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Design and trial fabrication of a dismantling apparatus for irradiation capsules of solid tritium breeder materials

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ABSTRACT

Irradiation experiments of solid breeder materials including Li_2TiO_3 have been being carried out in preparation for a test blanket module (TBM) of the International Thermonuclear Experimental Reactor (ITER). The present paper deals with design and trial-fabrication works for developing a dismantling apparatus for the irradiation capsules. The dismantling process leads to release of tritium which is left in free volumes of the capsule or in the breeder specimens. In the design of the dismantling apparatus, the released tritium is recovered safely by a purge-gas system during the cutting of the irradiation capsule by a band saw, and then the tritium is consolidated into a radioactive waste. Furthermore, an inner-box enclosing the dismantling apparatus works as a countermeasure of possible release of tritium in accidental events. Good performance of a trial fabrication model of the dismantling apparatus has been demonstrated by preliminary cutting runs using some mockups simulating the irradiation capsules. Thus, the present design of the apparatus, together with the trial mock-up runs, will contribute to the design of the TBM structure and to the planning of the dismantling process of the TBM.

1. Introduction

Japan Atomic Energy Institute (JAEA) has been developing solid blanket for demonstration (DEMO) fusion reactors [1]. In-pile functional tests of breeding blankets have been planned in the program of the test blanket module (TBM) to be loaded in the International Thermonuclear Experimental Reactor (ITER). In preparation for TBM, JAEA has been performing irradiation experiments [2,3] of solid breeder materials including Li_2TiO_3, which is the first candidate of breeder materials for the DEMO blanket in a water-cooled solid-breeder design concept.

The present paper deals with design and trial-fabrication works for developing a dismantling process for irradiation capsules which were employed in irradiation experiments using the Japan Materials Testing Reactor (JMTR) [4] of JAEA. The design was carried out to meet a guideline of Japanese Government [5] for facilities where more than 3.7×10^{14} Bq of tritium is treated.

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2. Irradiation capsules

Table 1 shows main specifications of irradiation capsules and specimens which were examined in this study. The generated tritium amount was estimated from the average thermal neutron flux and the irradiation time, and the recovered amount was estimated from measured concentrations of tritium during irradiation and subsequent recovery operation. Details of the capsules are described elsewhere [6].

The gas sweep capsule (96M-37J and 99M-54J) for in-situ tritium recovery experiments is comprised of a cylindrical outer-container (65 mm in outer diameter) and an inner-container [2]. The inner-container was loaded with Li_2TiO_3 pebbles. Tritium generated in the Li_2TiO_3 pebbles was swept with purge gas during and after the irradiation. The arrangement in the in-situ experiments and the structure of the irradiation capsule were displayed schematically in ref. [2].

On the other hand, a closed capsule (92M-47J) was loaded with Li_2O specimens. The tritium generated has been retained in the inner-capsules.

Table 1
Main specifications of the irradiation capsules and specimens examined in this study.

Capsule type	92 M-47 J Capsule	96 M-37 J Capsule	99 M-54 J Capsule
	Closed	Gas sweep	Gas sweep
Capsule dimension			
Outer diameter (mm)	34[a]	65	65
Total length (mm)	290 and 53[b]	about 1000	about 1000
Materials			
Tritium breeder (Shape)	Li_2O (Disks and Pebbles)	Li_2TiO_3 (Pebbles)	Li_2TiO_3 (Pebbles)
Neutron multiplier	None	Beryllium, Pebbles	None
Capsule structural materilas	Stainless Steel[c], Aluminum	Stainless Steel[c], Aluminum	Stainless Steel[c], Aluminum, Hafnium
Irradiation conditions			
Average thermal nuetron flux ($m^{-2}\ s^{-1}$)	3.2×10^{17}	2.4×10^{18}	4.4×10^{18}
Average fast nuetron flux[d] ($m^{-2}\ s^{-1}$)	3.5×10^{16}	1.1×10^{16}	4.3×10^{15}
Irradiation time (hour)	527	5197	17253
Cooling time[e] (year)	16	10	3
Activity of ^{60}Co[e] (Bq)	2.9×10^{8}	5.2×10^{10}	2.9×10^{11}
Tritium amount[e] (Bq)			
Generated	2.6×10^{13}	1.9×10^{13}	(4.7×10^{12})[f]
Recovered	None	1.8×10^{13}	(6.9×10^{12})[f]
Residual	2.6×10^{13}	1×10^{12}	(Small)[f]

[a] Typical diameter of three inner-capsules.
[b] Lengths of three inner-capsules (length: 290 mm for two, and 53 mm for one).
[c] Types 304 and 316 stainless steel.
[d] Eutron energy >1 MeV.
[e] As of end of July 2009.
[f] The calculated value for the generated or recovered tritium amount is uncertain. The residual amount is considered to be very small compared with the generated amount.

3. Investigation on the whole process for irradiation capsule dismantling

The above-mentioned Japanese guideline [5] requires that the tritium handling facility should be equipped with multiple partition containments, namely, (i) an experimental apparatus, (ii) a glove box, a cell, a hood or similar equipments, and (iii) a working room. Thus, a cell in which tritium and other irradiated materials are treated should have a leak-tight confinement against tritium.

At the first stage of the present investigation, therefore, utilization of existing facilities for post-irradiation examinations (PIEs) of uranium-plutonium mixed oxide (MOX) fuels was considered for dismantling of the irradiation capsules containing tritium. This is because the stainless steel lining on the wall of the MOX cells is capable of effective confinement of tritium.

In the course of the investigation, however, it was revealed that once the capsules are carried into the MOX cell and the specimens are taken out of the inner-container of the capsule, the capsule components and the specimens are inevitably contaminated by plutonium. Thereafter, decontamination of plutonium is very difficult. These results will bring much difficulty in subsequent PIEs and disposal processes, in addition to a significantly large cost for refurbishing of the MOX facility to enable of the dismantling.

Therefore, a conceptual design was elaborated which utilizes an ordinary hot cell. Fig. 1 shows a schematic diagram of the whole process for dismantling of the irradiation capsules and for recovery of tritium.

During the dismantling process, the capsule body is totally contained in the dismantling apparatus, and the released tritium is effectively confined inside of the apparatus itself. The dismantling apparatus was designed to have enough confinement capability with a He-gas leakage rate smaller than 10^{-8} Pa m^3/s. The tritium released during the dismantling is recovered by a carrier gas (He-1% H_2), and is oxidized by platinum catalyst to become tritiated water. The tritiated water is absorbed by molecular sieve, and is subsequently consolidated into a radioactive waste form made of concrete.

Furthermore, the dismantling apparatus is enclosed by an inner-box for additional confinement of tritium. The inner-box is safety equipment against tritium leakage in accidental events. Adoption of the inner-box enables to treat safely the tritium-contained specimens in an ordinary cell (a so-called beta-gamma cell) where radioactive nuclides emitting beta- and gamma-rays are treated, even if the cell adopts gas-permeable materials such as concrete for the cell wall.

4. Design and trial fabrication of the dismantling apparatus

4.1. Selection of cutting tool

In the design of the cutting component of the dismantling apparatus, a commercial band saw was selected as the cutting tool among various kinds of tools such as a round cutter and a lathe. This is because a band saw is capable of cutting a capsule with a large diameter up to about 150 mm, and also this tool can significantly spare the space compared with other tools. The cutting component was designed so that the capsule is cut at a stroke.

4.2. Design and trial fabrication of the cutting component

Fig. 2 shows the total view of the capsule dismantling apparatus prepared in the trial fabrication, and Table 2 gives main specifications of the cutting component of the dismantling apparatus.

As seen in Fig. 2, an irradiated capsule to be cut is set by a clamp mechanism which is fitted to a remote control for capsule handling works in a hot laboratory. The capsule is moved vertically by a reversible motor in order to control the axial cutting position of the capsule. The positions of the upper and lower clamps can also be controlled independently by each motor, and these clamps are adjusted to their optimum positions for different lengths and diameters of the irradiation capsules. A tilting control for the clamp mechanism was also employed to enable the capsule handling, in particular, the setting and removing of the capsule, in a limited operation space of a hot cell. Aluminum was employed for the

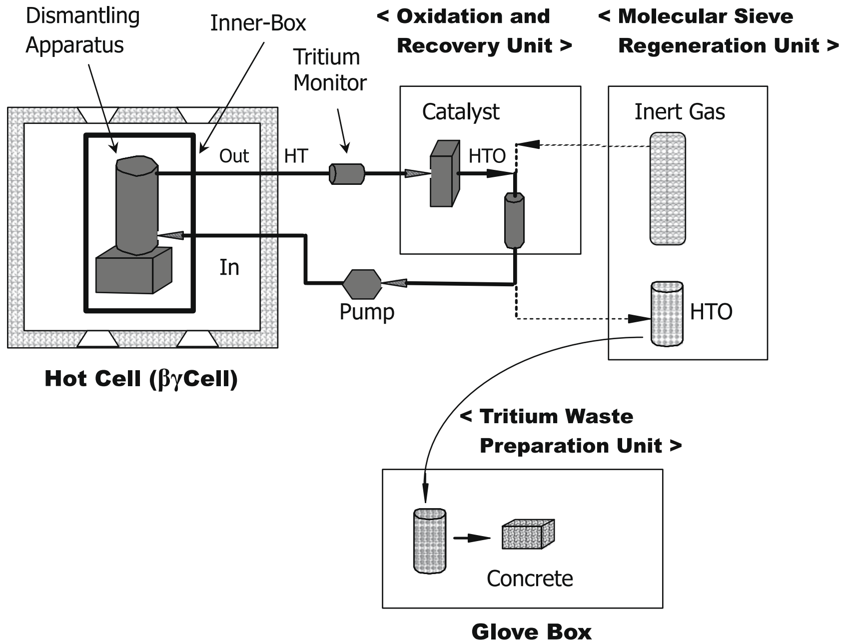

Fig. 1. Schematic diagram of the whole process for irradiation capsule dismantling with tritium recovery.

main structure and framework materials, considering the weight and strength to be required.

Preliminary cutting tests were carried out by using mockups which simulate the structures of the irradiated capsules. During the cutting, the capsule was fixed by the clamps, and the band saw was moved slowly by different cutting speeds for different runs in the range of approximately 0.18–4 mm/s, where the cutting speed is the feed rate of the band saw.

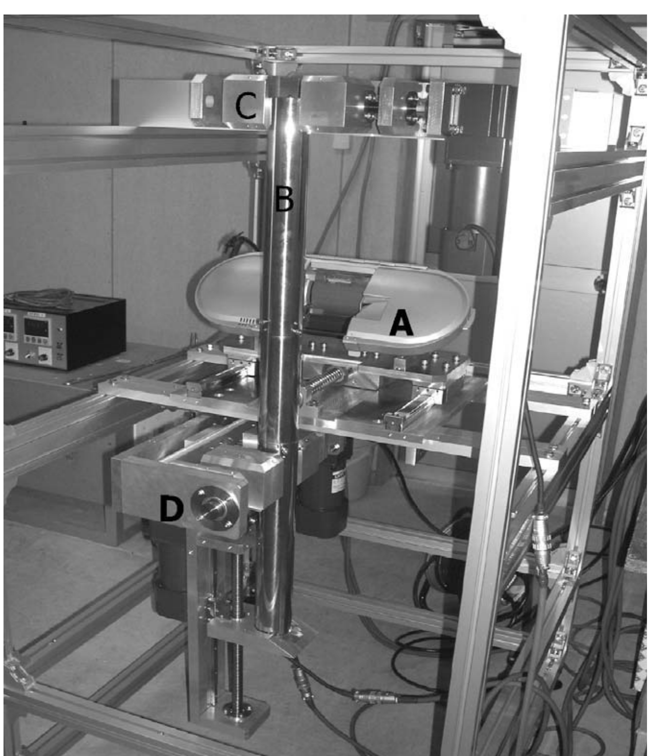

Fig. 2. The cutting component of the capsule dismantling apparatus; (A) band saw, (B) capsule mockup, (C) upper clamp, (D) lower clamp.

Fig. 3 shows a cross-section of a mock-up after a cutting run. As seen in this figure, good performance of the dismantling apparatus was confirmed by these mock-up cutting runs.

4.3. Improvements of the cutting component

Some improvements are being continued in the design and trial fabrication of the cutting component of the dismantling apparatus, as follows:

(1) The cutting speed range is shifted to a lower range (approximately 0.05–1.1 mm/s) for sharp and steady cutting, and a safety limiter of the band saw movement is adopted.

(2) If the saw is deteriorated or in trouble during the cutting, the band-saw machine can be drawn out of the dismantling apparatus, and the deteriorated saw can be replaced by a new one using manipulators.

Table 2
Main specifications of the cutting component of the capsule dismantling apparatus.

Items	Specifications
Capsule to be dismantled	
Shape	Cylinder
Diameter (mm)	30–70
Maximum length (mm)	About 1000
Minimum length (mm)	About 300 without a clamp jig
	About 50 with a clamp jig
Material	Stainless steel (Types 304 and 316), Aluminum
Cutting machine	
Type of cutting machine	Band saw
Voltage and power	100 V and 1 kW
Cutting speed[a]	
Original (mm/s)	0.18–4
Improved design (mm/s)	0.05–1.1
Travel for cutting (mm)	About 200
Capsule movement mechanism	
Axial travel[b] (mm)	250
Tilting (°)	30

[a] The horizontal feed rate of the band saw assembly during cutting.
[b] The distance between the upper and lower limit positions in axial movement of the capsule.

Fig. 3. Cross-section of a mockup of an irradiation capsule for tritium breeder materials. The mockup was cut in a test for trial fabrication of the dismantling apparatus.

(3) It is being investigated that the condition of the cutting position of irradiated capsules is monitored by using a television camera and/or a microphone during the cutting operation.

These improvements will lead to better control and safer and easier operation of the cutting machine.

4.4. Other components

As for components other than the cutting device described above, a conceptual design was finished and the results were summarized in an interim report [6]. For example, a tritium baking component was designed in order to remove tritium from the structural materials (contaminated with tritium) of the irradiation capsule, and to make the structural materials into radioactive wastes without tritium. The design was made under a provisional condition that the structural material specimens (i.e., stainless steel and aluminum) will be kept at 400 °C in an atmosphere of flowing nitrogen gas added with 1–10% humidity. More detailed conditions for the designing will be fixed after forthcoming investigations and examinations.

Further preparatory works are proceeding toward a detailed design of the whole dismantling apparatus as well as additional trial fabrication of other key components such as the tritium baking component. Thereafter, actual fabrication of the whole dismantling apparatus will be followed.

5. Conclusions

Design studies on the whole dismantling process of the irradiation capsules for solid tritium breeders and trial fabrication of the cutting component were carried out in order to develop the capsule dismantling techniques. The results are summarized as follows:

(1) Adoption of the inner-box and the tritium recovery system for the dismantling apparatus offered a good prospect to treat safely the tritium-contained irradiated capsule in an ordinary beta-gamma cell. This leads to realization of an effective, safe and economical dismantling process.

(2) Good performance of the cutting component was confirmed by the trial fabrication and cutting runs using the simulated mock-up capsules.

Thus, the present design and trial-fabrication works surely contribute to the capsule disintegration and subsequent PIEs of the irradiated specimens. Furthermore, the present works will also contribute to the design of the structure of the test blanket module (TBM) as well as establishment of the disintegration technology of the TBM to be loaded in ITER.

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