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## 23.4

# Present Status of Spallation Target Development - JAERI / KEK Joint Project -

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## Abstract

The Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) are promoting a plan to construct a neutron scattering facility under the JAERI / KEK Joint Project. Design and R&D works are being carried out vigorously for realizing the mercury target system consisting of the mercury target, moderators and reflectors working as a spallation neutron source, as well as a remote handling system for exchanging such components which will be highly irradiated. This report introduces an outline of the present status of design and development activities on the spallation target system.

## 1. Introduction

The Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) are promoting a plan to construct a neutron scattering facility at Tokai Research Establishment, JAERI, under the High-Intensity Proton Accelerator Project (the JAERI / KEK Joint Project). In the facility, a 1MW pulsed proton beam from a high-intensity proton accelerator will be injected into a mercury target in order to produce high-intensity neutrons for use in the fields of life and material sciences [1].

From the viewpoint of engineering, there are a lot of unknown technical factors involved in constructing the target system working as a spallation neutron source in the MW-class neutron scattering facility. Design and R&D works are being carried out vigorously for realizing the mercury target system consisting of the mercury target, moderators and reflectors, as well as a remote handling system for exchanging such components which will be highly irradiated.

This report introduces an outline of the present status of design and development activities on the spallation target system being carried out under the JAERI / KEK Joint Project.

## 2. Overview of the target station

Figure 1 shows a cutaway view of the target station. The mercury target and a mercury circulation loop are installed on a target trolley, which will be maintained or repaired in a maintenance cell after the target trolley is withdrawn from a bulk bio-shield. The mercury circulation loop supplies mercury to the target vessel at a maximum flow rate of 1m$^3$/min. The reflector- moderator assembly is fixed on the bottom of an exchanging plug and set in a helium vessel. Neutrons generated in the target are reduced in energy to the proper value in the moderators, and then the neutron beams are supplied to the users through the neutron beam lines. About 20 neutron beam lines are installed in the neutron scattering facility under the present design. An in-cell crane and a power manipulator are used to exchange the target vessel, mercury circulation components etc. Spent components such as the target vessel and mercury circulation components are stored in the storage room in the basement.

## 3. Mercury Target

### 3.1 Thermal Hydraulic Experiment & Analysis

JAERI proposed the Cross-Flow Type (CFT) target in which the mercury flows across the proton beam path, and has continued the optimization of the flow channel structure with the thermal-hydraulic analysis code. Figure 2 shows the concept of the CFT target for a 1MW operation [2,3]. The target vessel is a single-wall structure without an additional vessel cooling jacket, whose dimensions are 80mm in height, 460mm in width and 800mm in effective length. The cross-flow velocity distribution of mercury that conforms to the heat load distribution along the proton beam path can be achieved by placing the flow distributors properly in the target vessel. The target vessel is covered with a water-cooled safety hull to prevent mercury leakage into the helium vessel.

Based on the results obtained by thermal-hydraulic analytical work, a mock-up model of the cross-flow type target was fabricated to verify the analytical results under water flow conditions. Figure 3 shows pictures of the full-scale mock-up model, which is made of plexiglass and simulates the inner structure of the mercury target. Experiments have been carried out under water flow conditions up to 5m$^3$/min, and the water flow patterns in the target vessel have been measured with a particle imaging velocimetry (PIV) technique. In the experiments, the maximum inlet water velocity was set to 5m/s corresponding to the Reynolds number of $8.2 \times 10^5$, which also corresponds to the mercury velocity of 0.6m/s at the mercury temperature of 50 deg C.

Figure 4 shows the experimental and analytical results of the flow patterns in the target vessel obtained under the inlet water velocity of 3m/s [4]. The analytical result agrees well with the experimental result especially near the beam window where the heat deposition by the spallation reaction has its peak. Based on these results, we will optimize the computational grid for the thermal hydraulic analysis, which affects the accuracy of analytical results.

### 3.2 Heat Transfer Experiment by Hg Loop

A small-scale mercury test loop was constructed in 1997, in order to acquire the heat transfer data between mercury and the metal wall as well as long-term operation data of mercury circulation components such as mercury pumps, a flow meter and pipelines (pipe inner diameter of 25mm). Figure 5 shows an outer view of the test loop. Mercury is circulated either by an electro-magnetic pump (the maximum flow rate of 14 liters/min) or by a gear pump (20 liters/min), and the flow-rate is measured by an electro-magnetic flow meter. The mercury loop is installed in a movable box enclosed tightly with plexiglass plates and a steal pan. The volumetric capacity of the mercury loop is 30 liters, with 20 liters of mercury being used in the experiment.

Since the mechanical gear pump showed good performance for mercury circulation in the experiments, this type of pump is planned to use for the practical mercury circulation system. Presently, heat transfer experiments are being carried out to determine the turbulent Prandtl number (Prt) which is indispensable for the thermal-hydraulic analyses of the mercury target.

Figure 6 shows the relationship between the Peclet number (Pe) and the Nusselt number (Nu) [5]. Experimental data obtained with a circular test tube installed in the mercury test loop, as well as existing experimental data are shown in the figure. Analytical heat transfer rates obtained with Prt of 1 and 3.14 are lower than our experimental results in the region of the Peclet number greater than 2000 which is the operating condition of the mercury target. So, in order to estimate the mercury temperature conservatively, Prt of 1.5 is currently being used in the target design analyses.

### 3.3 Structural Analysis

From the viewpoint of structural integrity of the target vessel, dynamic stress caused by pressure waves is one of the most important technical issues, as shown in Fig.7. In parallel with the AGS spallation target experiments at the Brookhaven National Laboratory, which is an international collaboration among USA, Europe, and Japan, we have started to examine the propagation behaviors of the stress and pressure waves using an impact test apparatus [6].

Figure 8 shows the outer views and the schematic drawing of the impact test apparatus using the split Hopkinson pressure bar technique. This test apparatus can generate the maximum pressure of 150 MPa in mercury by using an air gun, which is 5 times larger than the analyzed pressure obtained under the condition of the 1MW proton beam incidence. From the test results of dynamic stress behaviors, it is supposed that cavitation bubbles would generate in the mercury or on the bar surface due to the pressure wave propagation. We are improving the analytical model to predict mercury behaviors more accurately in relation with the pressure wave propagation.

## 4. Moderator

Liquid hydrogen will be used as the cold moderator material in our present design. Figure 9 shows a concept of a MW-class cold moderator with a thin-walled structure, 120mm long x 120mm high x 50mm wide, which has almost the same configuration as that of the ISIS moderator except its thickness is less than 4mm. The photograph and the schematic drawing of the test apparatus for measuring the flow patterns in the cold moderator are also shown in the figure. The test model was made of plexiglass, which simulated the inner structure of the cold moderator vessel. Flow patterns were measured with the PIV system under water flow conditions [7]. In parallel to this experimental approach, the structural and thermal-hydraulic analyses have been carried out to prove the feasibility of this thin-walled structure concept. Through these activities, the structural strength issue will be met by using forged aluminum alloy such as A2219 or A7039, but this is currently in planning. The analytical flow patterns agreed well with the experimental results, and the result of the thermal hydraulic analyses showed that the hot spots in the hydrogen would be prevented at a flow-rate of more than 1liter/s.

For the R&D of the cold moderator system, we constructed a liquid nitrogen loop for testing cryogenic equipment and for examining the system dynamics of the cold moderator system. Figure 10 shows the outer view of the liquid nitrogen loop. The loop consists of a cryogenic pump, a buffer tank, transfer tubes and so on. Currently, the loop is in a trial operation phase, and the centrifugal cryogenic pump is being tested under the conditions of 1.5MPa and below 120K.

## 5. Beam Window

A proton beam window works as the boundary between a high vacuum region of the proton beam transport line and a helium environment around the target assembly. Figure 11 shows a concept of the water-cooled proton beam window available for the proton beam shape of 50x130mm and the present design of a window assembly connected with an exchanging plug, which will be withdrawn and inserted vertically. In order to suppress the proton beam diffusion at the window wall, a flat type window made of Inconel 718 alloy was adopted, whose thickness is less than 3mm [8]. Although a beam harrow monitor is shown in the figure, this is a sketch of an idea and the specifications of beam diagnostic devices such as a beam position monitor and a core monitor are not fixed yet.

Structural strength analyses coupled with thermal-hydraulic analyses have been carried out in order to verify feasibility under a MW-class proton beam operation. Analytical results showed expected performances of the stress distributions far less than an allowable stress and much lower surface temperature than the water saturation temperature under an operating pressure of 0.6MPa.

## 6. Remote Handling

Figure 12 shows a simplified scenario of the transfer procedure of the spent target vessel to the storage room [9]. Using the power manipulator, the spent target will be stored in an air-tight cask after being disconnected from the mercury pipelines, and then transferred to the storage room with the in-cell crane. In order to optimize the remote handling procedure, this scenario has been animated with the simulation code "ENVISION-TR" on the basis of 3D-CAD drawings.

Remote handling is an important issue not only for the spent target replacement but also for the maintenance and the repairing of the target system components which are highly activated. To verify and optimize the operational procedure as well as improve control system and devices, a test facility for the target remote handling is now being designed, and will be constructed at JAERI at the end of March in 2001. Figure 13 shows the schematic view of the test facility. This facility will be installed in a large experimental box (13.5m long x 10m wide x 15m high) and a simulated target and a piping system will be fixed on a simplified trolley. These components will be handled remotely using a power manipulator with 6 axis, which has an overhead traveling function.

## 7. Concluding remarks

We introduced the outline of present status of design and development activities on the MW-class spallation target system being carried out under the JAERI / KEK Joint Project. Now we are in the phase of engineering design and, if everything goes well, this facility will be in operation in 2007.

## Acknowledgement

We would like to thank Hitachi, Ltd., Mitsubishi Heavy Industries, Ltd., Ishikawajima-Harima Heavy Industries Co., Ltd., Kawasaki Heavy Industries, Ltd. and Fuji Electric Co., Ltd. for aggressively supporting our design work.

## References

[1] The Joint Project for High-Intensity Proton Accelerators, JAERI-Tech 2000-003 (2000).

[2] M. Kaminaga et al., "Thermal-Hydraulic Design of Mercury Target for the JAERI/KEK Joint Project", 15th Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-XV), Tsukuba, November 6-9, 2000.

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[7] T. Aso, et al., "Thermal-Hydraulic Experiments and Analyses on Cold Moderator", ICANS-XV, Tsukuba, November 6-9, 2000.

[8] T. Teraoku, et al., "Conceptual Design of Proton Beam Window", ICANS-XV, Tsukuba, November 6-9, 2000.

[9] J. Adachi, et al., "Conceptual Design of the Remote Handling System for a Spent Target Container", ICANS-XV, Tsukuba, November 6-9, 2000.

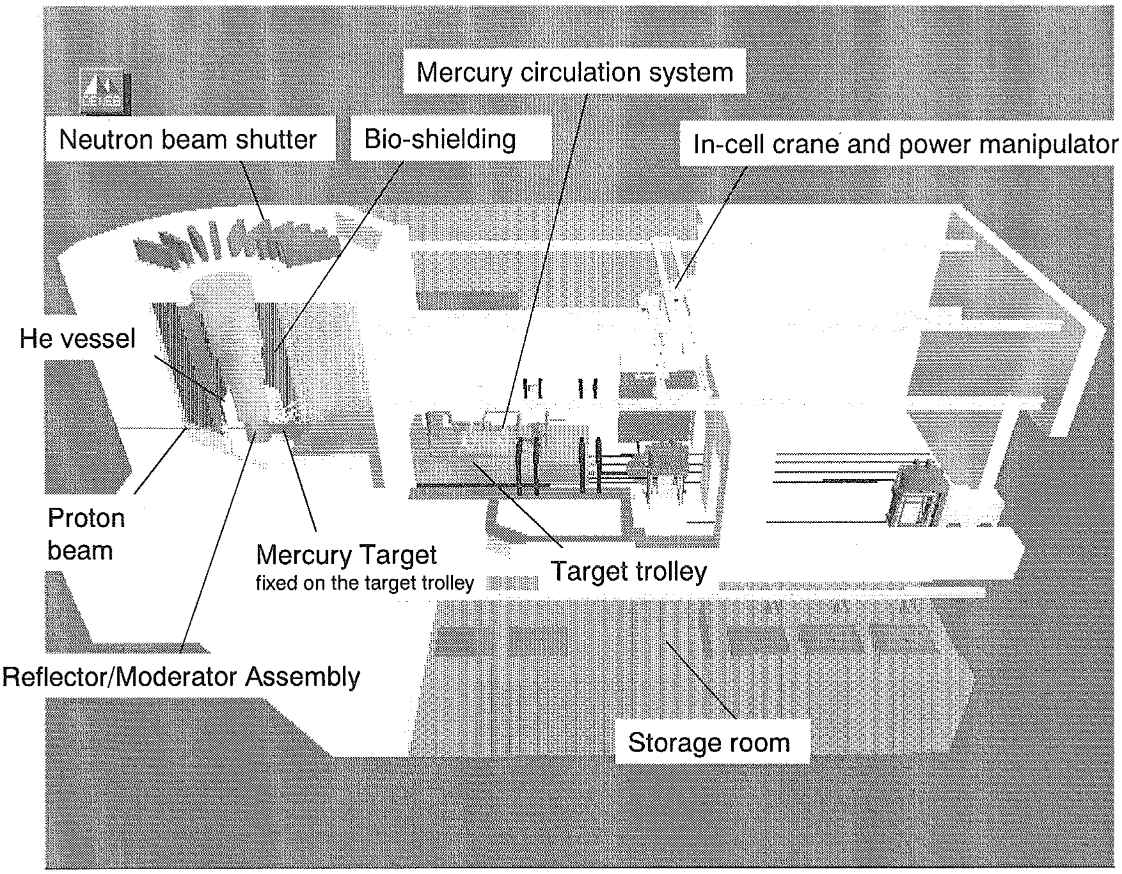
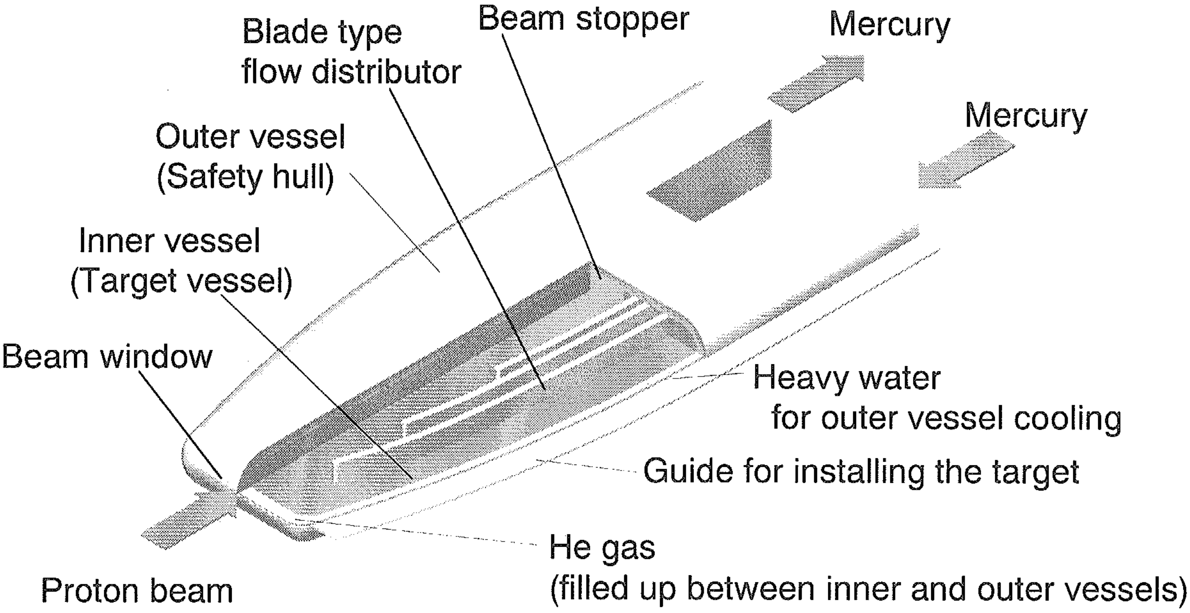


Fig.1 Cutaway View of the Target Station



Material : SUS316
Dimensions: 80 mm (height) x 260 mm (width) (at beam window),
Effective length 800 mm

Fig.2 Cross-Flow Type (CFT) Target with Blade Flow Distributors

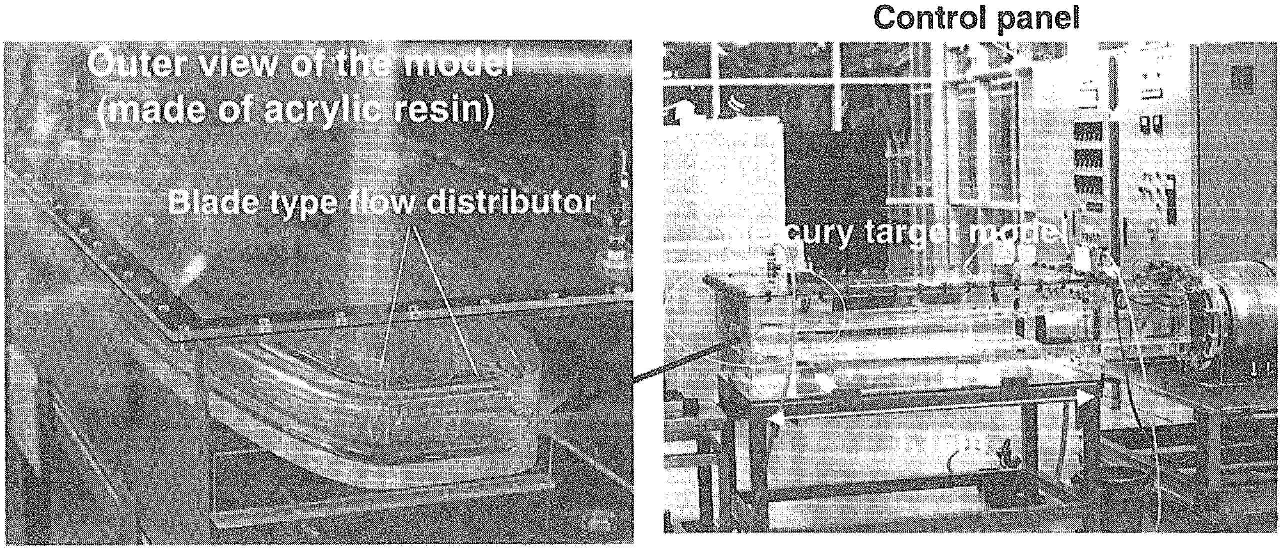
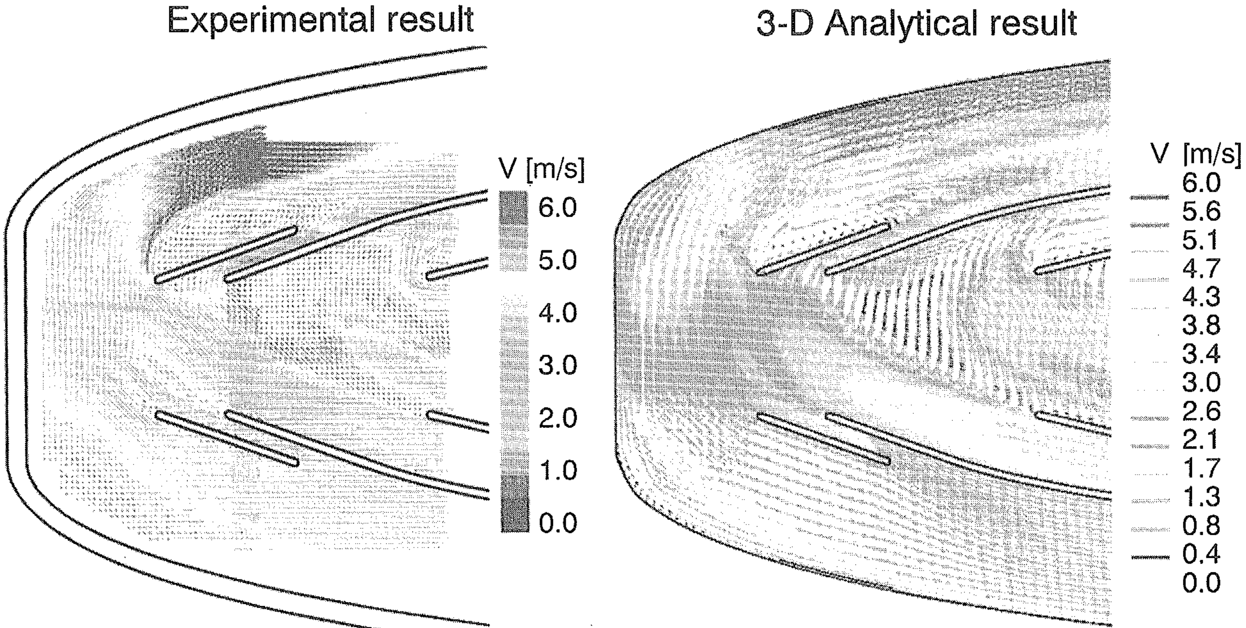
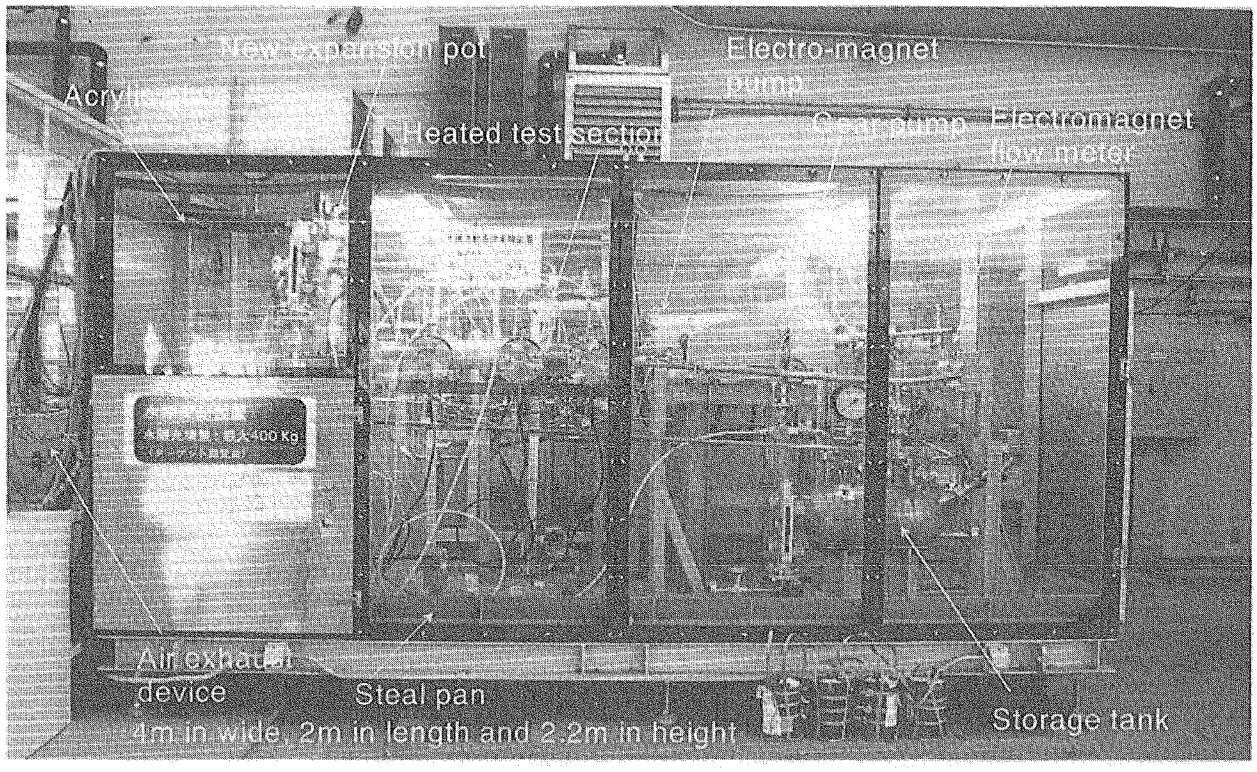


Fig.3 Outer View of the CFT Target Model
for Flow Pattern Measurements



Inlet Velocity : 3m/s
Reynolds Number : 480000

Fig.4 Velocity Distribution of Water Flow in CFT Target
Model Measured by PIV Technique



Outer View of Mercury Loop
Flow rate of mercury : 15L/min , Inventory of mercury : 400kg (maximum)

Fig.5 Outer View of JAERI Mercury Test Loop

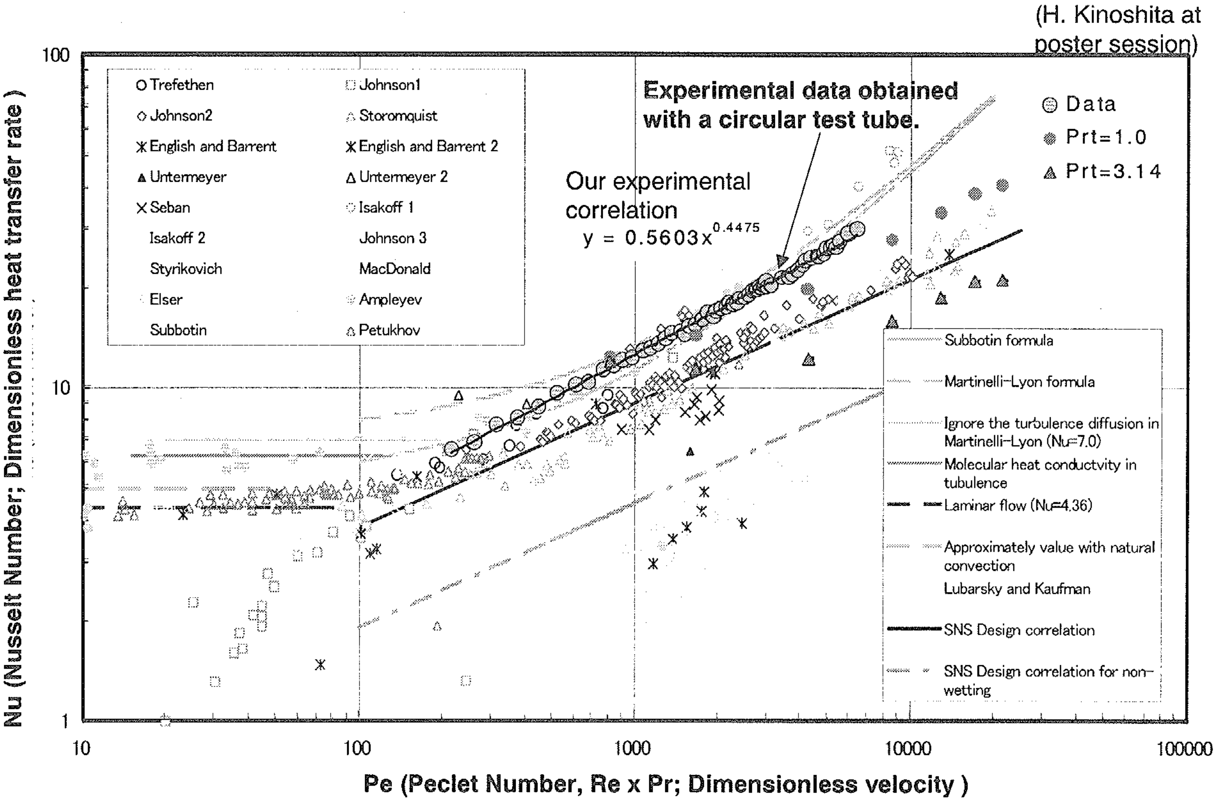


Fig.6 Heat Transfer Experiments Using Mercury Test Loop

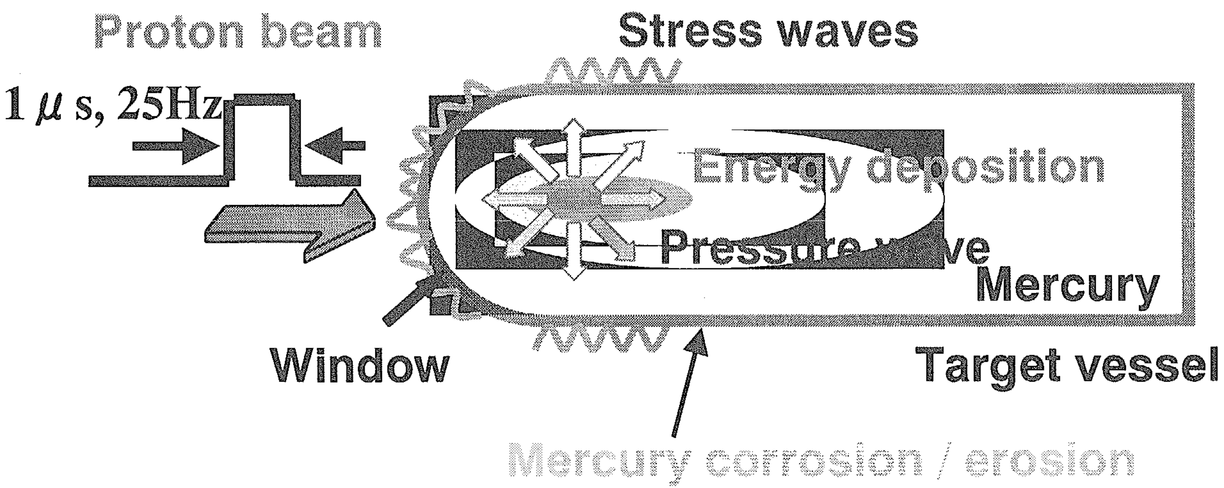


Fig.7 Pressure and Stress Waves Structural Integrity of Mercury Target Vessel

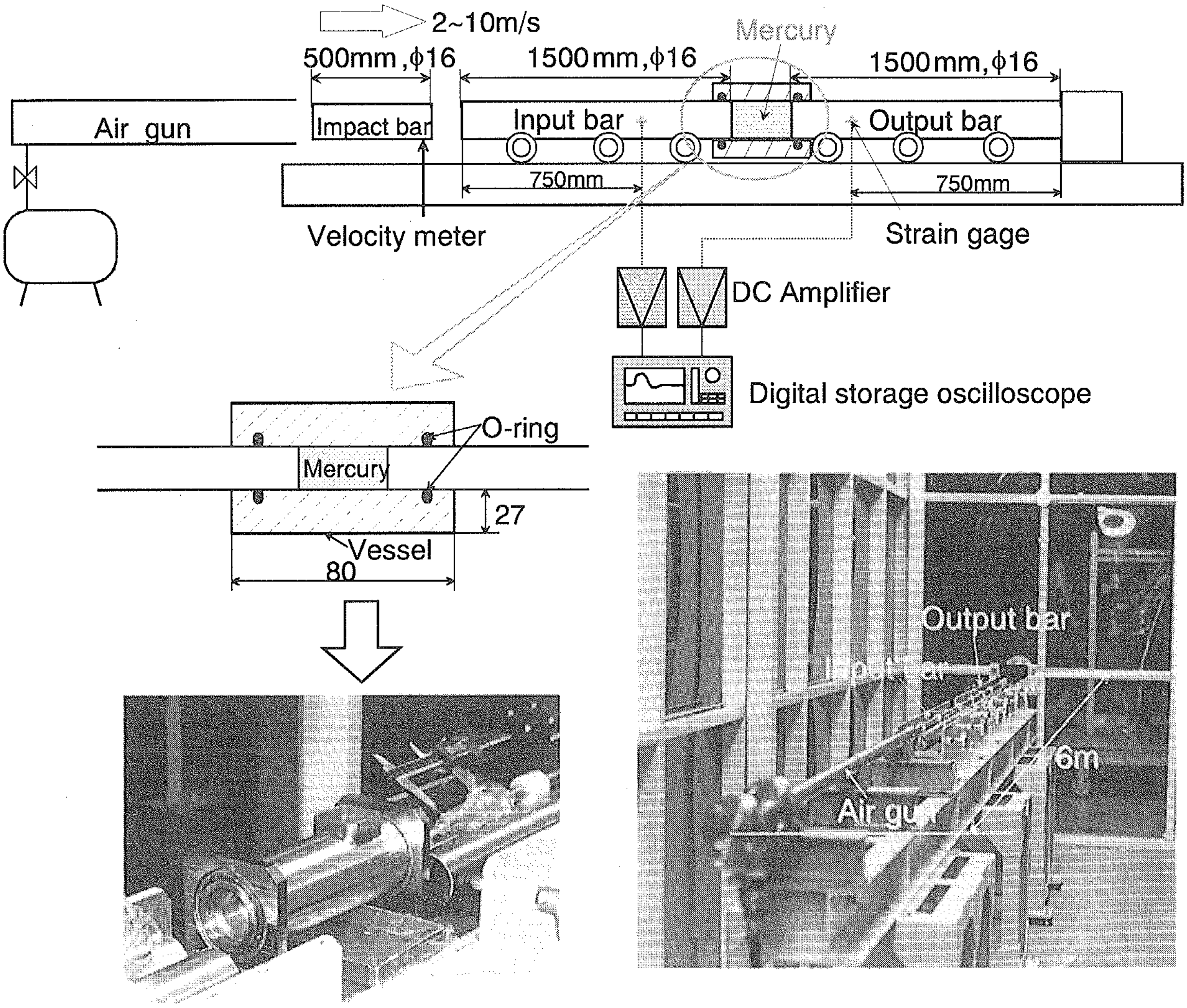
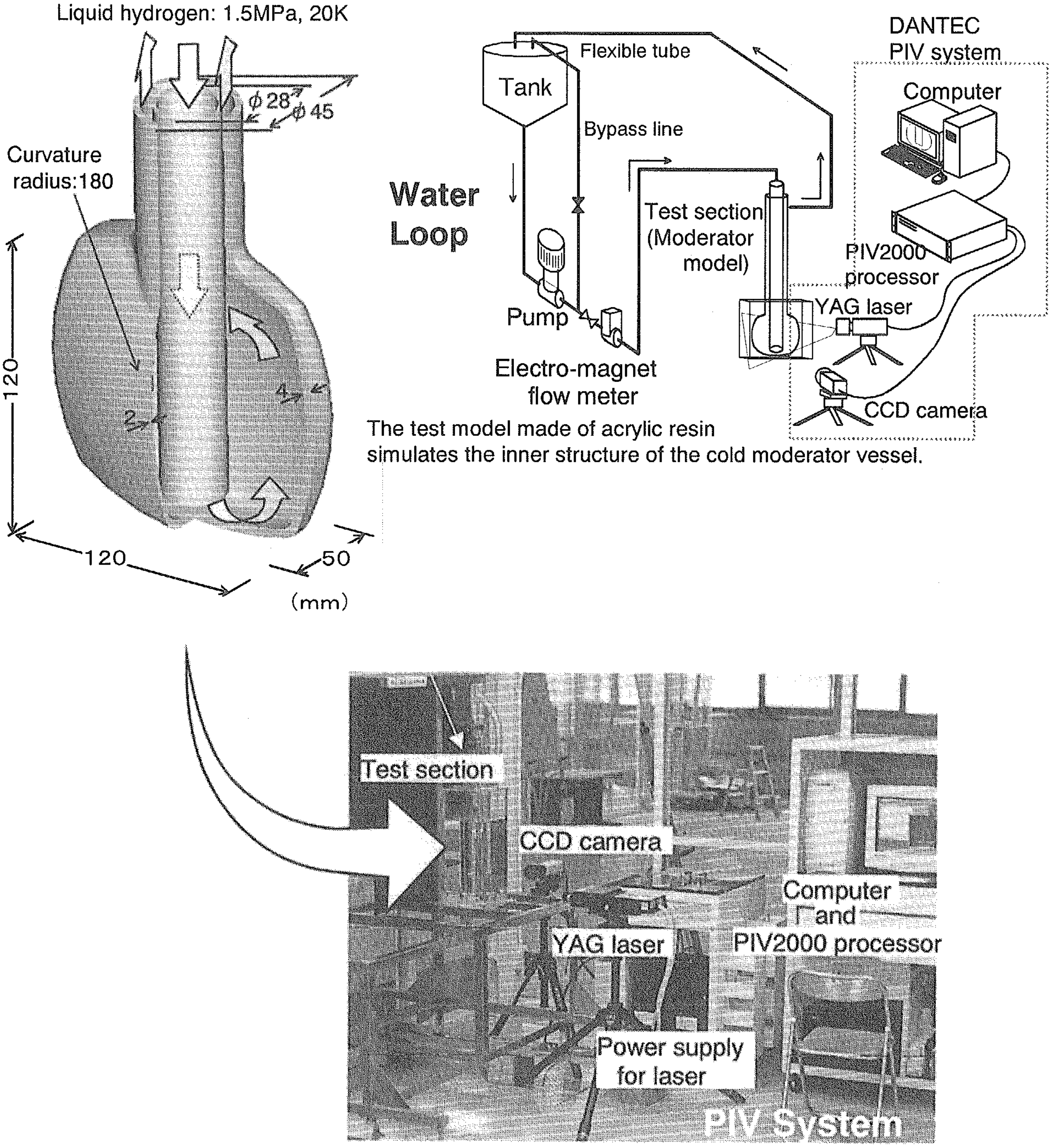


Fig.8 Impact Testing Device for Mercury



The test model made of acrylic resin simulates the inner structure of the cold moderator vessel.

Fig.9 Flow Pattern Measurements of Cold Moderator

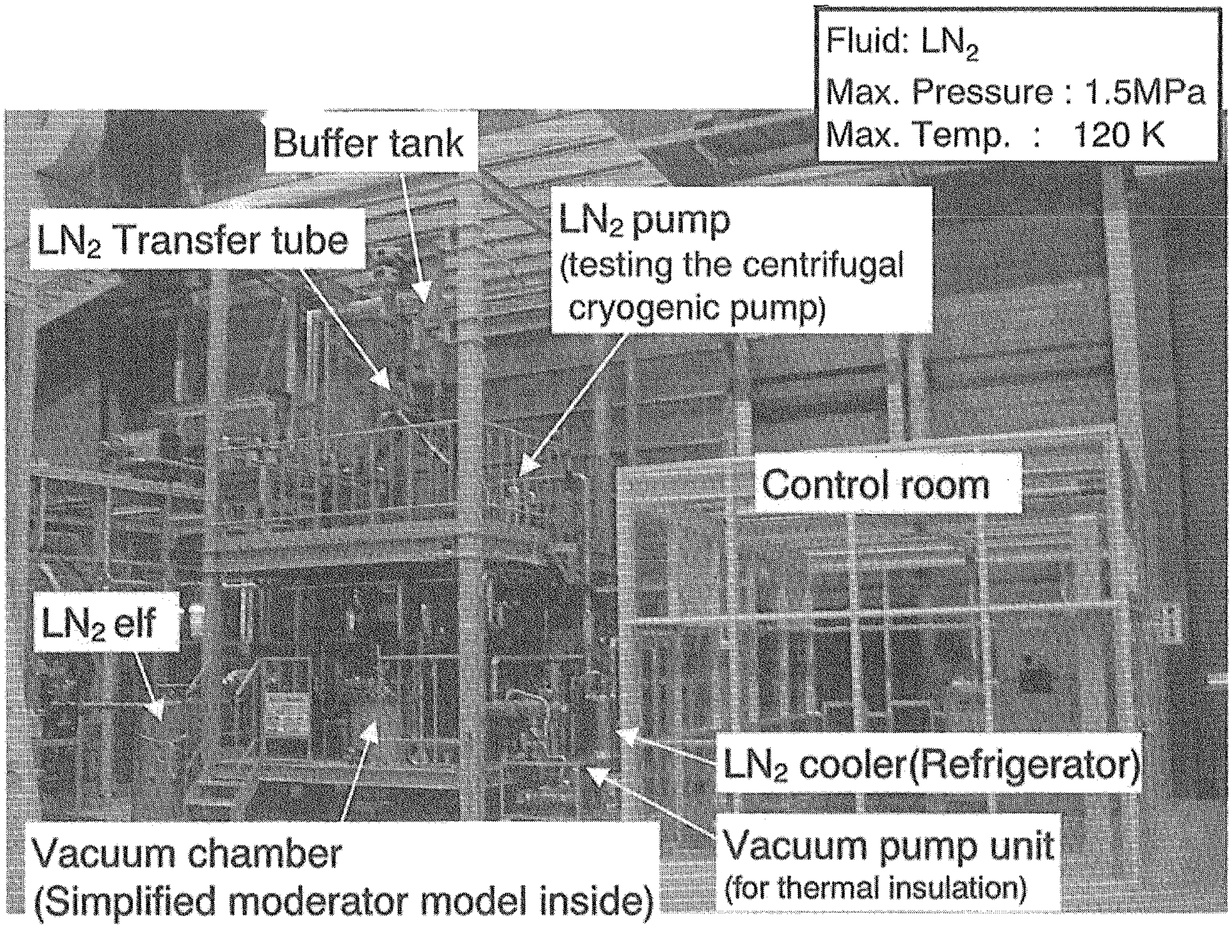


Fig.10 LN2 Loop for Cold Moderator System Test

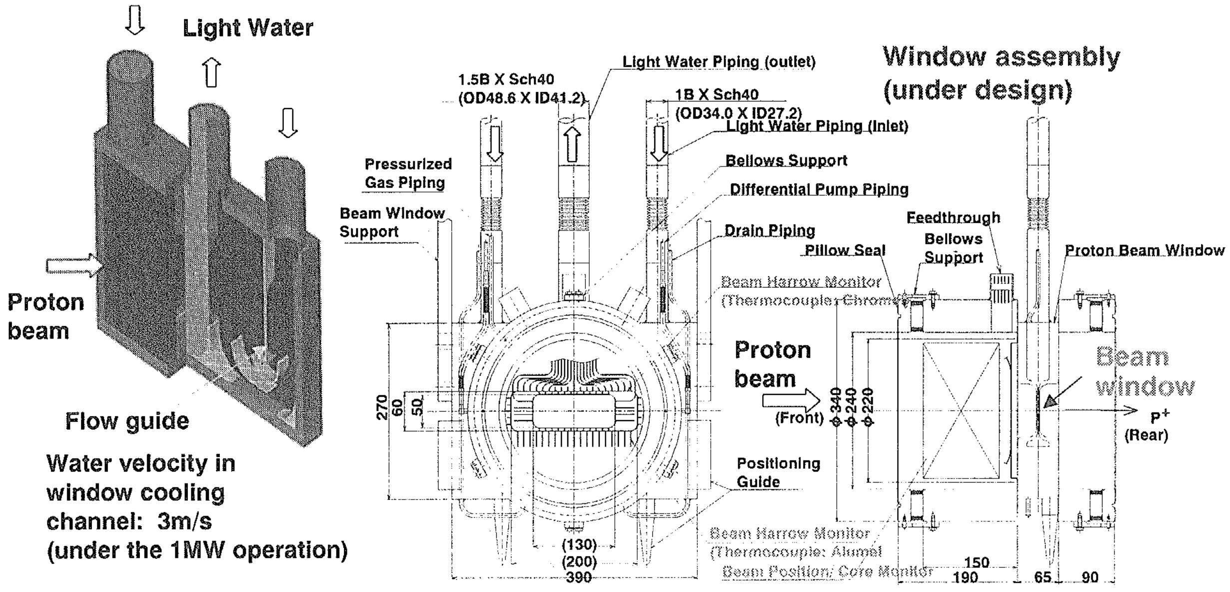


Fig.11 Flat Type Proton Beam Window

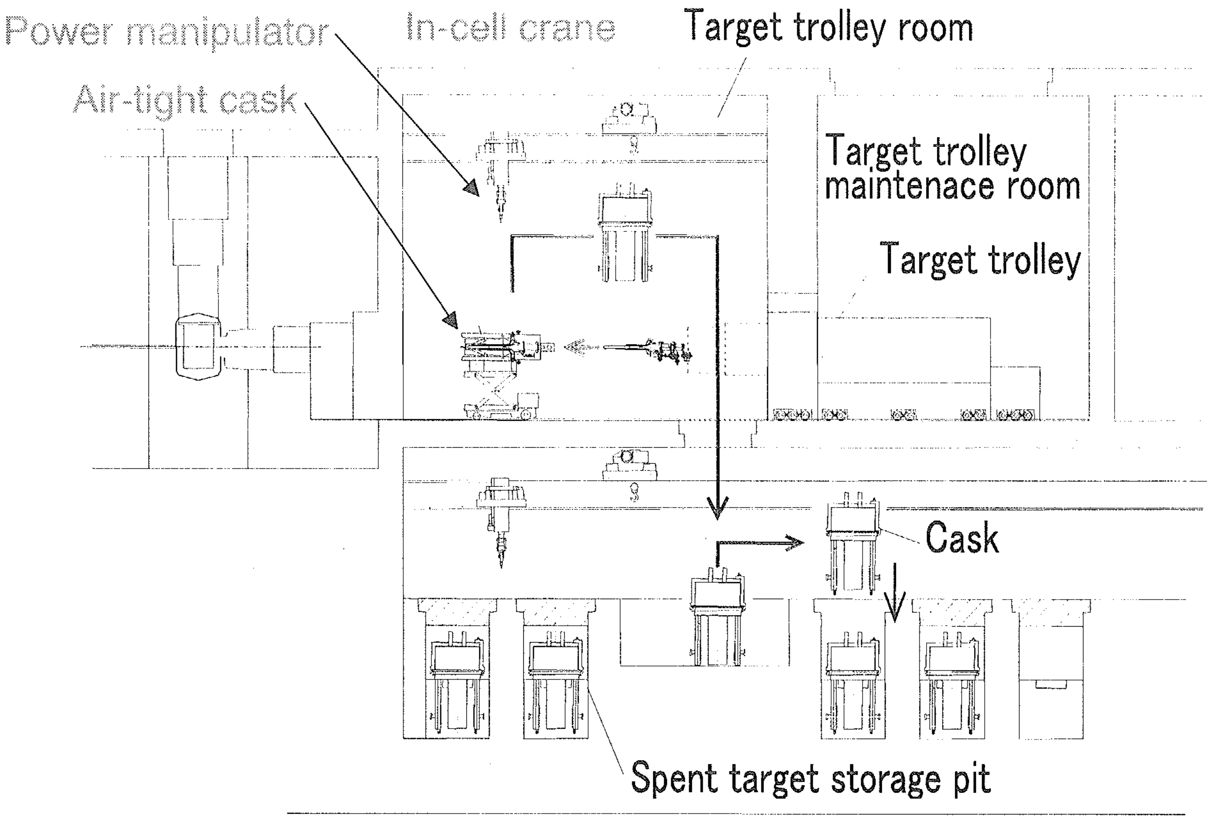


Fig.12 Transfer Procedure of a Spent Target Vessel to the Storage Room

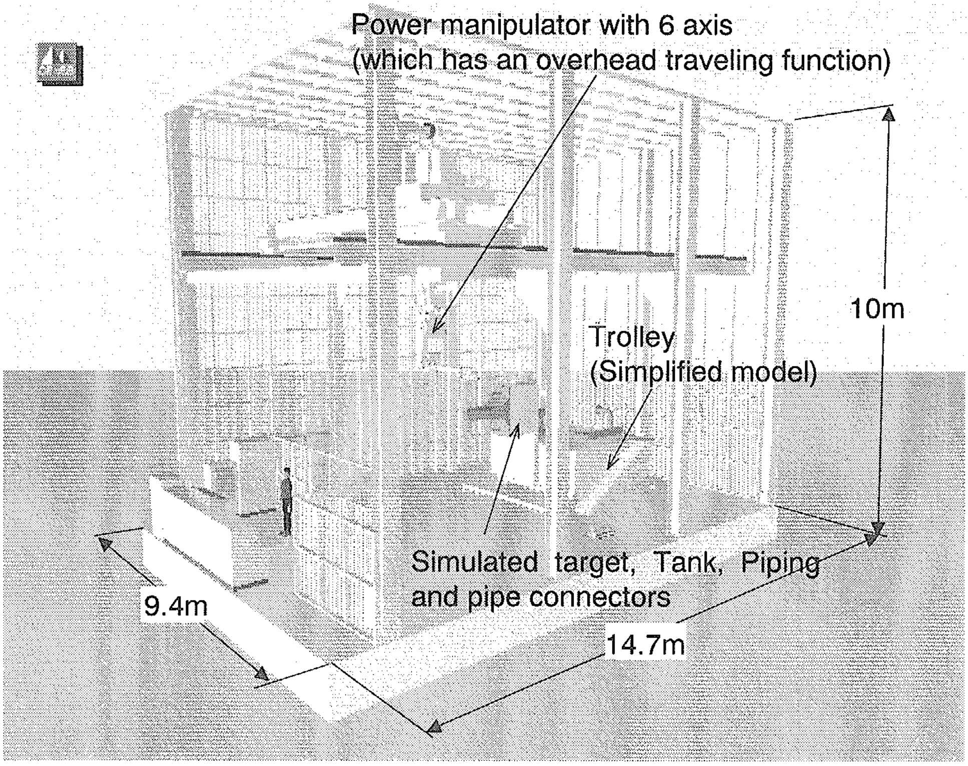


Fig.13 Test Facility for Target Remote Handling