# IFMIF: Status of the Validation Activities and of the Engineering Design Activities

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**Abstract**. The International Fusion Materials Irradiation Facility (IFMIF) concept was established many years ago under IEA auspices. The current phase, called Engineering Validation and Engineering Design Activities (EVEDA), is conducted in the framework of the Broader Approach agreement between Euratom and Japan since mid 2007. After three years the project is entering in a transition step from the preparatory and confirmation stage to genuine engineering and validation stage. Three major validation programs to ensure the technological demonstration of the performance of the main challenging systems are ongoing: (a) the low energy part of the accelerator system, prototype up to 9 MeV with 125 mA cw deuteron beam, (b) a liquid lithium test loop with free surface and 15 m/s nominal speed, and (c) full scale irradiation test module including temperature control instrumentation. These validation activities are scheduled to be completed within the next three years except for the accelerator prototype, which will require further 2-3 years. The engineering design of IFMIF, more recently launched as an overall collaborative effort, will reflect the results of these programs, so that the main part of the design will be provided by mid 2013. The engineering design activities will have to be continued beyond that date, in particular to adapt the design according to the specific site that will be chosen for IFMIF construction and include additional information from accelerator prototype tests.

## 1. Introduction

The Engineering Validation and Engineering Design Activities of the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) is one of the three projects of the Broader Approach agreement, signed between Euratom and the Government of Japan in February 2007. IFMIF is a unique irradiation facility satisfying the requirements of fusion materials researchers for developing DEMO relevant materials and breeder technologies. The fusion like neutron environment is achieved through nuclear reactions between deuterons and lithium, using high current deuteron accelerators and liquid lithium target system [1]. The irradiation conditions are optimized to conduct fusion relevant irradiation effects on material properties in particular from the aspects of damage production mechanism and neutron induced hydrogen- and helium-gas production.

The main missions of IFMIF have been reviewed in 2009 by the IFMIF Specification Working Group coordinated by the IFMIF/EVEDA project leader, and summarized as [2]:

1. Engineering design data for DEMO, which enables lifetime evaluation; in the first step more than 100 dpa are not deemed necessary even for structural materials, while a solid database would be needed up to about 30-50 dpa for major in-vessel components;
2. Definition of performance limits, in a second step key materials data up to about 100 dpa to fulfill end-of-life conditions, and, in some cases even more to validate the performance limits of the materials;
3. Completion and validation of (existing) databases, by gathering and confirming data required for licensing and safety assessment;
4. Selection or optimization of materials, based on data of IFMIF irradiation;
5. Validation of fundamental understanding of radiation response of materials, contributing to science-related modeling of irradiation effects to be validated and benchmarked at length-scale and time-scale relevant for engineering application;

6. Tests of blankets (specific technologies, and even small scale full mockups in a later phase) and functional materials prior to or complementary to ITER Test Blanket Modules.

IFMIF is an accelerator driven source of neutrons, using a stripping reaction between deuterium and lithium, producing neutrons which have an energy spectrum rather similar to those induced by the deuterium – tritium reaction of fusion plasmas, as shown in Figure 1 [3]:

$^{7}Li(d,2n)^{7}Be$ $^{6}Li(d,n)^{7}Be$ $^{6}Li(n,T)^{4}He$

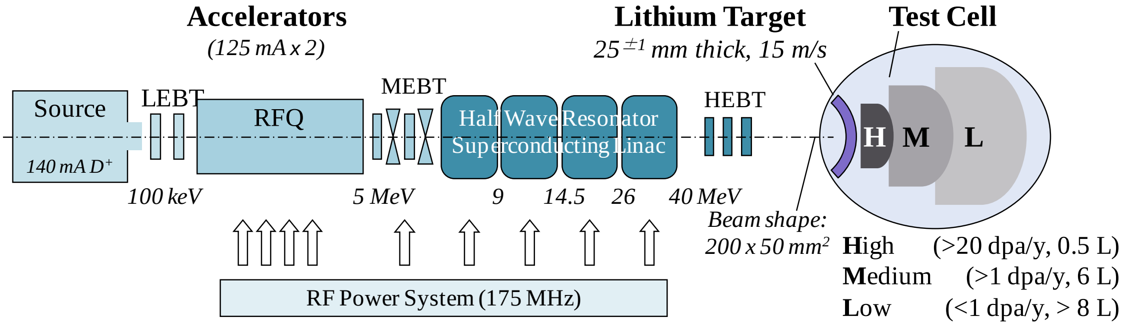

**Figure 1: Principle of IFMIF**

In the IFMIF/EVEDA project two different kinds of activities are being conducted:

- The validation of the main challenging technologies of IFMIF through the design, construction and tests of:
  - An Accelerator Prototype, fully representative of IFMIF low energy (9 MeV) accelerator (125 mA of $D^+$ beam in continuous wave)
  - A Lithium Test Loop, integrating all elements of IFMIF lithium target facility (same lithium flow of 25 mm thick at 15 m/s) and reduced width (100 mm instead of 260 mm)
  - The High Flux Test Module and its internal Rigs containing the future samples to be irradiated in a fission reactor at full scale
- The engineering design of IFMIF, with the goal to deliver all information enabling to take all decisions for its construction, operation and decommissioning (CODA)

The status of the validation activities and IFMIF design work are presented in Sections 2 and 3, respectively.

## 2. Status of the Validation Activities

### *2.1. Accelerator Prototype*

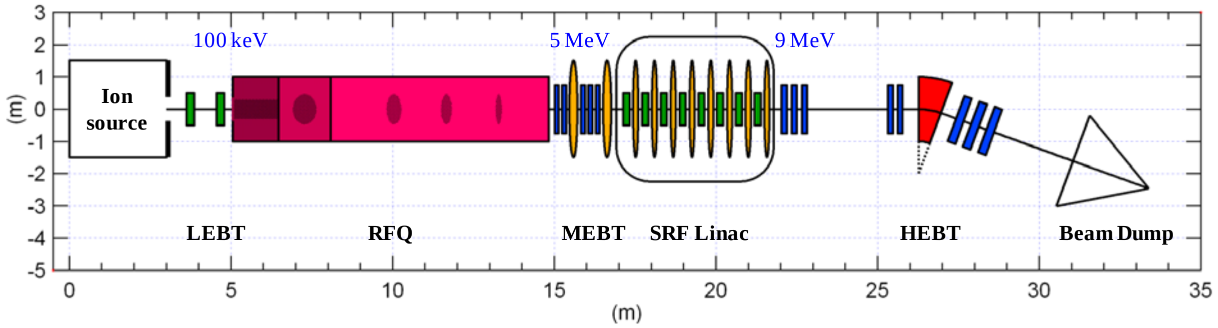

**Figure 2: Sketch of the Accelerator Prototye with successive energies of the 125 mA $D^+$ beam**

The accelerator prototype [4] of IFMIF/EVEDA project is a full scale mockup of one of two IFMIF accelerators, up to the first Half Wave Resonator Superconducting Linac module, and will generate a CW $D^+$ beam of 125 mA at 9 MeV as shown in Figure 1. The arrangement of components of the accelerator prototype in the accelerator vault in test building is schematically shown in Figure 2. All systems recalled in the sketch are now defined and some of them such as the injector, the radiofrequency quadrupole (RFQ), the radiofrequency (RF) system, are under fabrication.

See for example one of the two solenoids of the Low Energy Beam Transport (LEBT) line, part of injector and following the ion source, shown in Figure 3. This injector in now under assembly at CEA/Saclay (France) and tests will start beginning of 2011, before its transfer to Rokkasho in 2012.

**Figure 3: One solenoid of the injector under magnetic measurement**

A full scale aluminum mockup of the RFQ has been built to verify its frequency tunability and a module has been machined and successfully brazed by INFN (Italy) (see Figure 4). The required mechanical accuracy (a few tens of microns) has been confirmed after these two-step brazing.

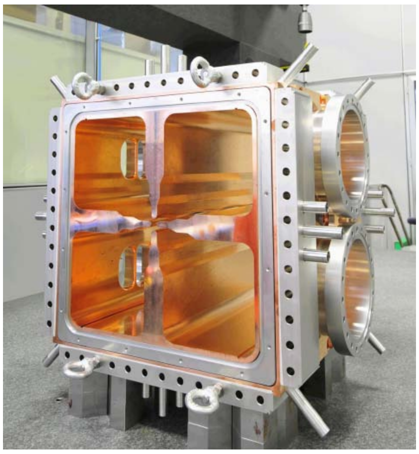

**Figure 4: One module (length about 544 mm) of the RFQ after brazing**

Two prototype half-wave cavities in niobium of the superconducting RF (SRF) linac have been manufactured in order to check their performance at 4.4 K (see Figure 5). The detailed design of the SRF Linac will be completed by first half of 2011, through a collaboration between CEA and Ciemat (Spain).

Other institutes, SCK•CEN (Belgium) and JAEA (Japan), are contributing respectively to the RF system and the RF couplers for the RFQ. JAEA is also in charge of the central Control System of the Accelerator Prototype, while the local systems are associated to their corresponding components. JAEA has completed in March 2010 the construction of the building that will host the accelerator prototype in Rokkasho and auxiliary systems (secondary water cooling loop, electrical distribution, etc) will be installed in 2011 and 2012.

Figure 5: One of the two Half-Wave Resonator prototypes ("naked" cavity) of the SRF Linac

### *2.2. EVEDA Lithium Test Loop*

The EVEDA Lithium Test (ELiTe) Loop [5] [6] [7] is in final assembly at JAEA Oarai, Japan, (see Figure 6) and its licensing (first part already successfully passed) is scheduled by end of 2010, in order to start the experiments in spring 2011, after the installation of the purification and diagnostic systems. The lithium itself (4.95 $m^3$, about 2.5 tons of Li are needed) has been also successfully qualified.

This ELiTe Loop will contain three traps for lithium purification, with the aim to reach a few 10 wppm for the main impurities (in particular oxygen, nitrogen and hydrogen isotopes):

- An oxygen trap, already installed;
- A nitrogen hot trap: proof of principle (by means of pebbles of iron/titanium) has been successfully demonstrated by the University of Tokyo, enabling the dimensioning of the trap for the ELiTe loop, and is planned to be installed before the start of experiments in April 2011;
- A hydrogen and isotopes cold trap, after successful demonstration by Kyushu University of its performance, to be installed in a later stage on the ELiTe loop.

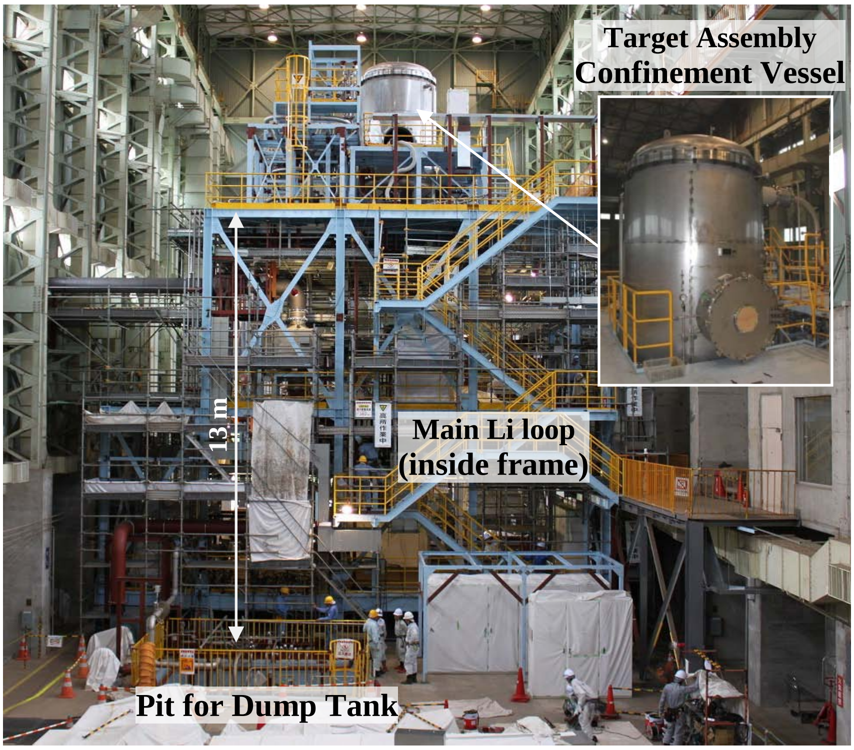

Figure 6: Front view of the EVEDA Lithium Test Loop constructed in Oarai

Diagnostics are an important part of the validation activities with a double aim:

- Scientifically qualify the lithium flow and all its characteristics (including impurities),
- Prepare for the operation of IFMIF (including interlock system) in a much more aggressive environment (neutron and gamma irradiation).

As shown in Figure 7, two types of target assemblies will be successively tested:

- An "integral concept" in stainless steel (by JAEA), already manufactured and installed in the confinement vessel,
- A more ambitious "bayonet" type backplate in reduced activation ferritic/martensitic steel (by ENEA, Italy), strongly limiting the amount of activated waste during IFMIF operation.

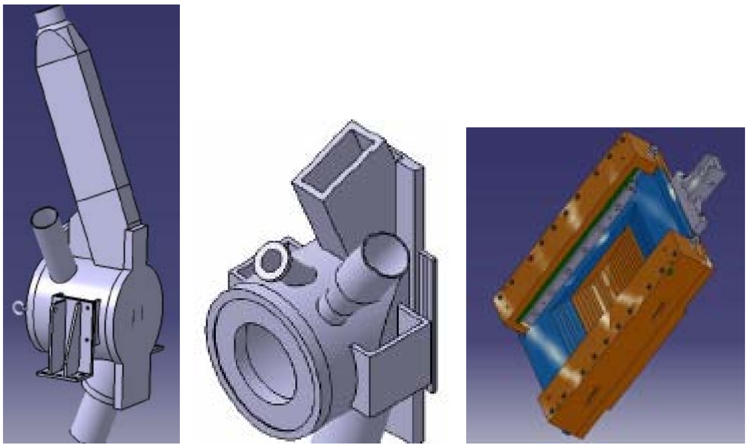

**Figure 7: Two types of Target Assemblies to be tested consecutively in the ELiTe Loop**
**Left: integral type in 316L stainless steel**
**Middle: modified target assembly in RAF/M steel to host the Bayonet backplate (right)**

The analyses of the surface wave structure have been resumed at the Osaka University, after replacement of the stainless steel nozzle by a RAF/M one and enlargement of the viewing port.

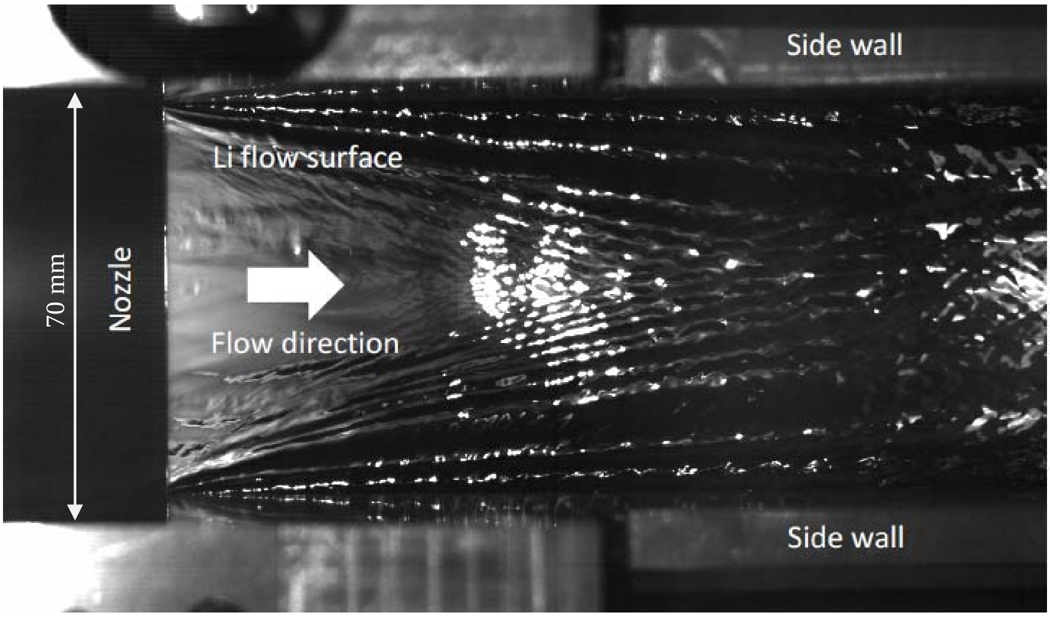

**Figure 8: Flow surface measurements after renewed geometry in Osaka University**

Figure 8 shows a photo taken by a high speed camera, the lithium flowing at a speed of 9 m/s. The flow has been dramatically improved with respect to the one generated by the old stainless steel nozzle, eroded after only several thousand hours of operation.

### *2.3. High Flux Test Modules*

A full scale prototype of High Flux Test Module (HFTM) [8] will be manufactured in order to test its thermohydraulic properties in the helium loop now completed in KIT (Germany) (see Figure 9). The nominal parameters are: inlet pressure of 0.3 MPa at 50 °C. The HFTM in its baseline design (triplets of vertical rigs filled with NaK) is shown in Figure 10.

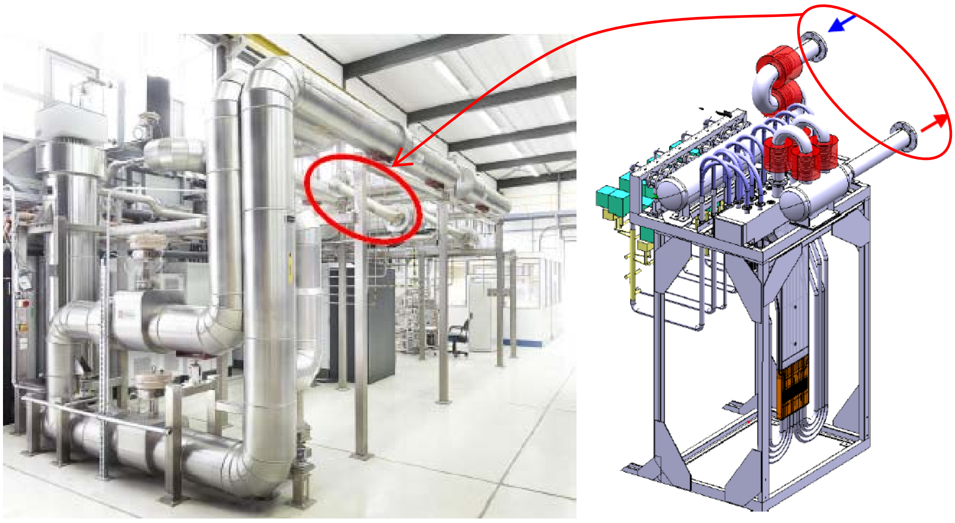

**Figure 9: Helium Loop (HELOKA-LP) in Karlsruhe (left) ready to test a full scale mockup of the High Flux Test Module (right)**

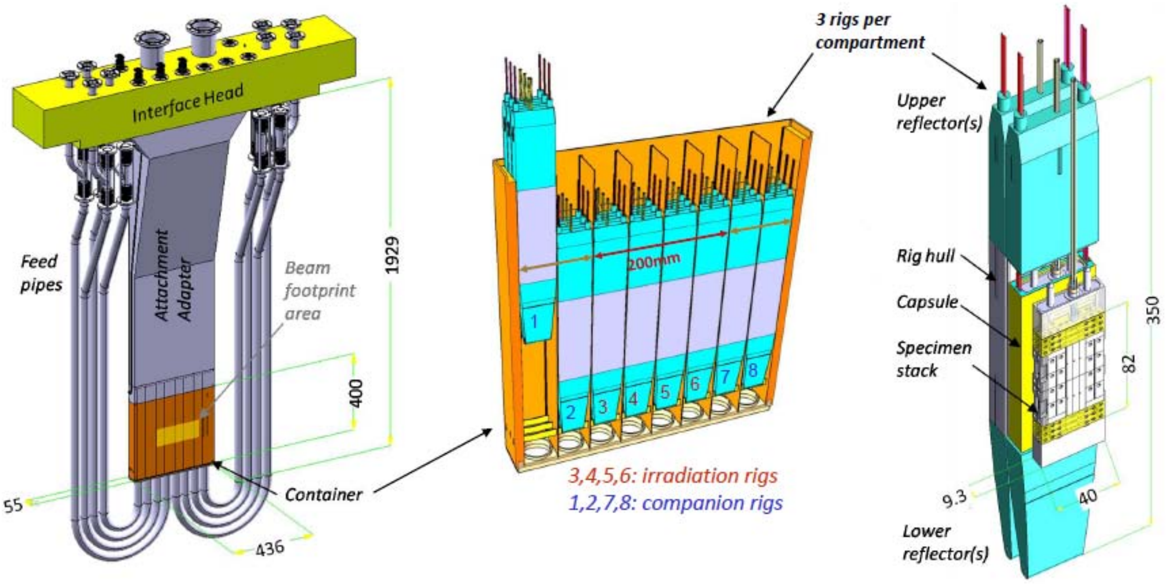

**Figure 10: Detailed structure of the High Flux Test Module Left: Whole assembly Middle: Core module part with 8 compartments of helium flow channels Right: Rigs containing test specimens**

Three HFTM capsules with heaters and thermocouples are under manufacture and will be irradiated from mid 2011 on in the BR2 reactor at Mol, contribution from SCK•CEN. This irradiation program also includes heater-plate used as an alternative design of the HFTM, under development at the Kyushu University (Japan) and two miniaturized fission chambers, already prequalified.

Engineering design work is also being conducted on the Medium Flux Test Modules with the definition of a Creep Fatigue Test Module by CRPP (Switzerland) and of a Tritium Release Test Module jointly by KIT and Ciemat. Conceptual activities on a Liquid Breeder Validation Module (Ciemat), and more recently Low Flux Test Module(s) and Startup Monitoring Module (SCK•CEN) are also ongoing.

As a supporting activity to design study, under JAEA coordination, Tohoku and Kyoto Universities, Hachinohe Institute of Technology, Kyoto and Tohoku Universities have progressed respectively on fatigue, crack growth rate and fracture toughness miniaturized samples, using the Small Sample Test Technique (SSTT).

## 3. Status of the Engineering Design Activities

With respect to the IFMIF Engineering Design Activities, the following developments will be conducted to achieve the required level of engineering design for IFMIF:

- **Feasibility phase**: establish a complete, coherent and achievable set of requirements for IFMIF, prepared to enable a proper communication with the users community. In 2010 the Specification Working Group, in charge of the definition of IFMIF top level specifications, delivered a report, “IFMIF Users Specifications and Proposals”, by extending the description summarized in the Comprehensive Design Report (CDR) [9]. The “Outline Design Report”, summarizing the referential design and including all major evolutions with respect to the CDR, is also necessary to prepare and maintain the new baseline.
- **Definition phase**: the definition report is the main outcome of the starting phase of engineering design; the Engineering Design and Integration group of the Project Team defines, coordinates and monitors all engineering activities performed in all contributing Institutes. The milestone at the end of this phase will be the Preliminary Design Review.
- **Development phase**: production of the Engineering Design Report of IFMIF plant, as the final goal of engineering design activities. Because of the resources limitation in the contributing institutes, a preliminary report will be delivered at the end of the current phase. This report shall be completed in a further phase. Site adaptations will also be necessary, when the IFMIF construction site is known. Feedback of the Accelerator Prototype experiments shall also be reflected in the IFMIF detailed design.

Mid 2010 all deliverables of the Engineering Design Activities have been defined and the responsibility of each contributing institute/organization has been also agreed. The definition of engineering processes, the coordination at the plant level and the definition of conventional facilities are covered by the Project Team, while the coordination at the facilities level and their detailed designs are conducted in both European and Japanese Home Teams:

- Europe mainly conducts design activities for the Accelerator Facility and Test Facility;
- Japan mainly conducts design activities for the Lithium Target Facility and the Post Irradiation Examination (PIE) Facility;
- The Project Team in Rokkasho mainly conducts the overall integration and design activities for the Conventional Facilities (building, HVAC, electrical system, water cooling, etc).

The Plant Integration Document (PID) is the main tool used to define the plant and coordinate interface management. The main milestones of the IFMIF Engineering Design Activities are:

- End 2010: end of feasibility phase to initiate work packages of EDAs
- Mid 2012: end of facilities definition phase; delivery of a Preliminary Design Report
- Mid 2013: completion of definition phase at plant level and development phase at facilities level; delivery of an Engineering Design Report

## 4. Conclusions

After three years the project is entering into a transition step from the preparatory and confirmation stage to genuine engineering and validation stage. The validation activities are scheduled to be completed within the next three years except for the accelerator prototype, which will need further 2-3 years. The engineering design of IFMIF, more recently launched as an overall collaborative effort, will reflect the results of these programs, so that the main part of the design will be provided by mid 2013. The engineering design activities will have to be continued beyond that date, in particular to adapt the design according to the specific site that will be chosen for IFMIF construction and include additional information from accelerator prototype tests.

## Acknowledgement

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