Influence of Great East Japan Earthquake on Neutron Target Station in J-PARC

K. Sakai, M. Futakawa, H. Takada, S. Sakamoto, F. Maekawa, H. Kinoshita, M. Seki, K. Haga, H. Kogawa, T. Wakui, T. Naoe, Y. Kasugai, H. Tatsumoto, T. Aso, S. Hasegawa, K. Oikawa, M. Ooi, A. Watanabe, M. Teshigawara, S. Meigo, K. Ikezaki, A. Akutsu and M. Harada

Neutron Source Section, MLF, J-PARC Center, Tokai, Ibaraki, Japan

E-mail: kenji.sakai@j-parc.jp

Abstract. This report describes the behavior and damage of each component in the Neutron Target Station (NTS) of J-PARC at the time of the Great East Japan Earthquake (GEJE). At the time, strong shocks caused by the GEJE were observed all over Eastern Japan. Around the NTS in a Materials and Life Science Experimental Facility (MLF) of J-PARC, strong quakes were detected at several instruments, an external power supply was lost, all of the circulation systems were shut down automatically and hydrogen gas was then released as planned. Leakage of activated liquids or gases did not occur. The quakes made gaps between shield blocks and the subsidence ruptured external pipe lines for compressed air and water. But significant damage on the components of the NTS was not found though the loss of compressed air supply affected lock systems with air cylinders and pneumatic values. These results substantiated a validity of safety design on the NTS for emergency.

1. Introduction

The Great East Japan Earthquake (GEJE) of magnitude 9.0 occurred at 14:46:18 on March 11, 2011 off the Pacific coast of Miyagi Prefecture [1]. The quake expanded along the Pacific coast of Eastern Japan in a few minutes. Strong shocks over 0.5 G of acceleration were observed all over Ibaraki Prefecture. After the first hard shocks, aftershocks continued intermittently and the maximum aftershock occurred at 15:15:34 off the coast of Ibaraki Prefecture. The facility of the Japan Proton Accelerator Research Complex (J-PARC) located at the seaside of Ibaraki Prefecture suffered heavy damage by the GEJE such as subsidence, loss of external electric power supplies, distortion of the buildings, leakage of ground water into accelerator tunnels. This paper investigates behavior and damage of each component in the Neutron Target Station (NTS) of the Materials and Life Science Experimental Facility (MLF) of J-PARC at the time of the GEJE and verifies the safety design of the NTS for emergency.

2. Outline of Neutron Target Station (NTS) of MLF

The NTS of the MLF generates neutrons by injecting proton beams into a mercury target, moderates high-energy neutrons, and supplies cold neutrons to experimental apparatuses in the experimental halls of the MLF building [2]. There are several annexed buildings around the building. Fig. 1 shows a cut view of the NTS. Its core components such as a mercury target, moderators, reflectors, water cooling shields are installed in a helium vessel filled with helium gas. Neutron beam line components such as neutron beam shutters, biological-shields and pre-shields are mounted around the helium vessel. The beam shutter stops or passes neutrons by moving a shutter block, which is a rectangular iron lump of 15 ton in weight. The shutter block has a vacuum beam duct, in which devices such as collimators and guide tubes are inserted. During beam operation, the shutter block is lifted up by a drive motor and set at an open or close position with an independent controller.

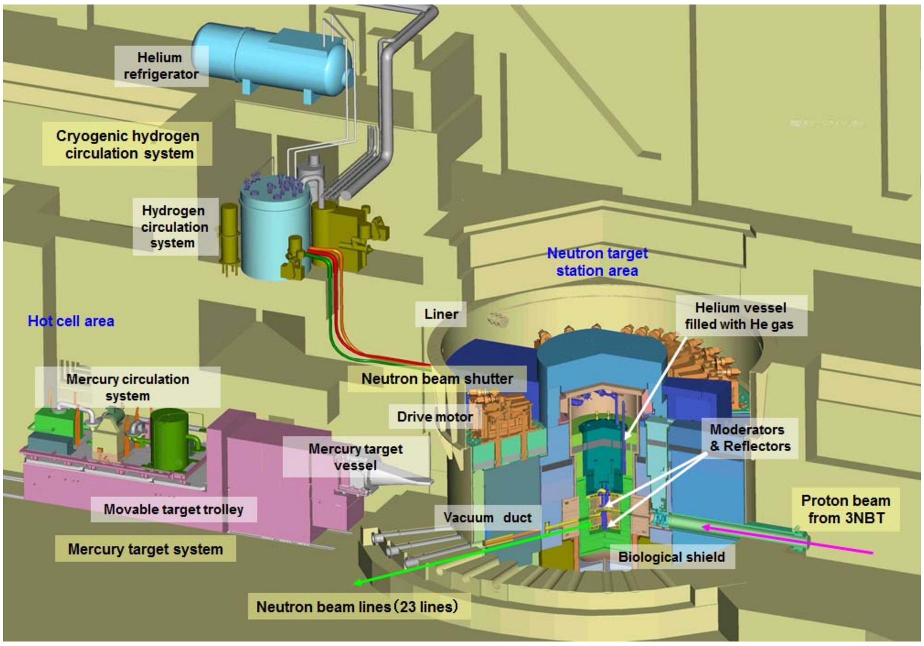

Figure 1. Cut view of the Neutron Target Station (NTS) in the Materials and Life Science Experimental Facility (MLF) of J-PARC.

The mercury target system consists of a target vessel and a mercury circulation system mounted on a movable target trolley. During beam operation, it is inserted into the helium vessel by moving the target trolley in the hot cell and fixed by lock systems with air cylinders. In order to keep the helium vessel airtight, the target vessel has a seal mechanism based on double bellows structure and a metal seal is pressed against the vessel flange by supplying gas between bellows. Mercury is supplied into the target vessel by an electromagnetic pump in the mercury circulation system. The circulation system is connected to an off-gas process system, which storages activated gas in four tanks temporarily, and discharges the gas after reducing their activation levels.

The cryogenic hydrogen circulation system consists of a hydrogen circulation system and a helium refrigerator system. The former consists of a helium-hydrogen heat exchanger, two hydrogen pumps, an accumulator, a heater and so on. It supplies supercritical hydrogen of 20 K in temperature into the three moderators. The latter consists of a compressor, an expansion turbine and so on. It refrigerates hydrogen in the former through the heat exchanger. Around the MLF building, there are a helium buffer tank, a liquid nitrogen tank and annexed buildings having a helium compressor and gas supply units for the cryogenic system. They supplied liquids and gases into the main parts of the cryogenic system through the pipes on external support racks.

The utility system in the MLF is composed of a cooling system, an electric power supply system and building equipment. The cooling system cools down the main components of the NTS and experimental apparatus. It consists of water and air circulators, helium gas supply and exhaust equipment and so on. The power supply system in the MLF receives high voltage power from the external electric power substation and supplies adequate electricity to several systems in MLF. It also has back-up generators for emergency and Uninterruptible Power Sources (UPS). The building equipment includes the ventilators, air conditioners, compressed air and water supplies and drainages.

It keeps the hot cell at slightly negative pressure so that activated gas does not leak out of the hot cell. It also supplies water from the annexed buildings to the main building through pipes installed under the ground.

The main components in the NTS are replaced periodically in the hot cell by remote handling devices such as a power manipulator, an in-cell crane, transfer casks and a cutting device for the reflectors and moderators, a target exchange truck. The components in the NTS are controlled by the MLF general control system (MLF-GCS) and their operation data are stored in a common data base server. The MLF-GCS also administers interlock systems including a veto to stop the proton beam in order to ensure the safety of personnel and machines in the MLF.

The 3-GeV proton beam transport (3NBT) line transports the proton beams from the Rapid Cycle Synchrotron (RCS) into the MLF. It is designed based on the demand for the high-intensity beam transportation with extremely low beam loss rate. The main components of 3NBT such as magnets, vacuum devices, beam monitors are installed precisely in the beam line tunnel, and additional instruments such as safety devices, pipes of water and air are placed along the 3NBT tunnel. They are monitored and operated by the independent integral control systems in the 3NBT and MLF buildings.

3. Behaviors and Damage of NTS at GEJE

The NTS is designed in consideration of safety for emergency as the follows.

- The building and NTS are designed to stand for the quake of 0.25 G.
- In the loss of external power supplies, the control functions for the NTS are kept by the UPS and the back-up generators and the operation data continue to be stored in the data base server.
- According to the interlock sequences in emergencies, a signal to terminate beam operation is transmitted, all the circulation systems are shut down automatically, hydrogen in the cryogenic system is released out of the building and movable instruments such as the target trolley and neutron beam shutters are locked by air cylinders and mechanical brakes.
- In the loss of compressed air, pneumatic valves of each instrument are opened or closed individually so as to protect the instrument without leakages of activated liquid and gas.

On the day of the GEJE, the user beam operation of the MLF was stopped in the morning, and all the components of the NTS were kept ready for restart of the beam operation from the evening. All the instruments in the utility system were in steady operations. Any remote handling devices were not operated. The MLF-GCS was running and kept ready. The mercury target was inserted into the helium vessel and the trolley was locked by the air cylinders. The helium vessel was filled with helium gas and kept airtight at slightly positive pressure. Mercury was circulated in steady flow rate. The off-gas process system kept gas in three tanks and one tank was empty for the beam operation. The cryogenic hydrogen circulation system was supplying hydrogen into the moderators in steady flow rate. The hydrogen pumps and the expansion turbine were running at high speed. All the beam shutters under operations were lifted by the motors and set at the shutter close position. The beam ducts in the shutter blocks were kept in vacuum. All the components of 3NBT were in operation.

Fig. 2 shows the values measured at typical components of the NTS and the building equipment as a function of elapsed time from 14:46:18 on March 11. Fig. 2 suggests behaviors of the NTS at the GEJE. In the MLF, strong quakes were detected by the sensors of liquid levels and pressures in many circulation systems after about 90 seconds and the external power supplies were lost after about 150 seconds. The control functions for the NTS were kept active and the operation data had been stored for more than 3 hours by using the back-up generators until the MLF-GCS was shut down manually. Immediately after the loss of external power supplies, all the circulation systems were shut down automatically based on their interlock sequences for emergency (Fig.2 (A)). Although all the ventilators stopped temporarily, the ventilator for the hot cell was restarted after about 10 minutes from the GEJE. Any leakage of activated water and gas in the MLF did not occur. Most of the remote handling devices did not damaged, but some parts were broken in the transfer cask and the cutting device. However, the hard quakes ruptured external pipes for water and compressed air under the ground by subsidence around the building (Fig. 3). Especially, the loss of compressed air by the rupture of the pipes affected the components with air cylinders, pneumatic values and so on. The behaviors and damage of the typical components in the NTS are described as follows.

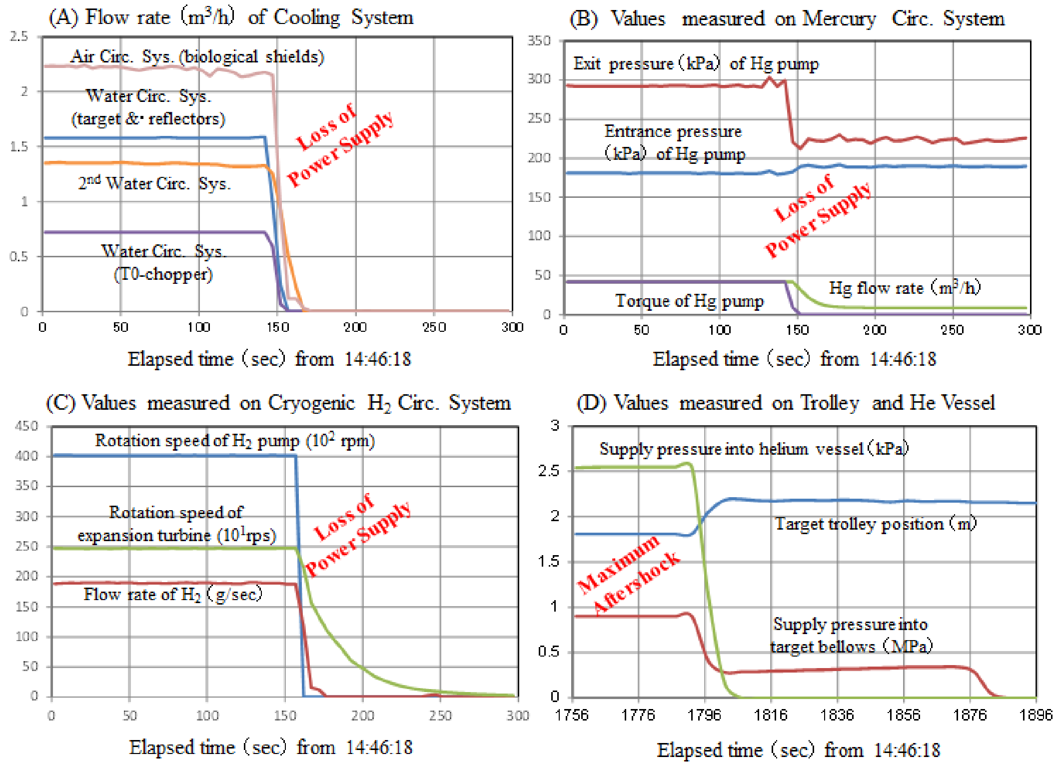

Figure 2. Values measured by instruments of (A) cooling system in MLF utility, (B) mercury circulation system, (C) cryogenic hydrogen circulation system and (D) target trolley and helium vessel as a function of elapsed time (sec) from the GEJE

Immediately after the loss of external power supplies, the mercury circulation system was shut down automatically without any damage (Fig.2 (B)). The leakage of mercury and activated gas in this system did not occur. The off gas process system was also kept normal without any leakage of gas. However, the lock systems with air cylinders for the target trolley were failed because of the loss of compressed air and the trolley moved about 30 cm backward after the maximum aftershock at 15:15:34 (Fig.2 (D)). As a result, the helium gas in the helium vessel was released into the hot cell, and the target vessel became unusable because the bellows were stretched beyond their permissible length. This broken target vessel was replaced with a new one within a micro bubbler (Fig. 4).

The cryogenic hydrogen circulation system was running normally until just before the loss of external power supplies in spite of the hard shocks. Soon after that, their shutdown procedures started according to their sequences in emergencies, the hydrogen pumps and the expansion turbine stopped automatically without damage (Fig.2 (C)), the helium gas in the refrigerator was collected into the buffer tank and the hydrogen gas was released out of the building through lines with a nitrogen gas. Although the external pipes on the support racks were deformed and the tanks were leaned by subsidence (Fig. 3), the airtightness of this system was kept and any leakage of hydrogen and helium did not occur.

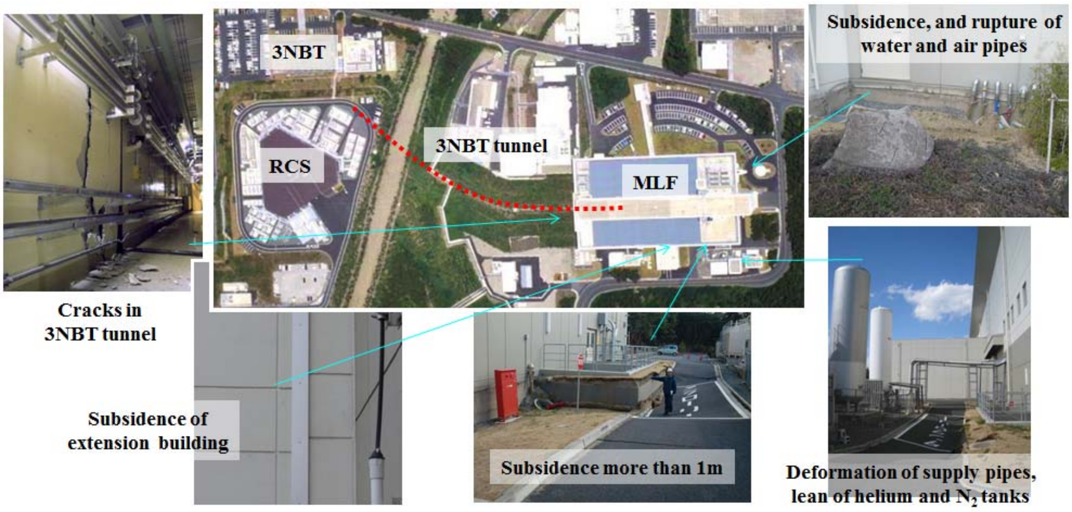

Figure 3. Damage around the MLF building caused by the GEJE.

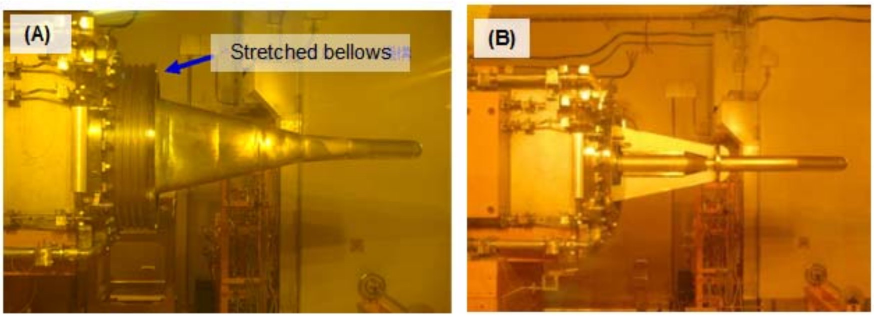

Figure 4. (A) Target vessel with stretched bellows at the GEJE, and (B) new one within micro bubbler fitted to the target trolley

The hard shocks also affected the neutron beam line components. The beam shutters began detecting the intermittent aftershocks by their position sensors after about 90 seconds from the time of GEJE. Under this situation, the shutters were kept at the previous position by the motor brakes as planned. But the airtightness of their vacuum beam ducts could not be kept because the bolts of the duct flanges were loosen by the impact force of the quakes. The quakes slipped the pre-shield blocks and made gap between the blocks to be uneven between 0 mm and 50 mm though the nominal values of the gaps were 20 mm (Fig. 5). In addition, some blocks slipped from the supports and leaned, but they did not break any instruments in the pre-shields fortunately. In restoration, the O-rings and bolts for the duct flange were improved so as to keep the airtightness against the similar impact force. In order to prevent the blocks from slipping, distance pieces were inserted into joints between the blocks during piling up the pre-shield blocks again.

After the loss of power supplies, almost all the components in the 3NBT such as magnets, beam monitors, air and water cooling systems were shut down as planned. Turbo-molecular pumps to evacuate the 3NBT beam ducts were stopped without damage. But the airtightness of the beam ducts in the downstream of 3NBT could not be kept because one of the fast closing valves failed to close due to the loss of compressed air. The 3NBT tunnel suffered heavy damage by subsidence and shocks (Fig. 3). The concrete wall of the tunnel was heavily cracked and almost collapsed, the support racks for pipes and cables on the wall were deformed, an overhead travelling crane became unusable and a beam plug for stopping proton beams safely became unable to be inserted because the rails and the bearings of the plug were broken.

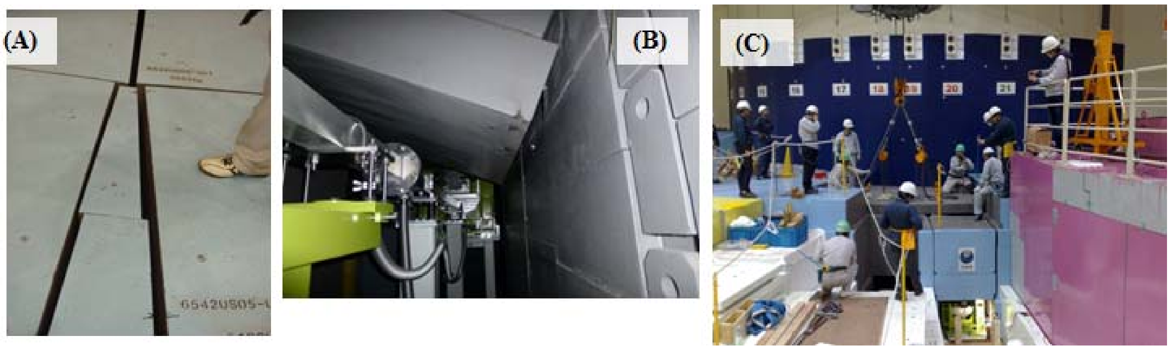

Figure 5. (A) Uneven gaps between the pre-shields blocks caused by slipping at the GEJE, (B) pre-shield blocks slipped and leaned at a beam line 20, but the blocks stopped without breaking neutron guide tubes, (C) piling up pre-shield blocks in restoration.

4. Restorations and Summary

From the end of March 2011, the minimum utilities such as the power supplies, lighting and the control system in the MLF were resumed in order to investigate damage by visual inspections and electric signals. In the middle of April, the restoration plan and the schedule were proposed based on the results of the investigated damage on each component. In the MLF, the damage of the tunnel and the buildings was much serious in comparison with that of the instruments. Especially, the rupture of the external pipes by subsidence restricted seriously the usage of the building equipment such as the ventilators, air conditioners, air and water supplies. Such a situation made it difficult to investigate damage and restore the instruments. In addition, the subsidence and the distortion of the ground by the quake affected the alignment of the beam line components such as magnets, beam monitors and vacuum ducts, which were installed precisely in order to transport the high-intensity proton beams. The alignment was recovered carefully based on the result of surveying displacements of standard points and markers.

Although many troubles occurred at the GEJE, significant damage that needs a few years for restoration did not occur at any components of the NTS of the MLF. These results substantiated the validity of the design for emergency in the NTS. During the beam stop period in 2011, not only the restoration but also the installation and the commissioning of new instruments such as the micro bubbler in the target vessel and Unified Hg-target Active Monitor (UHAM) were carried out in preparation to ramp up the proton beam power. The restoration was accomplished and beam operation of the MLF was resumed on December 22, 2011.

Acknowledgments

The authors are grateful to Dr. S. Nagamiya, Dr. M. Arai, Dr. Y. Ikeda, Mr. T. Kato, the members of Neutron Source Section and the staffs of J-PARC Center for their useful help and suggestions.

References

[1] Monthly Report on Earthquakes and Volcanoes in Japan, March 2011, ISSN 1343-4977, 2011, pp.57-148, (in Japanese)

[2] Y. Ikeda, “Current Status of 1 MW pulse spallation neutron source (JSNS) of J-PARC”, J. Nucl. Materials, 343 (2005) pp.7-13