Development of cut out machine for PIE test pieces from mercury target vessel in J-PARC

H Kinoshita, K Haga, M Seki, T Suzuki, M Ito, Y Kasugai, T Wakui, H Kogawa, T Naoe, K Hanano, M Teshigawara, F Maekawa, S Sakamoto M Futakawa

Neutron Source Section, Materials and Life Science Division, J-PARC Center, Japan Atomic Energy Agency (JAEA),
Shirakata-Shirane 2-4, Tokai-mura, Naka-gun, Ibaraki, Japan

E-mail: kinoshita.hidetaka@jaea.go.jp

Abstract. Post Irradiation examination (PIE) of the target vessel is planned the Materials and Life Science Facility (MLF) of J-PARC to get the information of the pitting damage on the surface of mercury side and the material damage by protons and neutrons irradiation. Test pieces have to be cut out from the target vessel for the PIE test. Therefore, the cut out machine dedicated to the target vessel was designed and fabricated. A hole saw was adopted to cut the proton beam window of the target vessel. Cutting tests were conducted to select a hole saw and a drill machine. After a number of trials, we succeeded in cutting out the mock-ups of the target vessel window, which had three layers of walls. It took about 10 minutes to cut out three layers of walls. Remote handling tests were also conducted to operate the machine in the hot cell of the MLF building. A series of operations with the master slave manipulator, such as replacing the hole saw and taking out test pieces from the hole saw, were rehearsed successfully. The cut out machine is now ready to cut the target vessel and produce PIE test pieces.

1. Introduction

The mercury target vessel in a high-power spallation neutron source suffers both pitting damage and irradiation damage by protons and neutrons. Post Irradiation Examination (PIE) is essential to estimate the life time of the target vessel. The PIE tests, such as the observation of the inner surface of the mercury vessel and the material tests, are planned at the replacement of the target vessel of Materials and Life Science facility (MLF) in J-PARC. In order to conduct the PIE, it is necessary that the part of the mercury target vessel is cut to produce test pieces.

The cut out machine was designed, fabricated and used to produce PIE test pieces from the used mercury target vessel in the SNS.[1] The cut out work for used target vessel was performed and test pieces were obtained successfully. However, the target vessel structure, the remote handling replacement sequence and the concept for the environment in the hot cell of J-PARC are very different from the SNS facility. Therefore, the cutting out work is necessary to be designed in our own manner in order to get the test pieces from the target vessel in J-PARC.

In this paper, the design of the cut out machine for cutting the mercury target vessel in J-PARC and the tests for the cutting machine are described. The first cutting work for the used target vessel is also reported.

2. Design of the PIE test pieces cut out machine

2.1. Design conditions

The target vessel in J-PARC consists of a mercury vessel and a safety hull. The image drawing of the target vessel and the cross-sectional view of the proton beam window part are shown in Figure 1. The safety hull covered the mercury vessel to prevent the mercury from spreading into the helium vessel in the case of mercury leakage. The safety hull has to be cooled by water and the safety hull has a double wall. Therefore the target vessel has triple wall structure. The target vessel is made of 316L stainless steel to stand for the corrosion by mercury. The window part is made as thin as 2.5 mm, which reduces the thermal strain by proton beam injection. The gap between the mercury vessel and the safety hull is designed as 10 mm. The gap for the coolant path in the safety hull is designed as 3 mm.

The mercury target vessel in J-PARC is fixed with bolts to a target trolley as shown in Figure 2. When the target vessel is replaced by remote handling operation, a target exchange truck is used to set a target storage container as shown in Figure 3. In addition, the used target vessel is stored in the target storage container after disconnected from the target trolley. The storage container is transported by an overhead traveling crane in the hot cell. The used target vessel is not designed to be taken out by remote handling from the storage container during its storage in MLF.

From the view point of the environment in the hot cell, the hot cell has to be kept as clean as possible so that personnel can enter the hot cell. Almost all the devices in the hot cell require hands-on maintenance by personnel.

To design a PIE test piece cut out machine, the following concepts are adopted.

- Cutting out is carried out before disconnecting the target vessel from the target trolley.
- The target exchange truck is used to fix and move the cut out machine during the cutting out work.
- Hole saw is used to cut the target vessel. The test piece is about 5 cm in diameter.
- To prevent spreading contamination of radioactivity, cutting out is carried out in dry condition. Oil or lubricant materials are not used to cut out.
- To prevent spreading mercury and mercury related pollution, ultrasonic washing is carried out in the hot cell.

The specifications required for a cut out machine are shown in below. The design of the cut out machine has to be carried out to satisfy these conditions.

- The machine is cutting out the target vessel horizontally by using hole saw.

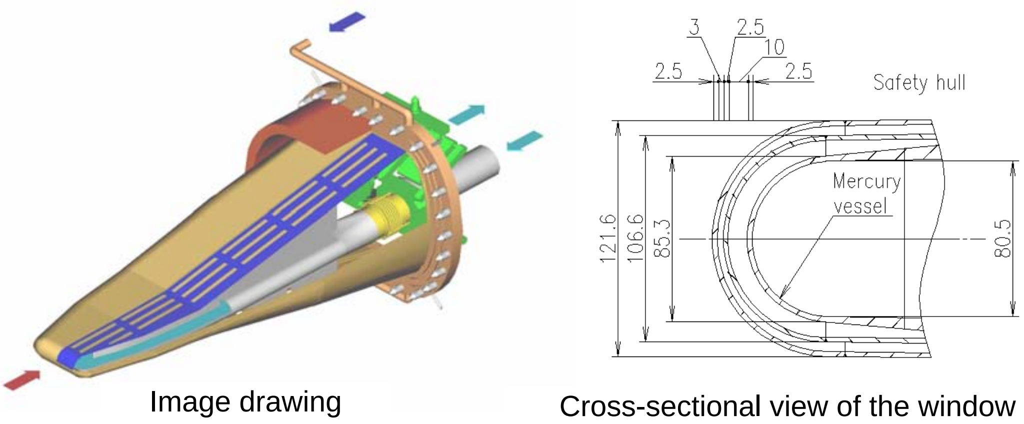

Figure 1. The mercury target vessel

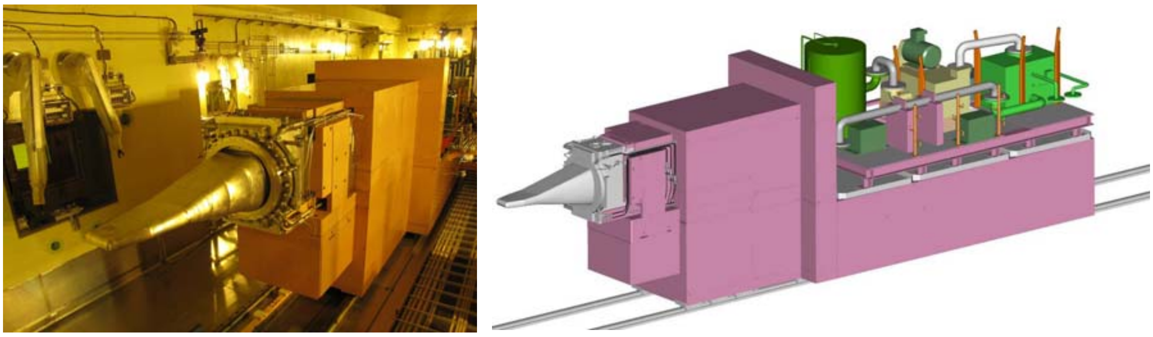

Figure 2. The mercury target trolley and the mercury target vessel

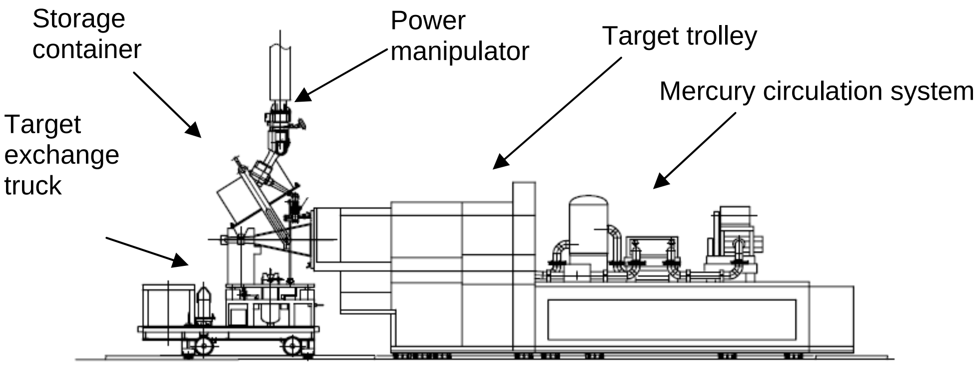

Figure 3. Drawing of the mercury target vessel replacement

- The machine is set on the target exchange trolley during cut out operation.
- The machine can be transported by an in-cell crane remotely.
- The actions of the exchanging the hole saw, taking out the test pieces and storing the test pieces in a storage container can be operated remotely by using the master-slave manipulator (MSM).

- During cutting operation, the machine has to be fixed stably.
- Mercury and other pollutions are removed from the test pieces by using an ultra sonic washer.
- The hole saw can be moved in the right and left direction to adjust the cutting position.
- The machine can be brought down from the ceiling hatch of the hot cell.
- The machine can be set on the floor in the hot cell.
- Cutting operation can be controlled from the outside of the hot cell.
- Cut chips must be prevented from spreading in the hot cell.

2.2. Design of the cut out machine

The image drawing of the cut out machine is shown in Figure 4. The cut out machine consists of a machine body, a mounting rack and an ultra sonic washer. The machine body has a frame structure, including a drill machine, a lateral moving device, a control unit, a cover to prevent spreading cut chips and a catch pan for cut chips. The machine has a sitting stand and is placed on the mounting rack. The rotation and the back and forth movement of the hole saw are controlled by the drill machine. The drill machine is set on the lateral moving device driven by another motor. The cover is set around the hole saw part to prevent cut chips from spreading. The cover plays the role of pressing the machine body to the target vessel firmly during cutting out operation. The cover can be removed from the machine body by using the in-cell crane, when the hole saw is exchanged. The ultrasonic washer is set

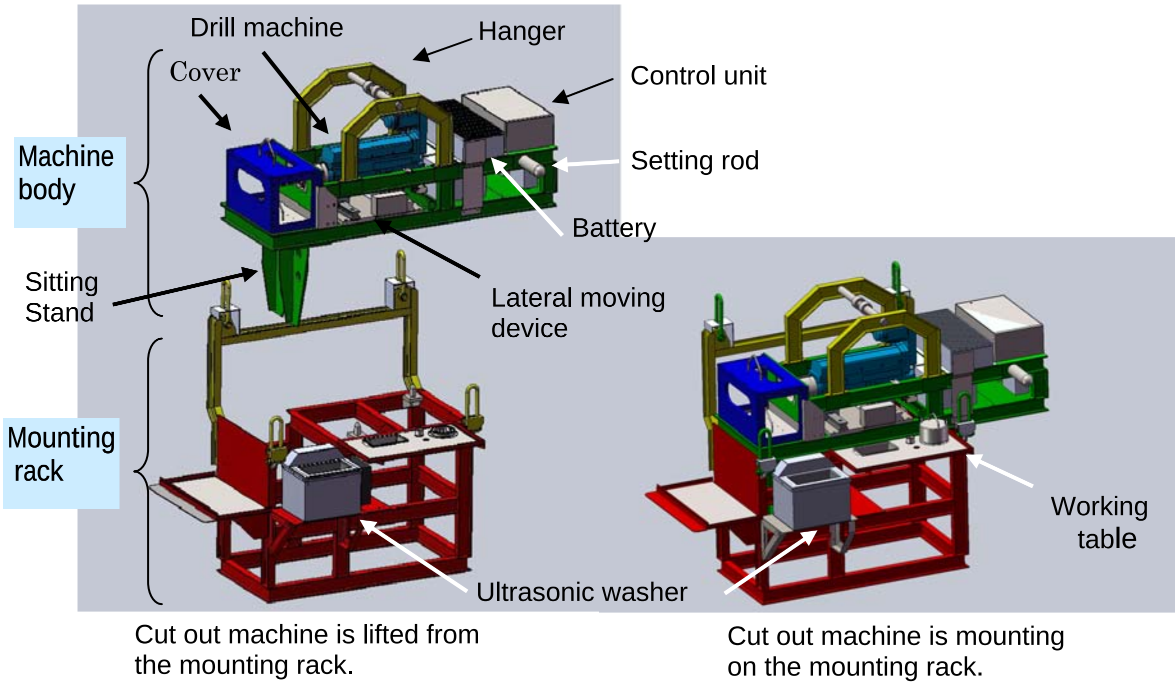

Figure 4. Image drawing of the cut out machine

on the rack and driven by another battery. The working table is set to the rack to take out test pieces form the hole saw and store the test pieces in the storage container. The working table is designed to accommodate a spare hole saw and the storage container.

Eternal power cables and communication cables are removed from the cut out machine to transfer it remotely in the hot cell. Therefore a wireless LAN is used to communicate with PLC (Programmable Logical Controller) and the motors are driven with batteries. The control panel is placed outside the hot cell and an antenna is penetrated through the cell wall. The machine is operated by wireless communication. It is assumed that radiation damage on the machine is very small in the present condition. Therefore any radiation shielding is not necessary for the cut out machine.

2.3. Cutting Scenario of the Target vessel

The cutting Scenario of the target vessel is described as follows.

1 While the target trolley stays at the operating position, the cut out machine is set in the hot cell. The machine with the setting rack is brought down through the ceiling hatch from the large component handling room by a crane.

2 After finishing the preparation of the cut out machine, the target trolley is moved back. Using the in-cell crane, the target exchange truck is transferred to front of the target trolley and set on the rails.

3 The cut out machine is set on the target exchange truck by the in-cell crane. (Figure 5, ①②)

4 The front and back position and the vertical position against the target vessel are adjusted by the target exchange truck driving. (Figure 5, ③④)

5 The left and right position of the hole saw is aligned by the lateral moving device in the cut out machine. (Figure 5, ④)

6 Cutting operation is carried out. (Figure 5, ⑤) The operation is controlled from outside the hot cell.

7 The cut out machine is separated from the target vessel by moving back the target exchange truck.

8 The cut out machine is returned on the mounting rack by the in-cell crane.

9 The hole saw with the test pieces inside is disconnected from the drill machine by the master-slave manipulator.

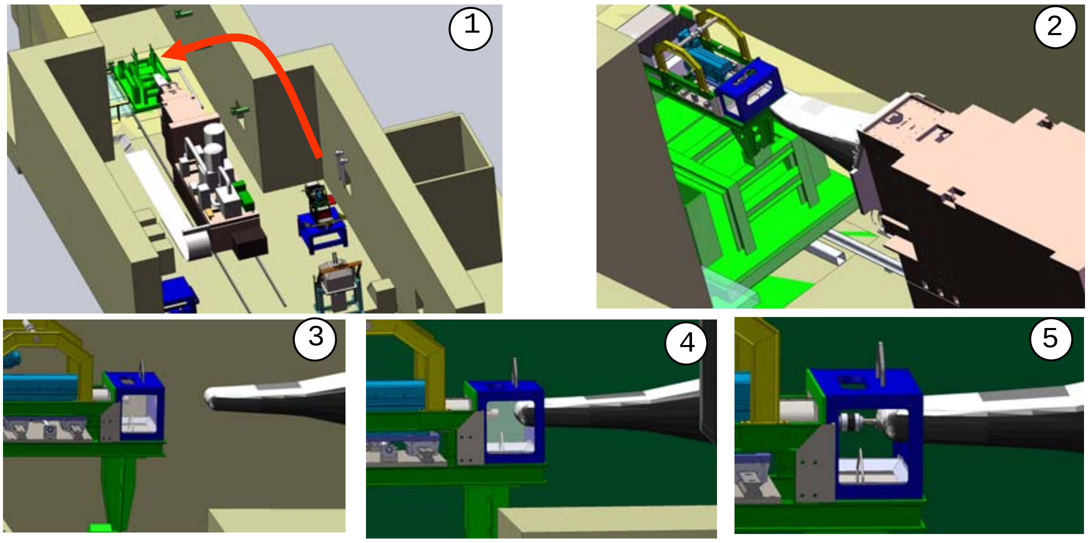

Figure 5. Scenario image of the cut out operation

10 The hole saw with the test pieces is washed to remove mercury and other pollutions by the ultrasonic washer.
11 The test pieces are taken out from the hole saw by the MSM.
12 The test pieces are stored in the storage container. The storage container is moved to another rack.
13 The catch pan with cut chips is stored in a container. The container is moved onto the floor of the hot-cell floor.
14 The insert tray of the ultrasonic washer with water is moved onto the floor of the hot-cell.

3. Test of the cut out machine

3.1. Cutting test of the cut out machine
The cutting tests were carried out to confirm the points as follows.
- A triple wall is cut out reliably.
- The cut out pieces don't come off and remain certainly in a hole saw.
- The temperature of the simulated body during the cutting operation is lower than the temperature of the target vessel during beam operation in the MLF.
- The Cut chips do not spread to outside of the cover.

The cutting tests of the hole saw were conducted using the simulated body of the target vessel window part. The specification of the drill machine and the shape of the hole saw are determined with the cutting tests. The parameters of the procedure, such as rotating speed and forward speed, are optimized throughout the tests.
In the initial test, the drill machine was relatively small considering the battery capacity, etc. The drill machine has 1,760 N of the forward moving torque. But the drill machine was often stuck in the tests and failed to cut out a triple wall. Therefore the drill machine was replaced with a large one, which has 7,760 N of the forward moving torque. A hole saw with 6 hard chips of 4 mm in thickness and 58 mm in outer diameter is used in the initial test. But the cutting was often failed. A diamond cutter was tried to reduce the rotation and forward torque for cutting. Finally, it was found that the hole saw with 12 hard chips of 2 mm in thickness and 55 mm in outer diameter would do. A small hole is made in a part of the hole saw to take out test pieces.
A quick exchange tool is adopted to fix a hole saw to the drill. After a cutting test, the hole saw was stuck and can not be disconnected easily. By using a large quick exchange tool, the disconnection after cutting can be conducted easily.

Almost all the cut chips were found to drop in the catch pan owing to the presence of the cover. Small number of cut chips got in between the cover and the catch pan, and flew toward the rotating shaft of the drill machine. Therefore, skirt shaped parts wee attached to the cover preventing cut chips from getting into small gap and the shaft was covered. It was confirmed that all the cut chips were corrected by the catch pan.

To prevent vibration, the rotating speed was adjusted to 300 rpm, which was relatively higher than the recommended speed for a hole saw. It was decided that fine forward and backward motions were repeated alternately to simulate the cutting operation by human. Considering the stroke and the time, the forward motion speed was selected as fast as possible so that the rotation torque did not exceed the limit value of the drill machine. As a result, it was determined that the forward speed was 0.02 mm/sec, forward motion of 0.3 mm and backward motion of 0.1 mm were repeated alternately.

A test was carried out to validate this condition as shown in Figure 6 and three stainless steel walls could be cut out reliable. It takes within 10 minutes. In this condition, the maximum temperature of the test pieces was about 80 ºC, which was measured by a non-contact infrared thermometer. In addition, more than 30 cutting tests were conducted in this condition, it was confirmed that the three test pieces always remained in the hole saw after cutting.

3.2. Remote handling test of the cut out machine

The capability to carry out the cutting procedure remotely is also essential to the cut out machine development. The radiation level of test pieces is very high and the test pieces can not be handled by hands-on. Therefore, the actions, such as setting of the cut out machine on the target exchange trolley, replacement of the hole saw, taking out the test pieces from the hole saw, etc., have to be operated by remote handling using the in-cell crane and the MSM. It is necessary to confirm by tests that all the remote handling operations can be conducted smoothly.

The cut out machine was tuned in the preliminary test in the manufacturer factory. The cut out machine was then brought in the hot cell of the MLF. All the remote handling operation were

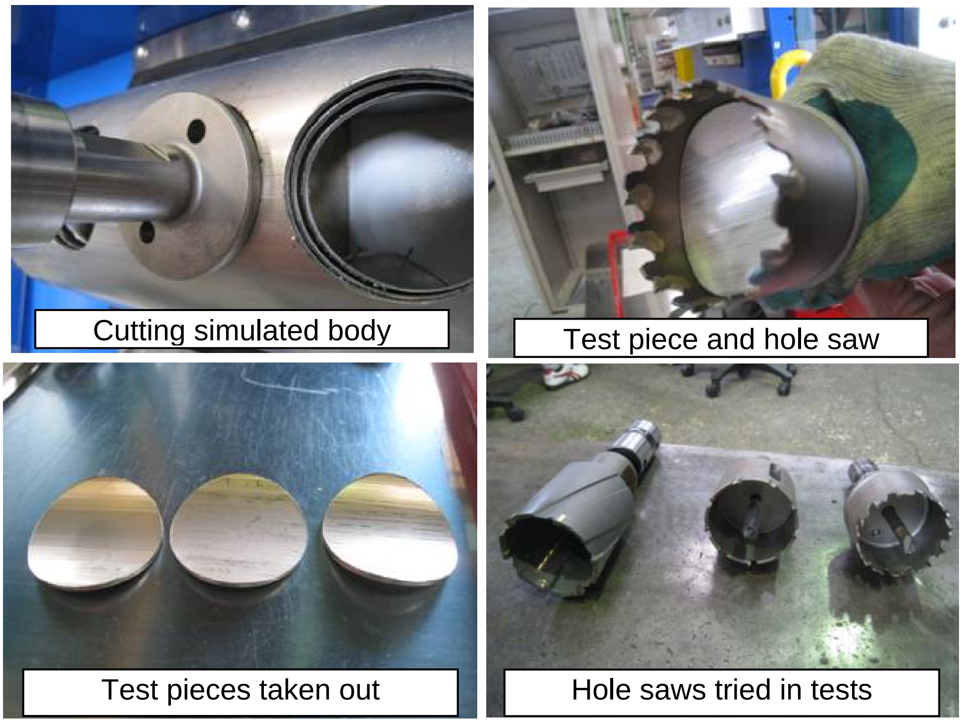

Figure 6. Photos of cutting tests

Figure 7. Photos of remote handling test in the hot cell

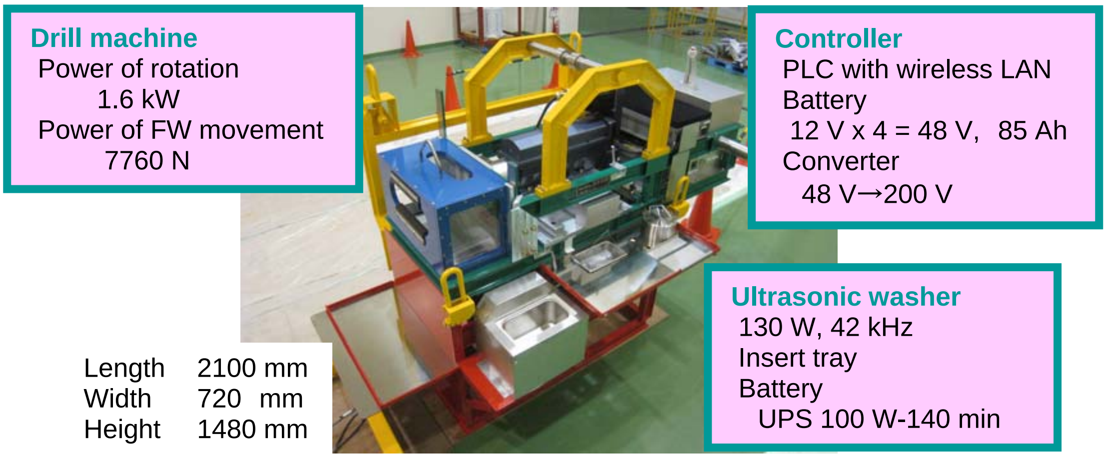

Figure 8. Specifications of the cut out machine

rehearsed using actual devices in the hot cell, such as the in-cell crane, the MSM, the target exchange truck, etc. It was confirmed that all the operations by remote handling were performed without any problems.

In conjunction with the remote handling tests in the hot cell, the wireless control tests for the cut out machine operation were carried out at the actual operating position. The drill machine control and the lateral moving device driving could be operated from the control panel outside the hot cell.

The photos of the remote handling tests in the hot cell are shown in Figure 7.

4. Cutting operation

The photo of the completed cut out machine and its specifications of the main components are shown in Figure 8. As shown in the figure, the actual machine is almost the same as the image drawing (Figure 4). But the battery connector for charger was changed to a coupler type connector to prevent short circuit. The battery capacity was determined from the cutting time and the power of the drill machine. The display for battery voltage was installed to show the information on the remaining power during the cutting out.

The photos of the cutting operation and the retrieved test pieces are shown in Figure 9. At the first attempt, the cutting was carried out smoothly. The cutting was stopped at the time when the drill had moved forward by the programmed amount of distance. It looked that the cutting out was successful. After transferring the cut out machine back to the mounting rack, the test piece from the most inner wall (the mercury vessel wall) was not found in the hole saw. Therefore a new hole saw was attached and another cutting out operation was carried out at the same point of the target vessel. The third wall

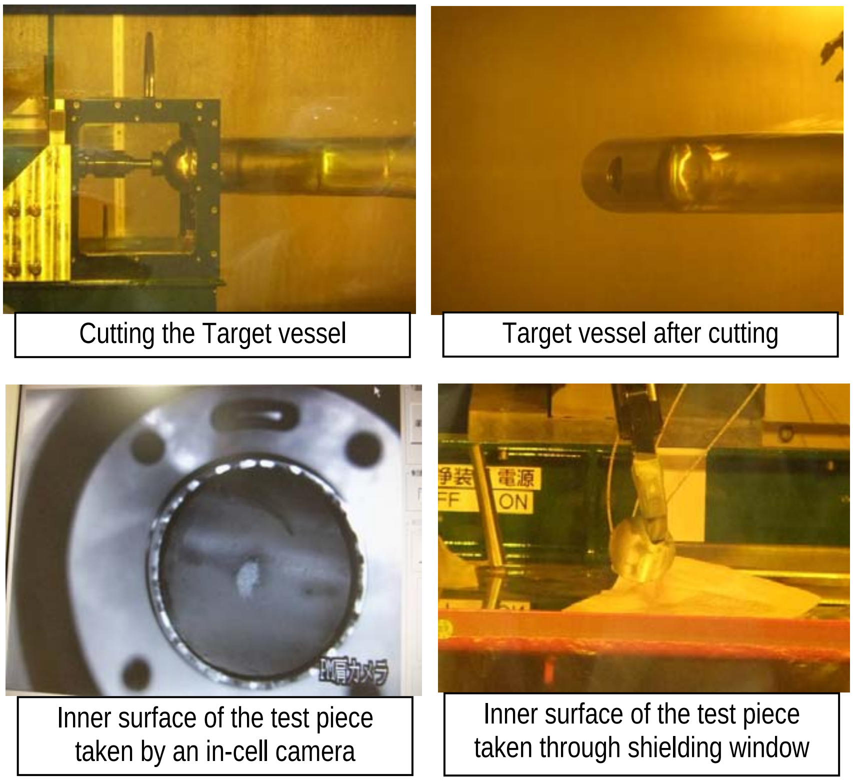

Figure 9. Photos of cutting operation and retrieved test pieces

could be then cut out from the target vessel. The photo of the inner surface of the test piece from the mercury vessel was shown in Figure 9, which was taken with an in-cell camera. In the center area, the mercury was left stuck. Also in Figure 9, the photo of the test piece after ultrasonic washing taken through shielded (lead grass) window is shown. The surface looked rough, but it was confirmed that there was no larger pit than estimated value.

5. Summary

All the works of cutting operation of the target vessel succeeded. The test piece was cut out from the proton beam window of the target vessel. The inner surface of the mercury vessel was observed and small pitting damage was confirmed. But it seems that the pitting damage did not exceed our estimation.

The cut out machine will be improved for coming operation, taking accounts of the issues identified during the first operation. It is also important that the operation scenario is considered in case of unscheduled replacement of the target vessel. PIE for other neutron source components, moderators and a proton beam window, will be carried out to get useful information for more reliable lifetime estimation. Therefore a cut out machine for the moderators and the proton beam window will be designed and tested.

6. Reference

[1] McClintock D A, Ferguson P D and Mansur L K 2010 Post-irradiation examination for the Spallation Neutron Source target module *J. Nuclear Materials* **398** 73-80