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Present status of the conceptual design of IFMIF target facility

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Abstract

The Conceptual Design Activity (CDA) for the International Fusion Materials Irradiation Facility (IFMIF) has been conducted. For the IFMIF Target Facility, the conceptual designs of the following two main components have been performed. The design concept of IFMIF utilizes a high energy deuteron beam of 30–40 MeV and total current of 250 mA, impinging on a flowing lithium jet to produce high energy neutrons for irradiation of candidate fusion materials. (1) *The target assembly*: The kinetic energy of the deuteron beam is deposited on a Li-jet target and neutrons are produced through the d–Li stripping reaction in this target. The assembly is designed to get a stable lithium jet and to prevent the onset of lithium boiling. For 40-MeV deuteron beam (total current of 250 mA) and a beam footprint of 5×20 cm^2 lithium jet dimensions are designed to be 2.5 cm thick and 26 cm wide. The lithium jet parameters are given. (2) *Lithium loop*: The loop circulates the lithium to and from the target assembly and removes the heat deposited by the deuteron beam containing systems for maintaining the high purity of the lithium required for radiological safety and to minimize corrosion. The maximum lithium flow rate is 130 l/s and the total lithium inventory is about 21 m^3. The IFMIF policy requires that the lithium loop system be designed to guarantee no combustion of lithium in the event of a lithium leak. This can be achieved by use of multiple confinement of the lithium carrying components. The radioactive waste generated by the Target Facilities is estimated. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

The Conceptual Design of the lithium Target Facility has been developed for the International Fusion Materials Irradiation Facility (IFMIF) through the IEA fusion materials cooperative works. The interim and final reports of IFMIF-conceptual design has been published in 1995 and 1996, respectively. An outline design of the target facility owing to the interim report has been published in 1996 [1]. This report is prepared based on the final report of the IFMIF-conceptual design [2]. The design concept of IFMIF utilizes a high energy deuteron beam of 30–40 MeV and total current of 250 mA, impinging on a flowing lithium jet to produce high energy neutrons for irradiation of candidate fusion materials. The target facility design has evolved and benefited from previous activities of similar purposes: the FMIT project (1975–1985) [3] at the Hanford Engineering Development Laboratory and the Energy Selective Neutron Irradiation Test Facility (ESNIT) (1987–1994) [4] at the Japan Atomic Energy Research Institute. The Target Facility will be designed to meet all applicable safety guidelines and quality assurance standards.

2. Target facility

The lithium target may be divided into two basic components. The first is the target assembly itself, which

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must present a stable lithium jet to the beam, where the kinetic energy of the deuteron beam is deposited and neutrons are produced. The second is the lithium loop which circulates the lithium to and from the target assembly and removes the heat deposited by the deuteron beam. This loop also contains systems for maintaining the high purity of the lithium required for radiological safety and to minimize corrosion of the loop structure by the hot flowing lithium. A single lithium loop provides flow to either of the target assemblies in the two Test Cells. A maximum 10% flow is provided to the inoperative target for decay heat removal.

2.1. Target assembly

The target assembly, shown in Fig. 1, consists of a 20 cm ID inlet pipe, a transition component from inlet pipe to a flow straightener, a nozzle, a replaceable backwall, a downstream diffuser with built-in drain baffles, a vacuum port for connection to the deuteron beam tube, and instrumentation station on the vacuum port. The Target Facility shall provide a stable lithium jet in the target

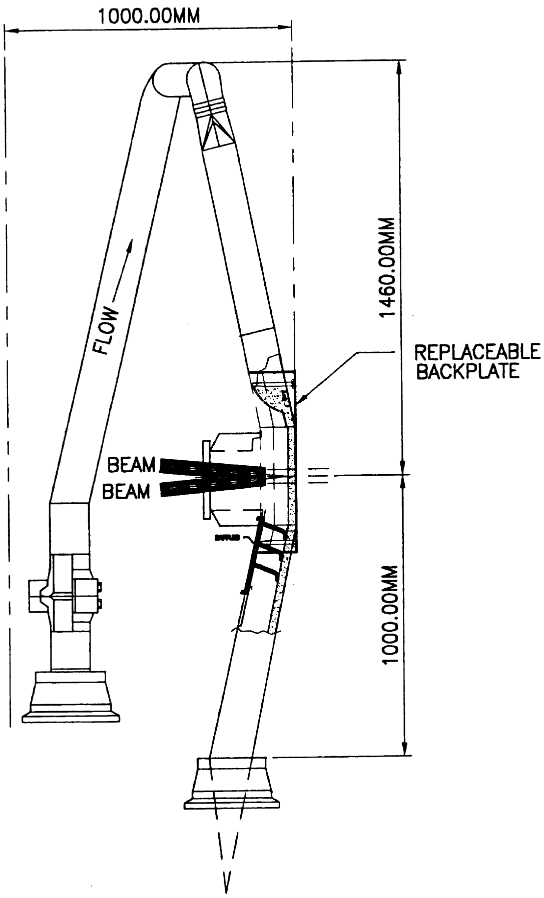

Fig. 1. Replaceble backwall lithium target assembly.

assembly for: (1) reactions with the deuteron beam to produce high energy neutrons for irradiation of materials and (2) removal of up to 10 MW of beam power. For 40-MeV deuteron beam and a beam footprint of 5×20 cm^2, the nozzle lip dimensions, (i.e., jet dimensions) will be 2.5 cm thick and 26 cm wide. Because of nuclear heating by backscattered neutrons, permanent target structure surrounding the beam footprint will be cooled separately on the outside by routing a small lithium stream from the inlet pipe. A flat backwall and a curved backwall are designed. The advantage of the flat backwall is ease of fabrication and installation for the replacement, on the other hand in the curved backwall the curvature stabilize the lithium jet flow and also to prevent the boiling at the peak temperature in the jet flow by producing the centrifugal pressure. The shape and dimension of the flow straightner (or flow reducer), nozzle, backwall curvature, and downstream diffuser will be tested in laboratories using water initially, and lithium in subsequent mockup experiment. Thermal and fluid dynamic analysis for lithium jet flow of the IFMIF target have been done and reported elsewhere [5]. The lithium jet parameters are depicted in Table 1. IFMIF shall have two test cells for optional alternate operation and simultaneous operation in future expansive use. There will be tow phases of operation. In the first phase (<2 yr), each campaign will last approximately three months. At the conclusion of a three month campaign, the beam and lithium loop will be switched to the second target assembly/test cell for the next campaign. These early campaigns are aimed at confirmation of the baseline target design and performance characterization of optional targets, as well as test assembly structures. In the second phase, each campaign is required to last approximately nine months with no change-out of backwall or target assembly.

A preliminary neutronic analysis was performed to determine the nuclear heating deposition and generation in the backwall and the High Energy Beam Transport (HEBT). Nuclear heating during normal operation as well as decay heat generation were analyzed [6]. Although the total heat deposition in the HEBT was found to be small, about 1.5 kW, separate cooling of this component will be necessary. This can be accomplished

Table 1
Lithium jet parameters

Jet thickness, m	0.025 (for 40 MeV D^+) [a]
Jet width, m	0.26
Jet velocity, m/s	15 (range 10–20)
Inlet temperature, °C	250
Outlet temperature, °C	300 (for 15 m/s)
Surface temperature, °C	290 (for 15 m/s)
Peak temperature, °C	450 (for 15 m/s)

[a] Jet thickness (m) for 36 MeV D^+ and 32 MeV D^+ are: 0.022 (for 36 MeV D^+) and 0.019 (for 32 MeV D^+).

by diverting a small stream of lithium coolant (about 15 cm^2/s) from the main flow to the external coolant tubes around the HEBT. Decay heat generated in the backwall can be removed by a few percent of normal flow after beam shutdown. In the case of a loop failure and loss of flow, argon gas will be circulated through the test cell to remove the decay heat actively in the target assembly.

2.2. Environments of the target chamber and target assembly/test cell

A vacuum condition of 10^{-3} Pa will be maintained in front of the lithium jet in the target chamber (accelerator interface). This vacuum condition is considered optimal to minimize or suppress lithium evaporation from the jet surface, jet will not have any significant interface with the deuteron beam. Target assembly/test cell environment requirements are dependent on a specific target design. Currently, the baseline target design is a modified FMIT-type target with a replaceable backwall. Two options are: (1) a scale-up of the original FMIT-type target and (2) a free jet target. Detailed description of the target design is presented in Ref. [2]. The requirements of target assembly/test cell environment are as follows:

- Vacuum condition of $\sim 10^{-1}$ Pa for the baseline design with a replaceable backwall.
- Vacuum condition of $\sim 10^{1}$–10^{3} Pa for the FMIT-type target. An alternative is to maintain a low-pressure inert gas (10^4, He or Ar).

2.3. Target assembly lifetime

For the replaceable backwall and the free jet targets, the target assembly with the exception of the replaceable backwall, will be designed to withstand neutron damage for a potential lifetime of 20 yr. To minimize the effect of neutron damage, permanent structure of the target assembly will be at least 10 cm from the edges of the beam footprint. However, possible nozzle erosion, detectable through degradation of jet stability, may shorten the lifetime goal.

The replaceable backwall for the baseline target assembly and the target assembly for the optional FMIT-type target will be designed for a lifetime of approximate nine months.

3. Lithium loop

A flow diagram of the lithium loop is shown in Fig. 2. The loop may be conveniently divided into three basic functionary systems such as the main loop, lithium purification system sub-loop and impurity monitoring sub-loop. The detailed conceptual designs of the loop systems are reported in Ref. [1] and this conference [7].

4. Safety concept and analysis

4.1. Description of hazard

The following potential environment, safety and health hazards associated with the operation of the IFMIF target lithium system have been identified:

4.1.1. Lithium liquid metal

The IFMIF lithium system contains approximately 21 000 l of liquid lithium. The approximate dimensions and lithium volumes in the loop components have been shown in Table 2.

Lithium is an alkali metal and is the lightest and least reactive of the alkali metal family. The melting point is 180.6°C. Solid Li does not burn spontaneously in air, but liquid Li is (very) reactive with air, water, concrete, carbon dioxide, and nitrogen. In Li/water reaction, most of the hydrogen is bound to the liquid metal as LiH. The hydride is decomposed when temperature exceeds 600°C. Hydrogen release in air is very dangerous; it can be explosively ignited, causing harms to the surrounding objects and personnel. To eliminate the probability of lithium combustion in the event of a lithium leak, a triple confinement scheme with argon atmosphere has been adopted, as described in Section 4.2.

A very large database of experience exists for alkali metal loop systems, particularly sodium from the LMFBR experience. Much of this experience in loop design and component performance has been utilized in the design of the IFMIF lithium loop.

A more limited but significant experience base exists for lithium systems, particularly from work performed for FMIT. Several small lithium loops, of capacity less than 100 l, were/are being operated at Argonne National Laboratory, Westinghouse, the University of Colorado, the Tokyo Institute of Technology, the Osaka University and the ENEA Brasimone. The primary objectives of these loops are to investigate material compatibility and liquid metal magnetohydrodynamic effects. In addition, a large FMIT prototypical loop was operated successfully at Westinghouse Hanford for over 14 000 h, under both argon cover gas and vacuum conditions. The loop piping and components were also similar in scale to that of IFMIF. No new safety related issues are expected to arise from the difference in scale. More recently, Argonne National Laboratory has been operating the ALEX facility, a 400-l capacity lithium loop, for the past two years in support of ITER advanced blanket development and DEMO self-cooled blanket development.

4.1.2. Radioactive materials

The two most hazardous radioactive materials related to the Target System are tritium and beryllium-7 orinating from d–Li reaction. IFMIF based on 75% duty factor will produce approximately 10 g/yr of tritium and

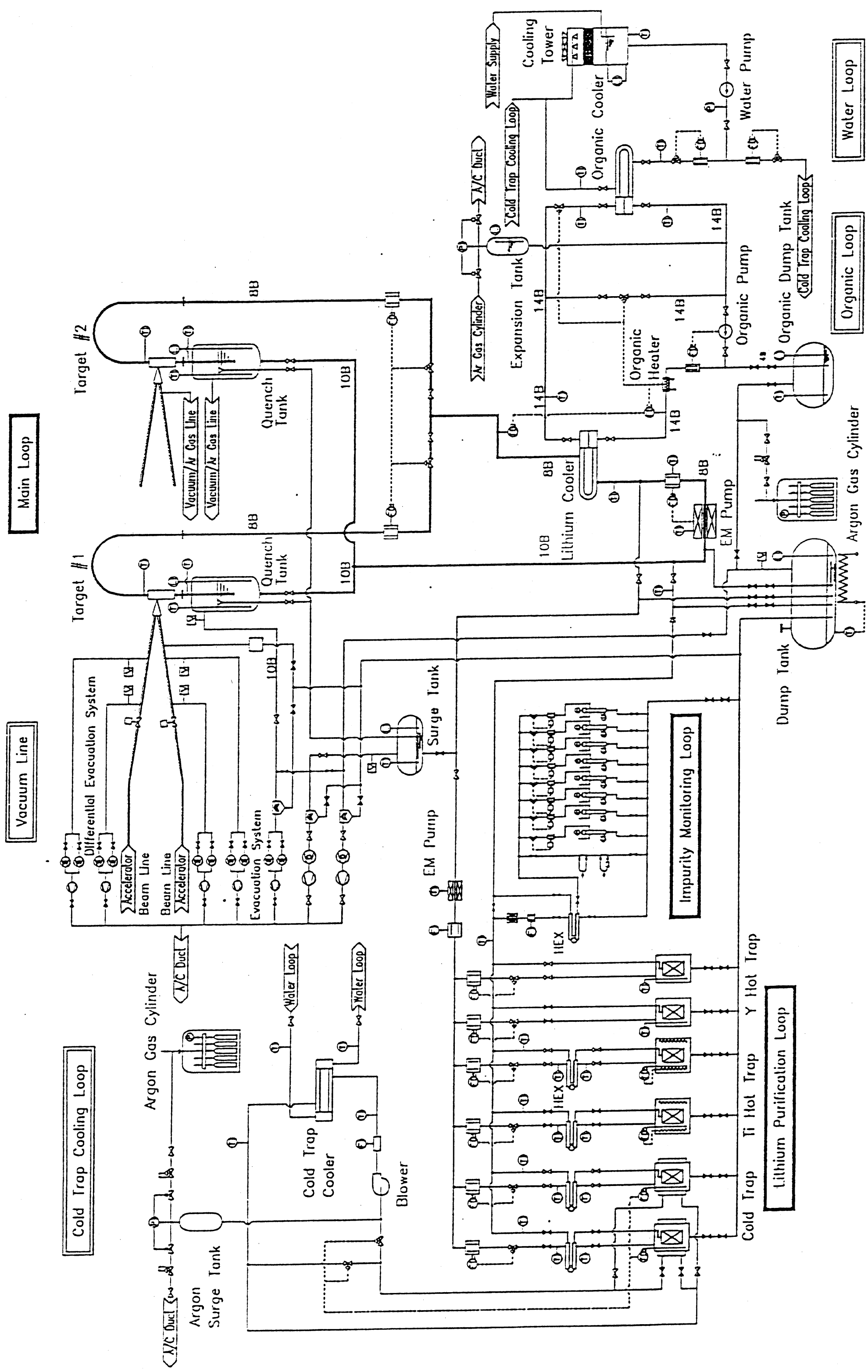

Fig. 2. Flow diagram of lithium loop facility.

Table 2
Approximate main loop component dimensions and lithium volumes

Loop system	Component	Lithium inventory (L)	Dimensions (m) Diam. × Length
Main loop	Target assembly	210 × 2	
	Quench tank	2250 × 2	1.2 × 3.1
	Surge tank	500	0.8 × 2.6
	EMP	230	
	Heat exchanger	4360	1.7 × 7.2
	Piping	4520	0.20 & 0.25 diam.
Purification	Cold trap	440 × 2	0.77 × 1.7
	Yttrium hot trap	110 × 2	0.45 × 0.8
	Titanium hot trap	330 × 2	0.85 × 1.3
	Economizer (cold trap)	30 × 2	
	Economizer (Ti hot trap)	100 × 2	
	Piping	50	0.01 & 0.02 diam.
Drain	Dump tank	4000	2.4 × 6.2
	Piping	160	0.1 diam.
	Total	20 680	

the equilibrium inventory of beryllium-7 (half life is 53 days) is about 0.3 g. Under normal operating conditions, a few grams (~3–5 g) of this tritium is confined in the loop components and the remainder of the tritium will be accumulated in the cold or hot trap. The frequency with which the trap will be regenerated, and the tritium removed for disposal, will depend upon subsequent detailed accident analyses, and local licensing restrictions. It is anticipated that cold trapping would reduce the circulating concentration of beryllium-7 by two orders of magnitude, so that under normal operating conditions the cold trap would contain most of the inventory of Be-7. Impurity control system in the IFMIF lithium loop is also reported in this conference [7].

4.2. Lithium loop hazard prevention plan

The potential hazard associated with the large quantity of lithium and radionuclides contained in the liquid metal described in Section 4.1. Lithium leaks must be assumed during the loop lifetime, resulting in a possible lithium fire through lithium/air reactions. Due to radiation concerns, personal access to the lithium cell is prohibited during operation, therefore manual fire extinguishing may not be timely and effective for preventing propagation following an initial fire. Lithium fire is also accompanied by the release of tritium and Be-7 in the forms of lithium aerosol. Therefore the IFMIF policy requires that the lithium loop system be designed to guarantee no combustion of lithium in the event of a lithium leak. This can be achieved by use of multiple confinement of lithium carrying components combined with an oxygen monitored and controlled argon gas atmosphere.

The primary confinement is the lithium carrying components such as pipes, tanks, heat exchanger, hot and cold traps. A simple sheet metal structure, referred to as a guard vessel, surrounding the primary confinement constitutes the secondary confinement. The guard vessel is not required to provide a high degree of gas tightness. The space between the primary and secondary confinement is filled with an argon gas which is circulated at a low flow rate for impurity monitoring and control.

The tertiary confinement is the lithium cell. The cell is air-tight and maintained under argon atmosphere at a slight positive pressure. It is equipped with oxygen meters to monitor the oxygen concentration. The floor and the wall are covered with steel liner to prevent lithium concrete reactions. Any lithium spill that fails to be contained within the secondary confinement will immediately freeze and never ignite.

4.3. Radioactive waste

The radioactive waste generated by the Target Facilities consists of solid, liquid, and gaseous waste. Solid waste includes: (1) the replaceable backwall which is designed for annual replacement; (2) the target assembly which is replaced once every 10 yr; and (3) the cold trap replaced annually. During the backwall replacement process, alcohol or other cleaning solvents will be used for cleaning the area of the target assembly where attachment of a new backwall will be performed. The cleaning solvent is treated and disposed of as a liquid radioactive waste. Gaseous waste consists of the small amount of tritium present in the vacuum exhaust of the target chamber. Tritium appears in the form of LiT aerosol originated from the Li evaporated jet free

Table 3
Radioactive waste of target system

		FREQUENCY	AMOUNT	REMARKS
Solid	Replaceable backwall	1/yr	30–60 kg	
	Target assembly	1/10 yr	600 kg	
	Cold trap with swamping/yttrium hot trap without swamping	1/yr	1200 kg/270 kg	Mesh volume 153 l/Y getter 35 l
Liquid	Alcohol or cleaning solvent	1/yr	10 l	For cleaning the permanent target assembly structure before installing a new back plate
Gaseous	Tritium in beam tube	–	0.25 μg/yr	Based on the amount of Li evaporated from the Li free surface as LiT aerosols

surface. Table 3 summarizes the amount of waste of the target system.

5. Conclusion

Detailed conceptual designs have been developed for all subsystems of the IFMIF Target Facilities. In order to meet several safety and reliability requirements, environments of the target chamber and target assembly, hazard of liquid lithium and radioactive waste are analyzed. The multiple confinement system is proposed for the lithium loop hazard prevention plan.

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