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This report introduces the present design status of remote-handling devices for activated and used components such as moderator and reflector in a spallation neutron source of the Material and Life Science Facility (MLF) at J-PARC (Japan Proton Accelerator Research Complex). The design concept and maintenance scenario are also mentioned. A key maintenance scenario adopts that the used components should be taken out from the MLF to the other storage facility after the volume reduction of them. Almost full remote handling is available to the maintenance work except for the connection/disconnection pipes of the cooling water. Remote handling for the cooling water system is under designing and it will be prepared before being significant radiation dose by accumulation of beryllium (^{7}Be) in future. Total six remote handling devices are used for moderator-reflector maintenance. They are also available to the proton beam window and muon target maintenance. Maintenance scenario is separated into two works. One is to replace used components to new ones during beam-stop and the other is dispose used components during beam operation. Required period of replacement work is estimated to be ~15 days, on the other hand, the disposal work is ~26 days after dry up work (~30 days), respectively. Study of the maintenance scenario and the remote handling design brings about the reasonable procedures and period of the maintenance work.

Keywords : Remote Handling Design, Remote Handling Device, Maintenance Scenario, Moderator, Reflector, Spallation Neutron Source, J-PARC

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JSNS モデレータ-反射体保守用遠隔操作機器の設計

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J-PARC の物質・生命科学実験施設に設置する核破砕中性子源の建設が進められている。その中心部に設置されるモデレータや反射体は、放射線損傷により定期的に保守を必要とする。設置される機器の保守に必要な遠隔操作機器の設計概念並びに保守シナリオの検討の現状をまとめた。使用済みモデレータや反射体は、減容した後、施設外に運び出し保管する。この計画に従って遠隔操作機器の設計を行った。保守作業は、配管の着脱等の一部人手による作業を除いて、すべて遠隔操作によって行う。配管の着脱作業については、ベリリウム（^{7}Be）の蓄積のため、将来的に配管接続部に遠隔化を図れる構造とした。６台の遠隔操作機器が必要となり、モデレータや反射体以外に陽子ビーム窓やミュオンターゲットの保守にも対応する。保守のシナリオは、使用済み機器の交換作業及び保管作業からなる。前者は、運転停止中に行う。運転停止期間を可能な限り短くするため保管作業と分離した。これら保守に必要な日数を見積もったところ、交換作業は約１５日程度必要となり、保管作業については、乾燥作業（約３０日）後に、約２６日程度となった。

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1. Overview of Moderator-reflector Maintenance

The world largest spallation neutron source facility is now under construction as one of the main facilities of "Material and Life Science Facility (MLF)" at the Japan Proton Accelerator Research Complex (J-PARC)[1,3]. The main part of the spallation neutron source consists of a target, moderators and reflector as shown in Fig. 1.1. These components will be activated and damaged through the beam operation. Then, their lifetimes were also estimated[4]; a target, moderators, and reflector are ~ 0.5, 6 and 6 years, respectively. These used components (target, moderator, reflector, etc.) will be finally taken out from the MLF after replacement. The point is how safe maintenance should be implemented for such components after the beam operation. This report mainly focuses on the moderator-reflector maintenance; target maintenance will be mentioned in the other report.

The moderator-reflector assembly consists of 3 moderators[5] (coupled, decoupled and poisoned liquid hydrogen (L-H_2) moderators), reflector, outer plug and inner plug as shown in Fig. 1.2. Moderators are composed of multi-layered vacuum insulated pipes with a curved shape (outer diameter of ~90 mm and length of ~4 m), made by aluminum (Al) alloy and stainless steel. The reflector, which is enclosed in Al container (1 m in diam. and 1.2 m in height), consists of beryllium (Be) inside and iron (Fe) outside. The weight of moderator and reflector is ~ 0.3 and 5 ton, respectively. The assembly is composed of two parts such as the inner and the outer assemblies as shown in Fig. 1.2. The outer assembly combines the coupled L-H_2 moderator, reflector and outer plug (~15 ton) by using the bolts and positioning pins, and the inner assembly combines the poisoned and unpoisoned L-H_2 moderators, and inner plug (~15 ton) by using the bolts and positioning pins. The inner assembly can be inserted into the outer assembly in the vertical direction using the positioning pins as shown in Fig. 1.2. Total weight of the assemblies is ~36 ton.

We provide an irradiated-components handling room (hot-cell) for the maintenance of used components neighboring the target station as shown in Figs. 1.4-1.6. Large components handling room (high bay) with a 65 and 130-ton ceiling crane is located on the hot-cell through hatches and floor valves. The used moderator-reflector assembly is transferred to the hot-cell using a transfer cask. An irradiated-components storage room and a dry up room are also prepared downstairs hot-cell to storage them temporarily and to dry up the remaining water inside of them. These rooms are connected to the hot-cell through the bottom hatches. Maintenance of the used moderator-reflector assembly is performed in the hot-cell. Four dedicated remote control devices, namely inner and outer plug support stands, moderator exchange device, cutting device, are installed in the hot-cell. And the following maintenance devices are prepared, 20-ton in-cell crane, a power manipulator and 11-pair master-slave manipulators in the hot-cell, and 12-ton in-cell crane in the irradiated components room. Two pairs of the lead loaded glass window together with master-slave manipulators are arranged at the wall of the hot cell with different height in order to improve visible maintenance operation as shown in Fig. 1.5. The outer and inner plug support stands are installed at the corner of the hot-cell near the lead loaded glass window. The moderator exchange device is equipped between the outer and the inner plug support stands to approach easily as shown in Figs. 1.5 and 1.7. Here, the brief maintenance scenario is shown;

(1) Disconnection of water pipes at the vessel

(2) Transportation of the moderator-reflector assembly from the vessel to the dry up room using 130 ton crane and transfer cask

(3) Drying-up of remaining water inside of the used components

(4) Transportation of the assembly from the dry up room to the hot-cell

(5) Replacement of the assembly in the hot-cell

(6) Transportation of a new moderator-reflector assembly from the hot-cell to the vessel

(7) Installation of a new moderator-reflector assembly.

(8) Temporal storage of the used components

(9) Transportation of them out of MLF

Remote control devices are designed according to the moderator-reflector maintenance scenario shown in the above. The design concept of remote control devices and detailed maintenance scenario are introduced in the following chapter.

2. Maintenance Concept and Consideration of Safety Handling

First, the following key concepts are determined;

(1) “Confinement” to prevent from spreading the radioactive materials

(2) “Shield” to reduce the radiation dose during the maintenance work

The radiation dose is commonly defined to be less than 12.5 μSv/hr out of shield (e.g. out of hot-cell). However, the radiation dose at the place such as the vessel top and the surface of transfer cask, where hands-on maintenance is required, is evaluated to be 0.1 and 1 mSv/hr, respectively so that rad-worker can access in a limited time.

(3) Vertical access to the moderator-reflector maintenance

Since the lifetime of the target (~0.5 years) and the moderator-reflector (~6 years) are different, the moderator and reflector can be accessed in the vertical direction (upper side of vessel top) and the target is in the horizontal. For the maintenance and accessibility, the target component is directly connected to the hot-cell in horizontal direction as shown in Fig. 1.4.

(4)Replacement per unit

The moderator-reflector assembly is separated into the inner and the outer assembly as mentioned in Fig. 1.2. The inner one can be selectively transferred to the hot-cell using a cask without whole component (moderator-reflector assembly) transfer, resulting in the reduction of unnecessary waste and shortening the maintenance period.

(5) Full remote control maintenance

The maintenance of the moderator and reflector adopts full remote control in the hot-cell.

(6)Partial hands-on maintenance

Connection/disconnection for cooling water pipes and hydrogen transfer couplers on the vessel top plans hands-on work. In pipe connection/disconnection work on the vessel top, main contribution of radiation dose is considered to be internal exposure from the tritium (T) in the cooling water, external exposure from ^{7}Be produced by the spallation reaction of oxygen in the cooling water and from activated materials caused by the beam operation. Measures for preventing from the internal exposure are as follows (see Fig. 2.1);

(i)Drain cooling water by blowing helium gas before the piping disconnection work,

(ii)Releasing the pressure inside cooling-water-pipe to prevent from water splash, and

(iii)Local exhaust and getting on the glove bag for the cooling water pipe disconnection.

To mitigate external exposure, pipe connection/disconnection work should be done in short time. Easy accessible piping layout and simple structure for connection/disconnection are necessary to prevent from excessive exposure. However, accumulation of ^{7}Be for long period of beam operation will make the hands-on maintenance difficult. Therefore, the design that enables remote-control piping connection should be required.

(7)Transportation by the transfer cask

The used moderator-reflector assembly, which is put into a transfer cask with required shield (surface dose rate: less than 1 mSv/hr), is transferred from the vessel to the hot-cell by using 130-ton ceiling crane. Main contribution of radiation dose in a used moderator-reflector assembly is from a silver-indium-cadmium (Ag-In-Cd) alloy that is used as a thermal neutron absorber of decupled, poisoned moderators, and reflector. The iron with at least 30-cm thickness is required as the shield to reduce the dose rate of less than 1 mSv/hr due to the gamma ray of ^{110m}Ag as shown in Fig. 2.2. The dose rate does not reduce for 2-3 weeks maintenance period due to relatively long half-life ($T_{1/2}$ = 250 days).

(8)Replacement work in a hot cell

Replacement work in the hot cell is performed by full remote control. Accordingly the full remote-control is available for the moderator-reflector and other components such as the target, proton beam window and muon target in the hot-cell[6, 7].

(9)Cutting device

A cutting device is installed in order to transport the used components out of the MLF. The cooling water pipe will be cut by using this device so as to reduce its volume (except for the target container). The dry-up room is provided below the hot-cell where the remaining water of the inside components will be dried up before the cutting work. This process will prevent unnecessary contamination from T.

3. Maintenance Device for the Moderator-reflector

Following design strategies are determined;

(1)Multiple protections: Double wire system is adopted for the lifting tools, manual-operation is available for the failure of the remote-control devices, and maintaining the condition before power supply loss

(2) Earthquake-resistant: 0.25G

(3)Radiation resistant: 1 MGy for the devices. The design dose means no need of maintenance within the lifetime of MLF. For the airtight, EPDM rubber is adopted because of radiation resistant with several MGy.

(4)Negative pressure in hot-cell: -230Pa to prevent from spreading the activated gases and materials such as Hg vapor, water vapor with T, etc.

The following sections introduce to the remote-handling devices that are provided in the maintenance.

3.1 Out-cell Device

Out-cell devices consists of the transfer cask and the floor valve

3.1.1 Transfer Cask

A transfer cask has a gripper for the lifting and a shield door at the bottom part as shown in Fig. 3.1. The gripper with the rotation mechanism can lift up the inner or the outer assembly. The 130-ton ceiling crane can convey the transfer cask including the used moderator-reflector assembly. The surface dose rate of the transfer cask with the used assembly is designed less than 1 mSv/hr as mentioned in Fig. 2.1. The necessary shield thickness is calculated to be about 30 cm at maximum. Total transfer cask weight including the used assembly is about 125 ton at maximum. The transfer cask has only shield function without airtight. Installation of the transfer cask is performed by hands-on work using the 130-ton ceiling crane. Figure 3.2 shows the installation of the transfer cask on the vessel. Shield blocks are removed before installation of the transfer cask. The transfer cask is fixed on the floor valve with bolts and positioning pins. The design dose rate on the vessel is assumed to be ~100 μSv/hr without distribution of ^{7}Be. In order to convey it with the 130-ton crane, the connection attachment is provided, which can detach and attach between the transfer cask and the crane hook. This connection attachment is installed by hands-on. The shield blocks are arranged so as to remove only required area. Some shield blocks at center region are removed for the moderator-reflector maintenance. Same shield block removal is adopted in case of the proton beam window maintenance. Without removal of all shield blocks, the maintenance work can be done, resulting the shortened maintenance period.

3.1.2 Floor Valve

Figure 3.3 shows the floor valve that has a function to connect the transfer cask to the inner and outer assembly, to airtight and to shield gamma ray from the vessel. At the maintenance, the valve is installed on the vessel by hands-on before installing the transfer cask. Five floor valves are prepared on ceiling of the hot-cell to connect the transfer cask.

3.2 In-cell Device

In-cell devices consist of four devices such as an inner and an outer plug support stand, a moderator exchange device, and a cutting device as mentioned in Fig. 1.6. Those in-cell devices are used to exchange the spent moderator and reflector with new ones with the power manipulator, master-slave manipulators and an in-cell crane that are also installed in the hot-cell.

3.2.1 Outer Plug Support Stand

An outer plug support stand is used for the replacement of the coupled moderator and the reflector. This equipment has a function to rotate and to support the outer assembly as shown in Fig. 3.4. The used outer assembly with the inner assembly is transferred through the hatch on the outer plug support stand. It is lifted down and attached to the outer plug support stand. In case of the coupled moderator replacement, the coupled moderator attachment as shown in Fig. 3.5 is attached to the coupled moderator using the power manipulator and the in-cell crane. The moderator exchange device approaches and holds it. After removing the fixed bolts of the coupled moderator by the power manipulator, the coupled moderator with this attachment can be removed from the outer plug support stand by using the moderator exchange device. In the case of the reflector replacement, after transferring the coupled moderator to the temporal storage rack (see Fig. 1.5) and the inner assembly to the inner plug support stand, the fixed bolts are removed between the reflector and the outer plug. Then, the outer plug is stored into the transfer cask. The reflector is carried to the temporal storage area by using the in-cell crane. New reflector is transferred from the temporal storage area to the outer plug support stand by using the in-cell crane.

3.2.2 Inner Plug Support Stand

An inner support stand is used for the replacement of two decoupled moderators, which are combined the inner assembly. This device can support the inner assembly with the two decoupled moderators and can rotate it. The moderator exchange device can remove decoupled moderators after attaching the decoupled moderators attachment. The inner plug support stand can also handle a muon target or proton beam window by exchanging the dedicated attachment for each component on the inner plug support stand as shown in Fig. 3.6.

3.2.3 Moderator Exchange Device

This device can approach and hold the moderators, the proton beam window or the muon target with each attachment as shown in Fig. 3.7. This device can rotate and move in vertical and horizontal. But, it does not have a nut-runner to fix the bolt. After removing the fixed bolts by the manipulator, this device can transport the used component with the attachment from the inner or the outer plug support stand. This device is arranged between inner and outer plugs.

3.2.4 Cutting Device

A hydraulic-operated shear-cutting device as shown in Fig. 3.8 is adopted as the cutting device to reduce the waste volume of the moderator, reflectors, the proton beam window, and the muon target. The feature of this cutting method is not to produce cutting scraps as compared with other cutting methods such as a saw. Cutting work is operated on a storage container and cut scraps are dropped into the container.

4. Maintenance Scenario for Moderator-reflector

4.1 Moderator-reflector Maintenance Scenario (Fig. 4.1)

In order to shorten the off-beam period, a reasonable maintenance scenario is considered. Accordingly, the maintenance works is divided into two kinds of works such as the replacement work and the disposal work. In the replacement work a new moderator-reflector assembly is preliminary prepared on the outer plug support stand in the hot-cell. The used moderator-reflector assembly is transfered to the dry up room, and the new assembly is transferred from the hot cell to the vessel and installed in the vessel. This work is performed during off-beam operation.

The waste disposal work can be performed despite on-beam or off-beam. After drying up the remaining cooling water inside of the used components at the dry-up room, we carry the used components to the outer or the inner plug support stand and then the moderator and the reflector are removed and cut to reduce the volume by using the cutting device. The cut parts are enclosed in the airtight container. This is also enclosed in the cask with a shield. After temporal storage, it is transferred to out of the MLF.

4.2 Estimation of Required Maintenance Period

Maintenance period for the moderator-reflector manipulation on replacement is also estimated according to the maintenance scenario as mentioned in the previous section. Though there are other maintenance works such as the target, proton beam window and muon target, here they are not taken into account of in the estimation. Estimation results are shown in the Table 1 to 4, where the working flow and required period of each maintenance are summerized. Working time of 8 hours per day is assumed. It takes 15 days in total for the replacement work. Seven days are required for the transportation of the used moderator-reflector assembly from the vessel to the dry up room, and it takes 8 days to carry and install a new moderator-reflector assembly to the vessel. Because the replacement work can not be performed during beam operation as mentioned before. Off-beam period of more than 2 weeks should be required for the moderator-reflector maintenance. The replacement work of moderator-reflector assembly is planned to be done every six years. Therefore, it might not affect the operation time of the facility.

On the other hand, the required period of disposal work is estimated to be about 26 days (used component replacement work: 14 days, cutting work: 12 days) after dry-up work (roughly~30 days). Then, relatively long period (~56 days in total) is required for the disposal work. The disposal work, however, can be performed during on-beam period. Accordingly, it can afford the time in the disposal work.

Up to above, the maintenance sequence is described without contingency. It is planning to perform all maintenance sequence in off-beam commissioning test, and then the scenario will be confirmed and the contingency will be evaluated. Finally, it is necessary to establish a realistic maintenance plan under the coordination of a maintenance with other apparatus such as the target, proton beam window, muon target, etc.

5. Conclusions

The present design studies determine the following maintenance scenario;

(1) Maintenance work of the moderator-reflector is performed by full remote handling except for the piping connection/disconnection work on the vessel. Design of the remote-handling for the piping is now underway.

(2) The used components (moderator, reflector and etc.) are finally taken out of the MLF (Materials and Life Science Facility) after their volume reduction by cutting.

(3) Remote-handling devices consist of 6 devices in total, the transfer cask and the floor valve in the high bay, the outer plug support stand, the inner plug support stand, the moderator exchange device and the cutting device in the hot-cell. These devices are also available to the proton beam window and the muon target maintenance.

(4) Maintenance scenario has two works, the replacement work to the new components during off-beam period and the disposal work of used components during on-beam period.

(5) The estimated maintenance period is about 15 days for the replacement work. On the other hand, the disposal work about 26 days after dry-up (roughly, 30 days) which is available to be performed during

on-beam period.

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Table 1 Replacement work for moderator-reflector maintenance scenario.

			Required period (days)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		【Common tool】															
		130 ton crane															
		Transfer cask, Floor valve															
		In-cell crane (20 ton)															
		Work flow															
(1)	1	Purge in vessel															
	2	Target drain															
	3	Cooling water drain															
	4	H2 release															
	5	Move target trolley backward															
	6	Remove roof seal plate															
	7	Remove shield blocks															
	8	Remove vessel shield															
	9	Remove vessel cover															
	10	Disconnect water pipe and H2 transfer															
	11	Attach hung tool for inner plug															
	12	Attach hung tool for outer plug															
	13	Install floor valve															
	14	Tighten bolts															
	15	Connect floor valve cable															
	16	Install transfer cask															
	17	Connect transfer cask cable															
	18	Open floor shield															
	19	Open transfer cask shield															
	20	Lift down gripper															
	21	Hold outer plug hung tool															
	22	Lift up gripper into transfer cask															
	23	Close transfer cask shield															
	24	Close floor shield															
(2)	25	Remove transfer cask cable															
	26	Loosen transfer cask bolts															
	27	Transfer the cask to vessel for dry up															
	28	Install transfer cask															
	29	Connect transfer cask cable															
	30	Open hatch over dry up room															
	31	Open floor shield															
	32	Open transfer cask shield															
	33	Lift down gripper															
	34	Release inner and outer plug hung tool															
	35	Lift up gripper into transfer cask															
	36	Close hatch over dry up room															
	37	Close transfer cask shield															
	38	Close floor shield															
(3)	39	Detach transfer cask cable															
	40	Transfer to hot cell															
	41	Connect transfer cask cable															
	42	Open floor shield															
	43	Open transfer cask shield															
	44	Lift down gripper															
	45	Hold outer plug hung tool															
	46	Lift up gripper into transfer cask															
	47	Close transfer cask shield															
	48	Close floor shield															
	49	Detach transfer cask cable															
	50	Loosen transfer cask bolts															
	51	Transfer to vessel															
(4)	52	Install transfer cask															
	53	Connect transfer cask cable															
	54	Open floor shield															
	55	Open transfer cask shield															
	56	Lift down gripper															
	57	Release inner and outer prug hung tool															
	58	Lift up gripper into transfer cask															
	59	Close transfer cask shield															
	60	Close floor shield															
	61	Detach transfer cask cable															
	62	Loosen transfer cask bolts															
	63	Transfer the cask to storage position															
	64	Detach floor valve cable															
	65	Loosen floor valve bolts															
	66	Transfer floor valve to storage position															
	67	Remove floor valve attachment															
	68	Transfer floor valve to storage position															
	69	Detach hung tool of inner and outer plug															
	70	Remove inner and outer plug hung tool															
	71	Attach water pipe and H2 transfer line															
	72	Leak test of H2 transfer line															
	73	Leak test of water pipe															
	74	Circulate H2															
	75	Circulate cooling water															
	76	Install vessel cover															
	77	Move target trolley forward															
	78	Leak test of vessel															
	79	Fill He in vessel															
	80	Install vessel shield															
	81	Install shield blocks															
	82	Install roof seal plate															
	83	Leak test of outer liner															

Table 2 Disposal work (coupled moderator and reflector replacement).

		Required period (days)						
		1	2	3	4	5	6	7
	【Common tool】							
	130 ton crane	■	■	■				
	Transfer cask, Floor valve	■	■	■	■		■	■
	Moderator dry up device, plug support stand				■	■		■
	Power manipulator, In cell crane	■	■		■	■	■	■
	Work flow							
1	Transfer cask over dry up room	■						
2	Install transfer cask	■						
3	Connect transfer cask cable	■						
4	Open hatch over dry up room	■						
5	Open floor shield	■						
6	Open transfer cask shield	■						
7	Lift down grippaer	■						
8	Hold inner and outer plug hung tool	■						
9	Lift up grippaer into transfer cask	■						
10	Close hatch over dry up room		■					
11	Close transfer cask shield		■					
12	Detach transfer cask cable		■					
13	Loosen cask bolts		■					
14	Transfer the cask over outer plug stand		■					
15	Tighten cask bolts		■					
16	Connect transfer cask cable		■					
17	Open floor shield		■					
18	Open transfer cask shield		■					
19	Lift down grippaer		■					
20	Release outer plug hung tool and hold inner plug hung tool		■					
21	Lift up gripper into transfer cask		■					
22	Close transfer cask shield		■					
23	Close floor shield		■					
24	Detach transfer cask cable			■				
25	Loosen cask bolt			■				
26	Transfer the cask over inner plug support stand			■				
27	Connect transfer cask cable			■				
28	Open floor shield			■				
29	Open transfer cask shield			■				
30	Lift down grippaer			■				
31	Release inner plug hung tool			■				
32	Lift up grippaer into transfer cask			■				
33	Close transfer cask shield			■				
34	Close floor shield			■				
35	Detach transfer cask cable			■				
36	Loosen cask bolts			■				
37	Transfer the cask over outer plug support stand				■			
38	Tighten cask bolts				■			
39	Connect transfer cask cable				■			
40	Transfer coupled moderator attachment from storage ruck to				■			
41	Rotate moderator exchange device				■			
42	Rotate outer plug support stand				■			
43	Join attachment to coupled moderator				■			
44	Loosen coupled moderator bolts					■		
45	Lift down coupled moderator with attachment					■		
46	Pull out coupled moderator with attachment					■		
47	Rotate moderator exchange device					■		
48	Join coupled moderator with atttachment to in-cell crane					■		
49	Transfer coupled moderator with attachment to storage stand					■		
50	Storage coupled moderator					■		
51	Lift up reflector flange support					■		
52	Loosen bolts between reflector and outer plug						■	
53	Open floor shield						■	
54	Open transfer cask shield						■	
55	Lift down grippaer						■	
56	Hold outer plug hung tool						■	
57	Lift up grippaer into transfer cask						■	
58	Close transfer cask shield						■	
59	Close floor shield						■	
60	Connect hung tool of reflector						■	
61	Transfer used reflector							■
62	Join new reflector to in-cell crane							■
63	Transfer new reflector to outer plug support stand							■
64	Lift down reflector flange support							■
65	Open floor shield							■
66	Open transfer cask shield							■
67	Lift down grippaer							■
68	Tighten bolts between reflector and outer plug							■
69	Release outer plug hung tool							■
70	Lift up grippaer into transfer cask							■
71	Close transfer cask shield							■
72	Close floor shield							■

Table 3 Disposal work (contd., decoupled moderators replacement).

		Required period (days)						
		8	9	10	11	12	13	14
	【Common tool】							
	130 ton crane							
	Transfer cask, Floor valve							
	Moderator dry up device, plug support stand							
	Power manipulator, In cell crane							
	Work flow							
73	Transfer decoupled attachment to moderator exchange device							
74	Rotate moderator exchange device							
75	Rotate inner plug support stand							
76	Join attachment to decoupled moderator							
77	Loosen decoupled moderator bolts							
78	Pull out decoupled moderator with attachment							
79	Rotate moderator exchange device							
80	Join decoupled moderator with atttachment to in-cell crane							
81	Transfer decoupled moderator with attachment to storage stand							
82	Storage decoupled moderator with attachment							
83	Join new decoupled moderator with attachment to in-cell crane							
84	Transfer new decoupled moderator to moderator exchange device							
85	Rotate moderator exchange device							
86	Connect decoupled moderator to inner plug							
87	Tighten bolts between decoupled moderator and inner plug							
88	Release decoupled moderator attachment							
89	Transfer decoupled attachment to storage ruck							
90	Storage decoupled moderator attachment							
91	Transfer poisoned moderator attachment to moderator exchange							
92	Rotate moderator exchange device							
93	Rotate inner plug support stand							
94	Join attachment to poisoned moderator							
95	Loosen poisoned moderator bolts							
96	Pull out poisoned moderator with attachment							
97	Rotate moderator exchange device							
98	Join atttachment to in-cell crane							
99	Transfer poisoned moderator with attachment to storage ruck							
100	Storage poisoned moderator							
101	Join new poisoned moderator with attachment to in-cell crane							
102	Transfer new poisoned moderator to moderator exchange device							
103	Rotate moderator exchange device							
104	Connect poisoned moderator to inner plug							
105	Tighten bolts between poisoned moderator and inner plug							
106	Release poisoned moderator attachment							
107	Rotate moderator exchange device							
108	Transfer attachment to storage ruck							
109	Storage poisoned moderator attachment							
110	Detach transfer cask cable							
111	Loosen cask bolts							
112	Transfer the cask over inner plug support stand							
113	Connect transfer cask cable							
114	Open floor shield							
115	Open transfer cask shield							
116	Lift down grippaer							
117	Hold inner plug hung tool							
118	Lift up grippaer into transfer cask							
119	Close transfer cask shield							
120	Close floor shield							
121	Transfer the cask over outer plug support stand							
122	Tighten cask bolt							
123	Connection transfer cask cable							
124	Open floor shield							
125	Open transfer cask shield							
126	Lift down grippaer							
127	Release inner plug hung tool							
128	Lift up grippaer into transfer cask							
129	Close transfer cask shield							
130	Close floor shield							
131	Join new coupled moderator with attachment to in-cell crane							
132	Transfer new coupled moderator to moderator exchange device							
133	Rotate moderator exchange device with attachment							
134	Connect coupled moderator to outer plug							
135	Tighten bolts between coupled moderator and outer plug							
136	Release coupled moderator attachment							
137	Transfer attachment to storage ruck							
138	Storage coupled moderator attachment							

Table 4 Disposal work (contd., used components cutting work).

		Required period (days)											
		1	2	3	4	5	6	7	8	9	10	11	12
	【Common tool】												
	130 ton crane												
	Moderator cutting device												
	Moderator exchange device												
	Power manipulator, 20 ton In cell crane												
	12 ton In cell crane												
	Work flow												
1	Open hatch over storage room												
2	Transfer storage container of coupled moderator to moderator												
3	Close hatch over storage room												
4	Loosen storage container bolts												
5	Open cover of storage container												
6	Open hatch over storage room												
7	Transfer coupled moderator with attachment to moderator exchange												
8	Close hatch over storage room												
9	Rotate moderator exchange device												
10	Cut pipe of coupled moderator												
11	Close cover of storage container												
12	Tighten storage container bolts												
13	Open hatch over storage room												
14	Transfer storage container to storage room												
15	Close hatch over storage room												
16	Open hatch over storage room												
17	Transfer storage container of decoupled moderator to moderator												
18	Close hatch over storage room												
19	Loosen storage container bolts												
20	Open cover of storage container												
21	Open hatch over storage room												
22	Transfer decoupled moderator with attachment to moderator												
23	Close hatch over storage room												
24	Rotate moderator exchange device												
25	Cut pipe of decoupled moderator												
26	Close cover of storage container												
27	Tighten of storage container bolts												
28	Open hatch over storage room												
29	Transfer storage to storage room												
30	Close hatch over storage room												
31	Open hatch over storage room												
32	Transfer storage container of poisoned moderator to moderator												
33	Close hatch over storage room												
34	Loosen storage container bolts												
35	Open cover of storage container												
36	Open hatch over storage room												
37	Transfer poisoned moderator with attachment to moderator												
38	Close hatch over storage room												
39	Rotate moderator exchange device												
40	Cut pipe of poisoned moderator												
41	Close cover of storage container												
42	Tighten storage container bolts												
43	Open hatch over storage room												
44	Transfer storage container to storage room												
45	Close hatch over storage room												
46	Open hatch over storage room												
47	Transfer storage container of reflector to moderator cutting device												
48	Close hatch over storage room												
49	Loosen storage container bolts												
50	Open cover of storage container												
51	Open hatch over storage room												
52	Transfer reflector with hung tool to moderator exchange device												
53	Close hatch over storage room												
54	Rotate moderator exchange device												
55	Cut pipe of reflector												
56	Close cover of storage container												
57	Tighten storage container bolts												
58	Open hatch over storage room												
59	Transfer storage container to storage room												
60	Close hatch over storage room												

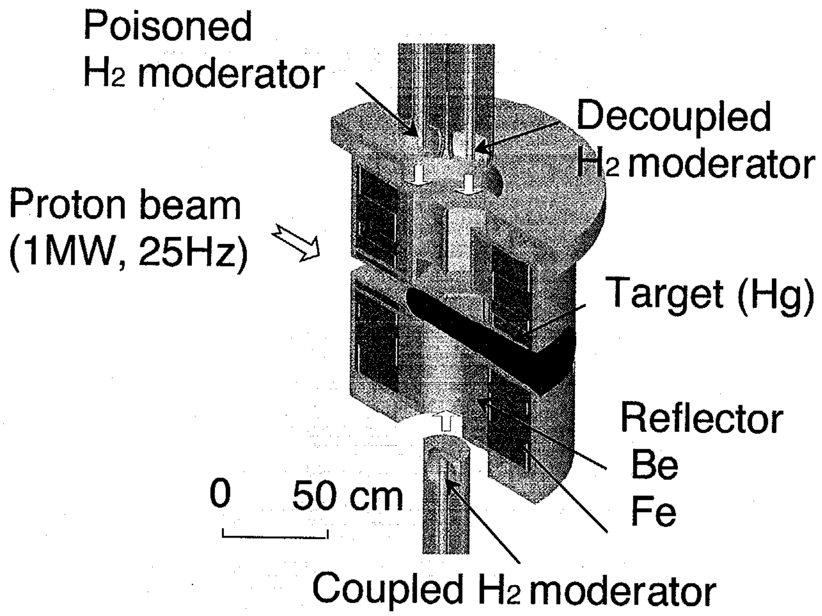

Fig. 1.1 Cross sectional view of target-moderator-reflector system for spallation neutron source in J-PARC.

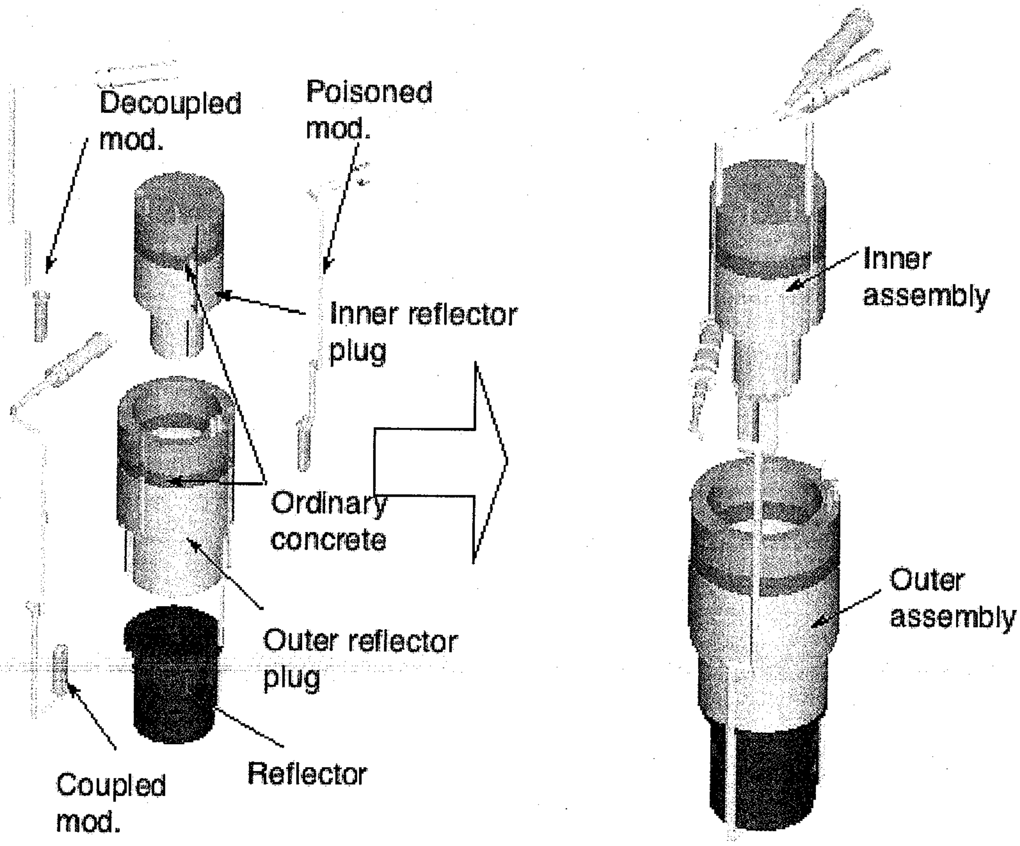

Fig. 1.2 Schematic view of inner and outer assembly.

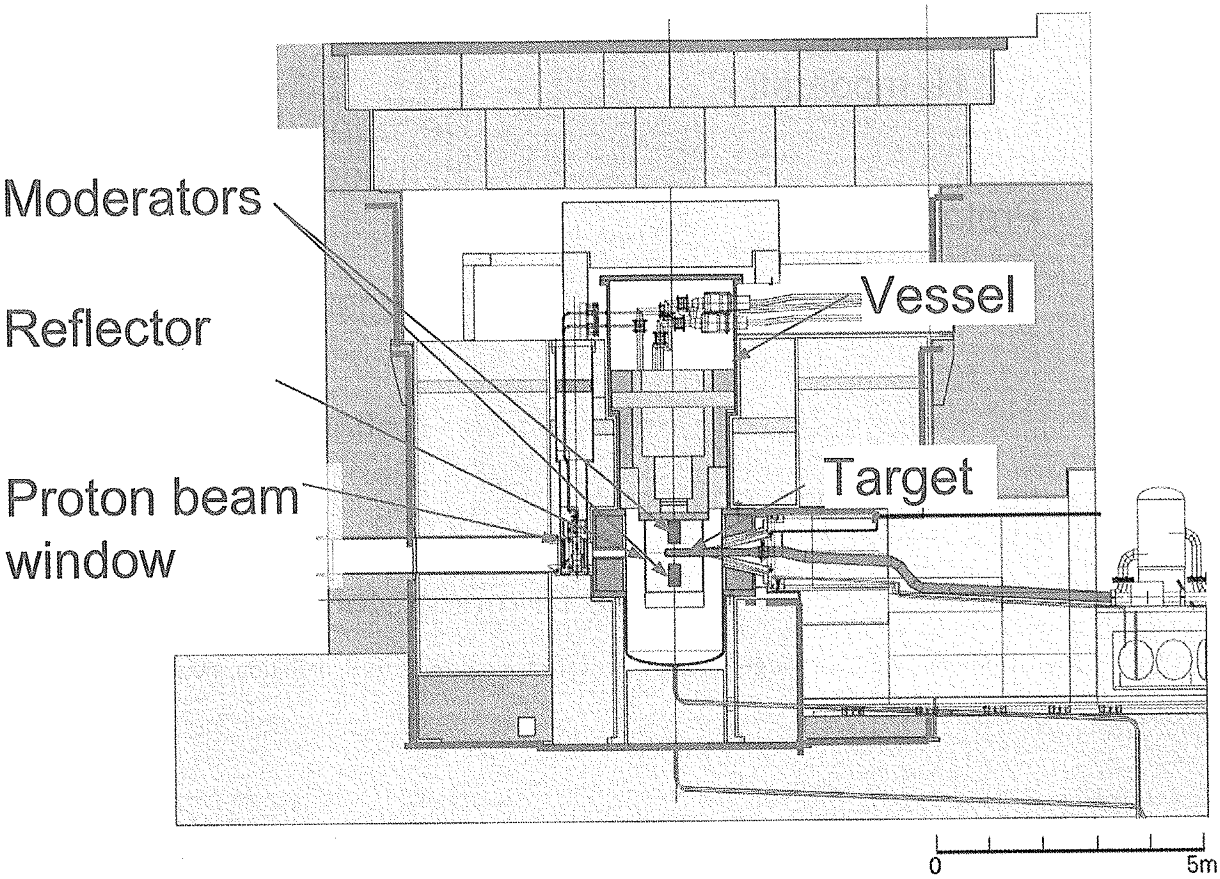

Fig. 1.3 Cross sectional view of target station.

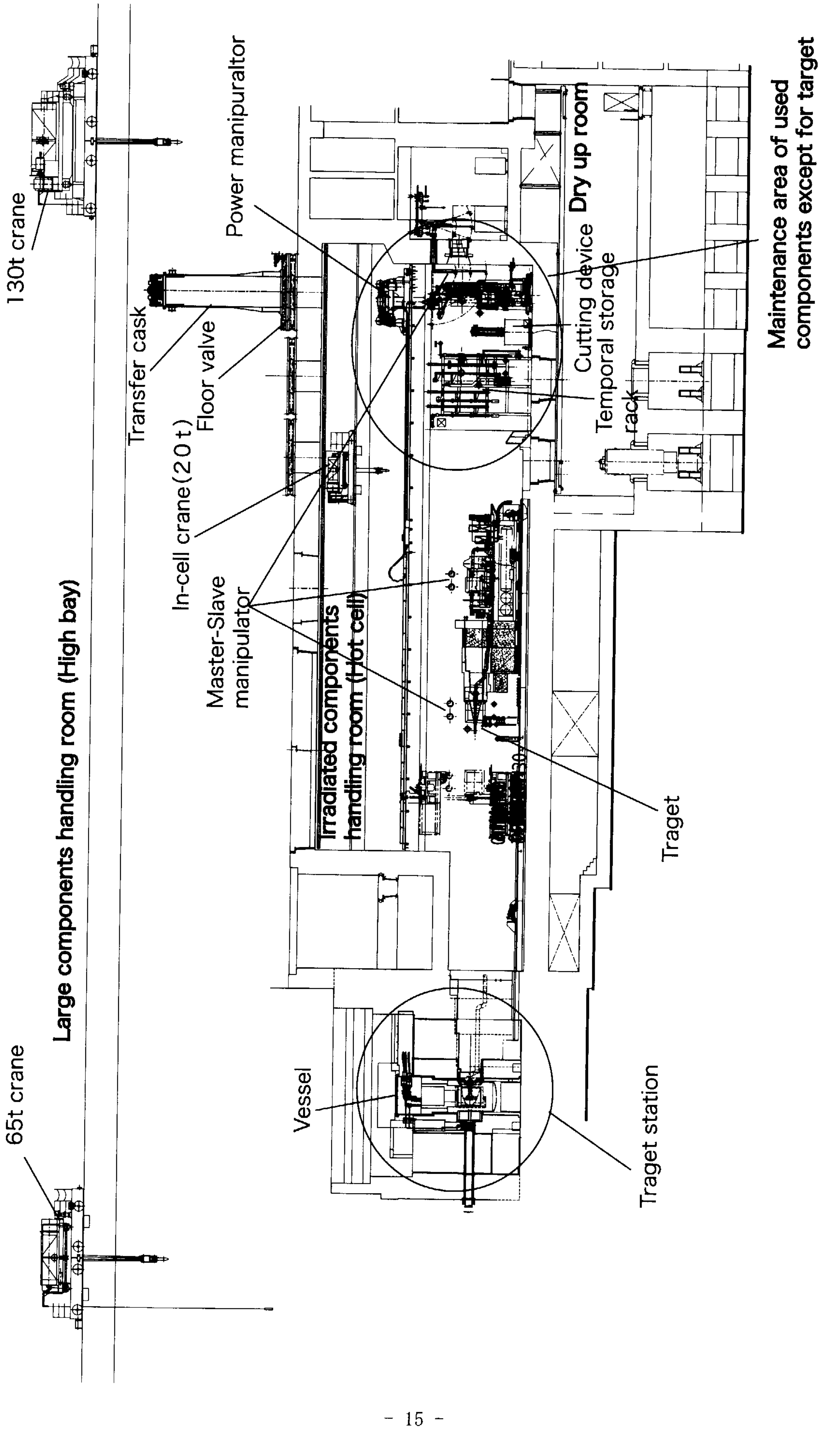

Fig. 1.4 Vertical cross sectional view of MLF.

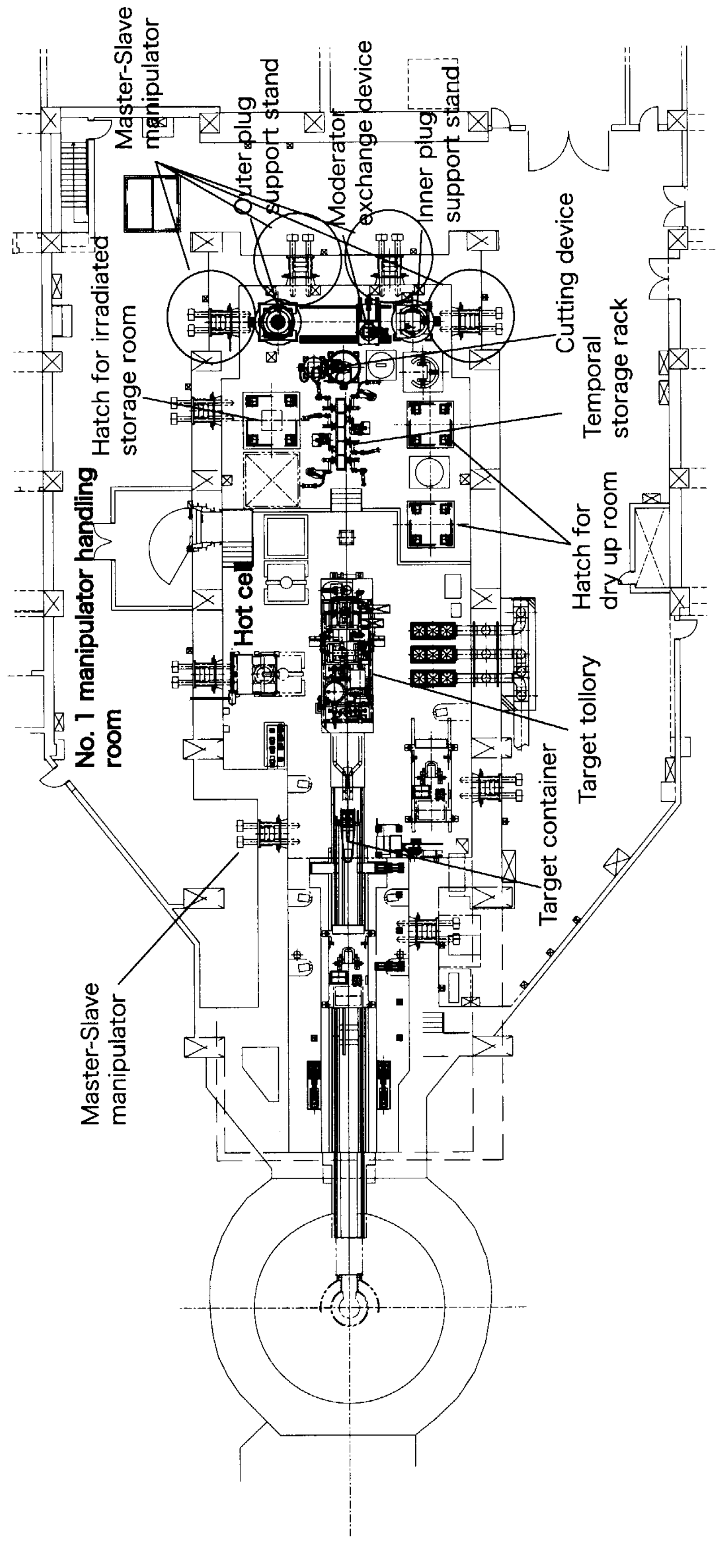

Fig. 1.5 Horizontal cross sectional view of 1st floor of MLF.

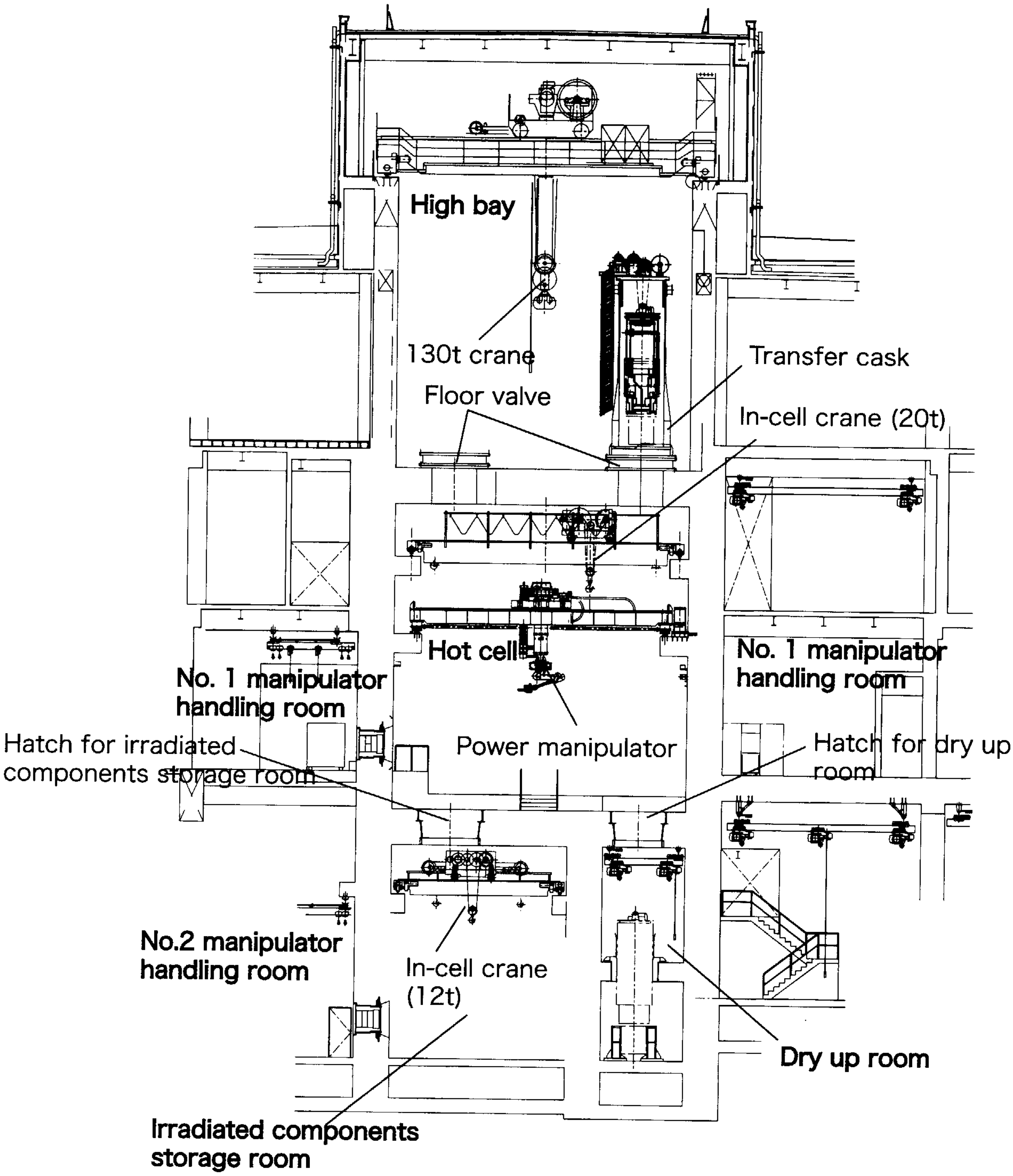

Fig. 1.6 Vertical cross sectional view of MLF.

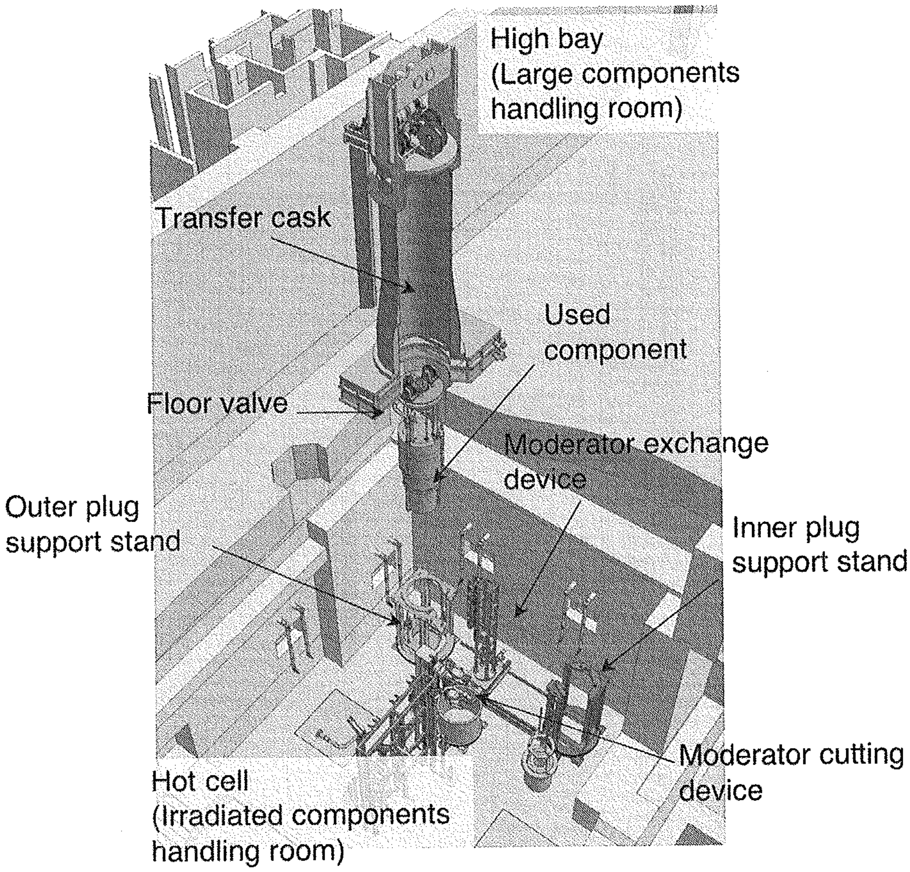

Fig. 1.7 Arrangement of remote control devices for the moderator-reflector assembly maintenance.

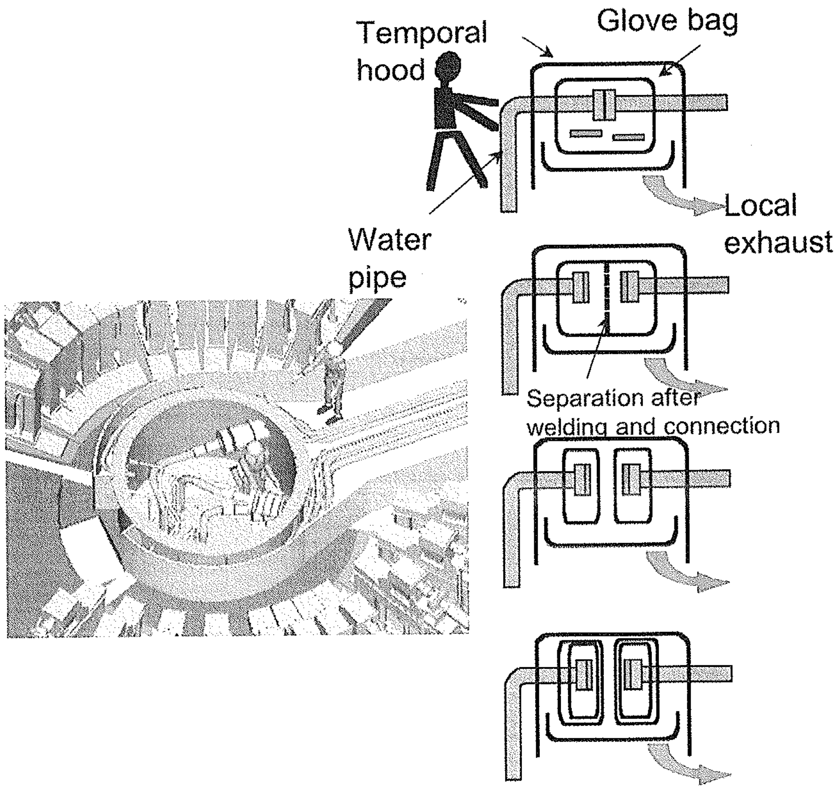

Fig. 2.1 Pipe connection/disconnection work at vessel top.

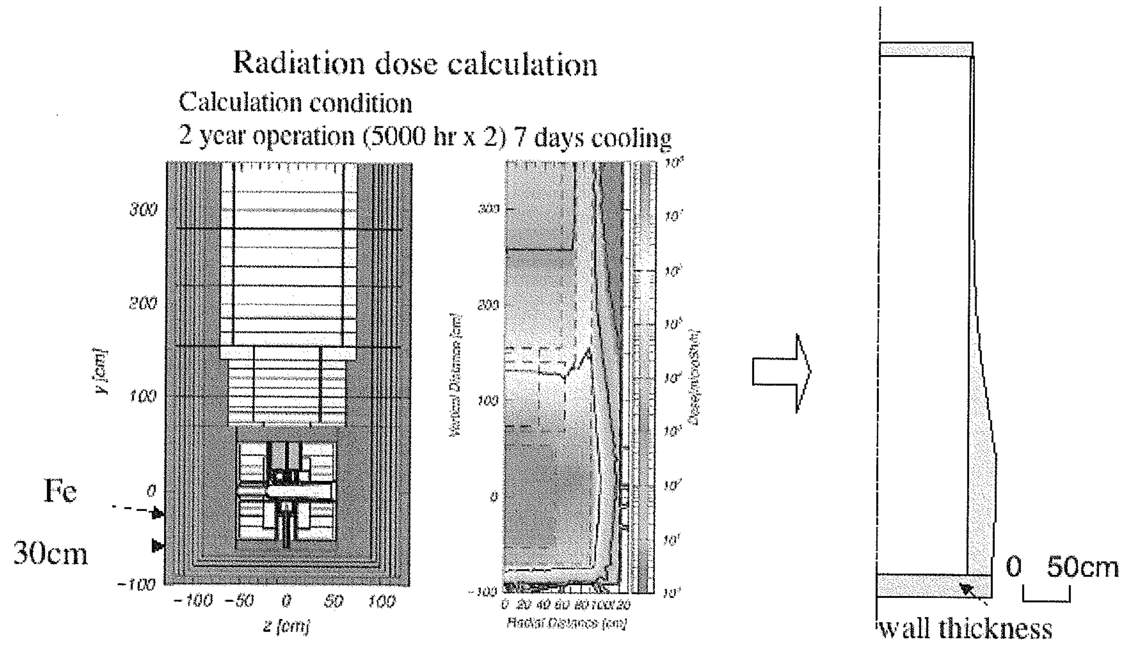

Fig. 2.2 Radiation dose calculation and necessary wall thickness of transfer cask for 1 mSv/hr.

- Transfer used components to hot cell
- Gripper for lifting used components
- Shield door
- Surface dose : 1mSv/hr
- Weight : ~120 ton at max. (included used components)
- Transportation : 130 ton crane
- Installation : hands-on

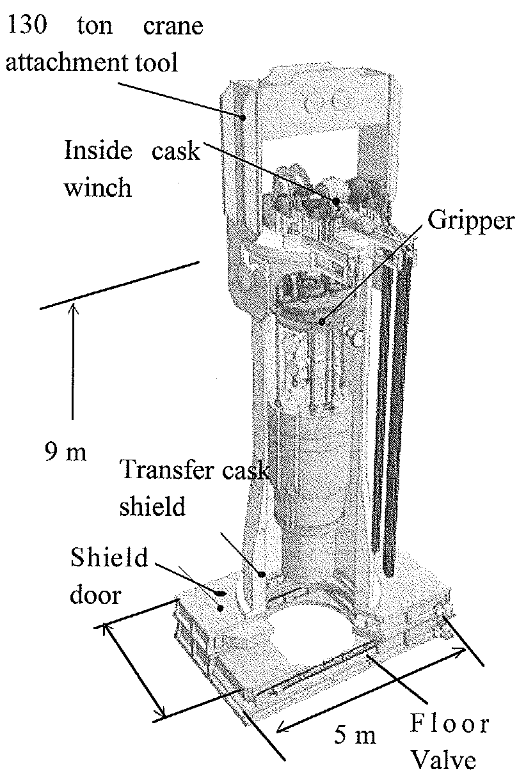

Fig. 3.1 Transfer cask for transportation of the used components.

- Hands-on installation
- Mounting on floor valve using positioning pin and bolt
- Partial removal shield block (not all)
  → Shorten working period

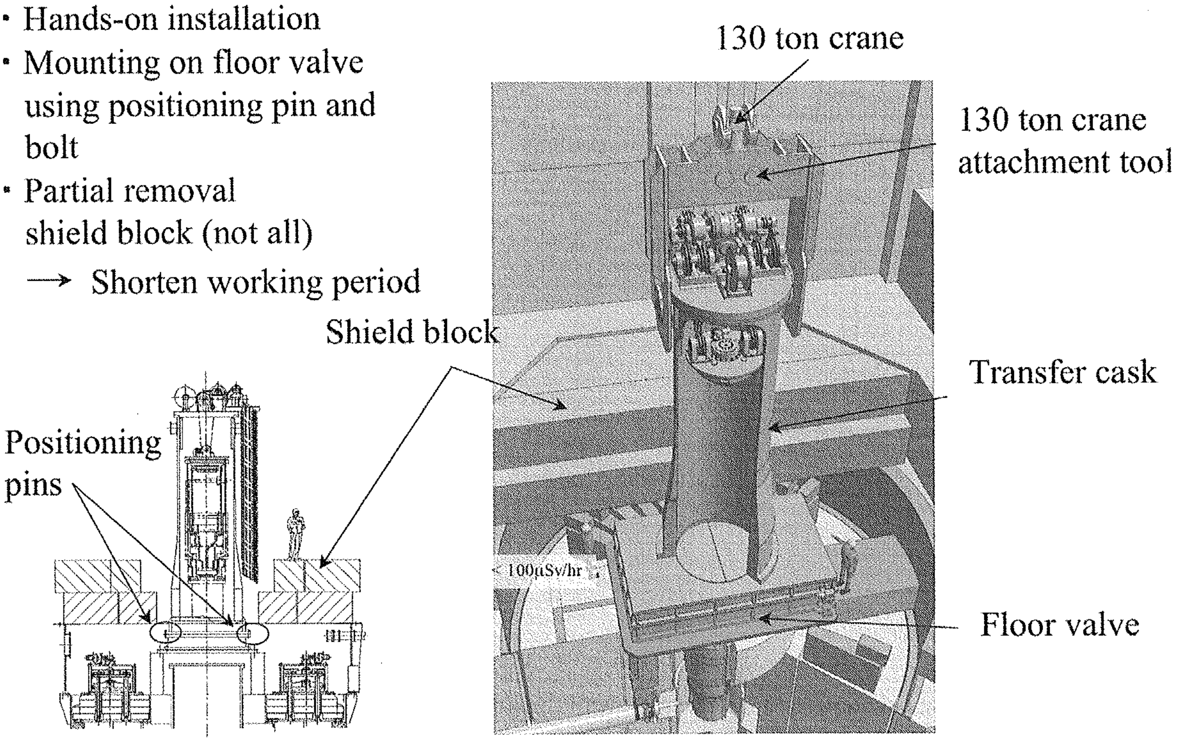

Fig. 3.2 Installation of transfer cask at vessel top.

- Connection to the transfer cask (positioning pin)
- Shield shutter (30 cm^T) for gamma ray from lower part
- Airtight using EPDM rubber seal
- Hands-on installation

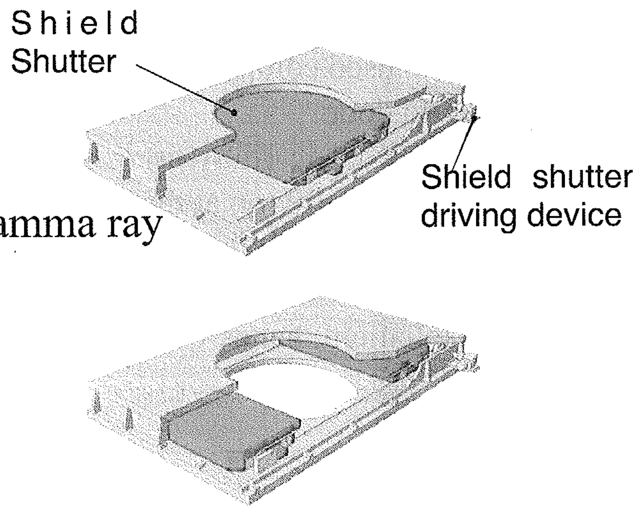

Fig. 3.3 Schematic view of floor valve.

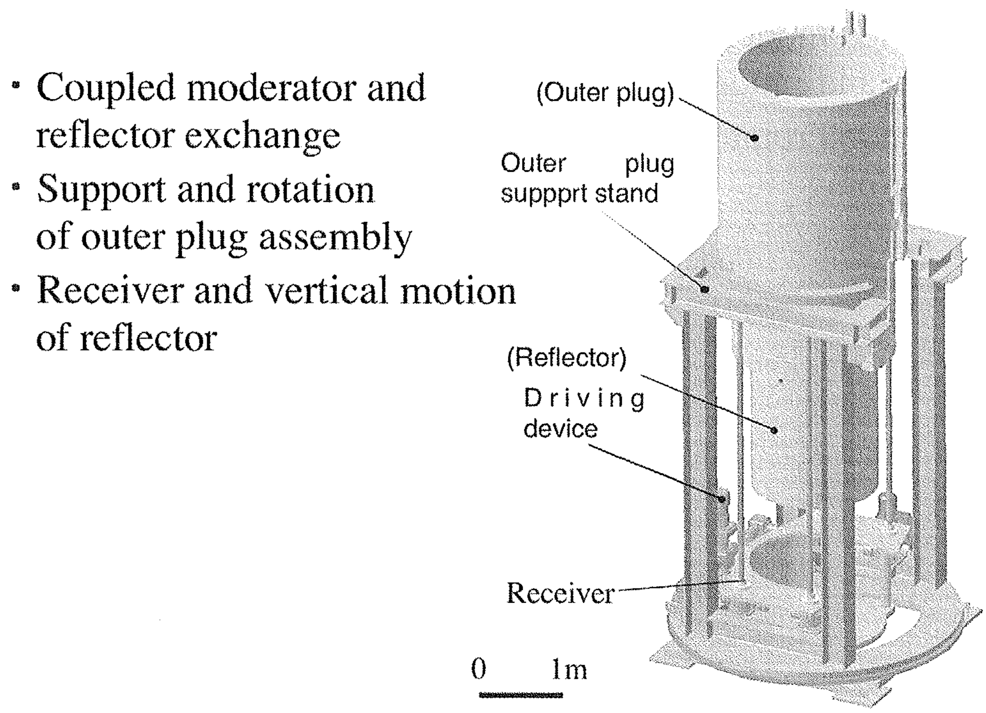

Fig. 3.4 Schematic view of outer plug support stand.

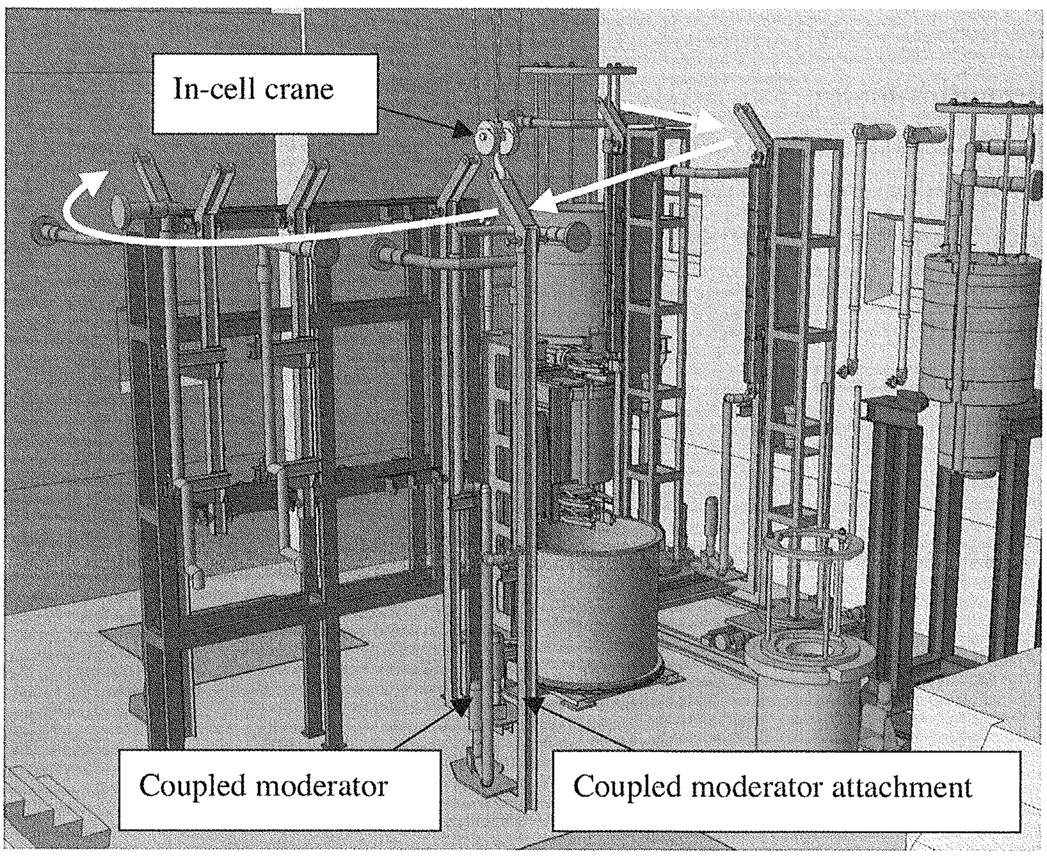

Fig. 3.5 Schematic view of coupled moderator attachment.

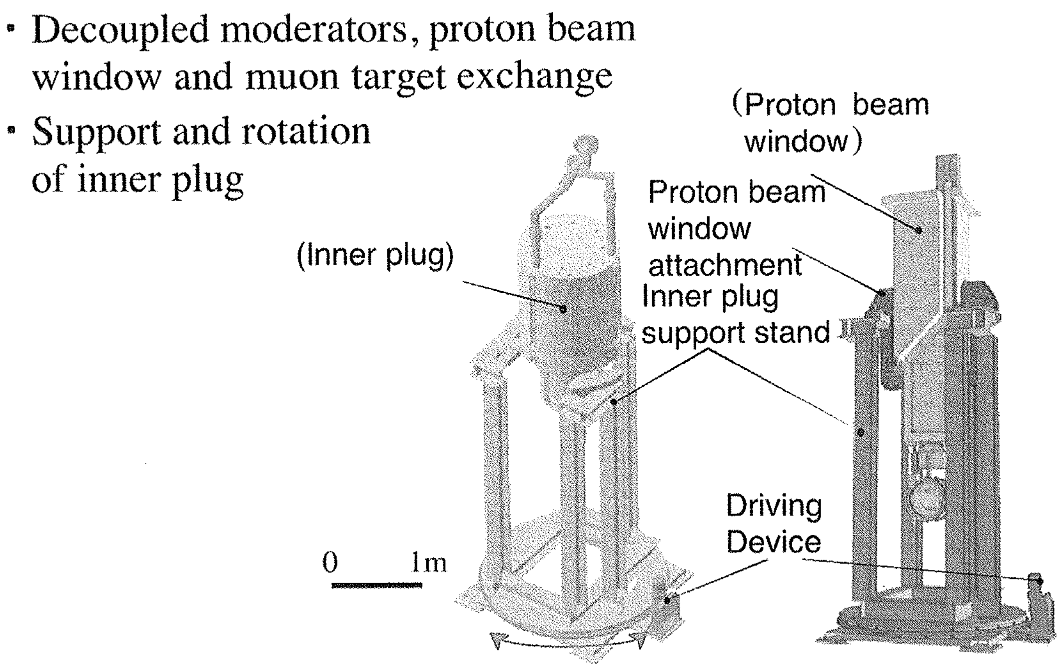

Fig. 3.6 Schematic view of inner plug support stand.

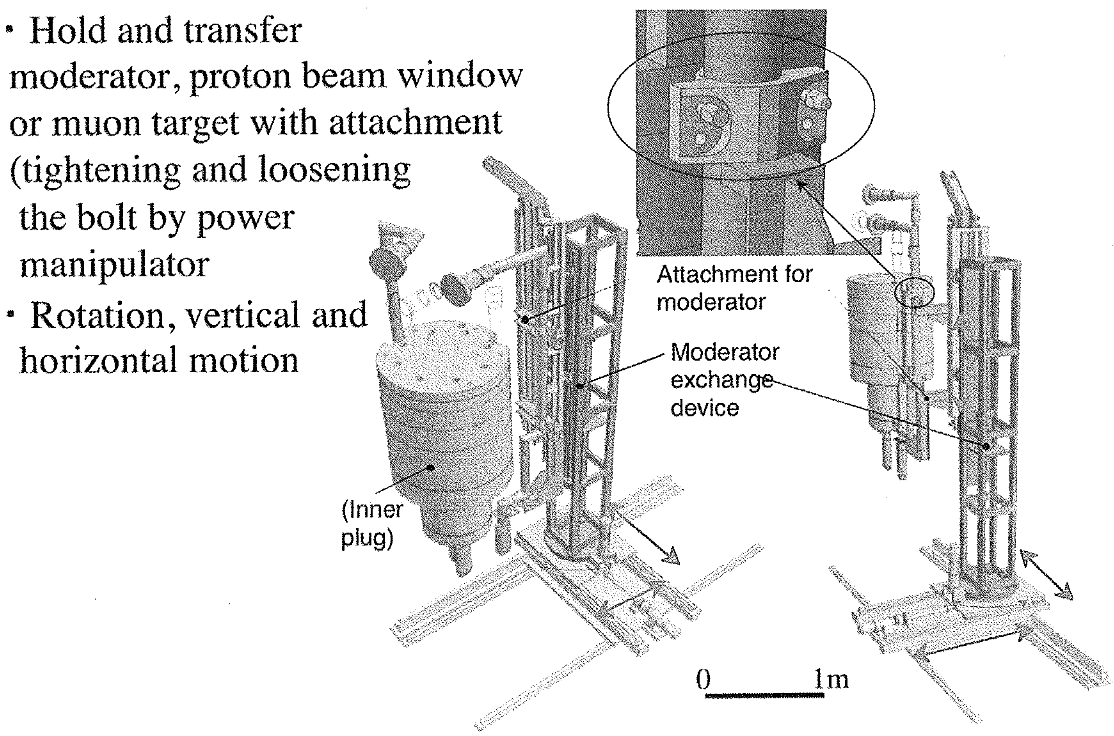

Fig. 3.7 Schematic view of moderator exchange device.

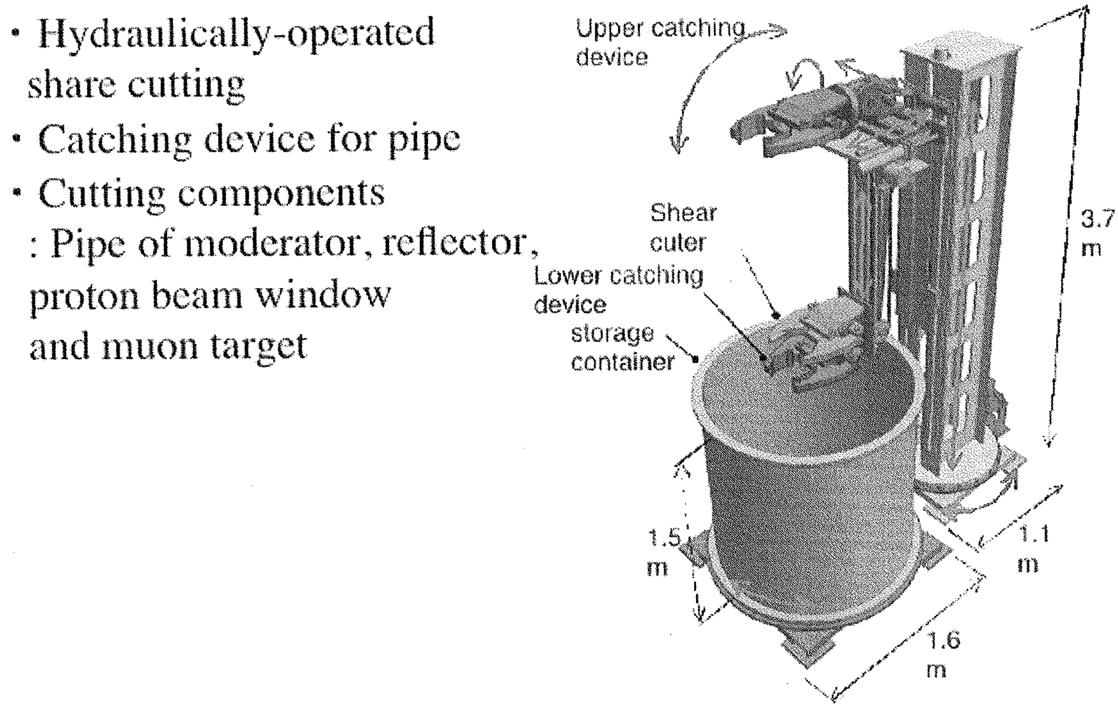

Fig. 3.8 Schematic view of cutting device.

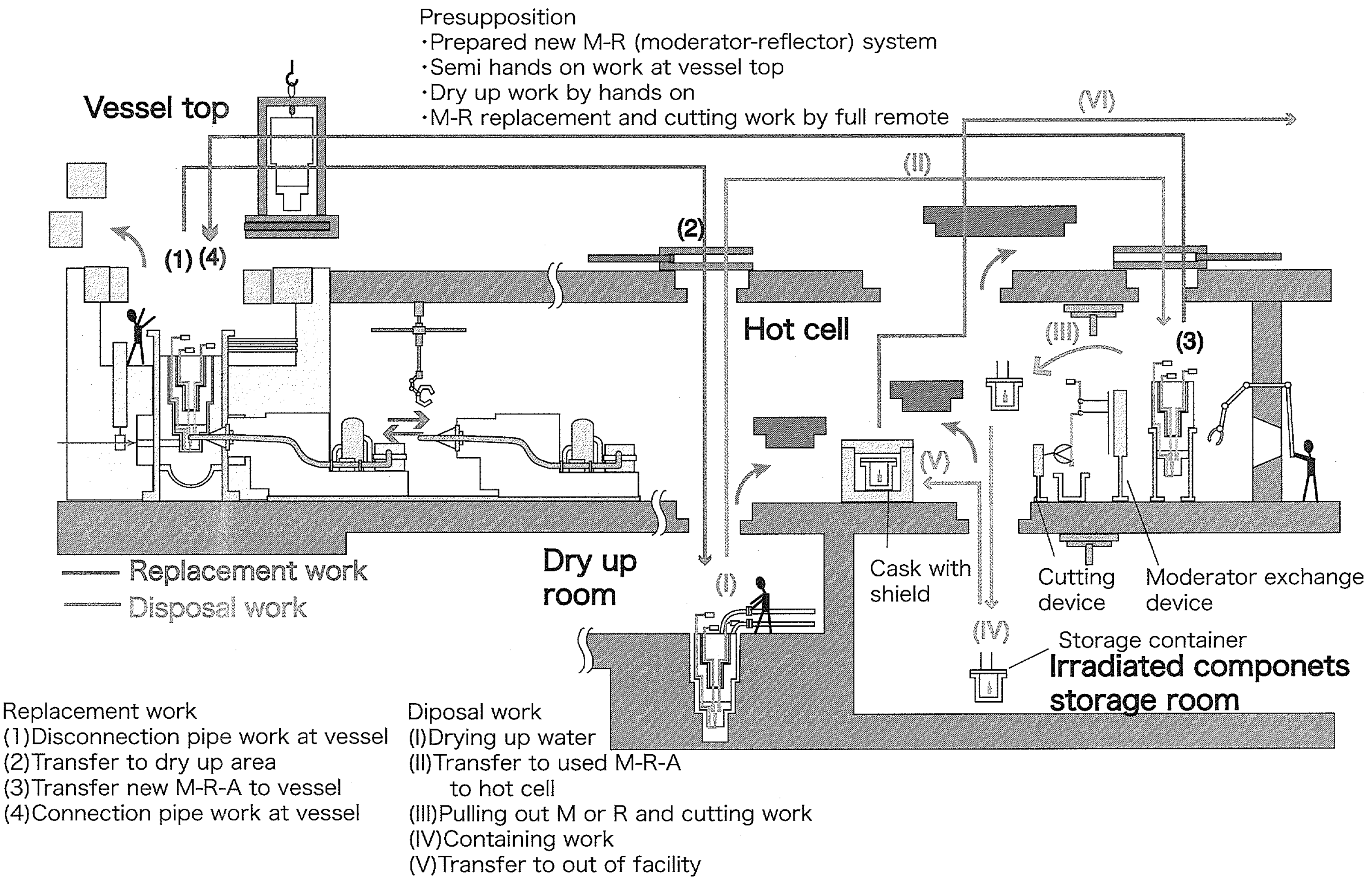

Fig. 4.1 Moderator-reflector maintenance scenario.

国際単位系 (SI) と換算表

表 1　SI 基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表 3　固有の名称をもつ SI 組立単位

量	名　称	記号	他の SI 単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m\cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー, 仕事, 熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位, 電圧, 起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表 2　SI と併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

表 4　SI と共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ Å = 0.1\ nm = 10^{-10}\ m$

$1\ b = 100\ fm^2 = 10^{-28}\ m^2$

$1\ bar = 0.1\ MPa = 10^5\ Pa$

$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

$1\ rad = 1\ cGy = 10^{-2}\ Gy$

$1\ rem = 1\ cSv = 10^{-2}\ Sv$

表 5　SI 接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

(注)

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および 1 u の値は CODATA の1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. bar は，JIS では流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令では bar，barn および「血圧の単位」mmHg を表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　$1\ Pa\cdot s(N\cdot s/m^2) = 10\ P$(ポアズ)(g/(cm·s))

動粘度　$1\ m^2/s = 10^4 St$(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal ＝ 4.18605 J（計量法）

＝ 4.184 J　（熱化学）

＝ 4.1855 J（15 °C）

＝ 4.1868 J（国際蒸気表）

仕事率　1 PS（仏馬力）

＝ 75 kgf·m/s

＝ 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

Remote Handling Design For Moderator-Reflector Maintenance in JSNS