Completion of Equipment for the Materials and Life Science Experimental Facility at J-PARC

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1. Introduction

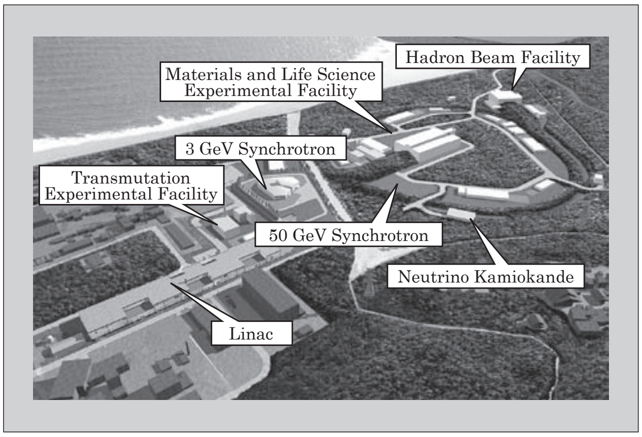
The Japan Proton Accelerator Research Complex (J-PARC) being constructed at the Tokai Research and Development Center's Nuclear Power Scientific Research Lab by the Japan Atomic Energy Agency (hereafter referred to as JAEA), an independent administrative agency, in Tokai Mura, Ibaraki Prefecture, Japan, is a research facility where neutrons and other secondary particles (mesons, neutrinos, muons, etc.), generated when the world largest-class high intensity proton beam is aimed at a target, are used to conduct research in various fields such as life science, materials science, atomic nuclei and elementary particles, astrophysics and energy research. Figure 1 shows an image of the completed facility.

The equipment that configures the Material and Life Science Experimental Facility was designed by JAEA, and from the design to manufacturing and installation stages of the construction, each part was procured through a competitive bidding process. The target and surrounding moderator pipes become highly radioactive due to the strong proton and neutron irradiation, and must be exchanged at intervals ranging from a half-year to several years. Fuji Electric has received orders for the design, manufacture, installation and adjustment of three types of relevant equipment: a target trolley for installing and moving a mercury target, moderator-reflector remote handling devices for exchanging moderator pipes, and irradiated component storage facilities for storing the mercury target and moderator pipes after having been exchanged.

This equipment is required to support remote handling and highly accurate interfaces between devices. Leveraging its remote handling technology which has been acquired over many years, from 2002 to 2007 Fuji Electric designed devices suited for remote operation, established interface conditions among equipment to be linked, and conducted comprehensive combination tests and performed installation and adjustments.

This paper introduces an overview of the aforementioned three types of equipment and describes their design, manufacture and testing.

Fig.1 Full-view of J-PARC (image of completed facility)



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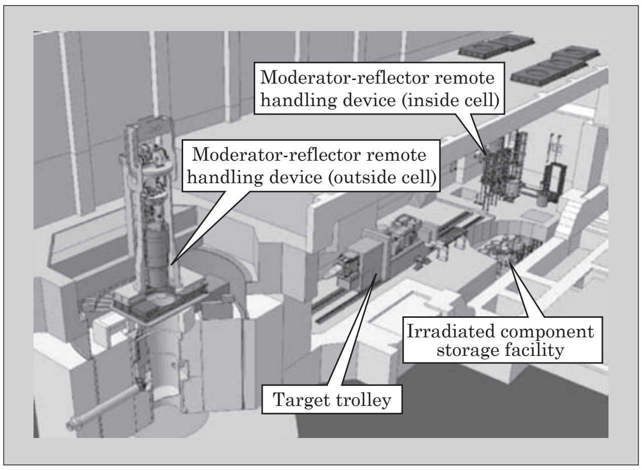
2. Equipment Overview

Figure 2 shows a schematic diagram of the three types of equipment, i.e., the target trolley, moderator-reflector remote handling devices and irradiated component storage facilities that are introduced herein.

2.1 Target trolley

Attached to the front of the target trolley is a tar-

Fig.2 Schematic of three types of equipment



get vessel which, when caused to collide with a beam from a high intensity proton accelerator, emits neutrons through a spallation reaction. The target trolley moves the target vessel between an operating position and a remote exchange position. The position of the target vessel during operation has a large effect on the neutron performance. The position accuracy for target trolley is required to insert the target vessel between a reflector and a moderator. Additionally, a function for shielding radiation rays emitted from the spallation reaction part inside the helium vessel and a function for supporting a 300 kN pressing force in order to maintain a sealed condition with the flange surface of the helium vessel are also requested.

The entire trolley, including the target vessel, has a total length of approximately 14 m, a height of approximately 4 m, and because a heavy shield is placed on the trolley, a mass of approximately 300 t. The drive function of the trolly is a rack and pinion system, and the trolley travels with a linear roller-way on an exclusive trajectory . The stopping accuracy in the forward and reverse directions is within ± 1 mm. The rear of the trolley is equipped with a mercury circulation system, tank, piping and the like for circulating mercury within the target vessel.

2.2 Moderator-reflector remote handling device

The moderator-reflector remote handling device operates remotely to take out such components as the reflector and moderator installed inside the helium vessel, the proton beam window that forms a boundary between the helium vessel and the proton beam line, and the like with the plug still attached, and then to exchange the components such as the moderator and proton beam window. Because these components are highly radioactive, they are collected in a shielded transfer cask, and then transferred to a hot cell where the component exchange operation is carried out.

A support stand whose orientation can be changed accurately and that supports an inner plug, an outer plug and the proton beam window exchange plug, and a moderator exchange device that can attach and detach moderator piping and the proton beam window through remote operation are provided in a hot cell. Additionally, floor valves for opening and closing 1.9 m-diameter passage openings are provided at five hatches located on the outside of the hot cell ceiling.

2.3 Irradiated component storage facility

The irradiated component storage facility is configured from various devices relating to the handling of irradiated components, such as an in-situ cutting device for cutting to reduce the volume of the moderator piping and the proton beam window that have been removed from their respective plugs by the moderator-reflector remote handling device, a storage facility primarily for the purpose of temporarily storing irradiated components that are planned to place in an irradiated component storage chamber beneath the hot cell, and a target vessel exchange device that performs supplemental tasks while the target vessel of the target trolley is being exchanged.

The cutting device is a shear-cutting type, and is requested to have the capability for cutting mostly 90 mm-diameter multi-layered pipes. The storage facility is equipped with a dedicated storage pit or frame structure. The target vessel exchange device aligns itself with the attaching part at the tip of the target trolley, and holds, transfers and receives the target vessels.

3. Device Design

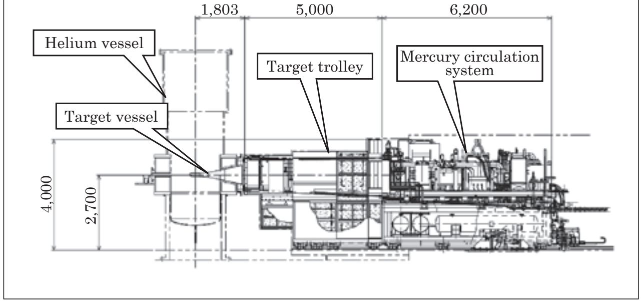
3.1 Target trolley

The target trolley is provided inside a hot cell as shown in Fig. 3, and is equipped with a large shield block that shields radiation rays emitted from the spallation reaction in the helium vessel. So that shield blocks can be assembled and dismantled by an in-cell crane, each shield block weighs less than 20 t and is aligned with vertical pins and stacked.

The building's shielded wall is provided with a rectangular-shaped penetrating part through which a target trolley attached with a target vessel can advance toward the helium vessel. In order to provide reliable shielding for the hot cell side, the gap between the shield and the penetrating part must be limited to 20 mm or less. In consideration of the manufacturing error in both the shield and penetrating part, and in order to maintain this gap across the 4.5 m insertion length for an opening of 2.6 m width × 4.0 m height, the outlines of all stacked shield blocks are pre-formed with a smallish size. In accordance with the finished dimensions on the building-side, a plate-shaped shield for adjusting outline dimensions is bonded over the entire surface of the shield block in the finishing method for the final dimensions, and the requested gap accuracy is achieved.

The target vessel must be exchanged every half-year because of radiation damage, and is bolted to the target trolley at the flange part. The two pipes from the mercury circulation system are connected by inserting the tool at the tip of a power manipulator into the attaching portion inside the tip of the target trolley,

Fig.3 Target trolley



and remotely operating the connection mechanism provided with the target vessel. Because the bolt coupling part of the target vessel flange and the bolt coupling part of the power manipulator insertion sealed flange are frequently screwed and unscrewed, exchangeable implanted screw fittings were used to prevent damage to the screw holes on the target trolley side.

Moreover, parts requiring maintenance or exchange, such as the drive device, mercury piping coupling part, and the wiring coupling part for power and instrumentation, all have a structure that enables removal or attachment operations to be implemented remotely using a power manipulator, master-slave manipulator and cranes.

3.2 Moderator-reflector remote handling devices

Moderator-reflector remote handling devices are classified as either hot cell-external devices or hot cell-internal devices. In the case of a hot cell-external device, the transfer cask shown in Fig. 4 is provided for removing the moderator-reflector plug from the helium vessel or the proton beam window plug in the forward direction of the beam.

The transfer cask is a cylindrical structure having an inner diameter of 1.9 m and a height of 11 m. The lower part of the transfer cask's cylindrical body is completely surrounded by a 290 mm-thick shield, and when housing the heavy moderator-reflector assembly (mass 36 t), the total mass becomes 130 t. The transfer cask is provided with a gripper and elevator, and with the plugs having been lowered into and housed in the transfer cask, a ceiling crane transports the transfer cask to a floor valve passage opening at a predetermined location on the hot cell, and lower the moderator-reflector assembly into the hot cell.

The gripper has a rotary-type claw capable of grabbing both inner and outer plugs or inner plugs only of the moderator-reflector assembly having a concentric cylinder shape with internal and external parts, and is provided with a vertical stroke of 35 m so as to be able to reach the deepest part of the irradiated component storage facility.

As shown in Fig. 5, inside the hot cell, an inner plug support stand and an outer plug support stand are provided, and the plugs are lowered onto these support stands. Moderator piping that is affixed to the plug, or the proton beam window, is rotated precisely to the appropriate required direction for exchanging operations with the moderator exchange device.

The moderator exchange device has a function for moving the entire assembly in the forward, backward, left and right directions and a function for raising, lowering and rotating a mechanism for coupling to an adapter for the moderator piping, and performs removal or attaching operations in conjunction with the power manipulator. When installing the moderator piping, a secure fit at the predetermined location is verified by a video image, and the pressing force is controlled by attaching a load sensor to ensure that an excessive force is not applied.

Fig.4 Transfer cask and object to be handled

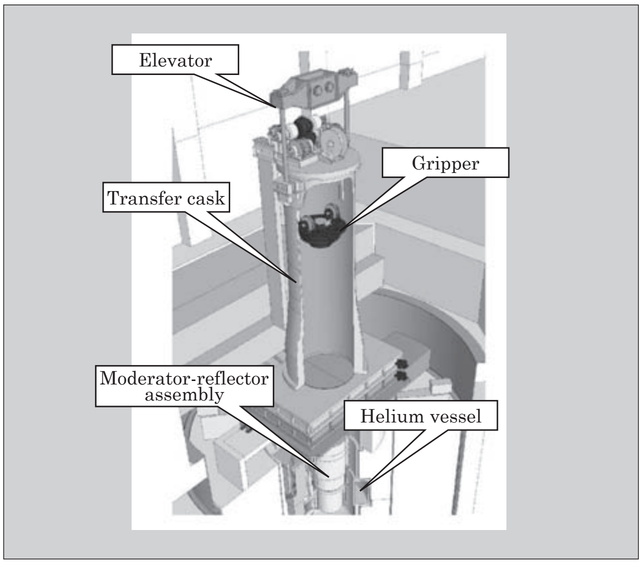
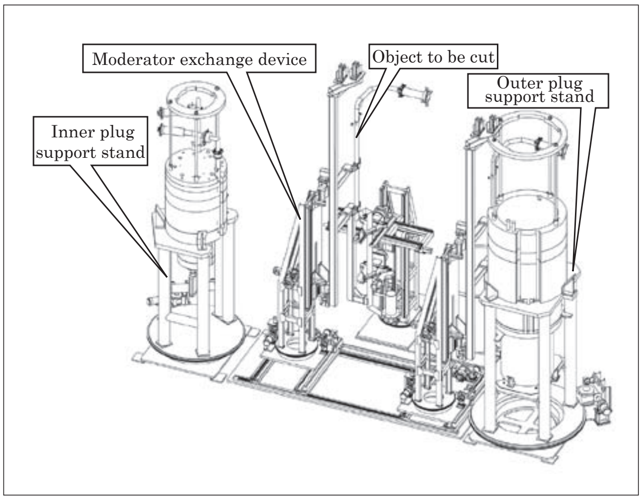


Fig.5 Configuration of hot cell-internal device



The moderator piping and proton beam window that have been removed are transferred to the cutting device of an adjacent irradiated component storage facility.

This series of operations is implemented from an operator panel outside the hot cell and is verified visually from a shield window and by using radiation tolerant cameras attached to the walls, floor, in-cell crane, and the power manipulator inside the hot cell.

3.3 Irradiated component storage facility

The cutting device is a shear cutting type, and the cutter is combined with two grippers for changing the cutting position by vertically feeding the object to be cut. The cutting device also has a function for rotating the entire device to change the orientation of the grippers and the cutter to two positions: the position of the cutting work and the transfer position of moderator

Fig.6 Cutting device

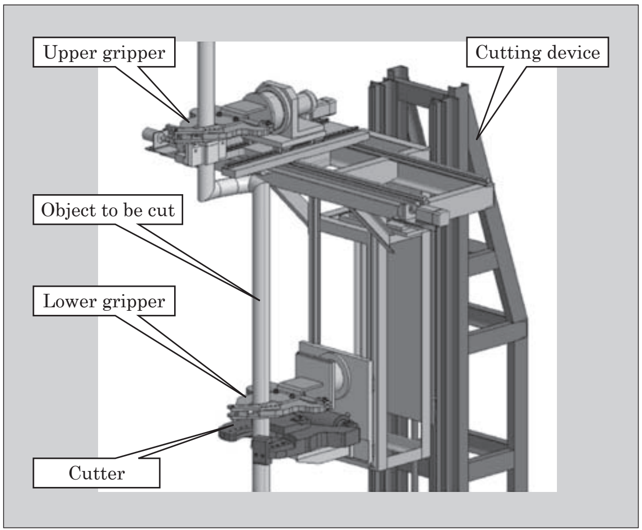
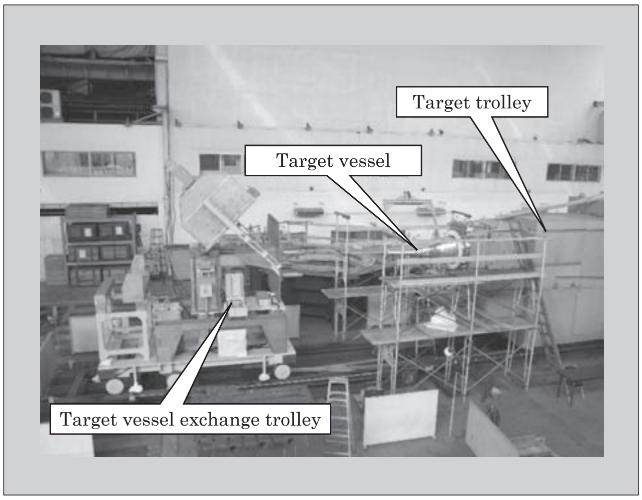


Fig.7 Comprehensive factory assembly test of target trolley



exchange device

The shear cutter, as shown in Fig. 6, operates by holding the object to be cut from the outside and cutting toward the inside, and is designed such that the object to be cut does not protrude outside the shears. The objects to be cut can have a wide range of diameter, ranging from 64 to 100 mm, and as in the case of the shear cutter, since the object to be cut is inserted on the inside between the gripping mechanisms, it will be secured at a predetermined location inside, regardless of its shape and dimensions.

The storage facility is configured from a variety of structures for storing irradiated components, such as the target vessel, moderator-reflector assembly, proton beam window exchange plug, muon target plug, and so on. So that of these objects to be stored or the moveable structures inside an irradiated component storage chamber can be handled by the hoisting attachment of an in-cell crane only, the shapes of the handling parts on the object side are standardized to appropriate uniform shapes.

The target vessel exchange trolley is arranged at the front of the target trolley in a hot cell on the upper stage of the irradiated component storage chamber when the target vessel is being exchanged, and while oriented to receive the target vessel, waits for completion of the bolt loosening by the power manipulator. After the removed target vessel has been received, a new target vessel is received and the orientation reverts to that prior to removal, and this orientation is maintained for the duration of the attaching work by the power manipulator.

4. Factory Tests

In factory tests, the performance of each of the aforementioned three types of equipment was verified using simulated objects. To test the operation of each type of equipment operating in conjunction with other equipment, the equipment was arranged under quasi-actual conditions and operation was implemented in conjunction with another equipment. Details that verify certain demonstrated performance parameters and tests to verify the cutting capability of the cutting device are described below.

4.1 Comprehensive factory assembly test of target trolley

Within the facility, the target trolley operates with a combination of target vessels and mercury circulation systems that have been manufactured in response to separate orders from multiple companies. Prior to being delivered onsite, factory test processes are adjusted for each company responsible for manufacturing, the target vessels and mercury circulation systems are collected and assembled together at Fuji Electric's Kawasaki Factory, and comprehensive factory assembly tests are conducted to verify their combined performance.

After having been put into operation, to verify the ease of remotely attaching and removing the target vessel at a frequency of once every 6 months, the assembled target vessel exchange trolley of the irradiated component storage facility was set up as shown in Fig. 7, the remote operation was simulated using the actual procedure and sequence, and adequate functionality was verified. The performance of the seal at the junction between the target vessel and the target trolley, having been attached using the above series of operations, was confirmed to be adequate.

On the other hand, the target vessel also required to maintain a tight seal with the helium vessel securely attached inside the facility. In this case, in order to assess the seal performance, a pressing force of 300 kN on the seal material is needed; the target trolley is requested to have a function for supporting the reactive force of this seal, and the accompanying rail equipment includes an anchoring apparatus to hold down the entire trolley. In a comprehensive factory assembly test, a simulated helium vessel flange was tightly secured to the test rail, and a series of actions were implemented, i.e., the target trolley was advanced in the forward direction, pressing force was generated due to the seal mechanism. The reaction force of the seal of the target trolley was supported, and the requested level of performance was verified for each action.

4.2 Cooperation between moderator exchange device and cutting device

The moderator exchange device of the moderator-reflector remote handling device and the cutting device of the irradiated component storage facility are arranged adjacently in the hot cell, and the moderator piping and the proton beam window removed by the moderator exchange device are delivered to the cutting device.

In the factory test, the stand-alone performance of each device was tested, and as shown in Fig. 8, both devices were installed in the same positional relationship as in an onsite installation, and using a simulated cutting object, the smooth performance of the actual cooperating operation was verified, and positioning data and operational performance data were acquired at that time for each device.

Fig.8 Test of moderator exchange device and cutting device

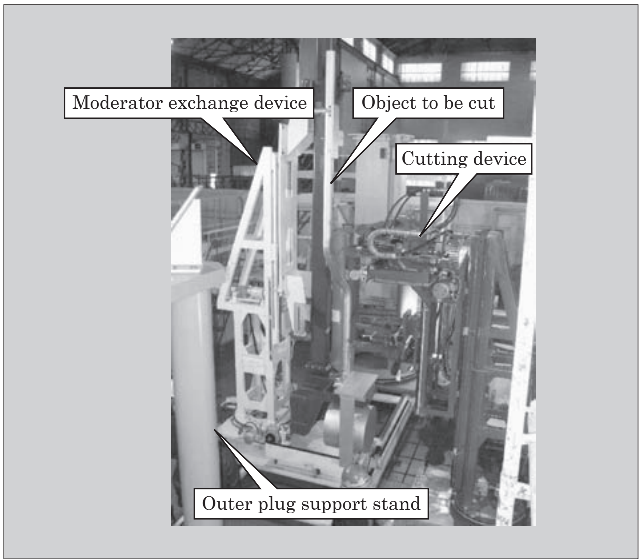
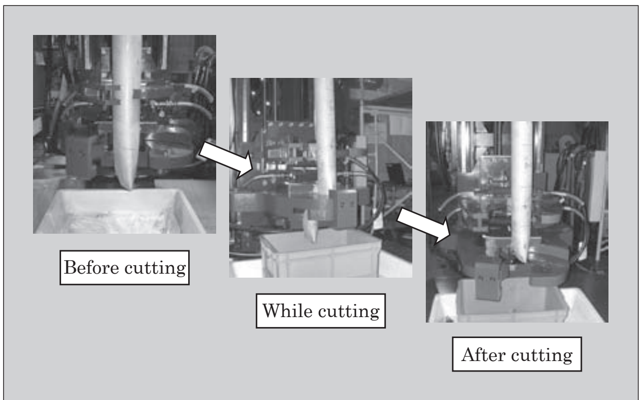


Fig.9 Cutting capability verification test



4.3 Cutting performance verification test of cutting device

On the cutting device, a custom cutting blade is attached to the shearing part, and the moderator piping is cut to a short length of approximately 1 m. To obtain data of the exchange frequency for the cutting blade, test objects were fabricated and a cutting test implemented based on actual operation plans.

A six-year supply of cutting test objects that simulate a muon target that is exchanged every 6 months, a proton beam window that is exchanged every 2 years and moderator piping that is slated to be exchanged once in 6 years were fabricated, and cutting was performed continuously with a single blade until an abnormality was observed in the blade tip.

Cutting was performed 49 times in total. The test objects prepared as entire 6-year supply were cut without any chips or cracks occurring in the cutting blade. This result verifies the adequate durability of the cutting blade.

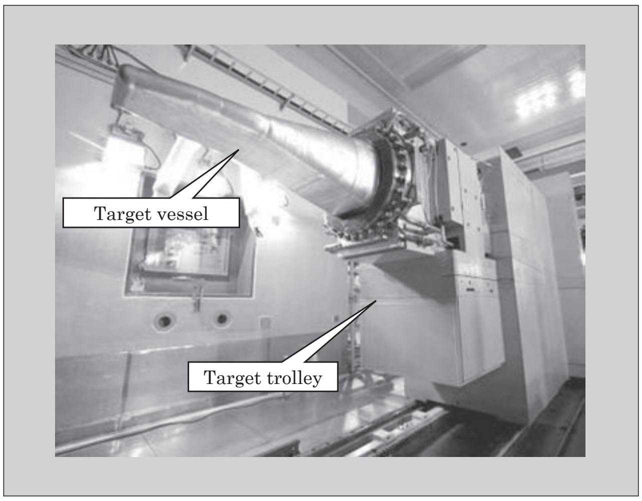
Figure 9 shows the appearance of the cutting test.

5. Onsite Installation and Assembly Test

5.1 Target trolley

A target vessel approximately 1.8 m long at the tip of the target trolley must be inserted between the moderator and reflector which are mounted inside the helium vessel, with no more than a 5 mm deviation in the vertical and horizontal directions. After the target trolley has been installed on an onsite rail, and using a separately installed helium vessel as a reference, dimensional measurement, jack-up and liner insertion operations are performed repeatedly to adjust its position. This method is being considered and prepared based on the progress of the factory assembly test, and settings within the targeted accuracy could be realized by following the procedure exactly as specified. However, since the location of interest was narrow and could not be verified directly, a tape-type contact sen-

Fig.10 Target trolley after completion of onsite installation



sor having a thickness of 2.3 mm was adhered onto the surface of the target vessel, and by inserting the target vessel carefully while verifying that it does not contact the surrounding periphery, we ultimately verified that there were no interfacing problems. Figure 10 shows the target trolley after completion of the onsite installation.

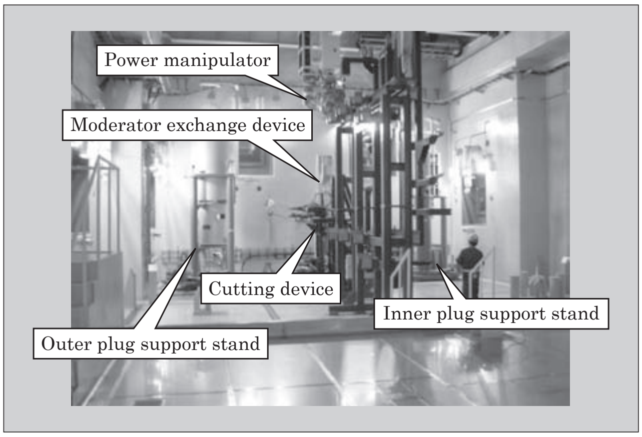
5.2 Moderator-reflector remote handling device and irradiated component storage facility

Devices internal to the hot cell of a moderator-reflector remote handling device and irradiated component storage facility were installed so as to reproduce the configuration of the aforementioned factory test. Figure 11 shows the installed state inside the cell.

In an assembly test after all devices have been installed, the transfer cask outside the hot cell is mounted on the top of the helium vessel, and the moderator-reflector assembly and proton beam exchange plug are removed and lowered into a temporary storage location of the irradiated component storage facility and then delivered to the devices inside the hot cell, and the predetermined positioning accuracy and the presence of a vertical stroke were verified.

Inside the hot cell, as a result of cooperative operation between the plug support stands and moderator exchange device and the hot cell-inner equipment of the in-cell crane and power manipulator, we verified based on visual observation from outside the hot cell and from monitoring camera image and operating signals that the moderator piping and the proton beam window could be removed and attached via remote operation.

Fig.11 Onsite installed state of devices in the hot cell



6. Postscript

All the devices designed and fabricated for the J-PARC Material and Life Science Environmental Facility are required to be remotely operable and maintainable. Because other devices are also related both structurally and operatively, cooperative tests were carried out at the factory test stage and onsite installation test stage, and the design and performance of each device were verified to be adequate for the entire facility.

Finally, the authors wish to express gratitude to the concerned parties at JAEA for the tremendous amount of guidance received in the design, fabrication and testing of the target trolley, moderator-reflector remote handling device and the irradiated component storage facility.