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Overview of the IFMIF test facility

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Abstract

During the past few years, a reference design has been developed for the International Fusion Materials Irradiation Facility (IFMIF). According to the mission and specification of the general requirements, this reference design includes relevant machine parameters and conceptual designs for the major device subsystems – Test Facilities, Lithium Target Facilities and Accelerator Facilities. Major engineering efforts have been undertaken to establish a test cell design that follows closely the users requirements of the fusion materials community and allows safe and completely remote controlled handling. After a short description of the facility requirements, concepts for the two independent test cells, various test assemblies, remote handling equipment and hot cell facilities are presented.

1. Introduction

There is a global consensus among materials scientists and engineers that the qualification of materials in an appropriate test environment is inevitable for design, construction and safe operation of advanced fusion reactors like DEMO, at least as long as the D–T reaction remains the basic approach in the fusion energy strategy. To test and qualify candidate materials up to the expected doses of fusion power reactors, a high flux neutron source with a suitable energy spectrum and sufficient test volume has to be built and operated. An evaluation process based on a series of technical workshops came to the conclusion that an accelerator driven D–Li stripping source would be the best choice to fulfill the requirements within a realistic time frame. In response to this need an IEA coordinated Conceptual Design Activity (CDA) phase of the International Fusion Materials Irradiation Facility (IFMIF) was started in 1994 and finished at the end of 1996.

The reference design [1] that has been developed during this CDA phase and beyond is based on two major considerations: (i) to fulfill the requirements [1,2] of the fusion materials community, and (ii) to use components with proven technologies in order to minimize the R&D efforts, the lead time and the technological risks. As described in more detail in Refs. [1,3], the IFMIF project is organized into five subsystems: (1) Test Facilities which expose, handle and examine specimens, (2) Accelerator Facilities which produce accelerated deuterons, (3) Target Facilities which produce a flowing lithium jet to convert the deuterons into neutrons, (4) Conventional Facilities, and (5) Central Control System and Common Instrumentation. The following is a review of the Test Facility design being developed to irradiate a variety of different materials and samples under appropriate conditions and to perform all post-irradiation analyses in hot cells at the IFMIF site.

2. Main test facility requirements

As described in more detail in Refs. [1,2], the IFMIF test cell and specimen testing areas must be capable of

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accommodating the wide range of environments associated with fusion reactor materials. According to these materials testing needs, the irradiation volume adjacent downstream from the neutron producing Li-target has been partitioned into a high flux region with a displacement damage accumulation of about 20–50 dpa/ full power year (fpy) and an available volume of 0.5 l, a medium flux region (1–20 dpa/fpy, 6 l), a low flux region (0.1–1 dpa/fpy, 7.5 l) and a very low flux region (<0.1 dpa, >100 l). All test modules used for the different flux zones have to be instrumented and be able to control the irradiation temperature that might vary from 250°C to 1000°C in the high and medium flux regions down to cryogenic temperatures in the low and very low flux zones.

Hot Cells will be necessary for the remote-controlled timely insertion and removal of the various irradiation modules, periodic maintenance of activated or contaminated devices, and complete post-irradiation examination (PIE) of all irradiated specimens and mock-ups. The post-irradiation examination area and its test equipment at the IFMIF site should be able to establish all relevant data for a fusion energy engineering database for the irradiated classes of materials within a sufficiently short time. The design should be as flexible as possible to provide access for the introduction of new materials or irradiation loading conditions. Because the test cell interior is highly activated by the irradiation, advanced remote handling technologies are inevitably required. To meet essential safety criteria and maintainability features that are consistent with the mission reliability and operational availability, the design principles shall also include simplicity, fail-safe and fault-tolerant design, structural integrity, redundancy, and testability. A more detailed description together with additional requirements is given in Ref. [1].

3. Facility configuration

The elevation view of the IFMIF Test Facilities is shown in Fig. 1. To significantly increase flexibility and redundancy, two nearly identically equipped test cells lying side by side are foreseen. In the test cell, the two 40 MeV deuteron beams with 2×125 mA beam current strike a single flowing lithium jet with a 20° impinging angle producing neutrons mainly in the forward direction. Directly above both test cells, the access cell houses the equipment for all remote handling manipulations in either test cell. The service cell, excluded from view in Fig. 1, and the test module handling cell are primarily necessary for disassembly and reassembly of specimens, specimen capsules, test modules and related maintenance operations. As already mentioned, the present design concept implies that after disassembling all irradiated specimens and materials of interest, they will be investigated in suitable PIE facilities. It is important to note that in the present design concept these facilities include conventional hot cell equipment as well as a tritium laboratory with integrated tritium processing systems. Various analyses and design layouts of the Test Facility configuration are described in more detail in Ref. [4].

3.1. Test cell

As shown in Fig. 2, the IFMIF test cell contains (1) two vertically oriented test assemblies, referred to as

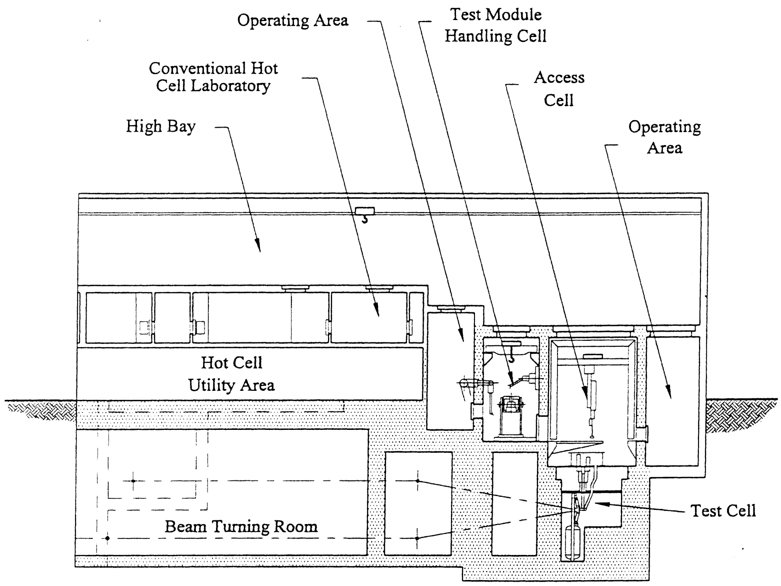

Fig. 1. Elevation view of the Test Facilities.

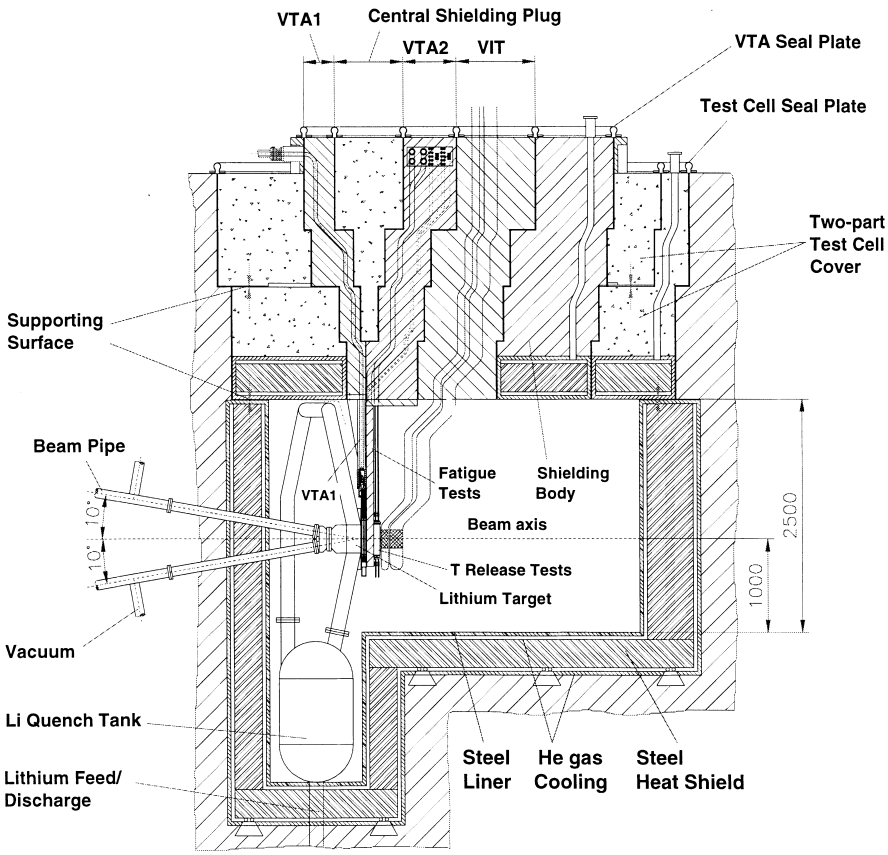

Fig. 2. Elevation view of the test cell arrangement with a stainless steel heat shield (all dimensions in mm).

Vertical Test Assemblies (VTAs) 1 and 2, which support the test modules used for long-term irradiation of specimens in the high and medium flux regions, (2) an array of tubes, referred to as Vertical Irradiation Tubes (VITs), used for inserting test capsules in the low and very low flux regions, (3) a vacuum liner that encloses the test modules and also accommodates the lithium target, which is the source of the high-energy neutrons, (4) a neutron shielding system that is gas-cooled to prevent overheating of the concrete, (5) the test cell removable cover, which can be removed with a universal robot system to gain access to the entire test cell, and (6) a seal plate for providing a vacuum seal (10^{-1} Pa) between the removable VTAs and the removable cover. Each of the test assemblies incorporates a set of test specimens, the primary cooling system for these specimens, and sensors used to monitor and control the irradiation environment.

A specific feature of the IFMIF design is, that the lithium target and all VTAs will be accommodated in one common test cell chamber without any barrier between the lithium target backwall and the high flux VTA. The test cell has a steel liner constructed from a low activation steel which also serves as a vacuum vessel for the confinement of radioactive material. This robust primary test cell pressure vessel provides accident protection to about 0.5 MPa absolute and allows for relatively easy cleaning of any liquid metal spills. The secondary test cell confinement is at least 2.2 m of massive concrete. Several advantages are combined by having a common test cell: (i) the produced activity is concentrated in the lowest possible volume, (ii) the common test cell without barrier improves the Li-target access and allows maximum usage of the high-flux test volume, and (iii) the common vacuum environment (10^{-1} Pa) serves several safety requirements.

In spite of these safety features, active systems will play a significant role in the actual operation of IFMIF. Among the active systems are heating, ventilation and air conditioning, detritiation, gamma monitoring, plant protection and emergency power supply as well as the argon backfill system for the test cell and redundant coolant supply for the removal of decay heat from the test modules after long-term irradiation and in off-normal events.

In order to cool the concrete shielding surrounding the test cell, two approaches have been developed. One approach uses a separate stainless steel heat shield between 300 and 500 mm thickness that is placed between the liner and the concrete. Active cooling using gaseous helium is provided between the test cell heat shield, the concrete shielding and the test cell liner (Fig. 2). The alternate approach for maintaining the concrete shielding at acceptable temperature levels utilizes an array of helium gas coolant passages embedded up to 1 m in the concrete shielding.

The test cell removable cover having a thickness of 2.2 m is positioned along the top of the test cell. Because of their large volume, the lower and the upper removable covers are split into parts. Taking into account bracing ribs, coolant tubes, sealing surfaces and nuclear grade concrete as filler, the total weight of all pieces is 67 tons for the lower cover and 58 tons for the upper cover. The test cell removable cover interfaces with the test cell liner to provide a vacuum enclosure within the test cell. Clear access to the entire test cell is achieved by removing the test cell removable cover during major maintenance operations such as lithium target replacement. It should be emphasized that either of the VTAs can be removed or inserted without removal of this test cell cover.

The vacuum seals for each VTA and the VIT plug are located along their upper surface. The test cell seal plate mates with these surfaces and another plate on the test cell removable cover to provide a vacuum tight arrangement. The sealing plate and each VTA is removed by lifting them straight up. Once the sealing plate has been removed, the VTAs can be lifted out of the test cell and into the test cell access cell in any sequence without interfering with the remaining VTA. As calculations have shown, the dose to the seal plates is small enough to allow the use of organic vacuum seals.

3.2. Vertical test assemblies

A specific feature of IFMIF is that the available irradiation volume has been consequently divided into the four different flux regions by independent test assemblies and irradiation tubes with vertical access through the test cell ceiling. Such an arrangement allows relative quick exchange and exact positioning of all test modules and specimen capsules with a minimum amount of tools and master/slave manipulators, it is cost effective and contributes to a high overall availability.

3.2.1. High flux region

For the majority of experiments with structural materials the irradiation in this flux region followed by post-irradiation investigation is the normal procedure. To avoid impurity pick-up from the coolant all seven types of samples will be encapsulated in packets. Based on such packets with miniaturized reference specimens, a detailed elaboration of test matrixes has shown [5,6], that in spite of the limited high flux volume of about 0.5 l a database up to DEMO reactor relevant damage doses can be achieved in several candidate structural materials. Therefore irradiation campaigns are foreseen in 10–20 dpa segments assuming a replacement of the high flux test assemblies during the planned out-cycles of IFMIF which would occur every 4–12 months. Conceptual designs for both NaK-cooled [1,7] and helium-cooled versions [1] of this test assembly have been developed. Although the detailed arrangement and temperature control of test specimens is quite different for these coolant schemes, the overall configuration for VTA1 is nearly identical for both coolants. The high flux VTA1 has been designed to utilize the maximum amount of the available test volume of 0.5 l, and consists basically of the test module and the shielding portion as indicated for the helium gas cooled version in Fig. 2. The shielding portion of the VTAs consists of a stepped, stainless steel liner that is filled with concrete. Steps in the test cell shield plug and removable cover conform to the steps in the shielding portion of each VTA to prevent radiation streaming. The coolant supply and return lines for the high flux module are contained within the shielding body of the VTAs.

The reference design of the NaK-cooled concept has a single module that is divided into three chambers, each of which is thermally controlled at a different temperature by a separate NaK loop. The equipment required for each coolant loop is located on top of the VTA1 and consists basically of a 5-l sump tank, a 2.5-kW cooler a 5-kW heater and a 1.7-kg/s induction pump. The NaK supply and return lines are contained within a passage that is provided in the shielding body. The three NaK cooled modules and the containing specimen packets have been dimensioned so that the maximum temperature difference between specimens and coolant remains within 20°C. While this liquid metal cooled concept can be characterized by a quite uniform temperature profile throughout the individual chambers governed by the relatively high heat capacity of NaK, the helium gas cooled test module follows a quite different concept. As outlined in more detail in Refs. [1,8], basic features of the He-cooled concept are about 30 vertically oriented rigs containing the specimen packets, and an active temperature control system that is characterized by defined gas gaps inside the individual rigs, an active ohmic heating system integrated in the specimen encapsulation and the thermohydraulic parameters of the helium gas coolant loop. Both, the NaK-cooled and the He-cooled concept are based in principle on proven technology and are able to remove the calculated [9] nuclear heating production of 30–55 W/cm^3 even at the lowest specimen temperatures of 250–300°C.

3.2.2. Medium and low flux regions

The majority of specimens made of structural materials will be irradiated in the high flux region followed by post-irradiation examination in Hot Cells. This is the usual procedure to generate a database for engineering design and fabrication. However, additional, more sophisticated experiments are necessary to measure the materials data properly under real loading conditions. Therefore, in the present reference design concept [1,4,10] the vertical test assembly VTA2 of the medium flux region is equipped with two individual test modules: (i) a module for in-situ creep-fatigue experiments housing a miniaturized universal testing machine for simultaneous testing of three independent push-pull fatigue specimens, and (ii) a module for in-situ tritium release experiments on various ceramic breeder materials. Instead of ceramic breeders, these subtest modules can also be equipped with any PIE specimens. The present reference design for VTA2 has been mainly guided by the requirements to effectively use the available volume of 6 l and to allow the simultaneous irradiation of both in-situ test modules. A variety of other instrumented experiments will be necessary at the IFMIF site [1,2]. Therefore, the vertical irradiation tube (VIT) system provides for the low and very low flux region an array of typically five tubes each. Specific features of the VIT system are individual temperatures between about 4 and 800 K, and pneumatic controlled assembly and disassembly of instrumented specimens at any time, that is, also during irradiation without shutting down the accelerator. Long term experience in a high radiation environment has been already made with a similar system at the HFIR reactor.

3.3. Access, service, and test module handling cells

The access cell (Figs. 1 and 2) is located directly above the test cells and contains the coolant loops for the VTAs and the VIT system and various remote handling equipment like telescopic master/slave manipulators and a universal robot system. The latter is the main device for routine VTA removal and reloading operations, for exact insertion of shield plugs and for all kinds of maintenance operations e.g. at the lithium target or the quench tank inside the test cell. After irradiation, the VTAs are removed and transported with the help of a transfer rail system into a large service cell, which is primarily dedicated to the assembly/disassembly of the test modules to the VTAs. This equipment is also used for maintenance work on VTAs and Li-target components. In the test module handling cell located directly adjacent to the Service Cell, rigs and packets containing the individual specimens will be removed from the test modules, and the capsules will be cut open to retrieve the specimens. Another important function of the test module handling cell is the re-capsulation of irradiated specimens for further irradiation. The irradiated specimens which have reached their target dose will be sent to the PIE facilities. All of these cells will have a steel liner and integrated through wall windows for the telescopic manipulator systems. In addition various auxiliary as well as diagnostic and control systems have been specified to achieve high reliability and to guarantee safe operation conditions [1].

3.4. Post-irradiation examination facilities

The PIE facilities dedicated to the users for qualified analyses include the conventional hot cell laboratory, the shielded glove box laboratory and the tritium laboratory.

3.4.1. PIE laboratory

Although the typical specimens irradiated in the high and medium flux regions of the Test Cell will usually be miniaturized, the activity will be sufficiently high that PIE must be performed in hot cells for high level radioactive specimens. A modular type design is being considered with a smaller maintenance room for personnel access, and a hot cell consisting of equipment tools, similar sized testing machines, and a removable exchange system with a small bridge crane and transfer lorry. The removable testing machines stand side by side in two arrays and can be rapidly replaced or exchanged to carry out service in the attached maintenance room. The bulk of the test equipment in this hot cell is dedicated to mechanical tests of specimens irradiated in the high flux region. Therefore, the PIE Hot Cell Lab includes a laser profilometry apparatus for pressurized creep tube tests and several universal testing machines equipped with vacuum furnaces and heating systems for tensile tests, push–pull creep fatigue tests, corrosion fatigue tests, and fatigue crack growth and fracture toughness tests.

3.4.2. Shielded glove box laboratory

Microstructural analyses will be indispensable to describe and understand the irradiation induced defects and their impact on materials properties. Because only very small specimens sizes are necessary for these analyses, shielded glove boxes are sufficient. According to international standards, this laboratory will be equipped with 10 bench-top glove boxes, modern scanning and transmission electron microscopes (SEM and TEM), TEM specimen preparation tools, an optical microscope, a microhardness tester, a temporary vacuum storage grid for TEM specimens, and an activation analysis system. The latter is important to confirm experimentally on low and reduced activation materials the predictions from activation inventory codes.

3.4.3. Tritium laboratory

The tritium laboratory has the capability to handle various forms of tritium contaminated materials generated in the operation of IFMIF. The capsules irradiated in the medium flux region will contain highly gamma-activated ceramic breeders with considerable tritium content. To minimize any cross contamination and to assure effective tritium retention, hot cells for tritium contaminated and containing materials are separated from that of other materials. The tritium laboratory is composed of three major subsystems: (i) the airtight tritium handling hot cells for disassembling, preparation of specimens and PIE of activated specimens, (ii) the airtight tritium glove boxes to analyze small pieces or low activated ceramic breeders, and (iii) the tritium processing systems based on technologies developed in modern tritium facilities with removal/retention systems and a temporary storage system for tritium contaminated specimens and devices. Detailed layouts have been developed [1] for tritium processing systems with effective detritiation and effluent tritium removal subsystems. In the present design, approximately 20 m^3/h tritiated gas and 1000 Ci/day can be processed.

4. Conclusions

During the past few years detailed conceptual designs have been developed for all subsystems of the Test Facilities, showing that in accordance with the mission of IFMIF, all major user requirements can be fulfilled. In order to meet several safety and reliability requirements, the neutron generating Lithium target and all irradiation modules are accommodated in a vacuum chamber with an area of 3 m $\times$ 4 m and a height of 2.5 m. Two VTAs and one VIT system are provided in each test cell as test beds for instrumented and/or in situ experiments that can be done for any loading regime from 50 to 0.01 dpa/fpy. This concept maintains a high degree of flexibility with respect to any future needs.

An access cell, a service cell and a test module handling cell are foreseen to assemble and disassemble test modules to the VTAs, and to cut open the capsules in order to retrieve the irradiated specimens. The present design concept implies that after disassembling all irradiated specimens and materials of interest, they will be investigated in PIE facilities at the IFMIF site. Major engineering efforts have been undertaken to conduct any maintenance and assembling/disassembling activities with a completely remote control maintenance system, to achieve a high reliability and to design the test facilities according to modern safety standards.

References

[1] M. Martone (Ed.), IFMIF international fusion materials irradiation facility, conceptual design activity, Final Report, IFMIF CDA TEAM, ENEA Frascati Report, RT/ERG/FUS/) 96/11, 1996.
[2] K. Noda, E. Ehrlich, S. Jitsukawa, A. Möslang, S. Zinkle, these Proceedings.
[3] T. Shannon, M. Rennich, H.J. Jameson, H. Katsuta, H. Maekawa, M. Martone, A. Möslang, these Proceedings.
[4] A. Möslang, R. Lindau (Eds.), Proceedings of the IEA Technical Workshop on the Test Cell System for IFMIF, Karlsruhe, FZKA Report 5633, 1995.
[5] S. Jitsukawa, ibid, pp. 131–156.
[6] S. Zinkle, ibid, pp. 157–185.
[7] J.R. Haines, S.J. Zinkle, D.M. Williams, Proceedings of the 16th IEEE Symposium on Fusion Engineering, Champaign, Illinois, 1995.
[8] J. Haines, S. Jitsukawa, A. Möslang, K. Noda, R. Viola, S. Zinkle, these Proceedings.
[9] E. Daum, P.H. Wilson, K. Ehrlich, U. Fischer, these Proceedings.
[10] A. Möslang, R. Lindau (Eds.), Proceedings of the IEA-Technical Workshop on the IFMIF Test Facilities, Karlsruhe, FZKA Report 5993, 1997.