Present status of JSNS and R&D for high power operation in J-PARC

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Abstract In May 2008, the JSNS target accepted firstly the proton beams accelerated by LINAC and 3 GeV RCS (Rapid Cycling Synchrotron) accelerators at J-PARC. After that we have steadily increased in the power up to 220 kW for user operation. Just after the operation over 200 kW reached 1000 h approximately, the tremendous earthquake, Great East Japan Earthquake, hit us and forced to suspend the operation. Fortunately, the components consisting of the neutron source were not suffered with heavy damages, as compared with the accelerators. In the paper, the experiences up to 220 kW operation, including the damage due to the earthquake, and some R&Ds to reach 1 MW operation will be introduced; troubles and improvements in the supercritical hydrogen loop, the exchange of the mercury target vessel, the pressure wave mitigation system, proton beam flattening technique, observation of PIE specimen cut out from the target vessel, etc.

1. Introduction

In May 2008 the JSNS, whose structure and main components are seen in Fig.1 accepted firstly protons and yielded neutrons. After that the proton beam power was increased steadily up to 220 kW, as illustrated in Fig. 2. In the operation at 220 kW, the number of neutrons emitted from the coupled hydrogen moderator per unit solid angle per pulse was found to be 3.8×10^{12} [1]. As of 2010, the corresponding neutron intensities in the world's major spallation neutron sources were 4.2×10^{12} at the Spallation Neutron Source (SNS) facility in U.S.A., and 4.0×10^{12} at the ISIS facility in UK as shown in Fig.3 [1]. Thus it was confirmed that the neutron intensity achieved at J-PARC was almost comparable with those at the world's major pulsed spallation neutron sources. J-PARC's neutron intensity will eventually be three times higher than that of SNS when the beam power is raised to the rated 1 MW.

The number of pulses per second is suppressed to 25, compared to 60 at SNS, to increase the number of neutrons in each pulse. The unique moderator design represented in its cylindrical shape, which was found through an extensive optimization study on the materials, dimensions, and configurations of the neutron source

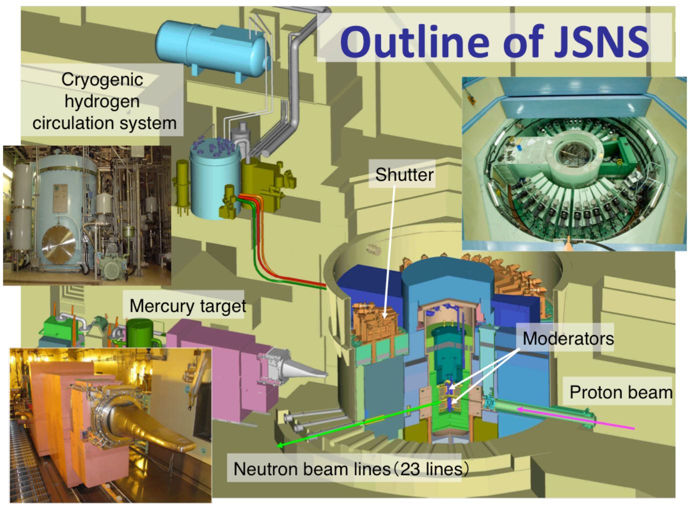

Figure 1 Structural outline of JSNS: Cryogenic hydrogen circulation system with 200 L of hydrogen inventory, mercury target system with 20 ton mercury inventory, 23 isolated shutter system for each 23 BLs.

components, is another reason to push up the neutron intensity.

Just after 1000 h operation over 200 kW, the tremendous earthquake, Great East Japan Earthquake, hit in J-PARC on 11th March 2012. The mercury target system was ready for the beam operation and the system was running with the rated mercury flow rate of 41 m^3/h just before the earthquake occurred. The proton beam transport facility had been kept in good condition and operated reliably even for 300-kW beam power.

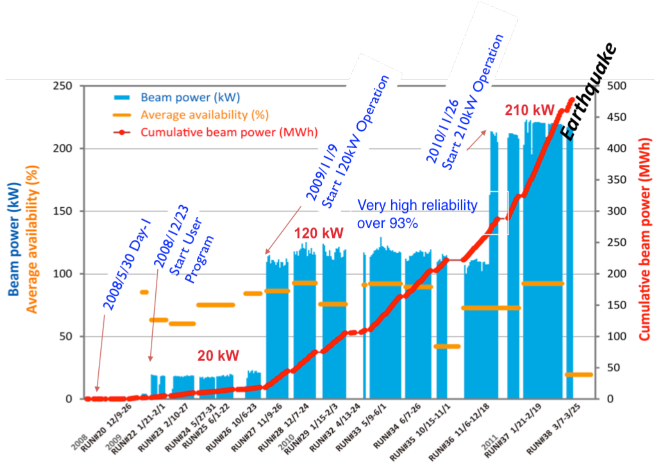

Figure 2 Proton beam power on JSNS target

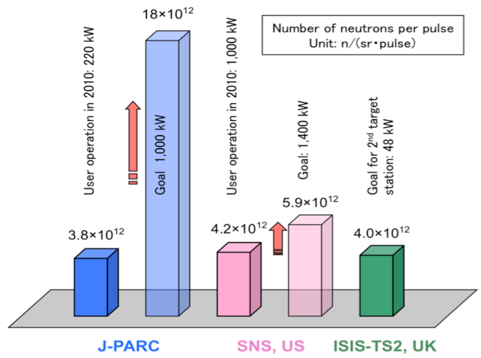

Figure 3 Comparison of neutron intensities of the world's major spallation neutron sources

2. Damages due to the earthquake

Damages around MLF (Materials and Life Science Experimental Facility) building induced by the earthquake were shown in Fig.4. Figure 5 shows the time-responses in main components at the earthquake; the first big quake occurred on 14:46, after about 30 min later the second quake on 15:16. The MLF building itself withstood the quake and suffered less damage. The damage to the mercury

Figure 4 Damages around MLF: Subsidence with 1.5 m depth, inclination of liquid nitrogen tanks, cracks on the wall of 3NBT tunnel, broken shutter flanges, seal bellow elongation of target vessel, etc.

circulation system, the remote handling systems and the coolant facilities in the building were limited and most of their components looked sound. One of the major damages in the neutron source components was a vacuum break of aluminum neutron beam ducts in neutron beam shutter blocks. Many bolts fastening a metal O-ring on a duct flange in more than half of the ducts were loosened because of an impact effect associated by a shutter movement and hitting the surrounding wall. All the 23 ducts were recovered in four months by taking countermeasure to prevent loosening of the bolts.

The cryogenic hydrogen system was in operation under the rated condition of 20K and 1.5 MPa at the earthquake. Several minutes after the beginning of the earthquake, the system was stopped by an interlock signal due to the power failure. The hydrogen gas was discharged safely through a release line as usual. Since the MLF building itself withstood against the quake, damages found in the cryogenic hydrogen system in the MLF building were not very serious. However, the ground surrounding the MLF building subsided severely, which broke the outside facilities. A liquid nitrogen storage tank and a helium buffer tank for the system, both of which are 2.5 m in diameter and 10 m in height, leaned to a degree and the associated pipes were bent due to the subsidence. After completing recovery of the ground subsidence in September, these tanks were made upright and the damaged pipes were repaired. The cryogenic hydrogen system was finally resumed successfully at the end of November 2011.

When the earthquake occurred, the mercury circulation pump stopped and the flow rate decreased to 0 due to the power supply shutdown, but the total system kept soundness. The mercury level at the surge tank was fluctuated at the first and the second quakes respectively. The trolley movement influenced the helium vessel seal system installed on the target vessel. The helium vessel seal system pushes the seal onto the helium vessel flange by the pressurized helium gas in the metal bellows chamber. As the counteraction, the force to move the target trolley away from the system operation position is generated, but the trolley stopper actuated by compressed air supplied to the air cylinder prohibits the target trolley from moving. Due to the ground sink around the MLF building, the pipeline of compressed air supply was broken and the trolley stopper lost its actuation force. This trouble, along with the strong seismic shaking, resulted in the release of the trolley stopper. The target trolley lost its constraint force and the bellows of the helium vessel seal system extended too much and ruptured with a crack. The first target would not be used anymore.

The facility building of the proton beam line was shaken tremendously and the cooling towers on its roof tilted cruelly. The beam line tunnel displaced and subsided substantially at the Great East Japan Earthquake and the wall at the expansion joint to the MLF building was severely damaged. Fortunately the most of the beam line magnets, the beam monitors and the vacuum systems managed to escape damage. The magnets and the beam monitors were aligned again.

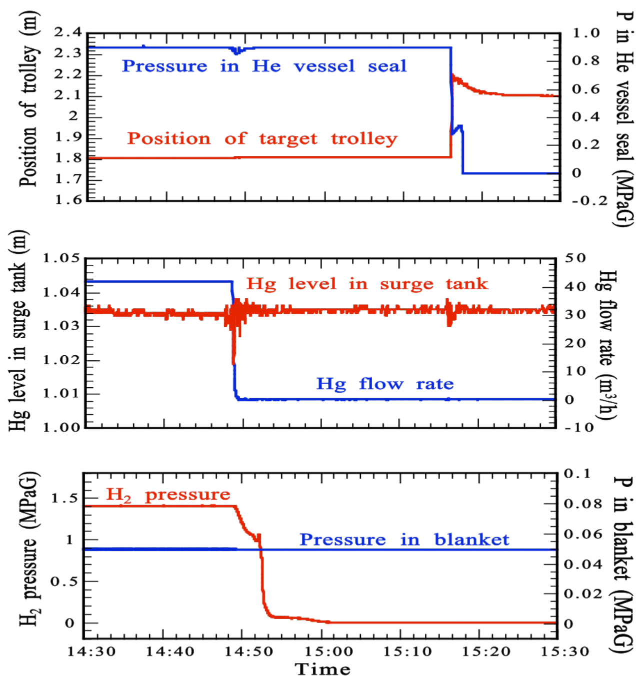

Figure 5 Time-responses in main components in MLF at the earthquake: He vessel pressure and position of target trolley; mercury flow rate and mercury level at a surge tank; hydrogen pressure and pressure in blanket.

3. Recovering after the earthquake

The first target was replaced to the new target in November 2011. Figure 6 shows the first target with elongated seal bellows and the replaced new target. The new target vessel equipped with a bubbler in it for mitigating pressure waves in mercury causing the cavitation damage, so-called pitting damage, had been fabricated as a spare target. It was the first time to replace the target vessel, i.e. the heavy and large radioactive component, by remote-handling system since the MLF began the beam operation. The target replacement was successfully completed in 7 days just the same way as the handling test under the cold condition. Unfortunately, the installation of the helium gas supply system, which supplies compressed helium gas to the bubbler, was not in time for the beam operation due to the trouble in the helium compressor. The mercury circulation operation of the target system started again in December 2011. Pressure drop of mercury in the target vessel increased due to the bubbler installation, but the flow test showed the operation property agreed well with the estimation.

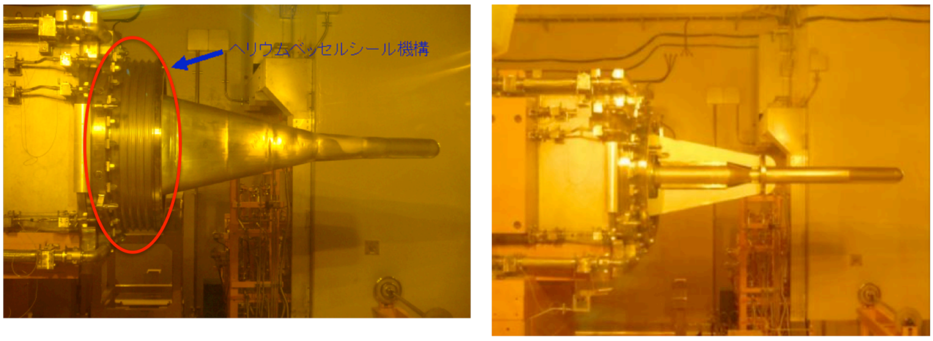

Figure 6 The first target vessel with plastically elongated seal bellows and the newly replaced target vessel, which was redesigned to be compact and reduce radioactive wastage.

The beam operation was resumed in late December 2011. The proton beams were transported from the accelerator to the mercury target and their beam orbits and profiles were tuned without any serious problems. The beam emiitances were measured and any significant changes were not found.

On December 22, the first proton beam after the earthquake was successfully delivered to the mercury target in MLF. On December 23, a neutron beam was introduced for the first time to the NOBORU instrument (BL10) under 1 Hz operation. A neutron beam profile was measured with an image plate, as shown in Fig 7. Neutron flux intensity was measured with the gold foil activation method. A neutron TOF spectrum was measured with a He-3 monitor counter, seen in Fig. 8. It was confirmed though these measurements that the earthquake did not affect meaningfully the neutron beam characteristics.

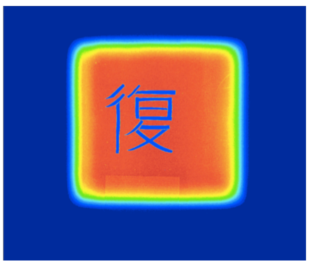

Figure 7 The first neutron beam in MLF after the earthquake on which a Chinese character ″復″, which has a meaning of "recovery", was emerged

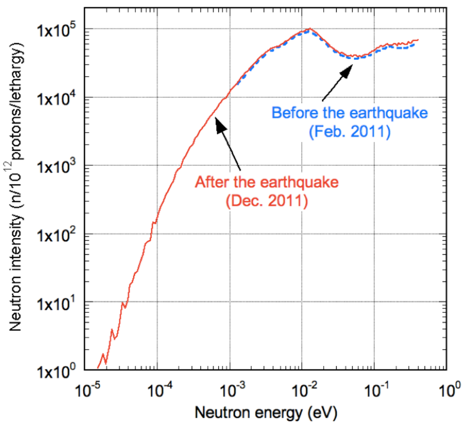

Figure 8 Neutron flux spectra before and after the earthquake.

4. R&D for high power and steady operation

In advance to the target vessel replacement, disk specimens were cut out from the beam window of the target vessel. Using the cutting machine specially developed for this purpose, three specimens were cut out by remote-handling. The dose rate at the surface of the target vessel was more than 10 Sv/h, which is beyond the measurable range in a used device. The specimens were cleaned in an ultrasonic cleaner and the surface appearance of the innermost specimen which is the wall of the mercury vessel was observed as shown in Fig. 9. There were pitting damage clusters at the center and the both sides of it. Many spots of pitting damages were also scattered all around the specimen. The depths of these damages were measured by getting the replicas of the specimen surface : i.e. silicon rubber was put on the specimen to transcribe the surface shape onto the rubber and it was measured by the laser microscope. Submicron order of damage depth can be measured by this technique. The maximum depth of the damage found in the measurement so far was roughly 250 μm, and there is a possibility that deeper damages which are not found yet. Further investigation of the specimens needs to be continued.

One of the technologies to mitigate the pressure waves is to inject microbubbles into flowing mercury. The expected mechanics are absorption, attenuation and suppression, which depend on the bubble conditions [2]. In fact, it was difficult to find an appropriate bubble generator, a so-called bubbler, equipped in mercury targets. Recently, we found a swirl type bubbler, which breaks gas column into tiny bubbles by strong shear forces to generate

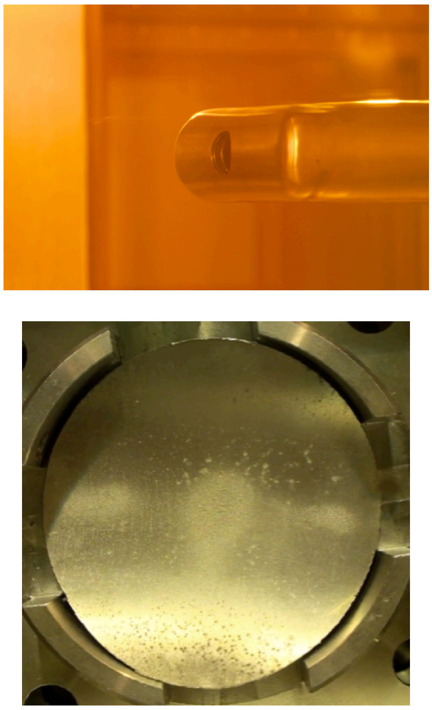

Figure 9 Disk specimen with ca. 5 cm in diameter cut out from the beam window of the target vessel

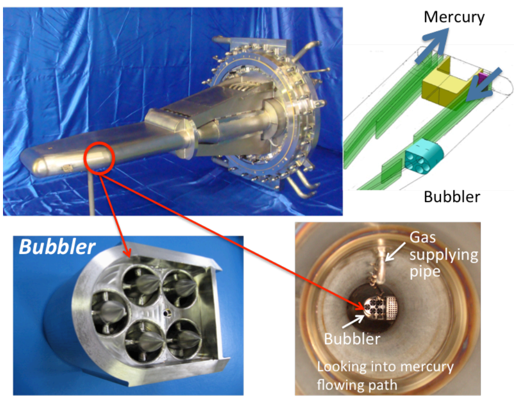

Figure 10 Target vessel with bubbler

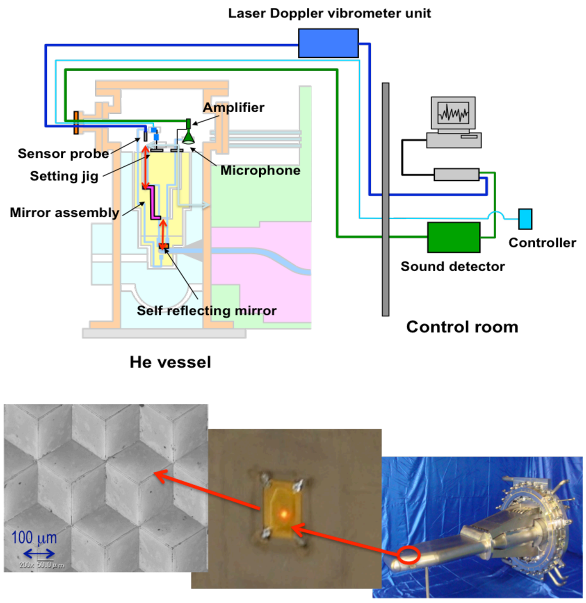

Figure 11 Diagnostic system for structural integrity in target vessel relating to pressure waves

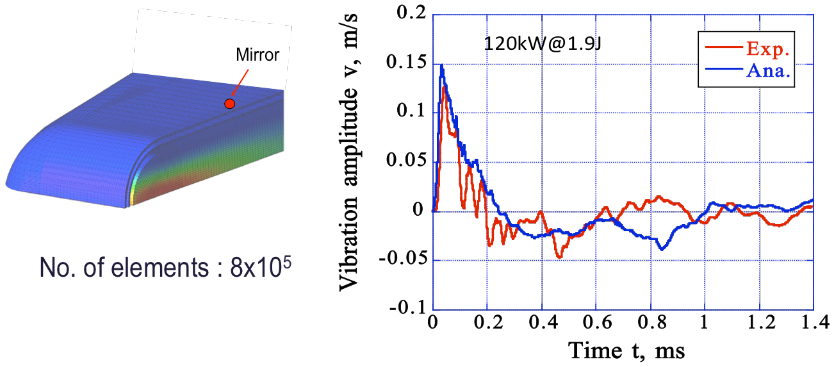

Figure 12 Comparison between experimental and numerical results on pressure wave response in mercury target vessel.

bubbles in 50 μm approximately [3]. The void fraction, i.e. bubble distribution, is affected by the mercury flowing pattern. The bubble distribution was evaluated through the numerical simulation and the experiment carried out at TTF loop by using a mock-up model of JSNS cross-flow-type mercury target under collaboration with SNS team [4]. Although the target vessel installed after the earthquake is equipped with the bubbler as shown in Fig. 10, the void fraction at the peak heat density, around 10^{-5} is not sufficient. The improvements on the bubble distribution in mercury flow and the bubbler are being carried out.

The diagnostic system was developed based on LVD (Laser Doppler Vibrometer) technique [5]. The laser path is formed through the clearance between moderator pipes and reflectors in the inner plug as illustrated in Fig.11. Fortunately the narrow path was not damaged by the earthquake. The mirror for laser beam equipped on the replaced target vessel improved to have a sufficient reflected intensity, which consists of micro-triangular-pyramids, which were machined precisely. Figure 12 shows the typical measured result of vibration responses to be compared with a numerical one. A good agreement was obtained to sufficiently verify the numerical model used for the design on target.

The proton beam optics was studied to reduce the current density of the proton beams on the mercury target by introducing a couple of octupole magnets into the present proton beam line. The bore radius of the magnets is 150 mm and the pole is 600 mm long. The maximal differential coefficient of third order in the magnetic field distribution is 800 T/m^3. The magnets and their DC power supplies were fabricated as shown in Fig.13 and scheduled to be installed during the summer shutdown period in 2013. The beam optics has been examined in advance without the octupole magnets in terms of maneuverability and beam loss.

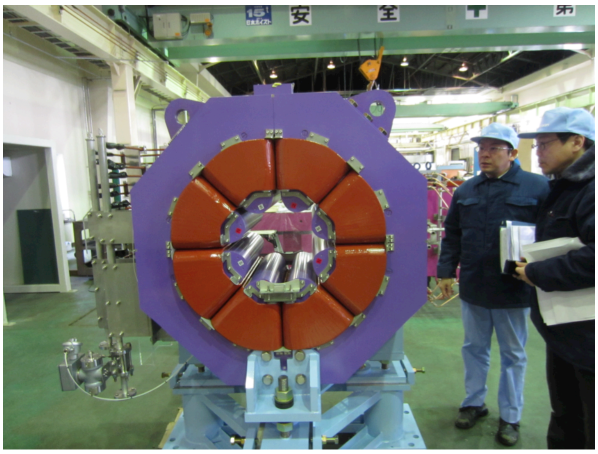

Figure 13 Fabricated octupole magnet.

The J-PARC neutron source is equipped with three supercritical hydrogen moderators, which have the thin fivefold coaxial tube structure made of aluminum alloy and stainless steel. Some R&D activities are going on to facilitate manufacturability of the moderators. A low

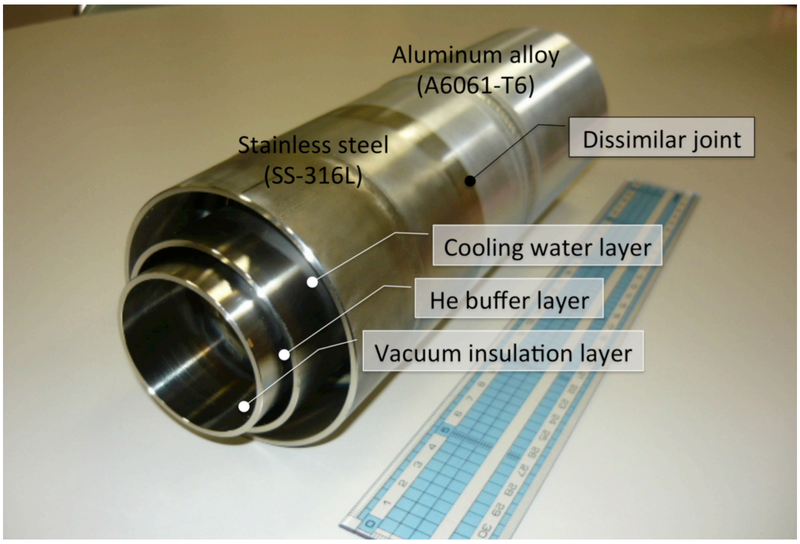

Figure 14 A combined component of triple tubes used for the room temperature region.

thermal expansion material "Invar" is to be introduced to minimize thermal shrinkage of the moderator tubes when they are cooled down to 20 K. Weldability and bendability of Invar tubes have been confirmed to be workable. A combined component of multiple tubes including a dissimilar joint of aluminum alloy and stainless steel was fabricated successfully as shown in Fig. 14, which will contribute for easier concentric alignment and definite airtightness at the joints

In the operation of the cryogenic hydrogen system, we encountered two challenges we need to overcome in JFY 2010: an accumulator failure and an impurity issue in the helium refrigerator system. In the beginning of February 2010, we discovered a leakage in the accumulator bellows. It was a serious leakage because the boundary function between the hydrogen and the helium regions was lost. The failed accumulator was replaced with a new one during the 2010 summer shutdown period as shown in Fig. 15. To decrease the mechanical load to the bellows and to improve its maintainability, the variable volume of the accumulator bellows was reduced from 16 L to 6 L. We carried out an on-beam commissioning operation to confirm that the new accumulator was functioning properly. The pressure rises were 4 kPa and 8 kPa for the 120-kW and 220-kW proton beam operations, respectively, as expected.

From October through December 2010 we had to halt the operation twice due to heat exchange degradation in the helium refrigerator system. Contamination caused by impurities (most likely water vapor) in the helium gas was the possible reason. A new charcoal filter in the helium refrigerator, which was exposed to ambient air during exchanging work during the summer shutdown period, could be the source of the impurities. A pressure drop in the heat exchanger increased gradually probably due to water adhesion to heat exchange surfaces. This caused decrease in the thermal conduction through the heat exchange surfaces and then increase in the outlet temperature of the heat exchanger. To solve the problem we have introduced a regeneration system, consisting of a cryogenic purification unit, a drier unit and a heater unit, into the helium refrigerator system during the 2011 summer shutdown period, as shown in Fig.15. As of February 2012 operations of the cryogenic hydrogen system are very smooth although inside of the system was exposed to ambient air for a long time during the recovery work in 2011.

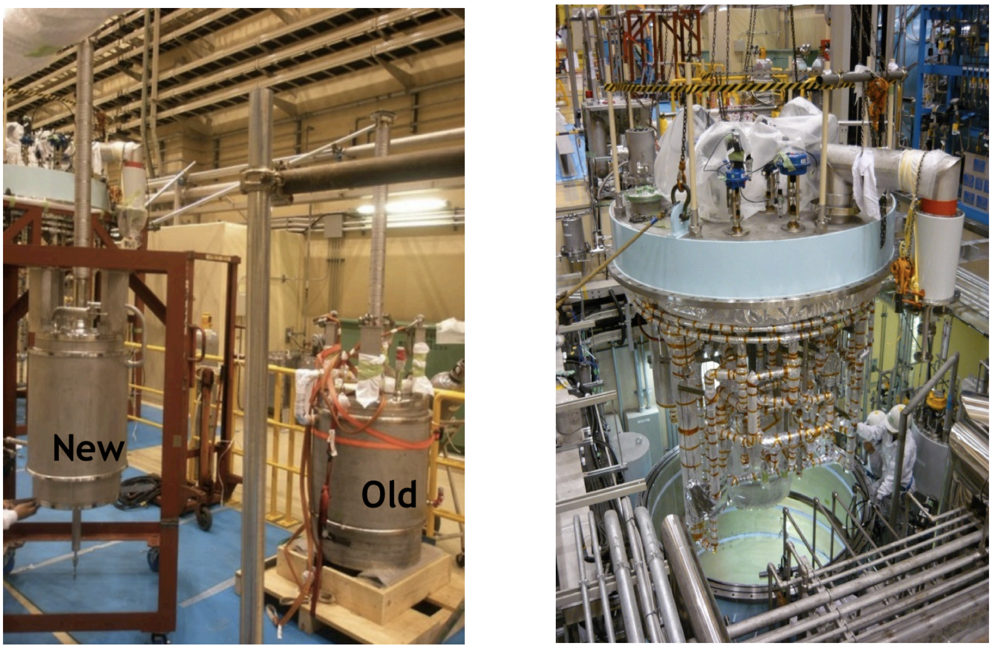

Figure 15 The new and old accumulators and inside of the hydrogen cold box.

5. Summary

The followings are summarized :

- Recovering commission was carried out after the earthquake under very strong team works and user operation was resumed in night 24th, Jan, 2012.
- The first replacement of target vessel was carried out. Before that the disk specimens for PIE were cut out from the target vessel to evaluate the cavitation damage, so-called pitting damage, induced by the pressure waves. It was found that the clusters of pits were imposed on the vessel wall even at low power operation less than 220 kW.
- Bubbling system will be workable soon. The effect of mitigation will be investigated by using the IN-SITU nondestructive inspection system based on LVD technique.
- 300 kW operation will start in 2012 after installation of the bubbling system.

References

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