Staged Deployment of the International Fusion Materials Irradiation Facility (IFMIF)

H. Takeuchi 1), M. Sugimoto 1), H. Nakamura 1), T. Yutani 1), M. Ida 1), S. Jitsukawa 1), T. Kondo 1), S. Matsuda 1), H. Matsui 2), T. E. Shannon 3), R. A. Jameson 4), F. W. Wiffen 5), J. Rathke 6), C. Piaszczyk 6), S. Zinkle 7), A. Möslang 8), K. Ehrlich 8), F. Cozzani 9), H. Klein 10), J-M. Lagniel 11), R. Ferdinand 11), E. Daum 8), M. Martone 12), I. S. Ciattaglia 12), V. Chernov 13)

1) Japan Atomic Energy Research Institute (JAERI), Tokai-mura, Japan
2) Tohoku University, Sendai, Japan
3) The University of Tennessee, Knoxville, USA
4) Los Alamos National Laboratory (LANL), Los Alamos, USA
5) US Department of Energy, Germantown, USA
6) Advanced Energy Systems Inc., Medford, USA
7) Oak Ridge National Laboratory (ORNL), USA
8) Forschungszentrum Karlsruhe (FZK), Karlsruhe, Germany
9) Commission of the EC, Brussels, Belgium
10) Johann-Wolfgang-Goethe Universitat, Frankfurt am Main, Germany
11) Commissariat a l'Energie Atomique (CEA)/Saclay, Gif-sur-Yvette, France
12) Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA), Frascati, Italy
13) SSC RF-A.A.Bochvar Institute of Inorganic Materials, Moscow, Russia

e-mail contact of the main author : takeuchi@fnshp.tokai.jaeri.go.jp

Abstract. The International Fusion Materials Irradiation Facility (IFMIF) employs an accelerator based D-Li intense neutron source as defined in the 1995-96 Conceptual Design Activity (CDA) study. In 1999, IEA mandated a review of the CDA IFMIF design for cost reduction without change to its original mission. This objective was accomplished by eliminating the previously assumed possibility of potential upgrade of IFMIF beyond the user requirements. The total estimated cost was reduced from $797.2 M to $487.8 M. An option of deployment in 3 stages was also examined to reduce the initial investment and annual expenditures during construction. In this scenario, full performance is achieved gradually with each interim stage as follows. 1st Stage: 20% operation for material selection for ITER breeding blanket, 2nd Stage: 50% operation to demonstrate materials performance of a reference alloy for DEMO, 3rd Stage: full performance operation (2 MW/m^2 @ 500 cm^3) to obtain engineering data for potential DEMO materials under irradiation up to 100-200 dpa. In summary, the new, reduced cost IFMIF design and staged deployment still satisfies the original mission. The estimated cost of the 1st Stage facility is only $303.6 M making it financially much more attractive. Currently, IFMIF Key Element Technology Phase (KEP) is underway to reduce the key technology risk factors.

1. Introduction

Development of a practical fusion reactor requires significant progress with respect to issues including environmental acceptability, safety and economic viability. In addressing these issues, development and qualification of radiation-resistant and low activation materials are key factors. These fusion materials must survive irradiation in a high intensity neutron field with energy of 14 MeV and annual damage doses around 20 dpa (displacements per atom). Having a potential to provide an irradiation test facility suitable for identifying and validating such materials, an accelerator-based neutron source using the Deuteron-Lithium (D-Li) stripping reaction has been selected. Development of the technology for this type of neutron source was initiated by the Fusion Materials Irradiation Test Facility [1] and continued by the

Energy Selective Neutron Irradiation Test Facility [2]. In the last decade, this development was further advanced during the International Fusion Materials Irradiation Facility (IFMIF) Conceptual Design Activity (CDA) [3] in 1995-96 under the IEA collaboration. Following the review of CDA, IEA recommended continuation of the effort as a Conceptual Design Evaluation (CDE) [4],[5] in 1997-98 to evaluate the remaining design uncertainties. In January 1999, IEA requested reconsideration of the IFMIF design with focus on cost reduction without changing its original mission. In addition, the option of staged deployment of IFMIF was also raised for reducing initial investment and lowering annual expenditures during construction.

This paper presents the current plan for development and construction of IFMIF. Section 2 presents a general description of IFMIF in CDA and CDE. In section 3, the results of the cost reduction study and staged deployment scenario evaluation are discussed. Section 4 is devoted to discuss the Key Element technology Phase (KEP) activities recommended by IEA in January 2000. In section 5, the current plan for IFMIF development is summarized.

2. Brief Description of IFMIF

IFMIF main specifications are summarized in Table I. IFMIF is an accelerator-based D-Li neutron source for production of an intense flux of high energy neutrons within sufficient irradiation volume to enable realistic testing of candidate materials and components up to about a full lifetime of their anticipated use in DEMO and beyond. IFMIF mainly consists of three subsystems: (1) Test Facilities which expose, handle and examine the irradiated specimens, (2) Target Facility which produces a flowing Li jet target for converting the D^+ beam into high energy neutrons, (3) Accelerator Facility which produces the accelerated beam. The required beam current is generated by the parallel operation of two accelerators. The two beams converge on the free surface of flowing Li circulated by the Li loop.

The technological approach adopted in IFMIF CDA design requires a relatively modest extension of the current state of technology. For examples, acceleration of 125 mA CW D^+ beams has not yet been demonstrated, although recent experiments with the 100 mA CW proton beams in Los Alamos National Laboratory represent a significant step towards this goal. Also, liquid Li jet systems with a free surface have not yet been demonstrated in steady state operation. In order to assure the high availability and reliability of IFMIF, these key technology elements require design and fabrication of suitable prototypes for performing the necessary endurance tests. The CDA study conducted during 1995-96 estimated IFMIF cost at 797.2 MICF [6], where 1 MICF = 1 Million IFMIF Conversion Factor units (~ $1M US in January 1996).

TAB. I : IFMIF TOP LEVEL SPECIFICATIONS

Neutron Flux	$\geq$ 2 MW/m^2 (@ 500 cm^3)
Operation Availability	70 %
D^+ Beam Current	250 mA (CW, 2 x 125 mA)
D^+ Energy	32, 40 MeV
D^+ Beam Size	200 mm (width) x 50 mm (height)
Li Jet Thickness	19, 25 mm (resp. for 32, 40 MeV D^+)
Li Jet Width	260 mm
Li Jet Velocity	10-20 m/s

3. Cost Reduction and Staged Deployment

Under the current budget limitations and the interactions with the International Thermonuclear Experimental Reactor (ITER) project, the strategy for constructing and operating the test facility had to be reviewed to minimize the associated financial burden without sacrificing essential performance parameters. Based on the design changes, the total cost estimate was reduced from 797.2 MICF to 487.8 MICF. [7]

3.1 Major Cost Reduction Items

The study of cost reduction and staged deployment considered the following major items:

1) The potential for a future upgrade to four accelerators with irradiation capability twice that of the current user requirements, assumed in the CDA, has been eliminated.
2) The building volume was reduced as allowed by the above design changes in accelerator systems and Li loop components.

3.2 Additional Design Changes for Cost Reduction

In addition to the above major items, the original CDA specifications were reviewed with the objective of improving component design and eliminating non-essential items. The following design changes, relative to the CDA, were made in IFMIF: The accelerator vault and the RF power bay were relocated to the same level and the RF transport length was reduced to 40%. In the high energy beam transport (HEBT) line, the energy dispersion- and buncher-cavities, their RF power source with RF transport and 90˚ beam turning line were eliminated. The circulator and the dummy load at the exit of RF final amplifier were removed by changing the reflection protection scheme. The transition energy between the RF Quadrupole and the Drift Tube Linac was reduced from 8 MeV to 5 MeV.[8] A single Li target was selected, instead of the two. The redundant impurity traps were removed. To reduce the building height, the layout of Li loop components was reviewed. An improved electromagnetic pump (EMP) allowed reduction of required Li head from 13 m to 6.5 m. As a result, the Li inventory was reduced from 21 m^3 to 9 m^3. These design changes reduced the building height from 21 m to 10.5 m. The reduced cost design has a single test cell, instead of the two, corresponding to the reduction of the number of Li targets. Also, a single remote handling system now serves both the test and the target facilities.[9] The layout of the test facilities was revised.

3.3 Staged Deployment

Here, the IFMIF deployment was assumed to proceed in three stages, each addressing a specific materials development issue as follows:

- 1st Stage: One accelerator with a maximum of 50 mA operation, used for material selection of the ITER breeding blanket test modules, fusion-fission data correlation and generic damage studies.
- 2nd Stage: One accelerator for 125 mA operation, used to demonstrate materials performance of a reference alloy for DEMO-relevant fluences.
- 3rd Stage: Two accelerators for 250 mA operation (2 MW/m^2 @ 500 cm^3), used to obtain engineering data for potential DEMO materials under irradiation up to 100-200 dpa and a systematic search for high performance fusion materials.

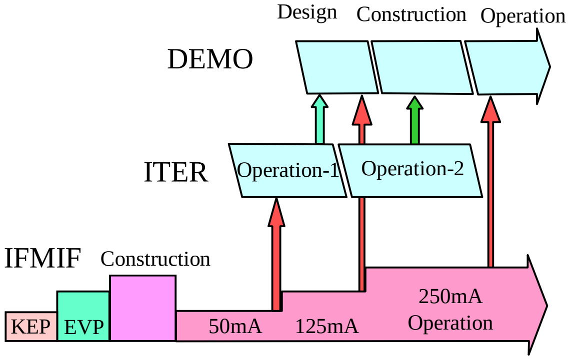

FIG. 1. Staged deployment schedule

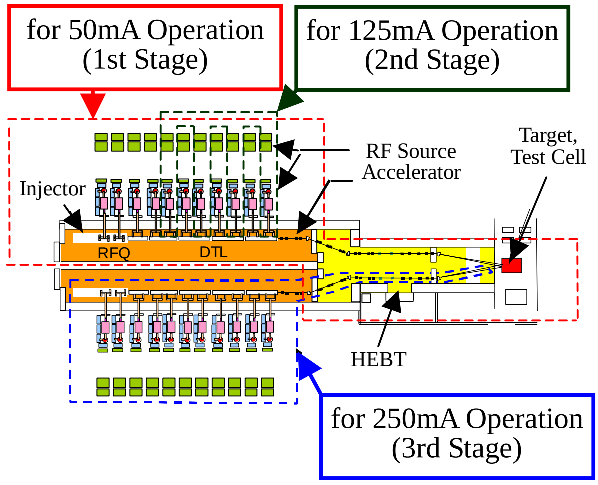

FIG. 2. IFMIF plane view

Figure 1 shows the staged deployment schedule in combination with the fusion reactor development schedule. Figure 2 shows the staged deployment of the reduced cost IFMIF. In the 1st stage, one accelerator is installed with enough RF power supplies to generate the 50 mA, 40 MeV D^+ beam. In the 2nd stage, more RF power supplies are added to reach the current of 125 mA. In the 3rd stage, the second accelerator is installed to bring the total beam 250 mA. It is also noted that although most of the conventional facilities are constructed in the 1st stage, the facilities for the second accelerator are constructed in the 3rd stage. The Li target is installed in its entirety in the 1st stage. While most of the test facilities are also installed in the 1st-Stage, the post irradiation examination facility is installed in the 2nd stage. The staged deployment of the IFMIF facility reduces the initial investment and lowers the annual expenditures while still providing significant interim capabilities for fusion material development for ITER and DEMO. The cost estimate for the 1st stage is now only 303.6 MICF [7], which may make the initiation of the IFMIF construction more attractive. It is understood that some of the additional changes listed here may result in a certain reduction of design robustness either by increasing the potential technology risk or by reducing the system reliability and availability and thus, potentially reducing the total annual fluence on the specimens. However, these risks will be balanced with the extra time available for additional technology improvements during the staged deployment.

4. Present Status and Future Plan

In 2000, a 3-year KEP has begun with the objective of reducing the key technology risk factors needed to achieve a CW D^+ beam with the desired current and energy, to reach the corresponding power handling capabilities in the liquid Li target system, and to satisfy the availability and reliability endurance tests. There are 83 proposed KEP tasks, with 27 tasks for the test facilities, 12 tasks for the Li target system, 26 tasks for the accelerator system, and 18 tasks for design integration [10]. The KEP tasks already showing significant progress include the development of stable injector operation, high transmission RFQ, DTL heat removal and magnet packaging, high power CW RF tube, and RF window for the accelerator system. Other tasks underway include a water jet experiment, Li loop experiment, and development of Li purification and performance monitors for the target system. Also, for the test facilities, development of temperature control for the test module and miniaturized specimen technologies has been started.

KEP also includes tasks for redesign of the IFMIF components to update the CDA/CDE design with the new elements developed during KEP. This will include a new design of the IFMIF building including facilities for processing of radioactive materials and updates of the controls and instrumentation. After the KEP results have been reviewed by the international development team, the IFMIF project will be ready for a possible international decision to proceed to the three year Engineering Validation Phase (EVP) where continuous, stable operation of each subsystem: accelerator system, target system and test facilities could be validated. After an international review of the EVP, the construction of IFMIF could be started and first operation could be expected as early as 2010.

5. Summary

An irradiation test facility producing neutrons of high flux and with a proper energy spectrum is indispensable to develop materials required for designing and building fusion reactors. IFMIF is a facility well suited for such a mission, and could be operational within the required time span. This paper described an approach where IFMIF could be constructed in stages to minimize the annual expenses while still contributing useful capabilities in its early stages to the process of fusion materials development. The proposed approach is compatible with the demands of the fusion reactor development schedule. The total cost estimate of the IFMIF was reduced to 61% of the CDA estimate, from $797.2 M to $487.8 M. Staged deployment reduces the initial investment even further, down to $303.6 M. The key element technology development, currently underway, is on track for demonstrating its critical technologies.

Acknowledgement

Appreciation is given to all members of the International IFMIF team on their contributions to this work. The IFMIF executive subcommittee has been highly impressed with dedication and enthusiasm of the IFMIF team. Also, appreciation is given to the IEA Fusion Power Coordinating Committee (FPCC) for their continued interest in the program.

References

[1] TREGO A. L., et al., Nuclear Technology Fusion **4(2)**, (1983) 695.
[2] NODA K., et al., Journal of Nuclear Materials **174**, (1990) 319.
[3] MARTONE M. (Ed.), ENEA Frascati Report, RT/ERG/FUS/96/11 (1996).
[4] MÖSLANG A. (Ed.), FZK Report, FZKA 6199 (1999).
[5] MÖSLANG A., et al., Fusion Energy 1998 (Proc. of 17th Int. Conf. Yokohama, 1998), IAEA, Vienna (1999) 1203 (CD-ROM file FT2/4).
[6] RENNICH M. (Ed.), ORNL Report, ORNL/M-5502 (1996).
[7] IDA M., et al. (Ed.), JAERI-Tech 2000-014 (2000).
[8] SUGIMOTO M., et al., Proc. Linac 2000 conference, Monterey, 25-26 Aug. 2000.
[9] NAKAMURA H., et al., Proc. 21st Symp. on Fusion Tech., Madrid, 11-15 Sep. 2000 (JAERI-Tech 2000-078).
[10] IDA M., et al. (Ed.), JAERI-Tech 2000-052 (2000).