater cable)</td>
<td>0.020900</td>
</tr>
<tr>
<td>19000</td>
<td>K (K-39 data is available)</td>
<td>NaK</td>
<td>0.008408</td>
</tr>
<tr>
<td>22000</td>
<td>Ti</td>
<td>concrete</td>
<td>0.002325</td>
</tr>
</tbody>
</table>
Global Geometry Model
EU Task 2004 003 D4

Materials

Which materials lack cross section data above 20 MeV?

Importance: medium

<table>
<thead>
<tr>
<th>Missing nuclides or elements</th>
<th>density</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>element</td>
</tr>
<tr>
<td>16000</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>73181</td>
<td>Ta</td>
</tr>
</tbody>
</table>

Approximations without distorting seriously the results:
Missing Nuclides were deleted

---

Global Geometry Model
EU Task 2004 003 D4

3. Remodeling the cover and VIT

CATIA models of VTA1, central and VTA2 shield blocks
Global Geometry Model

EU Task 2004 003 D4

3. Remodeling the cover and VIT

MCNP model: sample elevation and plane cuts
(the erroneous arcs in the plane view are due to problems with the plotter)

IFMIF

Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo

Global Geometry Model

EU Task 2004 003 D4

4. Remodeling the walls

Subdivision of the walls to provide sufficient spatial resolution for importance
(needed for variance reduction)

IFMIF

Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo
Computational Tools and Nuclear Data Base

- IFMIF neutron source simulation, neutron transport and nuclear responses calculations:
  - McDeLicious code - for the neutron source simulation (using d-Li evaluated cross sections) and neutron transport
  - neutron cross sections from INPE/FZK-50, LA-150 general libraries – for transport and nuclear responses

- Radioactive inventory calculations:
  - deuteron induced inventories in the Li loop - by McDeLicious code using evaluated Li(d,x)²H and Li(d,x)²Be cross sections files
  - neutron induced inventories in the IFMIF components by ALARA inventory code with IEAF-2001 activation data library (up to 150 MeV)

- IFMIF test cell model
  - detailed 3d geometry model describing all principal sub systems of the IFMIF test cell (d-beam tubes, Li-loop and target, test modules, test cell walls)

IFMIF Neutronics – from simplified to global geometry model

Neutron Spectra in IFMIF & FPR

The detailed geometry model affects the neutron spectrum below 0.5 MeV, hence does not touch the previous assessment of dpa, gas production ...
3D Nuclear Response
EU Task 2004 003 D5

HFTM elevation view

DPA and nuclear heating

Fe displacement damage
Nuclear heating

IFMIF
Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo A. Molsang

3D Nuclear Response
EU Task 2004 003 D5

Neutron energy fluxes in the IFMIF

Neutron fluxes & dpa in the IFMIF components
Induced Radioactivity in the IFMIF sub-systems

\[ \gamma \text{- Dose vs. Cooling Time after 1 year run} \]

Time after shutdown, years

10\(^{-3}\) 10\(^{-2}\) 10\(^{-1}\) 10\(^{0}\) 10\(^{1}\) 10\(^{2}\) 10\(^{3}\) 10\(^{4}\) 10\(^{5}\) 10\(^{6}\)

UTM frame, 10 years

Time after shutdown, years

10\(^{-1}\) 10\(^{0}\) 10\(^{1}\) 10\(^{2}\) 10\(^{3}\) 10\(^{4}\) 10\(^{5}\) 10\(^{6}\)

Element | Eurofer | SS-316 | Dominant Activation Reaction
---|---|---|---
B | 0.001 | 0.0002 | 
C | 0.015 | | 
N | 0.018 | | 
O | 0.010 | | 
Al | 0.008 | 0.05 | \(^{17}\text{Al(n,2n)}\text{Al}\) 
Si | 0.006 | 0.4 | 
P | 0.004 | | 
S | 0.003 | | 
Ti | 0.008 | 0.15 | | 
V | 0.20 | | 
Cr | 9.00 | 17.5 | | 
Mo | 0.42 | 1.3 | | 
W | 88.98 | 65.16 | \(^{54}\text{Fe(n,p)}\text{Cr}\) \(^{54}\text{Fe(n,p)}\text{Cr}\) | 
Co | 0.005 | 0.03 | \(^{56}\text{Fe(n,p)}\text{Co}\) \(^{56}\text{Fe(n,p)}\text{Co}\) | 
Ni | 0.005 | 12.3 | \(^{56}\text{Fe(n,p)}\text{Co}\) \(^{56}\text{Fe(n,p)}\text{Co}\) | 
Cu | 0.005 | 0.1 | | 
Nb | 0.001 | 0.005 | | 
Mo | 0.001 | 2.5 | \(^{54}\text{Fe(n,p)}\text{Nb}\) | 
Ta | 0.07 | | \(^{54}\text{Fe(n,p)}\text{Ta}\) | 
W | 1.10 | | | 

3D Nuclear Response

Activation Analysis

10 yrs irradiation of Universal Test Machine

Eurofer & SS-316 composition
3D Nuclear Response  EU Task 2004 003 D5

Tritium and Be-7 Inventories in the IFMIF Li Loop

$^3\text{H}$ and $^7\text{Be}$ production rates in Li-loop sub-systems

<table>
<thead>
<tr>
<th>Loop component</th>
<th>Mass, kg</th>
<th>Reaction</th>
<th>Inventory</th>
<th>Rate, g/ffpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li jet</td>
<td>1</td>
<td>$d + {\text{Li}}$</td>
<td>$^7\text{Be}$</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$d + {\text{Li}}$</td>
<td>$^3\text{H}$</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$n + {\text{Li}}$</td>
<td>$^3\text{H}$</td>
<td>0.4</td>
</tr>
<tr>
<td>Li injection tank</td>
<td>18</td>
<td>$n + {\text{Li}}$</td>
<td>$^3\text{H}$</td>
<td>0.2</td>
</tr>
<tr>
<td>Li quench tank</td>
<td>1200</td>
<td>$n + {\text{Li}}$</td>
<td>$^3\text{H}$</td>
<td>1.0</td>
</tr>
<tr>
<td>Li drain tubes</td>
<td>3</td>
<td>$n + {\text{Li}}$</td>
<td>$^3\text{H}$</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>$^3\text{H}$</td>
<td><strong>7.7</strong></td>
</tr>
</tbody>
</table>

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Medium flux test modules

In situ creep-fatigue test module

3 independent creep-fatigue tests within beam footprint

200 mm
3D Nuclear Response  EU Task 2004 003 D5

Creep-Fatigue Test Module (Plan view)

Non symmetric loading of HFTM

Creep-Fatigue Test Module (Elevation view)

Lattice cell

\[
\begin{array}{c}
\text{Beam footprint} \\
20 \times 5 \text{ cm}^2
\end{array}
\]

\[\varnothing=0.8 \text{ cm} \]
\[\Delta=0.04 \text{ cm} \]

0.5x0.5x0.25 cm\(^3\)
3D Nuclear Response EU Task 2004 003 D5

Creep-Fatigue Test Module

Cooling channels

Beam footprint 20 x 5 cm²

Fine grid

0.25x0.25x0.25 cm³

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3D Nuclear Response EU Task 2004 003 D5

Heat Deposition in Pulling Rods (Vert)

W/g

1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0

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Validation D-Li Cross Section  

$^7\text{Li}(d,d_0)^7\text{Li}$ microscopic angular distributions

4 MeV
- Abramovich+ (1976)
- Average CPM

6 MeV
- Abramovich+ (1976)

8 MeV
- Abramovich+ (1976)

10 MeV
- Abramovich+ (1976)
- Matsuki + (1969)

14.7 MeV
- Matsuki + (1969)

$^6\text{Li}(d,d_0)^6\text{Li}$

Comparison of global OMP predictions for $^6\text{Li}(d,d_0)^6\text{Li}$

10 MeV
- Abramovich+ (1976)
- Brigham + (1971)

11.8 MeV
- Unidentified + (1974)

12 MeV
- Abramovich + (1976)

14.7 MeV
- Matsuki + (1969)

19.6 MeV
- Chiu + (1971)

50 MeV
- Russo + (1969)

IFMIF  
Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo A Moslang
Validation D-Li Cross Section

EU Task 2004 003 D8

Comparison of global OMP predictions for \(^7\text{Li}(d,d_0)^7\text{Li}\)

Comparison of \(^6,7\text{Li}(d,d_0)^6,7\text{Li}\) experimental data

IFMIF
Validation D-Li Cross Section  EU Task 2004 003 D8

Conclusions

- Achievements
  - Appropriate optical model potentials: $^d + ^6Li (E < 50 \text{ MeV})$
  - $^d + ^7Li (E < 15 \text{ MeV})$
  - Enlarged analysis of $^d + ^7Li$ up to 50 MeV

- Important request
  - Additional experimental data to guide and benchmark the model calculations at incident energies above 15 MeV

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Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo  A. Motleng

X-Rax Microtomography  EU Task 2004 003 D6

Overall performances

- Magnification < 2000
- Spatial resolution ≈ 5μm
- Density resolution ≈ 0.5%
- 3D Reconstruction Time ≈ 5 min.
  (512x512x256 voxels)
- Probe dimensions:
  Diameter < 40 mm
  Height < 500 mm

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X-Rax Microtomography

Space resolution benchmark

High resolution microradiography

Metallic catalyst sample (thinnest wire – 3 µm)

TEM grid - Thick bar: 35 mm
Thin bar: 21 mm Letters: 14 mm

Tomographic reconstruction
Optical microscopy

X-Rax Microtomography

Radiography Density plot Sagital view

SUS traction probe
2 mm diameter

Calibration sample:
Cu tube 2.2 mm, Ag central wire 0.5 mm and coiled kanthal wires 0.18 and 0.08 mm

Steel bellows of 6.5 mm

Push-pull fatigue specimen
X-Rax Microtomography  EU Task 2004 003 D6

IFMIF High Flux Test Module: dummy irradiation capsule

Photo  Reconstruction

SUS specimens and thermocouple are clearly identified

X-Rax Microtomography  EU Task 2004 003 D6

Micro-tomography of complex dummy capsule

- Stainless steel bellows
- Aluminum square rod with simulated high density inclusions
- SUS hourly glass
- Stainless steel pipes
X-Rax Microtomography

3D reconstruction of complex dummy capsule

X-Rax Microtomography

2D cross-sections of complex dummy capsule
X-Rax Microtomography EU Task 2004 003 D6

Compressed pebble bed

Frontal cross-section (top) axial cross-sections through contact area between steel plate and aluminum pebbles (bottom-left) and through middle of bottom layer of aluminum pebbles (bottom-right)

OVERVIEW EU TASKS 2005

Test Facilities (1/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
<td>Dec. 2005</td>
</tr>
<tr>
<td>HAS</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
<td>Dec. 2005</td>
</tr>
<tr>
<td>FZK</td>
<td>Design of a horseshoe type neutron shielding block enveloping all test modules to reduce further the nuclear inventory and the gamma dose rate in the rooms surrounding the test cell</td>
<td>Dec. 2005</td>
</tr>
</tbody>
</table>
OVERVIEW EU TASKS 2005

Materials Properties Handbook

IFMIF
Materials Properties Handbook
IFMIF Test Facilities
MPH-TF - Draft -

Abstract

This document provides the basics and concepts of the IFMIF Materials Properties Handbook. It is of interest to all scientists, e.g. the IFMIF Test Facility, to assess the material design. The document is based on the IFMIF IFMIR Test Facility Development Planning Project. (A. Mroz)

Table

<table>
<thead>
<tr>
<th>Test Facility</th>
<th>IFMIF Test Facility</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>MPH-TF</td>
<td>Calculation of complete nuclear response through the entire test cell with consideration of an additional neutron shielding block: (a) 3D distribution of nuclear responses using McDeLicious and MCNP codes. (b) 3D distribution of the activity inventory using suitable activation codes and activation data (IEAF-2001/EAF-2005)</td>
</tr>
<tr>
<td>MEC</td>
<td>MPH-TF</td>
<td>X-ray microtomography for HFTM capsules and rigs: (i) influence of the sample radioactivity on the tomographic reconstruction quality and practical procedures to mitigate its effects, and (ii) experimental determination of resolution limits of specimens, capsules and rigs for complete rig assemblies.</td>
</tr>
</tbody>
</table>

OVERVIEW EU TASKS 2005

Test Facilities (2/2)

Assoc. | Description | Due |
-------|-------------|-----|
FZK    | Calculation of complete nuclear response through the entire test cell with consideration of an additional neutron shielding block: (a) 3D distribution of nuclear responses using McDeLicious and MCNP codes. (b) 3D distribution of the activity inventory using suitable activation codes and activation data (IEAF-2001/EAF-2005) | Dec. 2005 |
MEC    | X-ray microtomography for HFTM capsules and rigs: (i) influence of the sample radioactivity on the tomographic reconstruction quality and practical procedures to mitigate its effects, and (ii) experimental determination of resolution limits of specimens, capsules and rigs for complete rig assemblies. | Dec. 2005 |
OVERVIEW EU TASKS 2005

Test Cell with horseshoe type neutron reflector?

3D Dose rate distribution inside Test Cell concrete

Unit: pSv/h

Beam direction

IFMIF Target & Test Facilities Technical Meetings, May 17-18, 2005, Tokyo A. Moseng
JAERI progress for Test Facilities

T. Yutani
JAERI

IFMIF Technical Meeting
May 17-18, 2005, Tokyo, Japan

Content

• Design of He-cooled High Flux Test Module
• Irradiation Effect on Thermocouple
  (Change in the composition of the thermocouple materials due to transmutation)
Design of He-cooled High Flux Test Module

- Structural design of HFTM is on the basis of the concept of Kyushu Univ.
- Vessel is designed according to ASME Sec. VIII - Div. 1, Appendix 13, “Vessel of Noncircular Cross Section”.
- Detailed stress analysis and thermal hydraulic calculation will be carried out in future.
- Material: 316 LN SS
- Design Pressure: about 0.6 MPa

3D drawing of test module

He-cooled High Flux Test Module

- Vessels and terminal box cover are reinforced with plates or bars.
- Flow straighteners are composed of ceramics filters.
Procedure of Remote Handling

- Connection to shielding plug
- Installation of rig and connection of terminal (Installations of 2nd and 3rd rig)
- Welding of terminal box cover
- Connection of MI cable
- Adjustment of position (beam direction)

Rig

- Each capsule has eight heaters and three thermocouples.
- Each rig has three capsules.
- Rig can be assembled by manipulator and some tools.
- Three rigs are installed in a test module.
Cross Section of HFTM

Thickness of vessel depends on material and pressure.

Constitution of Capsule

Capsule can be assembled by manipulator and some tools.
Summary of HFTM Design

- The structural design of He-cooled HFTM was carried out on the basis of the concept of Kyushu Univ.
- This HFTM may be assembled by the remote handling.
- Therefore, re-irradiation of specimen is possible and the specimens can be irradiated up to the high fluence.

Irradiation Effect on Thermocouple

- It is well known that the variations in the thermo-electric characteristics (decalibration) of the thermocouples occur due to neutron irradiation in the fission reactor.
- Decalibration arises from transmutation and structural damage induced by fast neutron. The effect of structural damage is in general small (<2%)\(^1\).
- In review of sensor for ITER, both K-type (Chromel-Alumel) and N-type (Nicrosil-Nisil) thermocouples are assessed to be unaffected by neutron irradiation over the entire life time of ITER, because the neutron cross sections for transmutation reactions at a neutron energy of 14 MeV is small\(^1\).
- However, decalibration might occur in the IFMIF, because fluence of IFMIF condition will be higher than that of ITER condition.

ITER condition: 14 MeV, \(3\times10^{11} \text{n/cm}^2\) (end of life)
IFMIF condition: 14 MeV, \(1.5\times10^{12} \text{n/cm}^2\) (1 year operating with availability of 70 %)

Transmutation of Thermocouple Materials

- In fission reactor, transmutation due to thermal neutron is predominant because of large cross section of (n, γ) reaction.
- In fusion environment, reactions such as (n, np) having threshold energy of several MeV become substantial.

Example of Cross Section (Ni-58, JENDL-3.2)

Compositional Change under Monoenergetic Neutron

- For K-type, maximum decalibration is of the order of 1\% in fission reactor. Change of composition in IFMIF (1\%) is much larger than in fission reactor (0.03 \%).
- Change of composition of N-type is little in fission reactor. However, in IFMIF condition, it is the same level as K-type.
- Large decalibration might occur in IFMIF without depending on the type of thermocouple.

<table>
<thead>
<tr>
<th>Leg</th>
<th>K-type thermocouple</th>
<th>N-type thermocouple</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Element</td>
<td>Composition</td>
</tr>
<tr>
<td></td>
<td>Initial</td>
<td>Fission*</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>9.993</td>
</tr>
<tr>
<td>Fe</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Co</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ni</td>
<td>90</td>
<td>89.999</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>84.4</td>
</tr>
<tr>
<td>Al</td>
<td>2</td>
<td>2.000</td>
</tr>
<tr>
<td>Si</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>Mn</td>
<td>2</td>
<td>1.973</td>
</tr>
<tr>
<td></td>
<td>Fe</td>
<td>0.027</td>
</tr>
<tr>
<td>Ni</td>
<td>95</td>
<td>94.998</td>
</tr>
</tbody>
</table>

*: 0.025 eV, 1 × 10^{21} n/cm²
**: 14 MeV, 1.5 × 10^{23} n/cm² (1 year operating with availability of 70 \%)

Most of Fe exists as Co in IFMIF condition, because half-lives of Co-57 and Co-58 (formed nuclides) are 271.79 d and 70.82 d, respectively
Summary of Irradiation Effect on Thermocouple

- Compositional change of thermocouple materials under monoenergetic neutron was calculated.
- In the IFMIF condition, large compositional changes will be expected. Large decalibration might occur.
- Then, calculation for compositional change of N-type thermocouple will be carried out under fusion neutron spectrum (this year).
- In EVEDA, experiment to examine the relation between the composition change and the electromotive force may be indispensable to evaluate the specimen temperature exactly.
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Appendix D

Agenda and Documents of Target/Test Facilities Interface Meeting
May 18, 2005, Tokyo, Japan
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IFMIF Target / Test Facilities Interface Meeting
May 18, 2005, Tokyo, Japan

15:00-17:15 **Discussion session**

- Test Cell atmosphere including natural convection calculations
  (incl. short presentation by V. Heinzel)
- Start-up procedure of Li circuit and test modules
- Interface Li target – HFTM: design issues
- Horse shoe type shielding of test modules;
  (incl. initial calculations likely presented by V. Heinzel)
- Target and test module adjustments
- Thermal analysis of IFMIF Li target compatible with He environment (M. Ida)

17:00-17:15 **Summary and Miscellaneous**

17:15 Adjourn
Thermal Analysis of Target Assembly Compatible with He Environment in Test Cell

M. Ida, H. Nakamura and T. Yamamura

IFMIF Target / Test Module Interface Meeting
May. 17-18, 2005, Tokyo, Japan

IFMIF Target / Test Module Interface Meeting
JAERI Tokyo
May 18, 2005

CONTENTS

1. Thermo-structural design issues of target assembly
2. Thermal analysis for thermal shielding / insulation
3. Thermal Analysis of backwall
4. Summary
1. Thermo-structural design issues of target assembly

He environment of Test Cell was proposed in the Target Meeting, Sep 2004.

To clarify shielding/insulation and heater to avoid Li freezing at 180 °C at Li charge, thermal analyses were extended to for a case of He environment.

2. Thermal analysis for thermal shielding / insulation

Evaluation of thermal-isolation performance of thermal shield/insulation

Calculation Conditions:
Method: Heat balance (conduction, radiation)

Analysis Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Thermal Isolation</th>
<th>Test Cell atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Insulation</td>
<td>0.1 MPa Ar</td>
</tr>
<tr>
<td>A2</td>
<td>Insulation</td>
<td>Vacuum</td>
</tr>
<tr>
<td>A3</td>
<td>Shielding</td>
<td>0.1 MPa Ar</td>
</tr>
<tr>
<td>A4</td>
<td>Shielding</td>
<td>Vacuum</td>
</tr>
<tr>
<td>A5</td>
<td>Shielding</td>
<td>0.09 MPa He</td>
</tr>
</tbody>
</table>

A case with insulation and 0.09Mpa is under calculation

For Cases A3, A4, A5

Multi-layer heat shields
(316SS, t=0.2 mm, Δ = 5 mm, ε = 0.2)

For Cases A1, A2

Insulation (ceramic fiber)

0.1 MPa Ar
0.09 MPa He

Test Cell Wall
(T=20°C, Emissivity:ε=0.2)

1-D Cylindrical Calculation Model
**Results of Cases A1-A5**

<table>
<thead>
<tr>
<th>Case</th>
<th>Required thickness</th>
<th>Heat flux per unit length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>140 mm</td>
<td>165 W/m</td>
</tr>
<tr>
<td>A2</td>
<td>327 mm</td>
<td>94 W/m</td>
</tr>
<tr>
<td>A3</td>
<td>80 mm (17 Layers)</td>
<td>130 W/m</td>
</tr>
<tr>
<td>A4</td>
<td>75 mm (16 Layers)</td>
<td>46 W/m</td>
</tr>
<tr>
<td>A5</td>
<td>195 mm (40 Layers)</td>
<td>396 W/m</td>
</tr>
</tbody>
</table>

(Emittance: 0.2 for cases A3-A5)

- Multi-layer thermal shield is better than ceramic-fiber insulation as regards thickness.
- He environment needs larger number of shield plates.

**Required shield plate depending on its emissivity**

- Under 0.1 MPa-Ar condition (A3), required layer number can not be reduced less than 12 due to heat conduction between shield plates.
- Under vacuum condition (A4), the number can be reduced to 5 by using emissivity of 0.05.
- Under 0.09 MPa-He(A5) conditions, the number can not be reduced less than 39 due to heat conduction of He 8 times larger than Ar.
3. Thermal analysis of backwall

**Calculation Conditions:**

**Method:**
Heat balance calculation with 12 elements

**Boundary temperature:**
300 °C at shielded part

**Test Cell atmosphere:**
0.1 MPa-Ar, 0.09 MPa-He, Vacuum(0.1 Pa)

**VTA temperature:** $T_{VTA} = 50, 150 °C$

**Emissivity of Target Assembly, BW and VTA:**
$\varepsilon = 0.05, 0.1, 0.2$

**Heat transfer coefficient between Backwall and Target Assembly:**
$\alpha = 150 \text{ W/m}^2\cdot\text{K}$

---

### Results

<table>
<thead>
<tr>
<th>Case</th>
<th>TC atmosphere</th>
<th>$T_{VTA}$ (°C)</th>
<th>Emissivity: $\varepsilon$</th>
<th>Heater position</th>
<th>Minimum temp. (°C)</th>
<th>Heat loss (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>0.1 MPa-Ar</td>
<td>50</td>
<td>0.2</td>
<td>T.A.</td>
<td>74</td>
<td>180</td>
</tr>
<tr>
<td>B2</td>
<td>0.1 MPa-Ar</td>
<td>150</td>
<td>0.2</td>
<td>T.A.</td>
<td>162</td>
<td>133</td>
</tr>
<tr>
<td>B3</td>
<td>Vacuum</td>
<td>50</td>
<td>0.2</td>
<td>T.A.</td>
<td>185</td>
<td>149</td>
</tr>
<tr>
<td>B4</td>
<td>Vacuum</td>
<td>150</td>
<td>0.2</td>
<td>T.A.</td>
<td>215</td>
<td>116</td>
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<tr>
<td>B5</td>
<td>Vacuum</td>
<td>50</td>
<td>0.1</td>
<td>T.A.</td>
<td>216</td>
<td>79</td>
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<td>B6</td>
<td>Vacuum</td>
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<td>0.1</td>
<td>T.A.</td>
<td>236</td>
<td>61</td>
</tr>
<tr>
<td>B7</td>
<td>Vacuum</td>
<td>50</td>
<td>0.05</td>
<td>T.A.</td>
<td>244</td>
<td>43</td>
</tr>
<tr>
<td>B8</td>
<td>Vacuum</td>
<td>150</td>
<td>0.05</td>
<td>T.A.</td>
<td>257</td>
<td>33</td>
</tr>
<tr>
<td>B9</td>
<td>0.09 MPa-He</td>
<td>50</td>
<td>0.2</td>
<td>T.A.</td>
<td>51</td>
<td>241</td>
</tr>
<tr>
<td>B10</td>
<td>0.09 MPa-He</td>
<td>150</td>
<td>0.2</td>
<td>T.A.</td>
<td>150</td>
<td>171</td>
</tr>
<tr>
<td>B11</td>
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<td>50</td>
<td>0.1</td>
<td>T.A.</td>
<td>51</td>
<td>187</td>
</tr>
<tr>
<td>B12</td>
<td>0.09 MPa-He</td>
<td>150</td>
<td>0.1</td>
<td>T.A.</td>
<td>150</td>
<td>128</td>
</tr>
<tr>
<td>B13</td>
<td>0.09 MPa-He</td>
<td>50</td>
<td>0.05</td>
<td>T.A.</td>
<td>50</td>
<td>162</td>
</tr>
<tr>
<td>B14</td>
<td>0.09 MPa-He</td>
<td>150</td>
<td>0.05</td>
<td>T.A.</td>
<td>150</td>
<td>108</td>
</tr>
<tr>
<td>B15</td>
<td>0.09 MPa-He</td>
<td>50</td>
<td>0.2</td>
<td>T.A.+B.W.</td>
<td>212</td>
<td>4451</td>
</tr>
</tbody>
</table>

- In each case, the minimum temperature is at Backwall center.
- In vacuum cases, temp. $\geq 200 °C$ can be kept by using component with $\varepsilon \leq 0.1$.
- Temperature of B.W. center $\sim$ VTA temp. due to high conduction of He.
- In this case, high-capacity heater is required to kept the temp. $\geq 200 °C$
Temperature distribution in backwall

Backwall with 9 kW electric heater is compatible with 0.1 MPa He environment in Test Cell.

Backwall with electric heaters
(Heaters are attached to hatched region excepting 300 mm x 67.6 mm region around beam-footprint)

4. Summary

For He environment in Test Cell, required capacity of heat shield and heater is as follows;

- 39 layers of heat shield is needed due to large heat-conduction of He.

- Backwall with 9 kW electric heater is compatible with 0.1 MPa He environment in Test Cell.
### Future plan

- Detailed thermal analysis including Target Assembly and VTA
- Design and testing of the backwall with electric heater
- Design of thermal shield
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Appendix E

Agenda and Documents of Accelerator Technical Meeting
May 18, 2005, Tokyo, Japan
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IFMIF Accelerator Technical Meeting
May 18, 2005, Tokyo, Japan

13:00–13:05 **Welcome and overview of agenda**
R. A. Jameson
including feedback from Knoxville subgroup meeting

13:05–14:00 **Status of Accelerator Group Activity**
EU, Japan, US, (PRC)

14:00–15:00 **Discussion of recommendations from technical reviews**
EFDA/EU, JAERI/Japan

15:00–15:20 BREAK

15:20–16:00 **Discussion of planning of future activity**

16:00–16:30 **Other related topics and summary**

Adjourn
IFMIF Accelerator Facility

2005 Status Report
Tokyo, Japan

Status

- In 2005, work continues at a lower level on the IFMIF Accelerator Facility
- Status of work among the partners
- Overall status
**EU Contributions**

- **EU IFMIF Monitoring Meeting, January 2005, Karlsruhe FZK**
- Slac report - Contributions to IFMIF 2004 (8p) - short review of past presentations
- Discussions with IBA about their Work Package on rf system design, agreement that cost estimate is reasonable.
- Presentations from IAP will be covered by Prof. Klein in his presentation.
- No takers for first round of EU task proposals on raster-scan HEIT option or beam instrumentation.
- Appointment of Dr. Elizabeth Surrey, Culham as new EU coordinator for the EU IFMIF Accelerator tasks.
- Second round task solicitation - Culham Lab (Dr. E. Surrey) has taken on the two tasks: (next slide)

---

**Task Deliverables**

<table>
<thead>
<tr>
<th>Assnr.</th>
<th>Del No.</th>
<th>Description</th>
<th>Due Date</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA1</td>
<td>1</td>
<td>Evaluation on whether or not the beam raster scanning method is generally applicable to the IFMIF design. Calculation of beam profile shape, as well as temporal and spatial stability of flat top and edges. Safety consideration. Cost estimate of a complete beam profile assembly.</td>
<td>31-Dec-05</td>
<td>II</td>
</tr>
<tr>
<td>UKAEA1</td>
<td>2</td>
<td>System study and design of a beam monitoring system that combines sensitivity, fast interlock capability and long term reliability under 10 MW beam power operation.</td>
<td>31-Jul-06</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Draft Final Report</td>
<td>II</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Report</td>
<td>II</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Months after signing of the contract by the CEU or precise date</em></td>
<td>II</td>
<td></td>
</tr>
<tr>
<td>Contributing Institutions:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UKAEA (1,2)</td>
<td>Contact Person</td>
<td>Telephone</td>
<td>Fax</td>
<td>E-mail</td>
</tr>
<tr>
<td></td>
<td>Elizabeth Surrey</td>
<td>+44 1235 4644730</td>
<td>+44 1235 464826</td>
<td><a href="mailto:Elizabeth.Surrey@jrf.jr.uk">Elizabeth.Surrey@jrf.jr.uk</a></td>
</tr>
</tbody>
</table>
2nd round tasks preparation continues

EFDA proposes a task on beam loss modeling, combining new design work on the linac, more detailed loss modeling of the linac, and collaboration with the nuclear physics group of Dr. U. Fischer at FZK. This task would require very competent manpower to be found on the accelerator side. Refinement of the RFQ design should be done.

“Independent IFMIF Accelerator Cost Assessment” commissioned by EFDA

No official contact with the project. Draft submitted to European experts for comment resulted in project involvement. Additional information was commissioned from AES, particularly on DTL costing, and IBA’s help was solicited on the rf system. The report is still under preparation.

SubCommittee point. Again a situation with no formal coordination with the project.

Accelerator Database

Some archival material was received from Saclay on their previous work. Will be abstracted to the IFMIF server database.

RF Power system

- IBA has completed their Work Package report giving a detailed RF power system analysis. (available)
- Visit was made to IBA to survey their facilities and discuss the report. Their capability is very impressive and can be a real asset to IFMIF.
US Contributions

- As mentioned, AES was commissioned to provide information for the EFDA Independent IFMIF Accelerator Cost Assessment.
- Prof. Shannon will comment on the overall US situation with respect to IFMIF.
- The US Accelerator Team members stand ready to assist as items come up, but instant response is difficult, as extra funds have to be sought.

Japan Contributions

- Will be presented by Dr. Maebara at a side IFMIF Accelerator Team meeting at the Particle Accelerator Conference on 16 May 2005,
- And by Dr. Sugimoto and colleagues at the Tokyo Accelerator Team Meeting on 18 May 2005.
Transition Tasks
2004-05 - Japan

- AF-1 Development of critical accelerator components
  - Injector: no funding to extend and optimize the previous results.
  - RF window: necessary to find test stand. (Thales?)
- AF-2 Accelerator Physics /Engineering Design
  - RFQ design: multi-drive loop & tuner effects were examined.
  - Beam dynamics: design requirements for HEBT need to be clarified more explicitly.
  - Preliminary safety analysis: applicability of SNS document is under consideration - too strongly dedicated to DOE regulations?
- AF-3 Analysis of possible alternatives
  - H2+ source: no funding to realize optimized beam extraction.

Comments of Domestic Peer Review Committee

- IFMIF technical peer review was carried out during May – August 2004, organized by JAERI Planning Section.
- For accelerator technology, comments were summarized as:
  - Injector and RF source are in good positions to enter EVEDA
  - 175 MHz CW RFQ/DTL models need to be examined in more details (not for higher frequency as 350 MHz)
  - Required stable beam footprint at target seems to be hard to realize under current design
  - In EVEDA much more extensive efforts for system design including utilities specifications are necessary
- For the above comments we need to reply by proposing a task plan during transition phase and EVEDA.
China Contributions

Will be presented by Dr. Zhao at the Tokyo Accelerator Team Meeting on 18 May 2005.

Accelerator Design

(Summary will be added here based on the May 16th and May 18 Accelerator Team meetings)

(Basically, we have not changed the CDR design or position. Additional design work on the RFQ, coupled with beam loss model work in collaboration with FZK is proposed. Work by Culham on the feasibility of raster scanning and on beam instrumentation (including collaboration with developers of mini-neutron detectors) is underway.
Japan Work
China Work)
Accelerator Facility
Manpower, Outlook for 2006

(summary to be added here after the May 16 & 18 meetings)
Appendix F

Agenda and Documents of Technical Integration Meeting
May 19, 2005, Tokyo, Japan
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IFMIF Technical Integration Meeting
- IFMIF Group Leaders Meeting -
May 19-20, 2005, Tokyo, Japan

Thursday 19 May 2005

9:30 - 9:40  Welcome and overview of agenda  T. E. Shannon
9:40-10:20  Status of activity of Test Facilities Group  A. Möslang
10:20-10:40 BREAK
10:40-11:20 Status of activity of Target Group  H. Nakamura
11:20-12:00 Status of activity of Accelerator Group  R. A. Jameson
12:00-12:20 Status of activity of Design Integration Group  M. Sugimoto

12:20-13:30 LUNCH

13:30-14:00 Status of CDR review in Europe  R. Lässer
14:00-14:30 Status of CDR review in Japan (JAERI)  M. Sugimoto

14:30-15:20 Discussion of EVEDA tasks  M. Sugimoto
- Possible change of tasks (addition, deletion, modification)
- Possible change of time schedule for each task
- Possible change of cost allocation for each task

15:20-15:40 BREAK

15:40-16:30 Other related topics

16:30-17:00 Action Items and Tasks for December Meeting (Santa Barbara)

Friday 20 May 2005

9:30-10:20  Report to IFMIF subcommittee  Group leaders
10:20-10:40 BREAK
10:40-11:20 Summary and action plans  T. E. Shannon

Adjourn
IFMIF Test Facilities

Status Report

May 19 2005, Tokyo
Anton Möslang

Contributors


U. Fischer  G. Bürkle  V. Heinzel  S. Simakov  P. Vladimirov  I. Schmuck  T. Craciunescu  R. Läsör  A. Shimizu
### Tasks for Test Facility (1/3)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td><strong>HFTM</strong>: Experimental validation of the thermohydraulic code used for the design of the IFMIF-HFTM thermal heat coefficients to be used in the design of test module. Stress analysis of the HFTM reference design at stationary conditions; Analysis of the suitability of STAR-CD or a comparable code for simulating the natural convection in the test cell.</td>
</tr>
<tr>
<td>FZK</td>
<td><strong>HFTM</strong>: Implementation of suitable software package to link thermal hydraulics codes with stress analysis codes; exemplar application to HFTM reference design.</td>
</tr>
<tr>
<td>FZK</td>
<td><strong>MFTM</strong>: Optimization of the design outline of the in situ creep-fatigue test module; stress analysis and calculation of the temperature distribution of the entire module.</td>
</tr>
</tbody>
</table>

---

### Tasks for Test Facility (2/3)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>Neutronics application and users tasks: Development of reference test matrix.</td>
</tr>
<tr>
<td>(a)</td>
<td>Neutronics application and users tasks: (a) Update global geometry model for entire test module assembling.</td>
</tr>
<tr>
<td>(b)</td>
<td>Neutronics application and users tasks: (b) 3D calculation of entire nuclear response.</td>
</tr>
<tr>
<td>MEC</td>
<td><strong>HFTM</strong>: Implementation of suitable NDT inspection methods for the structural integrity assessment of instrumented capsules and rigs by micro-tomography. Experimental validation of real time micro-radiography of miniaturized samples under mechanical stress.</td>
</tr>
</tbody>
</table>
### Test Facilities Overview EU Tasks 2004

#### Tasks for Test Facility (3/3)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
</table>
| **FZK** | **HFTM: Manufacturing** of  
  a) an instrumented capsule with 3-fold heater  
  b) one rig and three dummies with heaters  
  c) an extended container length  
  d) one compartment  
  Up-grading the helium-loop |
| **MEC** | Evaluation and validation of D-Li cross-section data:  
  - Up-dated evaluations of d + 6.7Li data up to 50 MeV |
| **FZK** | Evaluation and validation of D-Li cross-section data:  
  - Preparation and processing of ENDF data files for d + 6,7Li  
  - Validation analyses and neutron yield uncertainty assessment |

---

**HFTM**

**Design integration:**  
spatial interaction of the container flange with the back plate – requires an extension of the container to 600 mm
Test Facilities Overview EU Tasks 2004

Design Integration – MFTM design:
all MFTM sub units are available in CATIA V5 drawings

- Creep-Fatigue Module
- Tritium breeding module
- Tungsten neutron spectrum shifter

Test Facilities Overview EU Tasks 2004

All components inside Test Cell in CATIA available

- Lithium inlet-tube
- Test-cell plugs and shielding
- Graphite shielding
- Concrete shielding steel liner
- Low flux test module
- Medium flux test modules
- High flux test module
Design integration:
container design changes:
the new container is welded to an inner flange which provide the necessary stiffening. It has a height of 400 mm which can be spark eroded by an existing machine.

Test Facilities Overview EU Tasks 2004

HFTM: Temperature distribution
Test Facilities Overview EU Tasks 2004

Commercial FM Steel T 91

- 260 MPa
- 5 MPa

Test Facilities Overview EU Tasks 2004

Austenitic Steel 316 L

- 290 MPa
- 50 MPa
Test Facilities Overview EU Tasks 2004

Conclusion: The Present Reference Material for the HFTM Container is austenitic steel 316LN.
Manufacturing technologies

Manufacturing:
grooves for the electric heaters

Assembling:
Specimen stack inside capsule
Test Facilities Overview EU Tasks 2004
Specimens, Capsules and Rigs

• Miniaturized Specimens
• The capsule with specimens will be provided for X-ray tomography

Test Facilities Overview EU Tasks 2004
Brazing of electric heaters

• Heating of the brazed inner cylinder revealed failures
ITHEX-II loop photo

Test Facilities Overview EU Tasks 2004

ITHEX variable flat duct testsection

gap 0.5mm
gap 1.0mm

variable gapwidth 0 - 4mm
ITHEX annular testsection photographs

Small Scale Specimens

Fixing tool for capsule assembling
Test Facilities Overview EU Tasks 2004

High Flux Volume Suggested Specimen Loading

CDE Report 2003

Fatigue A
Packet 2 Packet 1
Alloy A

Fatigue B
Packet 2 Packet 1
Alloy B

Test Facilities Overview EU Tasks 2004

IFMIF High flux test module (20-50 dpa/fpy)

Thermo couples
Ohmic heating
Capsule
4x3 Rigs
700-1150 Specimens
Reflector RAFM Steel

356-366 °C
High Flux Volume  Suggested Specimen Loading

- 2 packets per capsule
- 24 packets in 12 Rigs → 1032 Specimens
- 1 Temperature per capsule
- Each capsule contains packets with the same alloy class
- Additional space for:
  - Spacers (TEM, Modeling evaluation,…)
  - Online neutron/γ Monitors, 3-4 Thermocouples

HFTM design of Kyushu Univ.

- Capsules elongated in the spanwise direction promote uniform temperature profile in themselves.
- Specimens are housed in cast-type capsules.
- Capsules are made of the same material as specimens to make nuclear heating in the capsules the same as specimens.
- Temperature of a capsule is measured to identify that of specimens housed in it.
Capsule design

- specimens
- thermocouple
- cast-type capsule (the same material with specimens is preferred)
- Can be unified?
- plate heater (for temperature control)

Mica heater for non-uniform heating

- Ceramic heater for temperature control
- specimen for temperature measurement (Copper plate)
- Mica heater for non-uniform heating
- Non-heating plate

- Heating region = 50mm (23 W/cm²)
Temperature profile in spanwise direction

- Temperature distributions are quite improved by heaters for temperature control.
- The use of the end heater is effective.

"Heater-printed" Capsule

Printed Heaters

<table>
<thead>
<tr>
<th>Multi-layered Ceramic Coating</th>
</tr>
</thead>
</table>

Heat Flux

Neutron Flux

1.0

226.0

16.5

18.4
JAERI: Design of He-cooled HFTM

- Structural design of HFTM is on the basis of the concept of Kyushu Univ.
- Vessel is designed according to ASME Sec. VIII - Div. 1, Appendix 13, "Vessel of Noncircular Cross Section".
- Detailed stress analysis and thermal hydraulic calculation will be carried out in future.
- Material: 316 LN SS
- Design Pressure: about 0.6 MPa

Procedure of Remote Handling

- Connection to shielding plug
- Installation of rig and connection of terminal (Installations of 2nd and 3rd rig)
- Welding of terminal box cover
- Connection of MI cable
- Adjustment of position (beam direction)
Decalibration of Thermocouples in IFMIF?

- For K-type, maximum decalibration is of the order of 1% in fission reactor. Change of composition in IFMIF (1%) is much larger than in fission reactor (0.03%).
- Change of composition of N-type is little in fission reactor. However, in IFMIF condition, it is the same level as K-type.

### Composition of major element (wt%)

<table>
<thead>
<tr>
<th>Element</th>
<th>K-type thermocouple</th>
<th>N-type thermocouple</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Fission*</td>
</tr>
<tr>
<td>Cr</td>
<td>10</td>
<td>9.993</td>
</tr>
<tr>
<td>Fe</td>
<td>90</td>
<td>0.060</td>
</tr>
<tr>
<td>Ni</td>
<td>89.999</td>
<td>88.836</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>84.4</td>
</tr>
<tr>
<td>Al</td>
<td>2</td>
<td>2.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 0.025 ev, $1 \times 10^{11}$ n/cm²
** 14 MeV, $1.5 \times 10^{12}$ n/cm² (1 year operating with availability of 70%)

---

Test Facilities  Overview EU Tasks 2004

3. Remodeling the cover and VIT

CATIA models of VTA1, central and VTA2 shield blocks
3. Remodeling the cover and VIT

MCNP model: sample elevation and plane cuts
(the erroneous arcs in the plane view are due to problems with the plotter)

IFMIF
Target & Test Cell Technical Meetings, May 17-18, 2005, Tokyo A.Miessing

Global (detailed) geometry

Simplified geometry

Neutron Flux, $10^{10}$ /cm$^2$/MeV/s

FW/FPR/HCPB
FW/HCLL/FPR
HTM/IFMIF: global model
HTM/IFMIF: simple model

The detailed geometry model affects the neutron spectrum below 0.5 MeV, hence does not touch the previous assessment of dpa, gas production ...

IFMIF
Target & Test Cell Technical Meetings, May 17-18, 2005, Tokyo A.Miessing
Test Facilities Overview EU Tasks 2004

Induced Radioactivity in the IFMIF sub-systems

IFMIF Test Cell

γ-Dose vs. Cooling Time after 1 year run

Time after shutdown, years

Test Facilities Overview EU Tasks 2004

Activation Analysis

10 yrs irradiation of Universal Test Machine

Eurofer & SS-316 composition

Element Content, wt. % Dissimilar Activation Reaction
B 0.005 0.0002
C 0.105
K 0.016
O 0.010
Al 0.000 0.05
Si 0.006
P 0.0006
S 0.003
Ti 0.000 0.15
V 0.70
Cr 9.00 17.5
Mo 0.42 1.8
Fe 88.08 65.16
W 0.005 0.03
Ni 0.009 12.3
Cu 0.000 0.1
Nb 0.000 0.005
Mo 0.88 2.5
Ta 0.87
W 1.10

IFMIF Target Test Cell Technical Meetings, May 17-18, 2005, Tokyo A Völsing
Test Facilities Overview EU Tasks 2004

Tritium and Be-7 Inventories in the IFMIF Li Loop

Geometry model

$^3\text{H}$ and $^7\text{Be}$ production rates in Li-loop sub-systems

<table>
<thead>
<tr>
<th>Loop component</th>
<th>Mass, kg</th>
<th>Reaction</th>
<th>Inventory</th>
<th>Rate, g/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li jet</td>
<td>1</td>
<td>d + Li</td>
<td>$^7\text{Be}$</td>
<td>1.5</td>
</tr>
<tr>
<td>Li injection tank</td>
<td>18</td>
<td>n + Li</td>
<td>$^3\text{H}$</td>
<td>0.2</td>
</tr>
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<td>Li quench tank</td>
<td>1200</td>
<td>n + Li</td>
<td>$^3\text{H}$</td>
<td>1.0</td>
</tr>
<tr>
<td>Li drain tubes</td>
<td>3</td>
<td>n + Li</td>
<td>$^3\text{H}$</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>7.7</strong></td>
</tr>
</tbody>
</table>

IFMIF

Test Facilities Overview EU Tasks 2004

Medium flux volume
In situ creep-fatigue test module

Medium flux test modules

3 independent creep-fatigue tests within beam footprint

Target & Test Cell Technical Meetings, May 17-18, 2005, Tokyo  A. Missiang
**Test Facilities  Overview EU Tasks 2004**

**X-Ray Microtomography**

**Overall performances**
- Magnification < 2000
- Spatial resolution \( \equiv 5 \mu m \)
- Density resolution \( \equiv 0.5\% \)
- 3D Reconstruction Time \( \equiv 5 \text{ min.} \)
  (512x512x256 voxels)
- Probe dimensions:
  Diameter < 40 mm
  Height < 500 mm

---

**Test Facilities  Overview EU Tasks 2004**

**Space resolution benchmark**

- High resolution microradiography
- Metallic catalyst sample (thinnest wire – 3 \( \mu m \))
- TEM grid - Thick bar: 35 \( \mu m \)
  Thin bar: 21 mm Letters: 14 \( \mu m \)
- Tomographic reconstruction
- Optical microscopy
Test Facilities Overview EU Tasks 2004

Radiography
Density plot
Sagital view

SUS traction probe
2 mm diameter

Calibration sample:
Cu tube 2.2 mm, Ag central wire 0.5 mm and coiled kanthal wires 0.18 and 0.08 mm

Steel bellows of 6.5 mm

Push-pull fatigue specimen

Test Facilities Overview EU Tasks 2004

IFMIF High Flux Test Module: dummy irradiation capsule

Photo

Reconstruction

SUS specimens and thermocouple are clearly identified
Test Facilities Overview EU Tasks 2004

Micro-tomography of complex dummy capsule

- Stainless steel bellows
- Aluminum square rod with simulated high density inclinations
- SUS hourly glass
- Stainless steel pipes

Test Facilities Overview EU Tasks 2004

3D reconstruction of complex dummy capsule
OVERVIEW EU TASKS 2005

Test Facilities (1/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
<td>Dec. 2005</td>
</tr>
<tr>
<td>HAS</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
<td>Dec. 2005</td>
</tr>
<tr>
<td>FZK</td>
<td>Design of a horseshoe type neutron shielding block enveloping all test modules to reduce further the nuclear inventory and the gamma dose rate in the rooms surrounding the test cell</td>
<td>Dec. 2005</td>
</tr>
</tbody>
</table>

OVERVIEW EU TASKS 2005

Materials Properties Handbook

IFMIF

Materials Properties Handbook

IFMIF Test Facilities

MPIH-TF - Draft -

Document No. 1109

Materials

The document describes the structure and content of the IFMIF Materials Properties Handbook. It will primarily assist the IFMIF Test Facilities in managing the non-ferrous content of the document. Awareness and use of this document is required for the purpose of the IFMIF Test Facilities.

Revision 3.00

Table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Date</th>
<th>Revision</th>
</tr>
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</table>

IFMIF

Target & Test Cell Technical Meetings, May 17-18, 2005, Tokyo A. Mertang
OVERVIEW EU TASKS 2005

Test Facilities (2/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
<th>Due</th>
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</thead>
<tbody>
<tr>
<td>FZK</td>
<td>Calculation of complete <strong>nuclear response</strong> through the entire test cell with consideration of an additional neutron shielding block: (a) 3D distribution of nuclear responses using McDeLicious and MCNP codes. (b) 3D distribution of the activity inventory using suitable activation codes and activation data (IEAF-2001/EAF-2005)</td>
<td>Dec. 2005</td>
</tr>
<tr>
<td>MEC</td>
<td><strong>X-ray microtomography</strong> for HFTM capsules and rigs: (i) influence of the sample <strong>radioactivity</strong> on the tomographic reconstruction quality and practical procedures to mitigate its effects, and (ii) experimental determination of <strong>resolution limits</strong> of specimens, capsules and rigs for complete rig assemblies.</td>
<td>Dec. 2005</td>
</tr>
</tbody>
</table>

Near Future Tasks

- **Demonstration of heater-printed capsule**
  - Heat conductivity of conventional heater is poor, which leads to excessive pumping power for coolant.
  - Unexpected occurrence of gap between heater and capsule under operation makes temperature of capsule uncontrollable.
  - The higher the heater power is, the bigger a required size of electric terminal.
- **Accurate distribution of coolant flow rate**
  - Accuracy of coolant flow rate effects on cooling performance severely.
  - Large eddy motion before manifold makes unsteady change of coolant flow rate at each channel.
Interface Issues - TG&TC -

- Test cell atmosphere:
  Pros and Cons for Atmosphere and Pressure (ranging from 0.1 to $10^5$ Pa) needs to be evaluated in more detail.

- Gap between backwall and test cell module:

- Guide structure of test cell modules:
  Guide structure needs to be located structurally independent of the target assembly.

- Material data and selection for backwall & test modules:
  Need interaction with Uses group.

Action Item 1: Test Cell Atmosphere & Pressure
Interface Issues - TG&TC -

Action Item 2: Gap between Backplate & HFTM

Interface Issues - TG&TC -

Action Item 3: How to fix adjust Test Module & Target?

- Test cell cover
- VTA1; Shield plug
- VTA2; VIT
- Li target nozzle
- High flux test module
- Medium flux test modules
- Gas coolant
- Steel liner
- Li tank
- Cell depth 2500 mm

- The lithium containing components have temperatures between 250 and 300 °C.
- The test modules have temperatures between 50 and 150 °C.
- The temperature allowance for the shielding concrete is below around 100 °C.
**Interface Issues - TG&TC -**

**Action Item 4:** Additional shielding of Target & Modules?

- **Test cell cover**
  - VTA1; Shield plug
  - VTA2; VIT
- **Li target nozzle**
- **High flux test modul**
- **Medium flux test modules**
- **Gas coolant**
- **Steel liner**
- **Li tank**
- **Cell depth 2500 mm**

**Advantages (eventually)**

- **Manyfold:**
  - Reduction of T-inventory in Li-tank by ~35%
  - Significant reduction of nuclear inventory
  - Increased population of epi-thermal neutrons inside test modules
  - Impact on T and heat distribution

*IFMIF*

Target & Test Cell Technical Meetings, May 17-18, 2005, Tokyo A Mustang
Summary of Target Activities in 2004/2005

Hiroo Nakamura
JAERI

IFMIF Leaders Meetings
May 19, 2005, Tokyo, Japan

IFMIF Leaders meeting, May 19, 2005, Tokyo

Tasks in transition phase

Target Tasks in Transition Phase

<table>
<thead>
<tr>
<th>Task ID</th>
<th>Task Title</th>
<th>Overview of Task Content</th>
<th>Justification</th>
<th>Contributing Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG-1</td>
<td>Flow stability in Li and water experiment</td>
<td>- Long term Li loop experiment</td>
<td>Obtain additional data for EVEDA to reduce uncertainty margins</td>
<td>EU X JA X US X RF X</td>
</tr>
<tr>
<td>TG-2</td>
<td>Li purification/monitor corrosion/erosion</td>
<td>- Characteristics of impurity trap systems</td>
<td>Obtain additional data for EVEDA to improve reliability</td>
<td>EU X JA X US X</td>
</tr>
<tr>
<td>TG-3</td>
<td>Engineering Design (include RH test)</td>
<td>- Examination of interface items</td>
<td>Establish base design for EVEDA phase</td>
<td>EU X JA X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- EVEDA Li test loop</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Remote handling system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(IFMIF Ex.subcommittee, EFDA CSU-Garching, Nov. 2002)

IFMIF TG&TC TM, May 17-18, 2005, Tokyo
Summary of TG-1
- Li and Water Experiments

Li Experiment
- IPPE: Li loop has been completed and experiment starts on April 2005. First results up to 6 m/s under vacuum was reported. Successful start-up of curved Li flow was observed. But, gassing from steel and cavitation took place.
- Osaka University: Wave amplitude was successfully measured by an electro-contact probe. The amplitude was ±2 ~ 3 mm at 15m/s. Li sampling, evaporation study, ultra-sonic sensor are also planned.

IFMIF TG&TC TM, May 17-18, 2005, Tokyo
LTF-M parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant pressure</td>
<td>1.6 MPa</td>
</tr>
<tr>
<td>Coolant volume</td>
<td>1.0 L</td>
</tr>
<tr>
<td>Maximum flow rate</td>
<td>50 (220 g/s)</td>
</tr>
<tr>
<td>Electric heating capacity</td>
<td>1500 W</td>
</tr>
<tr>
<td>Electrode height</td>
<td>150 mm</td>
</tr>
<tr>
<td>Diameter of electrode</td>
<td>10 mm</td>
</tr>
<tr>
<td>Diameter of nozzle</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>Structural height</td>
<td>800 mm (480 mm)</td>
</tr>
<tr>
<td>Rate</td>
<td>3.0 g/s (2.6 g/s)</td>
</tr>
</tbody>
</table>

State-of-the-art LTF-M

- Li jet surface was observed and registered at 4 flow rates (up to 6 m/s) under vacuum
Cavitation phenomenon

Li speed – 6 m/s

Electro-contact probe device
(Osaka University)

- **Two needles**
  - mechanically fixed
  - electrically independent
- **Electric motor cylinder**
  - to move the needles
  - resolution: 2μm

set on second viewing port
(on the beam axis)
- 175 mm from the nozzle
- needle 1: 16 mm from the side wall
- needle 2: 35 mm (at the center of flow)
Average thickness and surface fluctuation

Average thickness on velocity are not similar in the case of 16mm and 35 mm from the side wall.

Amplitude of the fluctuation increases when velocity increases
Approx. 2mm at the center of flow in the case of 15 m/s.
2.8mm at the 16mm from the side wall.

Tests at the OSAKA University lithium loop (ENEA)

The loop hydraulic performances calculated at the Li temperature of 310°C
The onset of cavitation noise was detected at EMP inlet in 3 conditions:
  p= 0.05 MPa  v=12.0 m/s,  p= 0.085 MPa  v=13.3 m/s,  p= 0.09 MPa  v=15.0 m/s
No cavitation at EMP inlet detected at the Ar pressure of 0.11 Pa up to the max. v=15 m/s
No cavitation at flow straightener detected at  Ar  p> 0.05 Pa up to the max. v=15 m/s

Li flow at the nozzle outlet during cavitation at EMP
(R=250mm) ENEA

V-shaped pattern waves at 12° in laminar flow

Laminar flow at nozzle exit

Water rises at the lateral tray walls in transition laminar–turbulent flow

Water jet free surface oscillation in turbulent flow.

Turbulent flow at nozzle exit

Lateral effects in turbulent flow

---

Summary of TG-2
- Purification/Monitors/Corrosion&Erosion -

- ENEA: LIFUS-III has been completed and experiments started on March 2005. But, LIFUS-III was stopped due to pump failure. Hot-traps, off-line and on-line monitors were investigated.
- IPPE: Li purification of Li loop by cold trap and soluble getter has been done. Concentrations are 1-2 ppm for oxygen and 2-5 ppm for nitrogen. Modification of rotation disc device for corrosion measurement was completed. Basic results of monitors were reported.
- Univ of Tokyo: Nitrogen gettering effect of Fe-Ti alloy were investigated. Evaluation of the effect is in progress.
- Kyushu Univ: Reconsideration of tritium recovery by Y bed under dynamic flow-through operation has been done.

IFMIF TG&TC TM, May 17-18, 2005, Tokyo
Result of measurement (Univ. of Tokyo)

Fe-10at.%Ti successfully reduce N concentration to >20ppm.
In case of starting with high N concentration, limit of N reduction were around 100ppm-N. -> capacity of N gettering looks low

Reconsideration of recovery of tritium by Y bed under dynamic flow-through operation (Kyushu Univ.)

Equilibrium operation (previous evaluation)

Dynamic operation (new evaluation)

Tritium concentration in Li and Y
Tritium concentration at outlet of Y bed under dynamic flow-through condition

- When an Y bed is heated at $10^{-3}$ Pa and 800°C, the bed is desorbed until $YT_{0.006}$.

$$\frac{C}{\sqrt{Fr_z}} = 2.92 \times 10^{-6} \exp\left(\frac{23200}{R_e T}\right)$$

T solubility in Y

- Li in equilibrium with $YT_{0.006}$ at 500°C is $LiT_x$ ($x=1$ wppm) (equilibrium pressure $10^{-6}$ Pa).

$$\frac{C}{\sqrt{Fr_z}} = 8.5 \times 10^{-6} \exp\left(\frac{42300}{R_e T}\right)$$

T solubility in Li

**Zone saturated with feed concentration**

Li flow → Mass-transfer zone → Li flow

High T conc. → Mass-transfer zone → Low T conc.

unsaturated zone

*Absorption condition is relieved to 500°C (from 250°C) under dynamic operation. The total tritium capacity is not changed so much.*

It was predicted that Y bed at 500°C under dynamic flow-through condition can remove T down to 1 ppm in IFMIF Li loop.

---

**LIFUS-III (ENEA)**

**Operating parameters**

- Liquid metal inventory: about 20 kg
- Mass flow rate: 0.162 kg/s
- Maximum T: 450°C
- Minimum T: 250°C
- Maximum Li velocity: 12 m/s
- Minimum Li velocity: 2 m/s
Proof of concept is provided by the determination of resistivity data for solutions of nitrogen in liquid lithium as a function of time, composition and temperature.

The dominant feature of the resistivity-composition isotherms is a linear increase in resistivity with nitrogen composition.

The minimum nitrogen concentration which can be measured at that temperature is 0.007 mol % N (140 wppm N).

Basic results

Purification of Lithium. Soluble getters

<table>
<thead>
<tr>
<th>Getter</th>
<th>Impurity</th>
<th>Temperature, °C</th>
<th>Initial concentration, ppm</th>
<th>Final concentration, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Oxygen</td>
<td>350</td>
<td>10-20</td>
<td>1-2</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Nitrogen</td>
<td>350</td>
<td>50-100</td>
<td>2-5</td>
</tr>
</tbody>
</table>
Rotating disk facility

Modernized facility includes
- Rotating assembly
- Pool with liquid Li
- Loop for purification of Li in the pool and impurity monitoring
- Oxygen electrochemical cell
- Plug indicator
- Cold and hot traps

Rotating disk facility

Program:
1. Startup investigation
   (end of May – middle of July)
   - Calibration of loop volume
   - Vacuum testing
   - Degassing
   - Filling loop with Li
   - Research of wettability period
   - Li purification by cold and hot traps
   - Determination of Li impurity state
Summary of TG-3
- Engineering Design (include RH test) -

- JAERI: Thermal analysis of TG assembly & backwall compatible with 0.1 MPa He has been done. Thermo-structural analysis of the back wall and preliminary evaluation of permissible stress have been done. Dose rate analysis on Be7 around Li loop has been done. Preparation of the DDD and EVEDA task DD are slow due to manpower limit.

- ENEA: Thermomechanical analysis of Bayonet backwall concept (massive and thin option) has been done. When the backplate is made of AISI 316L the maximum stress generally exceed the elastic limit therefore the use of RAFM steel is required. Improvement of the prototype as well as the procedure modification have enabled a significant reduction in a replacement time (1 day). Backplate positioning accuracy has been estimated within the range of ±0.1 mm from the average position. Radiation dose rate has been estimated.

Temperature and Mises stress (t=5 mm, α = 15.8 W/m²-K) : JAERI

- Max. temperature: 445 °C (t=1.8mm) → 451 °C (t=5mm)
- von Mises stress: 504 MPa (t=1.8mm) → 487 MPa (t=5 mm)
Material Data and Sm Value

According to present data base, neutron irradiation increase tensile and yield strength by a factor of 3.
At 330 °C, $1.5S_m$ values are 250 MPa (unirradiated) $\approx$750 MPa (7 - 16 dpa)
(Material data base; K. Shiba)

Considering early stage of IFMIF operation, unirradiated value is selected as a permissible value (250 Mpa@330°C).
Further evaluation on peak stress, fatigue, creep, He effect, etc. are needed.

Temperature distribution in backwall

Backwall with 9 kW electric heater is compatible with 0.1 MPa He environment in Test Cell.

Backwall with electric heaters
(Heaters are attached to hatched region excepting 300 mm x 67.6 mm region around beam-footprint)
Design integration

Option 1: massive backplate

Option 2: thin backplate

Results: Case 2

Partial thermal contact Backplate–TG assembly
Backplate partially clamped on TG ass.
(u3=0) + bolts

Material: F82H

Max Mises 98 MPa

Temperature 364° C
### Option 1: massive backplate

<table>
<thead>
<tr>
<th>Boundary conditions</th>
<th>Tmax (°C)</th>
<th>σ_y (400° C) Unirr.</th>
<th>Mises max (MPa)</th>
<th>Max. displ. U3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li heat transfer coefficient 34000 W/m²K</td>
<td>470</td>
<td>135</td>
<td>420</td>
<td>0.09</td>
</tr>
<tr>
<td>Contact heat transfer coeff. 2000 W/m²K</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundary Temperature 300 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full contact Backplate-TG assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li heat transfer coefficient 34000 W/m²K</td>
<td>470</td>
<td>135</td>
<td>&gt;420</td>
<td>-0.27</td>
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<tr>
<td>Contact heat transfer coeff. 2000 W/m²K</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundary Temperature 300 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial contact Backplate-TG assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Option 2: Thin backplate

<table>
<thead>
<tr>
<th>Boundary Conditions</th>
<th>Tmax (°C)</th>
<th>σ_y (400° C) Unirr.</th>
<th>Mises max (MPa)</th>
<th>Max. displ. U3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li heat transfer coefficient 34000 W/m²K</td>
<td>408</td>
<td>120</td>
<td>81</td>
<td>0.23</td>
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<tr>
<td>Contact heat transfer coeff. 2000 W/m²K</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundary Temperature 300 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full contact Backplate-TG assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li heat transfer coefficient 34000 W/m²K</td>
<td>418</td>
<td>120</td>
<td>230</td>
<td>0.19</td>
</tr>
<tr>
<td>Contact heat transfer coeff. 2000 W/m²K</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundary Temperature 300 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial contact Backplate-TG assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Radiation dose rate (JAERI)

Dose equivalent rate is dominated by Be-7. The value is several orders higher than the criteria at beam stop, and still high in the maintenance duration of 1 month.

**Effect by activated BW**

[Graph showing dose equivalent rate vs. distance from Li pipe]

**Effect by Be-7**

[Graph showing dose equivalent rate vs. distance from Li pipe]
Based on the initial results of this analysis:

- Maximum personnel dose rates due to ACPs, during operation (at the instant of shutdown), in the vicinity of a large Li tank, are high
  - 11 Sv/hr in contact, 2.2 Sv/hr at 1 m.
- Maximum doses from pipework carrying Li, 1 hour after shutdown
  - < 100 μSv/hr in contact, < 10 μSv/hr at 1 m.

**Engineering validation tasks**

To establish reliable design of target assembly and backwall, update of EV tasks is proposed as follows.

- TG-1a : EVEDA Li test loop
- TG-1b : Target assembly and backwall
- TG-1c : Erosion/Corrosion
- TG-1d : Diagnostics
- TG-1e : Li purification system
- TG-1f : Remote handling system
- TG-1g : Li safety handling

H. Nakamura, IFMIF Target&Test Cell TM. Tokyo. May 17-18, 2005
Activities in 2005 (Japan)

TG-1 (Li experiment)
Electro-contact probe, ultrasonic,optical method (Osaka Univ.)

TG-2(Purification,monitor,corrosion)
Hot trap experiments (Univ.Tokyo, Kyushu Univ.)
Li sampling (Osaka Univ.)

TG-3(Design)
Thermal,thermostructural analyses
Dose rate evaluation
EVEDA task discription, DDD

<table>
<thead>
<tr>
<th>Deliverable description</th>
<th>Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Theoretical study on the conditions for cavitations generation in various parts of the IFMIF Li-loop</td>
<td>ENEA</td>
</tr>
<tr>
<td>2  Thermomechanical analysis of the Li-loop structures to identify the probable deformation of the backplate during normal operation</td>
<td>ENEA</td>
</tr>
<tr>
<td>3  Verification of the backplate sealing performance against Li-infiltration and corrosion-induced damage based on the bayonet back-plate concept</td>
<td>VR-Studsvik</td>
</tr>
<tr>
<td>4  Development of a dedicated clean-up system for massive precipitated/activated corrosion products in Li-loop (literature study and experimental verification of magnetic trapping technology)</td>
<td>VR-Studsvik</td>
</tr>
<tr>
<td>5  Deuteron induced activation of corrosion products and other species in the Li-loop: identification of important reactions and analysis of the reaction cross-section data</td>
<td>UKAEA</td>
</tr>
</tbody>
</table>
Future experiments (RF)

- Elimination of gassing
- Detailed observation of Li jet at velocities up to 15-20m/s
- Investigations of Li jet parameters with electric probes
- Testing of oxygen electrochemical cell
- Investigations of Li evaporation from jet surface
- Purification of Li in dump tank

Interface Issues - TG&TC -

- Test cell atmosphere:
  -> Further design of TG assembly and backwall compatible with He (0.1 Mpa).
- Gap between backwall and test cell module:
  -> Considering design update of the backwall, increase of 2 mm gap need to be considered.
- Guide structure of tect cell module:
  -> Guide structure needs to be located structually independnt of target assembly.
- Material data and selection:
  -> Need interaction with Uses group.
Action Items
- Compilation of purification system information sheet
  end May - mid June Nakamura
- EVEDA task description, DDD early July Nakamura
- Coordination of analyses on calculation conditions
  (Neutronics, Thermal stress) ASAP Ida, Riccardi
- Publication of presentation (JAERI report)
  mid Aug. Ida
- Continue interface issues activities between TG&TC
  (Test cell atmosphere, gap) All
Next meeting
Dec. 2005 in conjunction with ICFRM-12 (DI meeting ?)
- Discussion on Transition activities, EVEDA tasks
IFMIF Accelerator Facility

2005 Status Report
Tokyo, Japan

Status

In 2005, work continues at a lower level on the IFMIF Accelerator Facility

- Status of work among the partners
- Overall status
EU Contributions

- EU IFMIF Monitoring Meeting, January 2005, Karlsruhe FZK
- Saclay report - Contributions to IFMIF 2004 (8p) - short review of past presentations
- Discussions with IBA about their Work Package on rf system design, agreement that cost estimate is reasonable.
- Presentations from IAP will be covered by Prof. Klein in his presentation.
- No takers for first round of EU task proposals on raster-scan HEBT option or beam instrumentation.

- Appointment of Dr. Elizabeth Surrey, Culham as new EU coordinator for the EU IFMIF Accelerator tasks.

- Second round task solicitation - Culham Lab (Dr. E. Surrey) has taken on the two tasks: (next slide)

---

International Fusion Materials Irradiation Facility

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<table>
<thead>
<tr>
<th>Task Deliverables</th>
<th>Description</th>
<th>Due Date</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA11 11 Evaluation on whether or not the beam raster scanning method is generally applicable to the IFMIF design. Calculation of beam profile shape, as well as temporal and spatial stability of flat top and edges. Safety consideration. Cost estimate of a complete beam profile assembly.</td>
<td>31-Dec-05</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>UKAEA11 21 System study and adoption of a beam monitoring system that combines sensitivity, fast interlock capability and long term reliability under 10 MW beam power operation.</td>
<td>31-Jul-06</td>
<td>11</td>
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<tr>
<td>21</td>
<td>Draft Final Report</td>
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<td>21</td>
<td>Final Report</td>
<td>11</td>
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<tr>
<td>11</td>
<td>Months after signing of the contract by the CEU or precise date</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

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Contributing Institutions: UKAEA (1-2)

<table>
<thead>
<tr>
<th>Institution</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA (1-2)</td>
<td>Elizabeth Surrey</td>
<td>+44 1235 464473</td>
<td>+44 1235 464828</td>
<td><a href="mailto:Elizabeth.Surrey@stfc.ac.uk">Elizabeth.Surrey@stfc.ac.uk</a></td>
</tr>
</tbody>
</table>
2nd round tasks preparation continues

EFDA proposes a task on beam loss modeling, combining new design work on the linac, more detailed loss modeling of the linac, and collaboration with the nuclear physics group of Dr. U. Fischer at FZK. This task would require very competent manpower to be found on the accelerator side. Refinement of the RFQ design should be done.

"Independent IFMIF Accelerator Cost Assessment" commissioned by EFDA.

No official contact with the project. Draft submitted to European experts for comment resulted in project involvement. Additional information was commissioned from AES, particularly on DTL costing, and IBA’s help was solicited on the rf system. The report is still under preparation.

SubCommittee point. Again a situation with no formal coordination with the project.

Accelerator Database

Some archival material was received from Saclay on their previous work. Will be abstracted to the IFMIF server database.

---

RF Power system

- IBA has completed their Work Package report giving a detailed RF power system analysis. (available)
- Visit was made to IBA to survey their facilities and discuss the report. Their capability is very impressive and can be a real asset to IFMIF.
US Contributions

- As mentioned, AES was commissioned to provide information for the EFDA Independent IFMIF Accelerator Cost Assessment.
- Prof. Shannon will comment on the overall US situation with respect to IFMIF.
- The US Accelerator Team members stand ready to assist as items come up, but instant response is difficult, as extra funds have to be sought.

Japan Contributions

1. Mock-up loop antenna were fabricated & tested by low power test
   - Installed depth up to 3cm is a key technology to make phase difference small
   - A good power balance with four loops is obtained in comparing with the others

2. Electric field profiles in beam bore are calculated by MW-Studio
   - Diagonal injection is clearly better than adjacent injection for power balance
   - Field distortion by four loop injection is negligible, a peaking level is lower than two loop injection

3. Higher mode analysis for a longitudinal length of 4m
   - The difference between TE_{210} and TE_{111} for L=4m is 2.127MHz, it is concluded that operation mode(TE_{210}) is not affected by TE_{111} mode when 2 coupling plates are used.

   It is assessed that four loop antenna is one of feasibility for an RF Input Coupler of IFMIF RFQ
Transition Tasks
2004-05 - Japan

- AF-1 Development of critical accelerator components
  - Injector: no funding to extend and optimize the previous results.
  - RF window: necessary to find test stand. (Thales?)
- AF-2 Accelerator Physics /Engineering Design
  - RFQ design: multi-drive loop & tuner effects were examined.
  - Beam dynamics: design requirements for HEBT need to be clarified more explicitly.
  - Preliminary safety analysis: applicability of SNS document is under consideration - too strongly dedicated to DOE regulations?
- AF-3 Analysis of possible alternatives
  - H2+ source: no funding to realize optimized beam extraction.

Comments of Domestic Peer Review Committee

- IFMIF technical peer review was carried out during May – August 2004, organized by JAERI Planning Section.
- For accelerator technology, comments were summarized as:
  - Injector and RF source are in good positions to enter EVEDA
  - 175 MHz CW RFQ/DTL models need to be examined in more details (not for higher frequency as 350 MHz)
  - Required stable beam footprint at target seems to be hard to realize under current design
  - In EVEDA much more extensive efforts for system design including utilities specifications are necessary
- For the above comments we need to reply by proposing a task plan during transition phase and EVEDA.
China Contributions

- Ministry of Chinese Science and Technology is still waiting for ITER building site. The decision whether China will participate in IFMIF project can not be made until some key issues of ITER are finalized. Good news: Some officials at high position (from Ministry of Science and Technology) and some top scientists ever claimed recently that it would be very much beneficial to China if China would join IFMIF. At the moment we are just requested as an observer to track the IFMIF progress.

- It is believed that IFMIF cost could be reduced by at least 30-40% if some components or systems would be manufactured in China like some other projects such as GSI FAIR and CERN LHC.

- IMP (Institute of Modern Physics, CAS) is interested in development of raster scanning system which will be also adopted by heavy ion therapy system right now under development at IMP. Mg jet profile monitor may be used for IFMIF beam diagnostics. IMP already built two sets of Mg jet profile monitors and will be tested at HIRFL-CSR (Heavy Ion Research Facility in Lanzhou – Cooling Storage Ring).

Accelerator Design

- A technical meeting of IFMIF Accelerator was held in Tennessee, Univ. on May 16 by the host of Drs.J.Haines and Dr.T.Shannon

  Attendees: H. KLEIN, A. Schempp, H. PODLECH, H. LIEBERMANN, C. GABOR, G. CLEMENTE (IAP, Univ. Frankfurt), J. Haines(ORNL), E. MARGOTO (TED), T. FAVALE (AES), S. MAEBARA (JAERI), K. NAKAYAMA (Toshiba) (11 peoples)

1. Opening talk (18:00-18:05): S. Maebara in behalf of R. Jameson
2. Present Status and R&D plan (18:05-18:15) by H. Klein and S. Maebara
3. R&D activities related to IFMIF accelerator system (18:15-20:15):
   3.1 High power RFQs: A. Schempp:
   3.2 The superconducting alternative to the IFMIF reference design: H. Podlech:
   3.3 Design considerations of the superconducting CH structure: H. Liebermann
   3.4 The normal conducting CH structure: G. Clemente
   3.5 R&D of IFMIF RFQ: S. Maebara (30min ea. presentation)
4. Other issues (proposals for EVEDA etc.) (20:15-20:45):
   4.1 TED Diacrode technology, Eric MARGOTO
   4.2 Fruitful EVEDA, Sunao MAEBARA
5. Summary and closing talk (20:45-21:00): H. Klein
Accelerator Facility Manpower, Outlook for 2006

Personals
EU:
1) CEA, France (Coordinator -> R. Ferdinand, R. Duperrier, R. Gobin, D. Unirot) -> Until end of 2004
2) IAP, Germany (H. Klein, R. Ratzinger, A. Sauer, H. Podlech, H. Liebermann, O. Meusel):
   R. Jameson -> International Accelerator Team Leader
3) UKAEA, Great Britain, Since beginning of 2005 colleagues of the UK are also involved in IFMIF (M. Nightingale -> Cost estimation, E. Surrey -> Beam raster scanning + Beam monitoring)
   E. Surrey -> New EU-coordinator
4) IBA, Belgium (RF power systems, H-type-linac)
5) The activities of the EU are coordinated by EFDA (European Fusion Development Agreement); Especially: R. Andreani, R. Lässer, M. Gasparotto, J. Chen

Outlook for 2006 Activity

1. 4 Rod-High power RFQ and R&D concerning with superconducting CH structure were presented by IAP.
   The first superconducting CH-prototype is ready, the first cold test is expected to be done in 3 weeks in Frankfurt University.
   There is a comment that fabrication cost and running cost for superconducting CH structure should be evaluated in detail

2. R&D of 175MHz RFQ using a multi-drive loop antenna instead of Iris-type for an RF-Input coupler was presented by JAERI.
   In the next step, design of coupling-plate module, a beam dynamics in the RFQ and optimization of HEBT are planned.
Comment from Industry

1. Diacode for a 1MW-CW operation was presented by TED:

It appears necessary now to put some efforts in the development of an adapted cavity at 175 MHz and study the possibility of high VSWR operations. Following the successful 1,000 hours test made in 2002, it appears also useful to study the failure mechanisms and do some sub-assemblies testing in order to guaranty a long life time.

Priority List of Transition Phase Tasks

➢ Evaluate feasibility of raster-scan HEBT. Has been taken on by Culham.
➢ Develop potential for use of mini-neutron detectors for accelerator beam footprint and safety-protection instrumentation. Has been taken on by Culham.
➢ Further development of the beam-loss model. Involves work on the RFQ design, computation of particle loss amount and location, and collaboration with nuclear-physics personnel to develop activation model.

For EVEDA-phase we have discussed a priority task list also. For example, the engineering of CW-RFQ's, normal and superconductivity DTL, diagnostics, particle dynamics calculation, possibility of the development of a $H_2^+$ ion source.
Transition Tasks 2005-06
Design Integration

Masayoshi Sugimoto
Tokyo, Japan
May 19, 2005

DI Tasks in Transition Phase
Task list identified in 2002

<table>
<thead>
<tr>
<th>Task ID</th>
<th>Task Title</th>
<th>Overview of Task Content</th>
<th>Justification</th>
<th>Contributing Party</th>
</tr>
</thead>
</table>
| DI-1    | Basic Concept of Operation  | - Examination of specification for the whole system control
           | - Consistency check among all subsystems                                                 | In order to perform system design, a basic concept is needed. | EU | JA | US | RF |
| DI-2    | Survey for regulation concept | - Worker & public safety assessment
           | - Examination of guidelines and collection of data for licensing
           | - Estimation of Test Cell shielding performance                                           | To start the negotiation with authority, a regulation concept is needed. | EU | JA | US | RF |
| DI-3    | IFMIF database              | Set up of IFMIF web-site                                                               | To facilitate information exchange                    | EU | JA | US | RF |
| DI-4    | Reference Design            | Update Ref. Design Configuration and Cost Evaluation                                   | To Maintain integrated design and project management    | EU | JA | US | RF |
Summary of IFMIF Design Integration Activity

- In October 2004 – April 2005, the major activities related to Design Integration area were summarized as:
  - Preliminary assessments of workers dose were performed esp. for Target loop area (EU and Japan, independently)
  - Update information in IFMIF Web site to access FMIT files through ORNL library (US and Japan)
  - Update some drawings of reference design (EU, Japan)
  - Several reviewing activities were completed in each participant countries (EU-EFDA cost assessment, Japan-JAERI peer review)

- Following activities are planned in next period:
  - Update document of interface issues based on CDR & results in transition phase
  - Prepare preliminary safety document (incl. shielding & radioactivity assessments)
  - Update Web site for easy information exchange of documents & data.

➢ WE NEED DEFINE A CONTACT PERSON TO ORGANIZE ABOVE ACTIVITY.

Concept Map for IFMIF Project

- Proposal to transfer knowledge & experience to new comers -

- Diagram based knowledge representation is a useful tool.
- Simple user interface is preferred to reduce the load for learning.

Cmap system is a candidate for such a tool.
http://
Status of CDR review in Europe

R. Lässer

IFMIF Technical Integration Meeting

19 May 2005

„Technical Assessment of the IFMIF Comprehensive Design Report (CDR)“ was performed in the EU in 2004: by 15 independent European Scientists/Professionals of different areas. Chairman: G. Bauer (FZJ).

European IFMIF experts (EU-Project Leader, EU-Task Coordinators and Prof. H. Klein) made presentations to the Ad Hoc Group and answered detailed questions of the Ad Hoc Group.

EFDA produced an „EFDA Technical Assessment of the IFMIF Comprehensive Report (CDR)“ based on the report of the independent Ad Hoc Group.
Main general conclusions of the Ad Hoc Committee

- Although ambitious and requiring validation in some details, IFMIF as currently planned is judged as technically feasible, licensable and having a prospect to reach its specified design goals and users requirements.
- The validation programme proposed for the EVEDA phase is an important next step if properly prioritized.
- No "show stoppers" could be identified that would put the ultimate success of the project in doubt.
- The project is ready for a political decision to embark on its realization.
- Substantial savings on time and cost can be expected if such a decision is taken soon and a project management with the necessary competences and executive power to define and tightly control the necessary work is established and endowed with the sufficient annual budget authority.
- The availability goal of 70% of calendar time is very ambitious and will require a "low stress" design, i.e. sufficient design margin, and effective remote handling provisions for radioactive components.
- In an aggressive realization scenario it should be possible to shorten significantly the total time planned for the EVEDA, construction and commissioning phases (currently 15 years to full exploitation), which would be in the best interest of the Project's mission.

Test Cell Technical Meeting 18-May-05 R. Lässer

Main general recommendations of the Ad Hoc Committee 1/2

- The items to be dealt with in the EVEDA phase should be strictly classed according to their importance in terms of achieving the Project's performance objectives (including safety and remote handling needs) and priority should be given to those tasks which are highest on the list.
- In order to be able to proceed efficiently with the EVEDA phase a technical baseline should be frozen very soon and "options" or "alternatives" as mentioned in various places in the CDR and during the project presentations should be regarded as possible backup solutions but should be eliminated from the work plan for the moment in favour of focusing the available man power and funds on the chosen design.
- To the greatest extent possible, the targets of the EVEDA validation experiments should be quantified and linked to decision milestones.
- A more detailed plan for the construction phase must be devised including procurement lead times and industry confirmed estimates of manufacturing times to demonstrate the realism in the planning.
Main general recommendations of the Ad Hoc Committee 2/2

- A framework of codes and standards including a materials assessment report (MRA) to be used for the engineering design should be defined early on.
- A remote handling design handbook should be established prior to starting the detailed design phase.
- Early in the Project essential management tools should be introduced such as a practicable work breakdown structure, schedule and cost management software, a technical component identification system, a configuration and design integration and interface management plan, a quality assurance system, as well as a document on administration and change control system. These are especially important in view of the world-wide collaboration in the project, which will require a rather complex organizational structure.

Detailed issues of the Technical Assessment

with respect to the Accelerator Facility:
- Develop a strategy and the relevant diagnostic tools for detection and processing of beam profile errors. This is also relevant to protect the target against concentrated power deposition.
- Demonstrate that all proposed accelerator components are capable of CW operation at full specification.
- Assess the use of an H\(^+\) source instead of the proposed H\(_2\)\(^+\) source for commissioning purposes.
- Redefine the EVEDA accelerator tasks to accelerate procurement:
  - Agree on the final accelerator technology to be used as soon as possible.
  - Build the first part of the accelerator up to the first few DTL tanks for validation and use these components later in one of the two accelerators although the cost involved would be significantly higher than considered so far.
  - Launch the project and construction phases as fast as possible.
Detailed issues of the Technical Assessment

with respect to the Li Target Facility:

- Choose one of the back-plate options as soon as possible, specify the tests required for lifetime estimation and develop inspection tools.
- Determine the pressure values in the whole Li loop to exclude cavitation.
- Construct the Li target such that its full remote exchange is possible.
- Perform thermal analysis of the components in the neighbourhood of the Li target to exclude excessive heating. Provide for additional cooling if required.
- Develop tools required to monitor changes in the location of the footprint and/or intensity variations and to shut down the beam fast enough to avoid any damage to the Li-target. This diagnostic must be in addition to the one installed on the accelerator.

Test Cell Technical Meeting 18-May-05  R. Lässer

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Detailed issues of the Technical Assessment

with respect to the Test Facility:

- Assess the material data base of the structural materials under the conditions in the high flux test module (HFTM) (and even more for the target facility), develop engineering design guidelines if possible and estimate possible lifetime. Include surveillance specimens of the same structural materials in the HFTM for assessing the changes of the mechanical properties in agreed intervals.
- Define an integrated remote handling strategy for disassembly of the whole module, transfer of the rigs to the post-irradiation facilities, handling of the very tiny and brittle specimens, replacement of rigs at the end of their lifetime, etc.
- Develop the diagnostic tools required by the user's community to monitor reliably temperature, neutron flux and fluence.

Test Cell Technical Meeting 18-May-05  R. Lässer
Detailed issues of the Technical Assessment

with respect to Design Integration:

- Develop a consistent project safety approach and specify clearly the safety criteria and goals to be met.
- Prepare the Preliminary Safety Report (PSR).

Influence of CDR assessment on present EU R&D

Independent CDR Assessment in Europe finished in 2004, but it influences present EU R&D.

The work mentioned in the CDR assessment as requiring further R&D is now the basis of the present R&D in the EU and is used to fill the Transitional Phase between KEP and EVEDA and to preserve the knowledge and the scientific professionals dedicated to IFMIF in the European Associations.
**OVERVIEW EU TASKS 2004 1/1**

Further EU 2004 Tasks (5.1b) for IFMIF

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEA</td>
<td>Independent cost assessment of the IFMIF conventional facilities, central control and common instrumentation. (open)</td>
</tr>
<tr>
<td>UKAEA</td>
<td>Independent cost assessment of the entire IFMIF accelerator facilities:</td>
</tr>
<tr>
<td></td>
<td>a. Evaluation of the accelerator and power supply design from the point of view of cost effectiveness:</td>
</tr>
<tr>
<td></td>
<td>b. Evaluation of the methodology of the costing, to determine if it represents the optimum approach;</td>
</tr>
<tr>
<td></td>
<td>c. Evaluation of the itemised results of the costing, to assess if they appear reasonable by comparison with other recent accelerator construction projects. (open)</td>
</tr>
<tr>
<td>UKAEA, VR,</td>
<td>IFMIF Preliminary Safety report for a Generic Site (open)</td>
</tr>
<tr>
<td>ENEA, CIEMAT</td>
<td></td>
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</tbody>
</table>

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**OVERVIEW EU TASKS 2005 1/5**

EU 2005 Tasks for **Accelerator Facility** (1/1)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
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<tbody>
<tr>
<td>UKAEA</td>
<td>Evaluation on whether or not the beam raster scanning method is generally applicable to the IFMIF design. Calculation of beam profile shape, as well as temporal and spatial stability of flat top and edges. Safety consideration. Cost estimate of a complete beam profile assembly</td>
</tr>
<tr>
<td>UKAEA</td>
<td>System study and adaptation of a beam monitoring system that combines sensitivity, fast interlock capability and long term reliability under 10 MW beam power operation.</td>
</tr>
</tbody>
</table>

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## OVERVIEW EU TASKS 2005 2/5

EU 2005 Tasks for Lithium Target (1/1)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
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<tbody>
<tr>
<td>ENEA</td>
<td>Theoretical study on the conditions for cavitations generation in various parts of the IFMIF Li-loop</td>
</tr>
<tr>
<td>ENEA</td>
<td>Thermo-mechanical analysis of the Li-loop structures to identify the probable deformation of the backplate during normal operation</td>
</tr>
<tr>
<td>VR</td>
<td>Verification of the backplate sealing performance against Li-infiltration and corrosion-induced damage based on the bayonet back-plate concept</td>
</tr>
<tr>
<td>VR</td>
<td>Development of a dedicated clean-up system for massive precipitated/activated corrosion products in Li-loop (literature study and experimental verification of magnetic trapping technology)</td>
</tr>
</tbody>
</table>

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## OVERVIEW EU TASKS 2005 3/5

EU 2005 Tasks for Test Facilities (1/2)

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
</tr>
<tr>
<td>HAS</td>
<td>Materials properties handbook (MPH): Preparing a list of files which need extension for IFMIF and currently missed IFMIF MPH files, Assessing materials properties of selected materials (ferritic-martensitic (ODS), stainless steel and tungsten), preparing MPH extension files for IFMIF.</td>
</tr>
<tr>
<td>FZK</td>
<td>Design of a horseshoe type neutron shielding block enveloping all test modules to reduce further the nuclear inventory and the gamma dose rate in the rooms surrounding the test cell</td>
</tr>
</tbody>
</table>
### OVERVIEW EU TASKS 2005 4/5
**EU 2005 Tasks for Test Facilities (2/2)**

<table>
<thead>
<tr>
<th>Assoc.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZK</td>
<td>Calculation of complete nuclear response through the entire test cell with consideration of an additional neutron shielding block: (a) 3D distribution of nuclear responses using McDeLicious and MCNP codes. (b) 3D distribution of the activity inventory using suitable activation codes and activation data (IEAF-2001/EAF-2005)</td>
</tr>
<tr>
<td>MEC</td>
<td>X-ray microtomography for HFTM capsules and rigs: (i) influence of the sample radioactivity on the tomographic reconstruction quality and practical procedures to mitigate its effects, and (ii) experimental determination of resolution limits of specimens, capsules and rigs for complete rig assemblies.</td>
</tr>
</tbody>
</table>

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### OVERVIEW EU TASKS 2005 5/5
**EU 2005 Tasks for Design Integration (1/1)**

<table>
<thead>
<tr>
<th>Assoc.</th>
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</thead>
<tbody>
<tr>
<td>FZK</td>
<td>3D radiation shielding analysis of all rooms surrounding the test cell using state-of-the-art computational tools: Assessment of the effect of an additional horseshoe-type neutron shielding block inside the test cell.</td>
</tr>
<tr>
<td>TEKES</td>
<td>3D radiation shielding analysis of the test cell cover and the access cell in the presence of an additional horseshoe-type neutron shielding block inside the test cell.</td>
</tr>
<tr>
<td>UKAEA</td>
<td>Deuteron induced activation of corrosion products and other species in the Li-loop: identification of important reactions and analysis of the reaction cross-section data</td>
</tr>
</tbody>
</table>
Proposed EU tasks for WP2006 1/4

Proposed EU Tasks for Accelerator Facilities (TW6-TTMI-001):

- More detailed end-to-end simulation of the deuteron beam to determine the loads on the walls and possible activation under consideration of all possible errors and fluctuations in the accelerator components.
- Development of diagnostics for beam observation in the HEBT and its possible use for independent fast interlock strategy to stop the deuteron beam.

Proposed EU tasks for WP2006 2/4

Proposed EU Tasks for Li Target (TW6-TTMI-002):

- Li corrosion and chemistry:
  -monitoring of metallic corrosion products and their removal from the Li-loop.
- Development/improvement of neutron detection diagnostics and its possible use for independent fast interlock strategy to stop the deuteron beam.
- Production of the Remote Handling Handbook for IFMIF.
Proposed EU tasks for WP2006 3/4

Proposed EU Tasks for Test Facilities \textit{(TW6-TTMI-003)}:

- Further studies of He-flow and cooling conditions in the test facility for removal of the nuclear heat.
- Development of miniature instrumentation to measure the irradiation conditions, e.g. the important neutron parameters required for characterisation of the material specimen.
- Continuation of the production of a Materials Handbook for IFMIF (activity started in WP2005).
- Preliminary version of DDD for the test facilities.

Proposed EU tasks for WP2006 4/4

Proposed EU Tasks for Design Integration \textit{(TW6-TTMI-004)}:

- Shielding calculations of the Li-loop including the issue of deuteron activation of corrosion products.
- Validation experiments for the cross-section data calculated for the activation of corrosion- and gaseous products by deuterons of the IFMIF beam if required.
- Activities to promote
  - the decision on EVEDA,
  - an agreement on the location and composition of the central team,
  - an agreement between the participating countries on the financial sharing of the tasks to be performed during EVEDA.
Status of CDR review in Japan (JAERI)

"Report of Peer Review of IFMIF Project and Relevant Programs" (DRAFT)

Masayoshi Sugimoto
Tokyo, Japan
May 19, 2005

PREFACE

The International Fusion Materials Irradiation Facility (IFMIF) project is an international joint facility plan for developing, examining, and evaluating various kinds of candidate materials to realize a nuclear fusion reactor, by means of intense neutron irradiation simulating the fusion neutron environment. Since 1995, based on the Annex II "Experimentation on Radiation Damage in Fusion Materials" under the OECD-IEA collaboration "Implementing Agreement for a Programme of Research and Development on Fusion Materials", Japan (JAERI is a contractor of implementation agreement), EU, the U.S., and Russia have participated in the activity. In the past, Conceptual Design Activities, Conceptual Design Evaluation activities, and Key Element technology verification Phase (KEP) were carried out. KEP activities in Japan have been organized under cooperation between JAERI and Natural Science Research Organization - National Institute for Fusion Science (NIFS) with the universities. Now, the framework of implementation of the Engineering Validation and Engineering Design Activities (EVEDA) planned as the activity in the next stage is under discussion.
PREFACE (cont.)

JAERI, a contractor of the Implementing Agreement, domestically promotes the cooperation with the universities etc. while continuously participates in the IFMIF activities and greatly contributes to their progress. On the other hand, in EVEDA planned as the next activity an international cooperative organization strengthened much more is assumed. JAERI decided that it was needed to examine the necessity and the validity of the participation in EVEDA accompanied with an evaluation of the technical results of KEP activity and technical validity of the future plan, in advance of the decision for the participation. And JAERI requested to assemble a specialist group of the related fields in and out of the JAERI, and to perform "Peer Review of IFMIF Project and Relevant Programs".

Based on the above circumstances and background, this peer review covered the assessment of planning for developing power generation blanket and materials in JAERI, positioning of IFMIF in such a development, results of component engineering confirmed in KEP, technical feasibility of IFMIF, and the goals, technical issues, means of advancement, etc. in EVEDA. And the comprehensive evaluation based on them was performed. This report is a summary of the examined results ...
PART 1 CIRCUMSTANCE, OBJECTIVE AND METHODOLOGY OF PEER REVIEW

1. Circumstance and Objective
2. Methodology of the Peer Review

Upon such a background JAERI, a contractor of the Agreement, has domestically promoted the cooperation with the universities etc. while continuously participated in the IFMIF activities and greatly contributed to their progress. On the other hand, in EVEDA planned as the next activity an international cooperative organization strengthened much more is assumed, and a decision was made to examine the necessity and the validity of the participation in EVEDA accompanied with an evaluation of the technical results of KEP activity and technical validity of the future plan, in advance of the decision for the participation and to perform this peer review.

PART 1 (cont.)

In the peer review meeting it was demanded to argue broadly also about how to advance the nuclear fusion reactor engineering research in the future including development not only the IFMIF project but power generation blanket and materials development. Specifically, it aims at performing the assessment about the plan for nuclear fusion reactor engineering research in especially blanket development after power generation demonstration plant and materials development, the role and position of IFMIF in these development programs, the results of component engineering confirmed in KEP, the technical feasibility of IFMIF, and goals / technical issues / activity plan of EVEDA. It also carries out a comprehensive evaluation based on these.
PART 1 (cont.)

Points of Assessments:
1) About the positioning of IFMIF project in development of fusion power generation blanket and its materials, and whether IFMIF can satisfy the requirement for developing them.
2) About the technical feasibility of IFMIF based on the result of technical development up to date.
3) About what the EVEDA plan should be towards decision of IFMIF construction in future.

PART 2 CONSEQUENCES OF PEER REVIEW

1. Planning for Nuclear Fusion Reactor Engineering Development in JAERI
   1.1 About the Development of Blanket for Power Plant and Materials
   1.2 Positioning of IFMIF in the Development of Blanket for Power Plant and Materials
   1.3 Sufficiency of IFMIF Conceptual Design for Required Performance to Fusion Reactor Materials Irradiation Facility
      1.3.1 Feasibility to Attain the Characteristics of Neutron Irradiation Field
      1.3.2 Feasibility to Fulfill the Requirements for Operations
      1.3.3 Feasibility to Fulfill the Testing Conditions
   1.4 Planning for Performing IFMIF Activity
PART 2 (cont.)

2. Consequences of the Technical Development in KEP
   2.1 Goal Assignment and Achieved Level for Issues to Develop Accelerator System
   2.1.1 Assessment of Goal Assignment
   2.1.2 Assessment of Injector
   2.1.3 Assessment of RFQ
   2.1.4 Assessment of DTL
   2.1.5 Assessment of RF Source
   2.1.6 Assessment of Beam Diagnostics
   2.1.7 Assessment of Design using Beam Simulation
   2.1.8 Assessment of Peripheral Equipments
   2.1.9 Overall Evaluation
   2.2 Goal Assignment and Achievement of Development Issues on Target System
   2.2.1 Assessment of Assigned Goals
   2.2.2 Assessment of Target Assembly
   2.2.3 Assessment of Remote Handling
   2.2.4 Assessment of Design of Li Loop and Safety Assessment
   2.2.5 Assessment of Li Purification System and Li Burning Characteristics
   2.2.6 Overall Evaluation
   2.3 Goal Assignment and Achievement of Development Issues on Test Facilities
   2.3.1 Assessment of Assigned Goals
   2.3.2 Assessment of Temperature Control of Specimens
   2.3.3 Assessment of Estimation of Neutron Irradiation Field
   2.3.4 Assessment of Small Specimen Technology, Test Assembly, and Post Irradiation Test Equipment
      (like Remote Handling Property, etc.)
   2.3.5 Overall Evaluation
   2.4 Activity Planning of KEP

PART 2 (cont.)

3. Assessment of EVEDA
   3.1 Goal Assignment and Approach for Solving Technical Issues on Accelerator System
   3.1.1 Assessment of Assigned Goals
   3.1.2 Assessment of Engineering Validation Tasks
   3.1.3 Assessment of Engineering Design Tasks
   3.1.4 Overall Evaluation
   3.2 Goal Assignment and Approach to Solve Technical Issues on Target System
   3.2.1 Assessment of Assigned Goals
   3.2.2 Assessment of Li Test Loop
   3.2.3 Assessment of Li Purification System
   3.2.4 Assessment of Backwall and Remote Handling
   3.2.5 Assessment of Li Safety Handling Technology
   3.2.6 Assessment of Engineering Design Tasks
   3.2.7 Overall Evaluation
   3.3 Goal Assignment and Approach to Solve Technical Issues on Test Facilities
   3.3.1 Assessment of Assigned Goals
   3.3.2 Assessment of Engineering Validation Tasks
   3.3.3 Assessment of Engineering Design Tasks
   3.3.4 Overall Evaluation
   3.4 Approach for Design Integration and Buildings and Utility Tasks
   3.5 Planning of EVEDA and Significance of Participation

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PART 3 SUMMARY OF ASSESSMENT

(1) About planning for nuclear fusion reactor engineering development in JAERI and positioning of IFMIF

Nuclear fusion research and development are in progress aiming at the future energy source, and now ITER is going to be constructed as an international experimental reactor project to achieve the self-ignition condition and the long time burning of nuclear fusion plasma, and to demonstrate the integration of the fusion technology. About the reactor engineering technology required for development of the power generation demonstration plant, the next step from the experimental reactor, in our national guideline the development is advanced with emphasis on the power generation blanket and materials, demanding a long period for development period. Along this national guideline JAERI has earnestly advanced the development of solid breeder type blanket and its materials, of which R&D results have the advantage of having led the world so far, and the planning for nuclear fusion reactor engineering in JAERI is basically appropriate.

In order to design and construct the power generation demonstration plant where the first wall of blanket is irradiated by high-energy neutrons with a very high dose of about 150dpa, it is indispensable to develop the materials bearing the very severe irradiation environment and to acquire many kinds of reliable material databases. And it is assessed that IFMIF, the accelerator based neutron source using D-Li stripping reaction, is basically necessary to perform the fusion-like neutron irradiation tests for the above objectives.

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PART 3 (cont.)

(2) About technical consequences of KEP activity and proposed technical approach for EVEDA activity

In the IFMIF project carried out by the international cooperation of IEA, to achieve the neutron irradiation field conditions to be equipped by IFMIF, i.e. material damage parameters equivalent to nuclear fusion conditions such as He/dpa, necessary test volume, neutron flux (volumes of high neutron flux regions with more than 50 and 20dpa/y are 0.1 and 0.5i respectively), availability (70% or more), neutron irradiation dose (100dpa achievable in 3 years), flatness of neutron flux (neutron flux gradient: 10% or less), time structure of beam (pseudo continuous operation), it is considered for IFMIF to compose of two sets of deuteron linear accelerators with continuous-wave operation (175MHz: sufficiently seen as pseudo continuous operation) accelerating to 40MeV at beam current 125mA, liquid Li target with no beam window (flow velocity: 10~20 m/s) and its circulation system, and test cell systems (e.g. high neutron flux test module with temperature control by gas cooling). Also, by using the advanced beam shaping control, a design was employed to inject the almost uniform deuteron beam of 20cmx5cm beam footprint into liquid Li target, and to generate intense neutrons.
PART 3 (cont.)

The accelerator of IFMIF has a lot of issues to be solved as follows: the acceleration current in continuation wave operation is extraordinarily large compared with the existing accelerators; very prolonged stable operation is required as the character required to the accelerator for materials irradiation; and in order to obtain the needed irradiation the technical development of the advanced high energy beam transport system shaping to 20cmx5cm beam footprint. The purpose of KEP was to decrease the risk of technology as the key for attaining continuous wave operation with required deuteron acceleration current, to confirm the appropriate component design in a laboratory scale, and to verify the design codes. From such purpose, goal setup for some items of accelerator system in KEP are not always sufficient, and by considering the original purpose of KEP it is found that the results are not enough in part. However, as the KEP activity in a voluntary base, it is appreciated that the participating nations cooperated to carry out energetically the technical development activities.

PART 3 (cont.)

The EVEDA assumed currently as the next activity is aiming at performing the detailed engineering design and the related prototypical component test, i.e. completion of the fully integrated engineering design for making decision of IFMIF construction, in addition to reaching to the technology level capable to enter the construction action immediately, when the decision for construction is made, by accumulating the technical data used as the backing. Considering this purpose, it is assessed that about goal setup for main items necessary to accelerator system in EVEDA there is no big omission and it is almost covered. However, to attain the goals of EVEDA, it is required to promote the technical participation and through pursuit of technology at the level higher than currently planned for each engineering validation and engineering design tasks.
PART 3 (cont.)

In IFMIF target system, to obtain 0.5I of high neutron flux irradiation where neutron flux is region equivalent to 20dpa/y or more, the technical development is necessary to realize the flowing liquid Li target, which has the free surface stabilized for a long time while receiving 10MW (40MeV, 250mA) deuterom beam, and the circulation & processing system. A goal setup in KEP is generally appropriate in considering the original purpose, and as a whole the degree of achievement of the technical development is in the range of the level estimated to be appropriate in general, although it is recognized the necessity for the further technical development in Li purification system, etc. Also about a goal setup in EVEDA, it is generally appropriate that Li loop of 1/3-scaled Li inventory of the real system is built and various kinds of engineering validation tests using it are planned. And about the approach for solving the technical issue, as a whole it has generally reached to appropriate level although it is necessary to consider the technical development and validation, etc. fully taking into account the operating condition of the real system of Li purification system.

PART 3 (cont.)

In IFMIF test cell system, it is necessary to perform the technical investigation and development for realizing the irradiation tests surely under the conditions required for candidate materials of fusion reactor, neutron flux and irradiation dose, irradiation volume, irradiation temperature, and so on. Additionally it is necessary to develop the small specimen technology in a fully rationalized and advanced level to give the sufficient reliability to the testing data and to utilize the limited irradiation volume efficiently. A goal setup in KEP is generally in appropriate level and as a whole the degree of achievement is assessed almost appropriate as for the KEP stage, although the issue was left about the improvement of accuracy of specimen temperature control and the further advancement of the small specimen technology. About the goal setup in EVEDA, in addition to the planned items, it is required to optimize the concrete test matrix and to evaluate the irradiated specimen temperature and the neutron flux distribution, etc. with a high accuracy. Also about the approach for solving the technical issues, it is required to rationalize and advance the small specimen technology consistent with the remote handling and sorting technologies, to optimize the test matrix, and to enhance the small specimen technology and evaluation of irradiation conditions and irradiation field characteristics, such as evaluating the temperature control and the irradiation field characteristics by assuming the concrete set of specimens and the realistic irradiation rig. system.
PART 3 (cont.)

(3) About the technical realization of IFMIF based on the results up to KEP activity

The requirements to be equipped by IFMIF should be fundamentally attained, if the technical development is surely carried out for each components of accelerator, target, test cell, and others like building and utilities defined in conceptual design, and for integrated system. As mentioned above, at the present stage it is still left for a part of issues to be developed and verified technically in accelerator system, and for the issues relevant to test cell system, which must be greatly expected during activity in EVEDA. Therefore, it is concluded that the technical realization of IFMIF to satisfy the required performance for fusion reactor materials irradiation test (irradiation field characteristics, operation and testing conditions, etc.) is not in the level to completely foresee, as a whole.

PART 3 (cont.)

(4) About implementation plan of EVEDA towards decision of IFMIF construction

As mentioned above, the EVEDA activity is aiming at completion of the fully integrated and synthetic engineering design for making decision of IFMIF construction, in addition to reaching to the technology level capable to enter the construction action immediately, when the decision for construction is made, by accumulating the technical data used as the backing. About EVEDA activity the goal setup is generally in appropriate level, however, it was pointed that the approach for the technical issues needs to be more advanced and enhanced. Each nations and organizations participating to IFMIF project have a potential of technical development and they produced many results though KEP activity was carried out in voluntary base. Therefore, in EVEDA it is expected to advance the technical activity at high level efficiently under the international cooperation.
PART 3 (cont.)

The nuclear fusion research and development in our nation are mainly aiming at achievement of the self-ignition conditions and realization of the prolonged burning of nuclear fusion plasma in addition to foundation of the engineering technology basis required to develop prototype nuclear reactor for demonstrating power generation (power generation demonstration plant), in addition to. Unless such a plan is changed, it seems to be appropriate to participate EVEDA in IFMIF project within the limits of the resources, which aims at to realize the nuclear fusion materials irradiation facility to provide the material data required for design and construction of a power generation demonstration plant, from the viewpoint of sharing the advanced technical development and large fund in the international cooperation.

PART 3 (cont.)

(5) About planning for performing IFMIF project and others

The fusion reactor research and development in JAERI is planned to advance the cooperation in ITER project, the upgrade & modification of JT-60 with accompanying plasma research, and the fusion reactor engineering development focusing on blanket and materials development, synthetically. However, based on the situation that the budget of R&D for atomic energy is very tight, it argued about how to perform the IFMIF project, what the expense and the like should be, etc. In this discussion there was an argument about utilizing the computational science, recently progressed greatly, and the spallation neutron sources, such as US Spallation Neutron Source (SNS) and Japan Proton Accelerator Complex (J-PARC). It might be useful to construct the material damage model, etc., however it cannot become a substitution to the IFMIF, mainly aiming at the material data acquisition with high reliability towards construction of power generation demonstration plant, etc. In parallel, there was an argument that the concrete direction should be found for rationalizing the IFMIF specification / scale and reducing the cost, after making a reasonable and rationalized IFMIF test matrix in advancing the small specimen technology, restricting the testing materials by giving priority to the reduced activation ferritic steel, and so on, through the future advancement of small specimen technology concerning the data acquisition with a needed reliability and the reexamination of test matrix with a broader view of restricting materials, etc.
PART 3 (cont.)

About the construction of IFMIF, in consideration of the construction period and the testing time for candidate materials, it is necessary to make a decision including start time of IFMIF construction, from ten to 20 years prior to the construction start time of nuclear fusion generation demonstration plant. In addition, the fusion reactor engineering for the power generation demonstration plant is positioned as almost directly being succeeded to the practical fusion power generation plant. To examine the validity of an IFMIF project including its construction decision, it is important to examine whether the conceptual design, specification, etc. of presently assumed power generation demonstration plant are appropriate as those of the practical fusion power generation plant, based on the aspect of definition of the suitable materials testing conditions as the prerequisite for IFMIF construction. However, in this peer review, such argument and examination were omitted from a viewpoint of specialties of review members. Therefore, it is appropriate to make a judgment of IFMIF construction after the conceptual design and the validity of specifications of power generation demonstration plant assumed now in the future.

POSTSCRIPT

The activity of IFMIF project is in a stage that, through the completion of KEP in the past, it is examined for the implementation framework of EVEDA expected as an activity of the next stage. For examining the appropriateness of participation to EVEDA, peer review of IFMIF project and relevant programs was performed to synthetically assess the planning for nuclear fusion reactor engineering development in JAERI, focusing at materials and blanket development, the positioning of IFMIF in the development of power generation blanket and materials, the consequences of component technology confirmation obtained in KEP, the technical feasibility of IFMIF, and the goals, the technical issues, and planning of activities in EVEDA, etc.
EVEDA Tasks

Masayoshi Sugimoto
Tokyo, Japan
May 19, 2005

### EVEDA task list for Test Facilities

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF-1a</td>
<td>Engineering design and fabrication of full-scale HFTM</td>
<td>Engineering design and fabrication of a full-scale prototype with assembled rigs, capsules, specimens, instrumentation and active heating capacity</td>
</tr>
<tr>
<td>TF-1b</td>
<td>Tests on full-scale HFTM</td>
<td>Operate full-scale prototype with assembled rigs and specimens to test (1) remote handling of assembling/disassembling procedures, and (2) thermal hydraulics, instrumentation and cooling</td>
</tr>
<tr>
<td>TF-1c</td>
<td>Upgrade existing helium gas loop</td>
<td>Significant upgrade of existing He gas loop (compressor, instrumentation, tubing, purification system) for prototype testing of HFTM and MFTMs</td>
</tr>
<tr>
<td>TF-1d</td>
<td>Irradiation test of instrumented rigs in fission reactor</td>
<td>Irradiation of instrumented rigs in materials test reactor to verify system design and active heating under real loading conditions</td>
</tr>
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</table>
## EVEDA task list for Test Facilities (cont.)

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
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<tbody>
<tr>
<td>TF-1e</td>
<td>Engineering design and system evaluation of full-scale and system evaluation prototype for three instrumented push-pull fatigue of full-scale MFTM for specimens, and integrated neutron moderator. in-situ creep fatigue tests</td>
<td>Engineering design and system evaluation of full-scale and system evaluation prototype for three instrumented push-pull fatigue of full-scale MFTM for specimens, and integrated neutron moderator. in-situ creep fatigue tests</td>
</tr>
<tr>
<td>TF-1f</td>
<td>Engineering design and system evaluation of full-scale and system evaluation prototype with purge gas tubes and instrumentation for of full-scale MFTM for every individual rig, and integrated neutron moderator in-situ tritium release tests on ceramic breeders and compatibility tests</td>
<td>Engineering design and system evaluation of full-scale and system evaluation prototype with purge gas tubes and instrumentation for of full-scale MFTM for every individual rig, and integrated neutron moderator in-situ tritium release tests on ceramic breeders and compatibility tests</td>
</tr>
<tr>
<td>TF-1g</td>
<td>Engineering design and system evaluation prototype of an instrumented mock-up, and integrated of full-scale MFTM for neutron moderator in-situ experiments for insulation coatings of structural materials</td>
<td>Engineering design and system evaluation prototype of an instrumented mock-up, and integrated of full-scale MFTM for neutron moderator in-situ experiments for insulation coatings of structural materials</td>
</tr>
</tbody>
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## EVEDA task list for Test Facilities (cont.)

<table>
<thead>
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<th>Task</th>
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</thead>
<tbody>
<tr>
<td>TF-1h</td>
<td>Engineering design and system evaluation of full scale and system evaluation prototype of a VIT system</td>
<td>Engineering design and system evaluation of full scale and system evaluation prototype of a VIT system</td>
</tr>
<tr>
<td>TF-1i</td>
<td>Construction, fabrication and test of less-than-full-scale VTA prototype</td>
<td>Construction, fabrication and test of VTA mock-ups with integrated coolant ducts and instrumentation to test (1) remote controlled precise positioning, (2) sealing, (3) assembling and disassembling of test modules</td>
</tr>
<tr>
<td>TF-1j</td>
<td>Full evaluation of source term D-Li nuclear reactions to reduce significantly the current neutron yield uncertainties of ±20%</td>
<td>(1) Broad based neutron time-of-flight measurements from IFMIF relevant Li(d,nx) reactions, (2) Data processing and incorporation of experimental data in existing libraries</td>
</tr>
<tr>
<td>TF-1k</td>
<td>Nuclear data above 20 MeV</td>
<td>(1) Completion of data file preparation, (2) Neutron transport benchmark tests</td>
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</tbody>
</table>

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### EVEDA task list for Test Facilities (cont.)

<table>
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<th>Task</th>
<th>Contents</th>
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<tbody>
<tr>
<td>TF-1l</td>
<td>Calculation of the complete neutron response throughout the entire test cell equipped with reference test modules</td>
<td>MCNP, NYOY and McDeLi-code calculation for 3D distribution of all nuclear responses, including decay heat and nuclear inventory.</td>
</tr>
<tr>
<td>TF-1m</td>
<td>Prototype fabrication and test of on-line miniaturized neutron / gamma monitors</td>
<td>After fabrication the monitors are tested (1) in a fission reactor, (2) in a light ion particle accelerator.</td>
</tr>
<tr>
<td>TF-1n</td>
<td>Prototype fabrication and test of IFMIF micro-tomography system</td>
<td>Transmission and emission tomography systems will be tested to verify suitability for structural integrity tests on assembled rigs and HFTM</td>
</tr>
<tr>
<td>TF-1o</td>
<td>RAM studies</td>
<td>RAM studies</td>
</tr>
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### EVEDA task list for Test Facilities (cont.)

<table>
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<th>ID</th>
<th>Task</th>
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</thead>
<tbody>
<tr>
<td>TF-1p</td>
<td>SSTT: Development of miniaturized fracture toughness specimen</td>
<td>User specific development; (1) Data generation from irradiated and reference samples, (2) Modeling of size effects</td>
</tr>
<tr>
<td>TF-2a</td>
<td>Test cell improvement design of entire test cell, access cell, and test module handling cell</td>
<td>(1) Design improvement of entire test cell (including steel liner, shield plugs, VTAs, VIT and test cell cover), (2) Engineering design</td>
</tr>
<tr>
<td>TF-2b</td>
<td>Specification, engineering design of complete maintenance and remote handling systems, incl. universal robot system and auxiliary systems</td>
<td>Design based on (1) detailed evaluation of all remote handling scenarios, (2) manufacturer experience from reactor decommissioning</td>
</tr>
</tbody>
</table>
### EVEDA task list for Test Facilities (cont.)

<table>
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<tr>
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<tr>
<td>TF-2b</td>
<td>Specification, engineering design of complete maintenance and remote handling systems, incl. universal robot system and auxiliary systems</td>
<td>Design based on (1) detailed evaluation of all remote handling scenarios, (2) manufacturer experience from reactor decommissioning</td>
</tr>
<tr>
<td>TF-2c</td>
<td>Test Cell Technology room and Test Facility control room; specification of instrumentation and design of all devices</td>
<td>Layout and specification of both rooms</td>
</tr>
<tr>
<td>TF-2d</td>
<td>Engineering design of post irradiation examination facilities</td>
<td>Neutronics and manufacturers' supported design of (1) Conventional hot cell laboratory, (2) Shielded glove box laboratory, (3) Tritium laboratory</td>
</tr>
</tbody>
</table>

### EVEDA task list for Target Facilities

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG-1a</td>
<td>Construction of Li test loop</td>
<td>Construction of EVEDA Li test loop. This includes component cost of a main loop, an electromagnetic pump, a primary/secondary heat exchanger. Diagnostics and tritium/impurity monitors and traps are not included</td>
</tr>
<tr>
<td>TG-1b</td>
<td>Operation and tests</td>
<td>Operation of Li test loop and validation of the Li loop performance in long-term operation</td>
</tr>
<tr>
<td>TG-1c</td>
<td>Erosion/Corrosion</td>
<td>Erosion/corrosion measurements in material loop and Li test loop</td>
</tr>
<tr>
<td>TG-1d</td>
<td>Diagnostics</td>
<td>Li jet free surface and thickness monitor in Li test loop, distortion monitor of the target assembly, surface temperature monitor, Li vapor monitor</td>
</tr>
<tr>
<td>TG-1e</td>
<td>Li purification system</td>
<td>Validation of removal and monitoring of tritium, $^7$Be, C, N and O</td>
</tr>
<tr>
<td>TG-1f</td>
<td>Remote handling system</td>
<td>Development and verification of remote handling system for the back wall and target assembly</td>
</tr>
<tr>
<td>TG-1g</td>
<td>Li safety handling</td>
<td>For safe operation - additional tests on Li leak, combustion, extinction, and radioactive materials behavior as aerosols</td>
</tr>
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</table>
### EVEDA task list for Target Facilities (cont.)

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG-2a</td>
<td>Target assembly, Main and Purification Loops</td>
<td>Design of the target assembly, the Li main loop, the Li purification loop</td>
</tr>
<tr>
<td>TG-2b</td>
<td>Diagnostics</td>
<td>Design of various diagnostics and arrangements</td>
</tr>
<tr>
<td>TG-2c</td>
<td>Remote handling system</td>
<td>Design of the remote handling system for the target assembly and/or the back wall</td>
</tr>
<tr>
<td>TG-2d</td>
<td>Safety, Vacuum, Control Systems</td>
<td>Safety analysis and design of vacuum system and control system</td>
</tr>
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</table>

### EVEDA task list for Accelerator Facilities

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
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<tbody>
<tr>
<td>AC-1a</td>
<td>Develop H$_2^+$ ion source</td>
<td>Development of H$_2^+$ ion source for beam commissioning</td>
</tr>
<tr>
<td>AC1b</td>
<td>High power RFQ load cavity and engineering prototypes to support design</td>
<td>Design and construction of high power RFQ-type load cavity used for high power RF test and as a beam matching diagnostic for the injector test stand prepared by Task AF-1g. Engineering prototypes for manufacture of DTL and other components.</td>
</tr>
<tr>
<td>AC-1d</td>
<td>Engineering prototypes to support design</td>
<td>Design, construction and integration of complete RF power system including one RF window/coupler and RF controls</td>
</tr>
<tr>
<td>AC-1e</td>
<td>Complete RF power system to one coupler</td>
<td>Design, construction and integration of complete RF power system including one RF window/coupler and RF controls</td>
</tr>
<tr>
<td>TG-1c</td>
<td>Beam diagnostics and instrumentation</td>
<td>Development of beam diagnostics, instrumentation</td>
</tr>
<tr>
<td>TG-1f</td>
<td>CW injector with LEBT</td>
<td>Design and construction of CW injector with Low Energy Beam Transport line and performing transport optimization to minimize neutron production</td>
</tr>
</tbody>
</table>
### EVEDA task list for Accelerator Facilities (cont.)

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-2a</td>
<td>Engineering design activity</td>
<td>Complete the design for the accelerators to insure overall consistency of the conceptual design and to bring the overall accelerator design to the construction.</td>
</tr>
<tr>
<td>AC-2b</td>
<td></td>
<td>approval level for all components, sub-systems and support structure, including specifications, thermal/structural analysis, system activation, safety, and interface issues. Prepare detailed design for long lead time and staged contract procurements on critical path.</td>
</tr>
<tr>
<td>AC-2c</td>
<td></td>
<td>Trade-off design study of SC linac vs. NC linac for 8-40 MeV region.</td>
</tr>
<tr>
<td>AC-2d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC-2e</td>
<td></td>
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### EVEDA task list for Design Integration

<table>
<thead>
<tr>
<th>ID</th>
<th>Task</th>
<th>Contents</th>
</tr>
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<tbody>
<tr>
<td>Di-2a</td>
<td>Design of buildings</td>
<td>Design buildings in enough detail to make procurement specifications for construction.</td>
</tr>
<tr>
<td>Di-2b</td>
<td>Design of utilities</td>
<td>Designs for power and water supplies, ventilation, evacuation etc. to procurement specification level.</td>
</tr>
<tr>
<td>Di-2c</td>
<td>Analysis of operation flow and design of central control</td>
<td>Operation flow is analyzed from start-up to shutdown in normal/off-normal conditions, and design central control system.</td>
</tr>
<tr>
<td>Di-2d</td>
<td>Revise of radiation shielding</td>
<td>Adequate specification of radiation shielding is determined by shielding calculation and other methods and used for the building design.</td>
</tr>
<tr>
<td>Di-2e</td>
<td>RAM analyses for staged IFMIF</td>
<td>Availability of whole facility is calculated using failure probability of every component, mean time of repair, etc., to validate IFMIF adequacy as an irradiation facility.</td>
</tr>
<tr>
<td>Di-2f</td>
<td>Safety assessments for staged IFMIF</td>
<td>Failure mode and its effect are analyzed, to validate that the facility is able to deal with failures and their effects.</td>
</tr>
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### EVEDA task list for Design Integration (cont.)

<table>
<thead>
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<th>ID</th>
<th>Task</th>
<th>Contents</th>
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</thead>
<tbody>
<tr>
<td>DI-2g</td>
<td>Preparation for licensing and analysis to show compliance with regulations</td>
<td>Preparation for licensing hearings and demonstration of compliance with regulations on radiation, nuclear fuel materials, electromagnetic waves, dangerous materials, high-pressure gas, earthquakes, and fire.</td>
</tr>
<tr>
<td>DI-2h</td>
<td>Cost estimates using results of EVEDA and design advances</td>
<td>Cost evaluation is performed on IFMIF construction, operation and decommission using component specification as clarified through EVEDA activity.</td>
</tr>
<tr>
<td>DI-2i</td>
<td>Systems Engineering for Design Control</td>
<td>International project necessitates establishment of rules and monitoring procedures for control of facility designs and interfaces.</td>
</tr>
<tr>
<td>DI-2j</td>
<td>Initiate Construction Phase Mgt.</td>
<td>Construction phase management must be established prior to construction approval to coordinate the preliminary design and advanced procurement activities. This should be done during the last two years of EVEDA.</td>
</tr>
<tr>
<td>DI-2k</td>
<td>Preparation for Advanced Procurement</td>
<td>Define and prepare procurement packages for long lead items (i.e. RF power system, possibly RFQ rough machining, etc.) so that purchase orders can be placed immediately after authorization for construction.</td>
</tr>
</tbody>
</table>

### Preliminary Concept Map of EVEDA-DI Tasks

- **IFMIF site**
  - Design of buildings (DI-2a) [Gives location, volume, etc.]
  - Design of utilities (DI-2b)
- **Main building**
- **Satellite buildings**
- **Personnel**
- **Operation flow (DI-2c)**
- **RAM analysis (DI-2e)**
- **Safety assessment (DI-2f)**
- **Radiation shielding (DI-2d)**
  - Radiation safety info.
- **Cost estimate based on EVEDA (DI-2h)**
- **System engineering for design cont (DI-2i)**
- **Initiate construction phase mgt. (DI-2j)**
- **Prepare advanced procurement (DI-2k)**
- **Licensing analysis (DI-2g)**
### 表1 SI基本単位および補助単位

<table>
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### 表2 SIと併用される単位

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<td>電子荷量単位</td>
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1 eV = 1.60218 × 10⁻¹⁹ J
1 u = 1.66054 × 10⁻²⁷ kg

### 表3 固有の名称をもつSI補足単位

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### 表4 SIと共有に拡大的に

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### 表5 SI換算表

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### 機械

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### 縦

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### 級

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### 放射能

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### 級

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