Nuclear Materials and Energy 17 (2018) 15–23

Contents lists available at ScienceDirect

Nuclear Materials and Energy

journal homepage: www.elsevier.com/locate/nme

The design and thermo-structural analysis of target assembly for high intensity neutron source

E. Wakai[a,*], K. Watanabe[b], H. Kondo[c], F. Groeschel[d]

[a] Japan Atomic Energy Agency, Tokai-mura, 319-1195, Japan
[b] Research Organization for Information Science and Technology, Kobe 650-0047 Japan
[c] National Institutes for Quantum and Radiological Science and Technology, Naka 311-0193 Japan
[d] Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

ARTICLE INFO

Keywords:
High intensity neutron source
Target assembly
Thermo-structural analysis
Li target
IFMIF
F82H

ABSTRACT

The engineering design of an integrated target assembly of IFMIF lithium target was performed in IFMIF/EVEDA project for a high intensity neutron source. In the evaluation of the design, a thermos-structural analysis of was evaluated by ABAQUS code, and the modeling region was a part of the target assembly which was from the inlet nozzle to the outlet pipe. The material of the target assembly including the back plate was F82H steel. In the thermal-structural analysis, the normal operations and start/stop or abnormal operations were evaluated at 250 or 300 °C operation of Li flow in inlet pipe. The result showed that the temperature of the target assembly was evaluated to be still lower than the Li boiling point of 344 °C under a vacuum pressure of 10^{-3} Pa. In a temperature constant operation, the calculated stresses and displacements were small enough for thermal soundness of the target assembly in steady states. In a transient cooling process from 300 °C to 20 °C through 250 °C, the maximum Mises stress was found to be 372 MPa, which was lower than the yield stress at 300 °C.

1. Introduction

The main function of the International Fusion Materials Irradiation Facility (IFMIF) or the other neutron source facilities is to generate the high intense neutrons by injecting the deuteron or proton beams accelerated to high energy onto the target material such as liquid target of Li [1-4], Hg [5–7] Pb-Bi [8,9] and solid target [9–12]. The highest beam power in them is 10 MW of the IFMIF. The engineering validation and design activities (EVEDA) for IFMIF were performed to start from 2007 in a jointed program between the EU and Japan as a Broader Approach (BA) for fusion demo reactor. Some validation test and engineering design for lithium target facility of IFMIF were completed [13–28].

The objective of IFMIF is to generate high intensity neutrons, which are similar to fusion neutrons with 14 MeV, by injecting the deuteron beams accelerated to high energy onto the 260 mm wide and 25 mm thick free-surface lithium flow. Guiding the liquid lithium along the concave back plate at a speed of 15 m/s is required to increase the pressure in the lithium flow by centrifugal force, to avoid boiling by the heat input of the deuteron beams, and to remove heat by the lithium flow circulation [2,29]. This enables the target geometry to be maintained at the time of heat input, which is unexpected for solid target, and realizes the steady-state neutron source. IFMIF is composed of lithium target facility, accelerator facility, test facility with high flux module [14,30] and the other modules, and conventional facility.

In IFMIF operation after EVEDA, intense neutrons are emitted inside the Li flow through a thin back plate attached to the target assembly. Since the back plate is operating under a severe neutron irradiation of 50 dpa/year and a maximum nuclear heating rate of 25 W/cm^3, thermo-structural design is one of critical issues in a target design. The back plate is replaced in annual maintenance after every 11 months operation because of neutron irradiation damage. Two design options of the target assembly for the back plate replacement are under investigation. The first option is an “Integrated type” target assembly where the Li flow channel includes an integral back plate. This option requires replacement of the entire target assembly prior to life time of a portion of it. The second option is a target assembly with replaceable bayonet-type back plate. In this option, only the back plate will be replaced [21,22]. The Guiding the lithium flow along the concave back plate in target assembly at a speed of 15 m/s at 250 °C is required to increase the pressure in the lithium flow by centrifugal force, to avoid boiling by the heat input 10 MW by the 40 MeV deuteron two beams with 250 mA in total, and to remove heat by the lithium flow circulation. In this study, the thermos-structural analysis and the design of an integrated target assembly (TA) of IFMIF lithium target was evaluated.

* Corresponding author.
E-mail address: wakai.eiichi@jaea.go.jp (E. Wakai).

https://doi.org/10.1016/j.nme.2018.07.005
Received 15 December 2017; Received in revised form 27 June 2018; Accepted 11 July 2018

Table 1
Main specification of Li flowing target in IFMIF. Temperature will be increased to 350 °C inside lithium flow by the beam injection. The surface temperature will be elevated up to 280 °C. The margin of boiling temperature at the surface is about 40 °C.

Item	Condition
Heating power	10 MW
Vacuum	$10^{-3} \sim 10^{-2}$ Pa
Li temperature in inlet pipe	250 °C
Flow velocity	15 m/s (max. 16 m/s)
Li flowing thickness and width	0.025 m, 0.26 m
Li thickness variation	$\leqq \pm$ 1 mm
Li amount	9 m^3 (4.5 tons)
Li flow rate	130 l/s

Some of engineering design of lithium target facility of IFMIF were presented by some studies [2–4,13]. The main specification of lithium target facility of IFMIF engineering design is shown in Table 1.

2. System diagram of target assembly of lithium target facility of IFMIF

The system diagram of the lithium target facility was given in Fig. 1. The facility is composed of main lithium loop, lithium target system and target assembly, lithium flow measurement system and diagnostics, target test cell, beam duct, electro-magnetic pump system, impurity monitoring loop, impurity control system (lithium purification loop), quench tank and drain tank system, heat removal system, and remote handling systems.

In the main lithium loop and target assembly, the main Li loop circulates liquid Li through the TA by the main electro-magnetic pump (EMP). The TA with the Li inlet pipe with an outer diameter of 165.2 mm (in JIS, 6B, Sch.40), a part of the Li outlet channel and parts of the beam ducts are in the TC. Temperature of the BP, thickness of which is the thinnest among Li components and most severely irradiated by neutron and gamma ray, is monitored. There is no vacuum port in TC. Beam duct vacuum pressure is maintained by vacuum pumps through vacuum ports both outside of TC. Downstream end of the Li outlet channel is below the Li level in the QT by 0.2 m to suppress Li splash by confinement by duct and Li boiling by the head pressure. Also downstream end of the bypass is below the Li level to avoid cavitation under vacuum condition of QT with reflecting experiences at the EVEDA Lithium Test Loop (ELTL) operation. Temperature and Li level of QT are monitored. A Li overflow line is near the top of QT. Height difference between the overflow and the reference Li level in operation is about 0.2 m corresponding to Li volume beyond the reference level. Vacuum of the QT is maintained at 10^{-3} Pa or less through the surge tank (ST). Also Ar is supplied or evacuated through the ST. There is a gate valve under QT, which is closed at each TA replacement to limit volume exposed atmosphere containing air (O and N). All valves for Li components are opened and closed remotely by pressurized Ar gas, since no worker is accessible to the areas in beam operation when radiation is too high for workers and the areas are filled with Ar gas. Outer diameter of pipes between the QT and the main EMP is 267.4 mm (10B, Sch.20S) for smaller pressure drop to avoid cavitation at the inlet of the EMP located at the lowest among operating Li components, 6.5 m below the Li level in QT. Branch lines to/from the Impurity Reduction System (IRS) are connected to this section. Pressure in this section is low in comparison with the other part of the main Li loop. This condition eases design pressure of the ICS. Li flow rate at the exit of the EMP is finely controlled by feedback with a flow rate measured at the electro-magnetic flow meter (EMFM). Temperature of the EMP coil is monitored for a feedback control on a start of blower for cooling. Outer diameter of pipes downstream the EMP is 216.3 mm (8B,

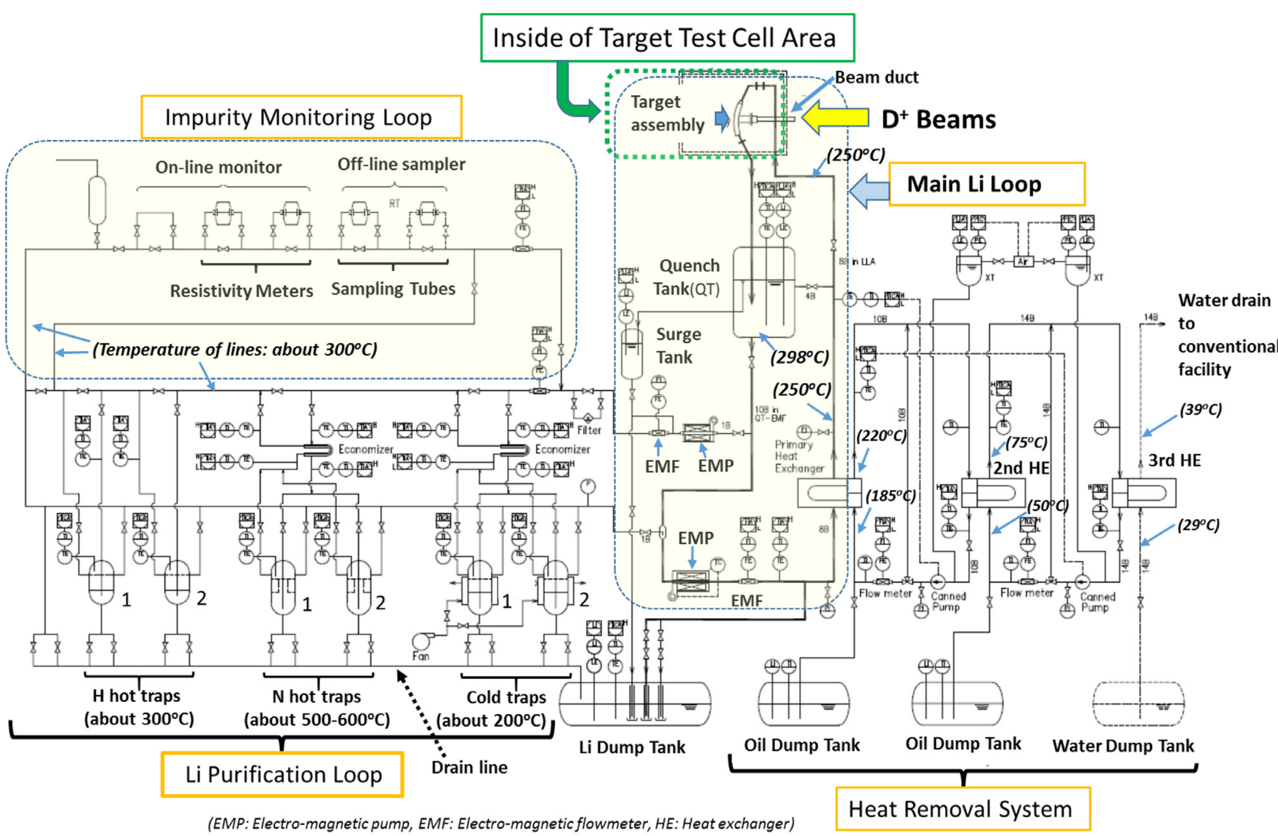

Fig. 1. System diagram of lithium target facility of IFMIF. *(FE: Flow element, FI: Flow indicator, FM: Flow meter, LE: Level element, LI: Level indicator, PE: Pressure element, PI: Pressure indicator, TC: Temperature controller, TE: Temperature element, TI: Temperature indicator, TIC: Temperature indicator controller, XT: Expansion tank).*