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JAERI/KEK TARGET MATERIAL PROGRAM OVERVIEW

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Abstract

Mercury target was designed for megawatt neutron scattering facility in JAERI/KEK spallation neutron source. The incident proton energy and current are 3 GeV and 333 μA, respectively: the total proton energy is 1MW in short pulses at a frequency of 25 Hz. Under the guide rule the mercury target was designed: the maximum temperature of target window is 170°C and induced stresses for the type 316 stainless steel are within limits of design guide. In order to demonstrate ADS transmutation critical and engineering facilities have been designed conceptually. In engineering facility lead-bismuth spallation target station is to be planned. Objective to build the facility is to demonstrate material irradiation. According to neutronics calculation irradiation damage of the target vessel window will be 5dpa per year.

1. Introduction

Under the framework of joint project between JAERI and KEK, a liquid mercury target has been designed in the accelerator complex [1]. The objective of the target system facility is to employ advanced neutrons scattering research by means of a megawatts spallation target. There are two-neutron source in both organizations: JRR3M is a fission reactor neutron source at a power of 20MWt and KENS is a pulsed spallation neutron source with proton energy of 500MeV and 3kW. A demand for intensified neutron source, however, is supported by potential industrial-aided application as well as scientific research. There is the other facility where a principal of mechanism of nuclear transmutation is to be proven in conjunction with high intense proton accelerator. A liquid lead-bismuth target will supply materials irradiation and corrosion experimental facilities. The accelerator complex consists of a normal conducting proton linac, a superconducting proton linac, mercury spallation target for neutron scattering, 3 GeV synchrotron ring 50 GeV synchrotron ring and ADS which consist of critical assembly and engineering-aided lead-bismuth target.

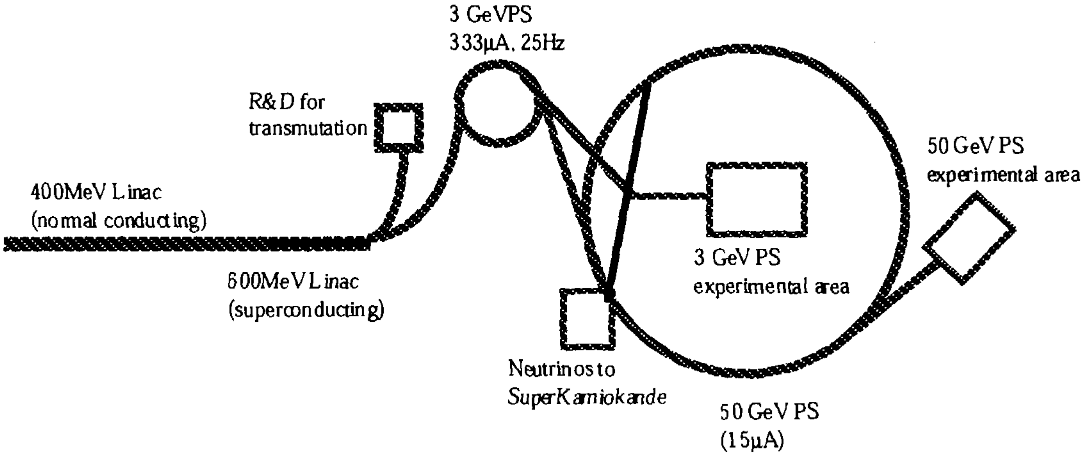

Fig. 1 Conceptual arrangement of accelerator and test facilities.

2. Material in mercury spallation target

Table 1 summarized current status of mercury spallation target design.

Mercury target was selected as our design of megawatt neutron scattering facility in the following specification:

- The incident proton energy and current are 3 GeV and 333 µA, respectively: the total proton energy is 1MW in short pulses at a frequency of 25 Hz.
- The duration of pulse width is about 1 µs and the reputation rate of pulses is approximately 40 ms.

As a consequence of short pulse, the deposit heat in the target leads to the production of pressure waves at the speed of sound in the target. In the mercury it is estimated to be 1400m/s when no bubbling occurs. A response of target container against the pressure wave in the mercury was reported [2] through ASTE collaboration at BNL. The target container must endure against proton and neutron irradiation under the condition of pressure wave and thermal cycling in the mercury environment. Accelerator beam trip is the reason why the target container suffers thermal cycle loading. So it needs a proper modeling in order to know induced stress intensity as a function of time. Next items are main works relevant to target engineering design.

-Pressure wave experiment at BNL insures proper simulation of pulsed spallation target.
-Target fluid tests insure the favorable structure for heat removal.
-Pressurizing test of moderator proves design criteria for the transient condition.
-Impacting test of split Hopkinson bar demonstrates a pressure wave in the mercury.
-Corrosion test in the mercury shows a corrosion rate.

Design guide is referred to ASME code[3] or domestic code. Stress intensity value, Sm, is defined by yield stress σy and ultimate strength σu as shown in eqn(1). For short-pulsed spallation target a fatigue life is important. Allowable cycles to failure, Nd, is evaluated by eqns.(2) and (3), here $\Delta \varepsilon t$: total strain, Nf: number of cycles to failure, Cp, Ce, ap, ae: coefficients, n: design cycles. Candidate materials for mercury target are type 316 stainless steel and F82H ferritic steel. These materials have the database of mechanical properties of post irradiation examination under the proton and /or neutron. The value of Sm is nearly 200MPa for SS316 austenitic stainless steel and 400MPa for F82H ferritic steel, respectively, under the unirradiated condition. Fabrication method and weldment condition will be determined after finalizing target geometry.

A change of mechanical property of irradiated material is a key issue to assess a lifetime of target vessel. And potential parameters to determine the target lifetime are combinations of damage elements listed in the table. Yield stress tends to increase with increasing of dpa. Uniform elongation, however, reduces with increasing of dpa and fracture surface may change from transgranular to intergranular features. Design temperature of target vessel is under 200C and corrosion rate will be ignored. Fatigue is a repeated loading. One of the main reasons is accelerator trip. The target is designed within an allowable cycles. Fracture toughness K tends to decrease with increasing of dpa. Anyway as long as corrosion is controllable it does not become a problem. Cavitation erosion may cause surface damage. Fatigue crack growth rate will estimate a time of crack penetration along a plate thickness. So the diagnoses of target vessel are further R&D items in the prototype target.

Table 1 Design status of mercury target

Items	Current parameters and status	Comments
Proton beam and neutronics	3GeV and 330μA: 1 MW at 25Hz. 1μs pulse width	Update path: 3GeV and 2.5MW at 25Hz
Engineering design	History of T,σ, ε and pressure as a function of time	
Design guide	ASME code or MITI 501	$Sm = \text{Minimum} \{ 2/3\sigma y, 1/3\sigma u \}$ (1) $\Delta\varepsilon t = CpNf^{-ap} + CeNf^{-ae}$ (2) $\Sigma (n/Nd) < 1$ (3)
Material choice	Type 316 and F82H	Fabrication Weldment
Life assessment	Dpa/ σy:	Strain hardening
	Dpa/ ductility:	Fracture mode
	Corrosion:	Rate
	Cavitation erosion:	Pits
	Fatigue	Allowable cycles
	Dpa/ K	Fracture toughness
	Fatigue crack growth	Growth rate
	Diagnoses	Method

Fig. 2 shows the design view of mercury spallation target [4]. Design works of mercury target have been doing in conjunction with neutronics, structural mechanics, fluid dynamics, heat transfer and safety. From the point of view of high neutron intensity, moderators favor to locate near target. So target shape is flattened and moderators will be put upon the top surface and beneath the bottom surface. Blade type flow distributor in the cross-flow target controls mercury flow. Flow guide plates also keep shape of target container. Target window will be a critical design part because of damage by proton-neutron irradiation, mercury corrosion and thermal stress cycling. It is emphasized that target container is a replacing component and must be done according to an operating schedule before a failure. In the pulsed spallation target there are small changes of temperature corresponding to short pulses. But within seconds, a temperature in the mercury container becomes steady state condition [5]. The maximum temperature of target window is 170$^{\mathrm{o}}$C at the beam window and the minimum temperature of the window is 130$^{\mathrm{o}}$C in the engineering target design.

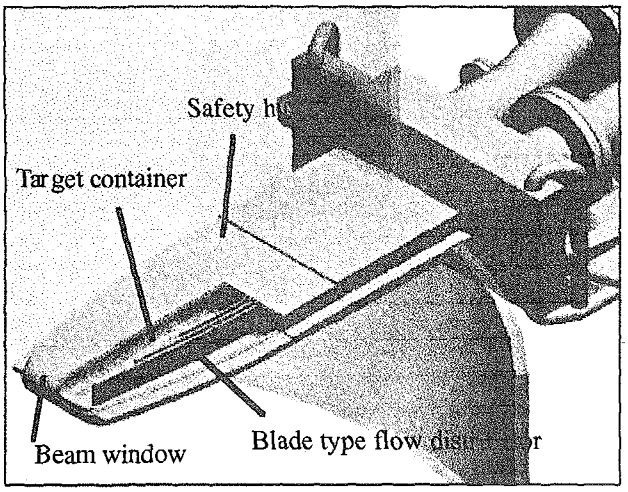

Fig.2 Mercury spallation target[4].

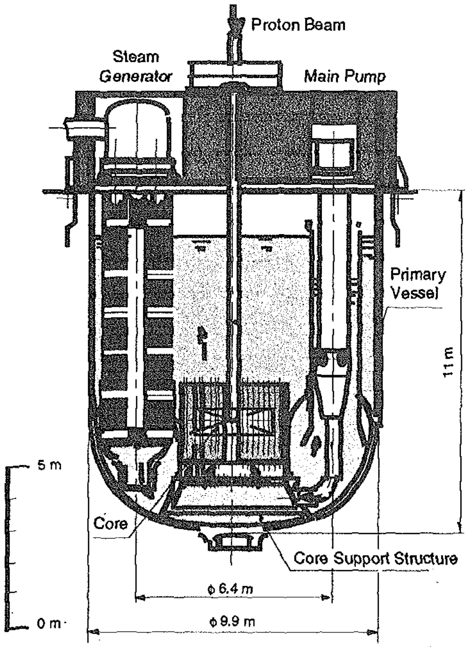

Fig. 3 Conceptual design of nuclear transmutation plant[6].

3. Material for ADS target

R&D on ADS coupled with nuclear transmutation has been deployed [1]. A conceptual design goal is shown in Fig.3[6]. The plant consists of Pb-Bi target in the center beam duct, fuel region in the core, pump and steam generator. First neutrons produced in spallation target will be used for changing long-lives nuclei to short-lives ones in the fuel region surrounding the target. The lead-bismuth cooled option is the primary candidate for the ADS. Lead-bismuth plays roles of both spallation target and coolant. It also offers the possibilities to achieve a harder neutron energy spectrum and to avoid a positive void reactivity coefficient. Its chemical inertness is particularly favorable for safety in the event of coolant leakage. But disadvantage is generation of reaction products such as Po, Hg. Again technical issue for developing ADS, from points of views of engineering matters as a first step, is a beam window material. The beam window must endure against

- ***Proton and neutron radiation damage,***
- ***Thermal stress cycling and***
- ***Corrosion-erosion.***

In order to demonstrate ADS transmutation critical and engineering facilities have been designed conceptually[7]. In engineering facility lead-bismuth spallation target station is to be planned. Fig. 4 is a conceptual view of the engineering facility. Access cell is behind a target station to prepare a further PIE. Objective to build the facility is to demonstrate material irradiation by the incident proton and neutron under the Pb-Bi flow. Potential degradation of the material performance is radiation damage, liquid metal corrosion and liquid metal embrittlement. Post irradiation examination will be done for development of materials available to ADS. Specification of the test facility is:

- The incident proton energy and current are 600 MeV and 333 μA, respectively: the total proton energy is 200 kW in pulses at a frequency of 25 Hz,
- The duration of each pulse is about 500 μs and the period between pulses is approximately 40 ms,
- Target is lead-bismuth.
- Average beam density is less than 30 μA/cm^{2,}
- Beam profile I ϕ 4cm, flat,
- Target material is Pb-Bi Alloy （45%Pb-55%Bi） ,
- Target temperature is 450/350 ^{O}C (Inlet/Outlet)
- Target shape is cylinder, 20 cm dia. x 60 cm length.

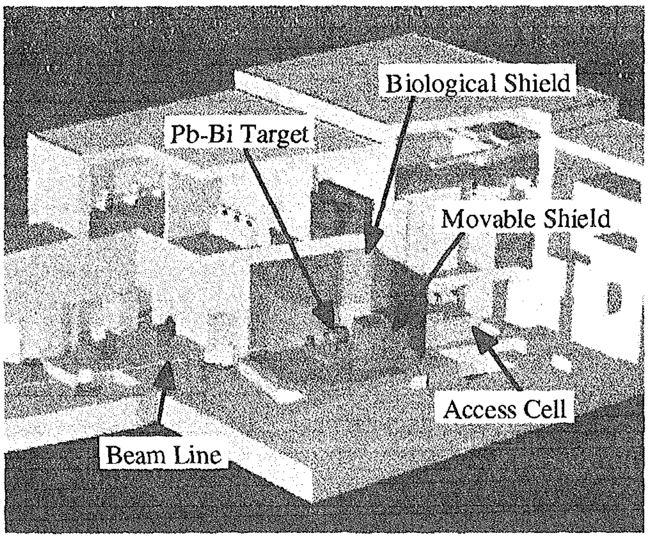

Fig. 4 Conceptual view of the engineering facility.

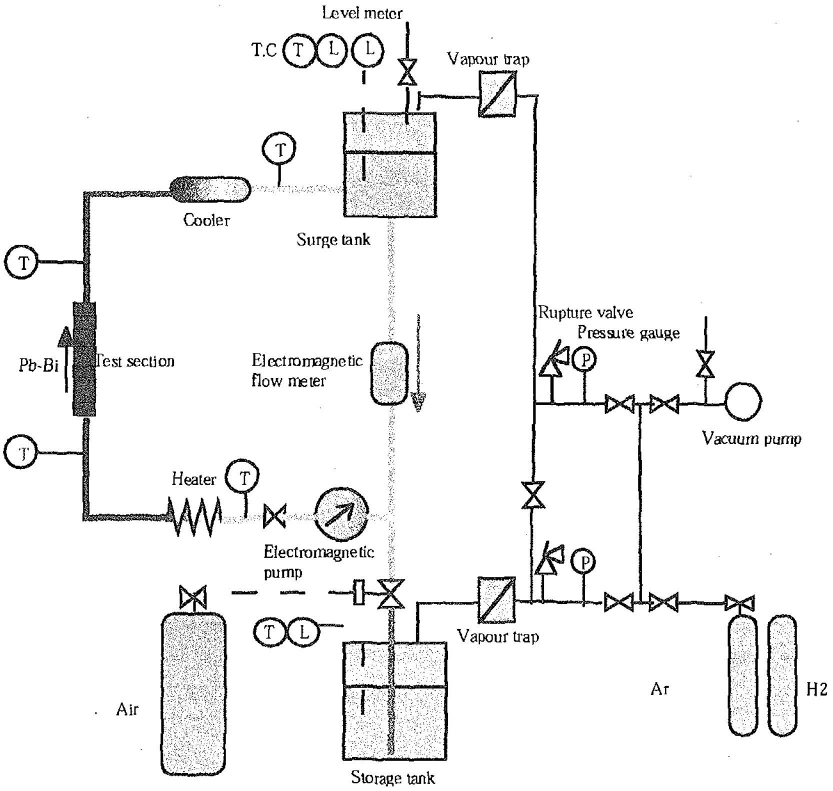

Fig.5 Illustration of lead-bismuth corrosion test loop.

Pressure waves will not be a major technical issue, as it plays important roles in the mercury spallation target of 1μs short pulse because duration of pulses is long, 500μs. According to neutronics calculation done by ATRAS [8] irradiation damage of the target vessel window will be

5dpa per year. The best sample of post irradiation experiment for future ADS material is the target window itself. A lead-bismuth loop for material corrosion test is shown in Fig.5. Test facility consists of test section, heater, cooler, electromagnetic pump electromagnetic flow meter, and storage tanks. The facility performances are as follows:

- Coolant: Pb-Bi (45%-55%),
- Maximum Pb-Bi temperature: 450 °C,
- Flow rate: 5 000 cc/min.

Changing the tube diameter varies flow speed in the test section. We expect around 1m/s at the ADS target window. There are three Pb-Bi test loops inclusive this one in Japan. Through CRIEPI experience under the condition of uncontrolled oxygen environment modified 9Cr-1Mo and 2.25 Cr-1Mo steels showed good evidence against corrosion at 500 °C during 6000hrs. On the contrary type 304 stainless steel showed corrosive in the Pb-Bi [9]. First candidate material for our target container is type 316 austenitic stainless steel. Alternative material is F82H (8Cr-2W) ferritic/martensitic steel [10]. Another candidates are oxide dispersion strengthened materials of ferritic/martensitic steel and high Cr/Fe steel[11]. In these tests oxygen concentration in the lead-bismuth will be controlled. Through IPPE experiences oxygen concentration must be within a particular range[12]. Low concentration will remove oxide scales from the material surface and high oxygen concentration makes lead oxide. It is important issue to find suitable values of oxygen concentration but a careful decision must be made if it is a right way to rely on thin film on the material surface or not in the huge nuclear transmutation system.

5. Summary

Material program related to JAERI/KEK spallation target project was overviewed. R &D of mercury target system and an international collaboration experiment on pressure wave have been doing. As a result the mercury target vessel was designed. Induced stresses for the type 316 stainless steel are within limits of design guide. There are parameters to assess a lifetime of target vessel which is to be replaced periodically; that is, a change of mechanical properties due to proton and neutron irradiation, repeated cycles of loading and the effects of cavitation are weighted parameters. The spallation target irradiation program (STIP) at SINQ has been progressing[13]. Post irradiation examination of STIP-I will start in 2001. The second spallation target is Pb-Bi in the nuclear transmutation facility. The objective of these facilities is to irradiate candidate materials for spallation target vessel under the flow condition of target. So before construct test facilities material corrosion test is performed. Liquid metal corrosion and liquid metal embrittlement will be examined first without proton and neutron irradiation.

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