The radioactive material leak at the Hadron Experimental Facility of the Japan Proton Accelerator Research Complex (J-PARC) (2nd Report)

1. Introduction

This is the 2nd report that follows the 1st statutory report submitted on May 31, 2013, regarding the radioactive material leak that occurred at the J-PARC Hadron Experimental Facility on May 23, 2013. The 2nd report is meant to be a status report on our investigations and examinations performed so far. Its contents are hence subject to further scrutiny and will be updated and summarized in our final report after due reviews.

1.1 Circumstances of the accident (based on the 1st report dated May 31, 2013)

On May 23, 2013, due to a malfunction of the beam extraction system of the J-PARC 50 GeV Synchrotron, its proton beam was extracted in a period (5/1000 of a second) much shorter than the normal two seconds, and was delivered to the gold target which is intended for production of secondary particles. As a result the target was most likely heated up instantaneously to a very high temperature and was partially damaged, causing dispersion of radioactive material in the chamber that housed the target assembly. The radioactive material then leaked into the hadron experimental hall. Consequently, 34 radiation workers in the hall engaged in preparation of experiments, etc. were exposed to radiation. The total (internal and external, added) amounts of their radiation dose were in the range of 0.1-1.7 mSv. In addition, operation of ventilation fans of the hadron experimental hall with the air contaminated by radioactive material caused the release of the radioactive material into the environment (outside of the radiation controlled area). The readings of the area monitors, which had been installed on the external boundary of the controlled area near the hadron experimental hall, showed increases. Momentary increases of radiation level that exceeded the normal range of variation were also observed at the monitoring posts and a station of the neighboring Nuclear Fuel Cycle Engineering Laboratories. We estimated that the maximum integrated radiation dose due to this radiation release to be 0.29 μSv at the site boundary closest to the Hadron Experimental Facility.

1.2 Current status of the analysis of causes

After submitting the 1st report on May 31, 2013, we have been conducting investigations of the causes of the accident and development of preventive measures against its recurrence. Complete understanding of the causes of the accident requires detailed inspection of the gold target. However, since the radiation level around the target is believed to be still rather high, opening the primary beam line area that houses the target assembly has to be waited. We are now formulating the required procedure to access the target including the evacuation of the area. It is thus expected that full clarification of the causes of the accident would take some more time.

In parallel with the investigations and examinations of the hardware related to the accident, we are now compiling data on the chronological sequence of events relevant to the accident by interviewing individuals involved and by examining various records, and are putting them into a “timeline table of judgments and actions” (attachment). We are also working on revisions considered necessary on our safety-related rules and on verification of our safety management system and criteria for reporting. “The timeline table of judgments and actions” summarizes the chronological sequence of events and actions taken by the relevant individuals after the onset of the accident, including those that caused delays of the first reporting of the accident until around 21:00 the next day, May 24, which was 33 hours after the target had been damaged.

1.3 Contents of this report

This 2nd statutory report summarizes the results from our examinations on the following two points, together with “the timeline table of judgments and actions”,

(1) Review of radiation controlled areas in provision against possible anomalous leak of radioactive material
(2) Issues regarding our safety management system and emergency procedures, and basic policy for countermeasures

Point (1), “Review of radiation controlled areas in provision against possible anomalous leak of radioactive material”, addresses the present configurations of the radiation controlled areas in various J-PARC facilities and puts in perspective possible revision of the management policy concerning the radiation controlled areas in the Hadron Experimental Facility where the accident occurred.

（Point (2), “Issues regarding our safety management system and emergency procedures, and basic policy for countermeasures” presents the direction of countermeasures based on the detailed examinations of possible issues in the safety management system and understanding of the criteria for reporting, etc., using “the timeline table of judgments and actions”.

At the end of this report, we summarize the present status of currently ongoing investigations and subject matters to address in the near future.

2. Review of radiation controlled areas in provision against possible anomalous leak of radioactive material

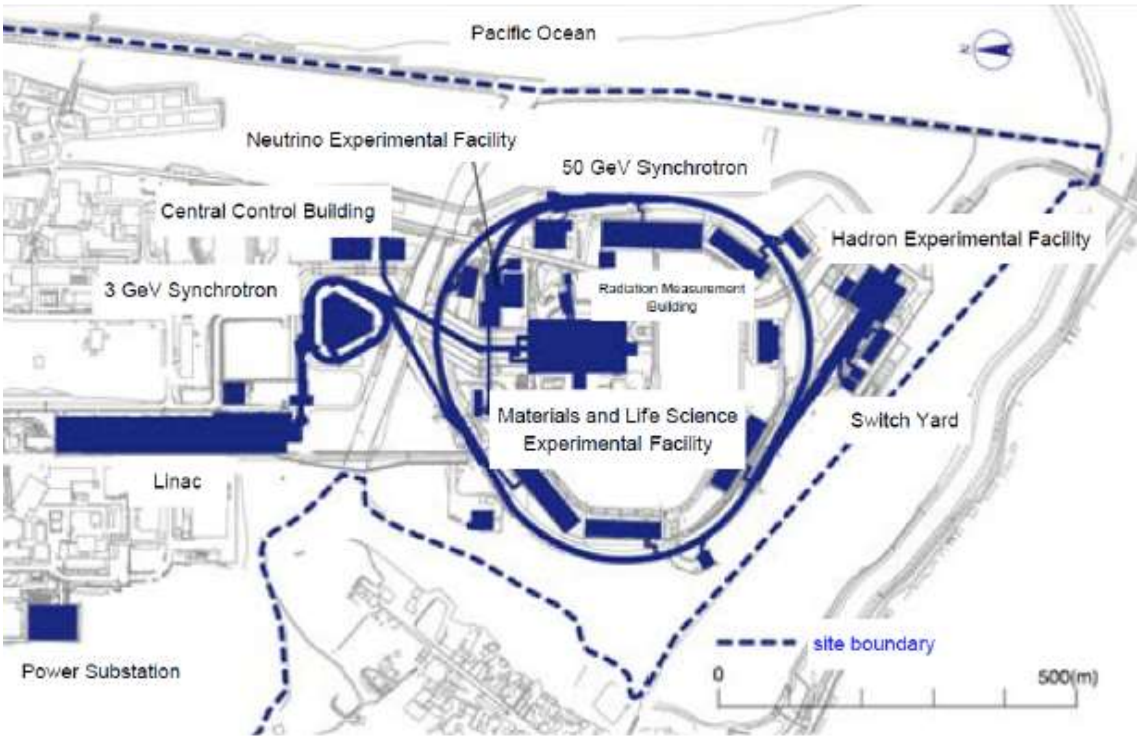

Fig. 2.1 General view of the J-PARC facilities

Figure 2.1 shows the general view of the J-PARC facilities. J-PARC consists of the Accelerator Facility (the Linac, the 3GeV Synchrotron, and the 50GeV Synchrotron), the Hadron Experimental Facility, the Materials and Life Science Experimental Facility (MLF), and the Neutrino Experimental Facility.

Note that the radiation hazard prevention regulations at J-PARC categorize the radiation controlled areas into the following two classes. A class 1 radiation controlled area is defined to be “an area where either the concentration of radioactive material in the air or the surface density of an object contaminated by radioactive material would exceed or could exceed the limits prescribed by Paragraphs (2), (3), and (4) of Article 4 of the public notice”. A class 2 radiation controlled area is defined to be “an area where radiation dosage regarding external exposure would exceed or could exceed the value prescribed by Paragraph (1) of Article 4 of the public notice concerning a radiation controlled area and that does not fall under the class 1 category”. Here, “Article 4 of the public notice” stands for Article 4 of the Science and Technology Agency Notification No.5.

2.1 Present state of radiation controlled areas of each facility

In what follows, we describe the present state of radiation controlled areas in the Hadron Experimental Facility, the Materials and Life Science Experimental Facility, the Neutrino Experimental Facility, and the Accelerator Facility (the Linac, the 3 GeV Synchrotron, the 50 GeV Synchrotron).

2.1.1 Hadron Experimental Facility

The radiation controlled areas of the Hadron Experimental Facility comprises a class 2 radiation controlled area as of the radiation hazard prevention regulations that is set in the Hadron Experimental Hall as well as in its surrounding area, and a class 1 radiation controlled area that just covers the primary beam line room in the class 2 area. Figure 2.2 illustrates the present extent of the class 1 radiation controlled area. At present a single layer shield is set up near the boundary of the primary beam line room to confine the air inside the class 1 radiation controlled area. While the 50 GeV Synchrotron is in beam operation, the air within the class 1 area is circulated and cleaned by letting part of it go through a filter to remove radioactive material. Before allowing personnel into the class 1 area for maintenance, etc. after beam operation, we exhaust the air through filters, while monitoring the concentration of radioactive material.

It is considered that the air-tightness of the target system was insufficient for the extent of radioactive material released in this accident, and the radioactive material from the class 1 area leaked into the hadron experimental hall which is categorized as class 2. Then part of the radioactive material was released from the experimental hall and then the radiation controlled area due to operation of ventilation fans.

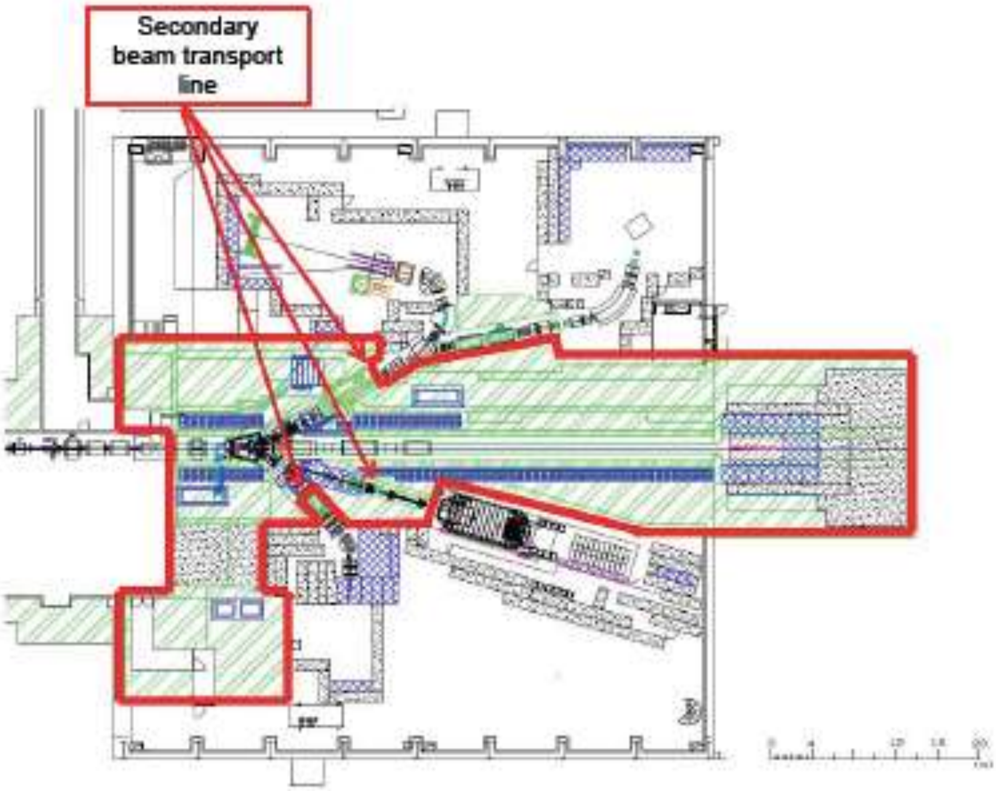

Figure 2.2: Present configuration of the Hadron Experimental Hall. The class 1 radiation controlled area is surrounded by a thick red line.

2.1.2 Materials and Life Science Experimental Facility

Materials and Life Science Experimental Facility accommodates a neutron production target (Neutron Target) and a muon production target (Muon Target) for studies of material structures and other subjects. The present configuration of the radiation controlled areas in the MLF is as shown in Fig. 2.3.

In the MLF, “the radiation generator room” containing the proton beam transportation line, the Muon Target, and the Neutron Target and the area that involves radio-activated instruments, primary cooling water, the gas exhaust system dealing with radioactive gases, etc. are defined to be a class 1 radiation controlled area, while “Experimental Halls 1 and 2” having secondary beam lines that deals with muons and neutrons are defined to be a class 2 radiation controlled area.

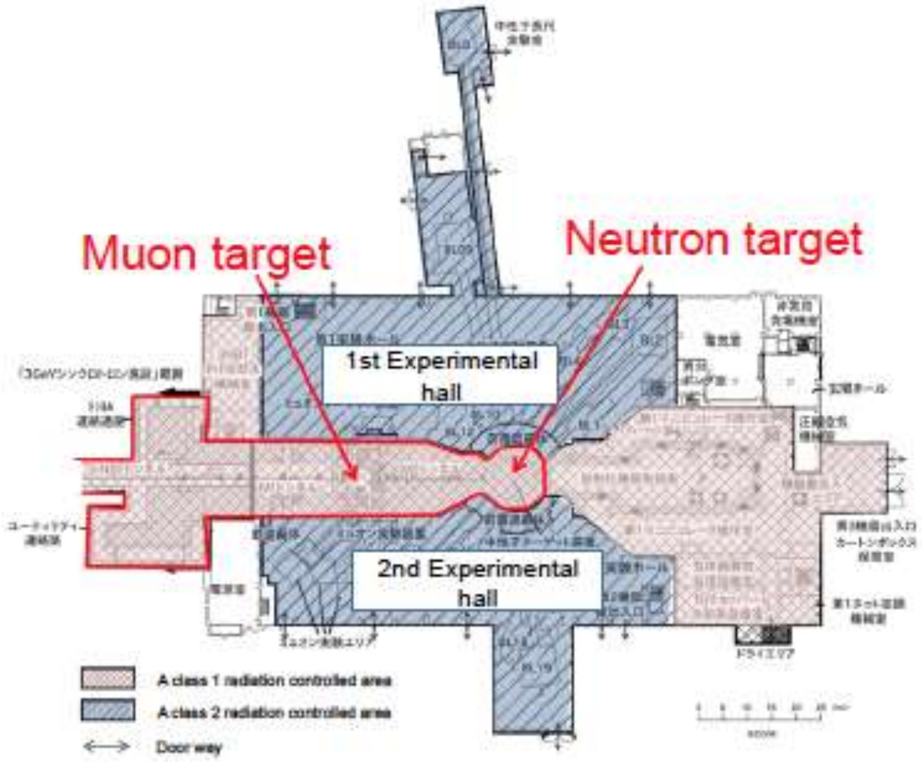

Figure 2.3: Present configuration of the radiation controlled areas of the MLF. The area surrounded by a red line shows the extent of the radiation generator room containing the proton beam transportation line and the Muon and Neutron Targets.

Amid the class 1 radiation controlled areas, “the radiation generator room” is air-tight and is isolated from other areas. Its air is conditioned by closed loop circulation without exhausting the air to an outer environment during beam operation. The room pressures of these class 1 and class 2 areas are controlled on an area-by-area basis at negative pressures configured hierarchically and the air in these areas is filtered in an air exhaust system. The air is exhausted from the exhaust chimney of the MLF, with the concentration of radioactive material in the exhaust air being monitored continuously. This ensures no leakage of radioactive material from the class 1 area to the class 2 area.

The Neutron Target uses mercury as its target material. The target mercury is contained in a hermetic vessel with a multi-layer protective structure (Fig. 2.4), and the whole of the container is in turn installed in a multi-layer protective container consisting of a Helium vessel and an outer liner. This containment design prevents radioactive material from leaking into the experimental hall, which is a class 2 area, even if the target were damaged. In addition, the facility is equipped with a multi-level detection system (a detection system for target temperature, a radiation monitoring system for the He layer, a leak detector for the target mercury) that will detect radiation leak immediately, if any, and will fire an interlock system to stop the beam.

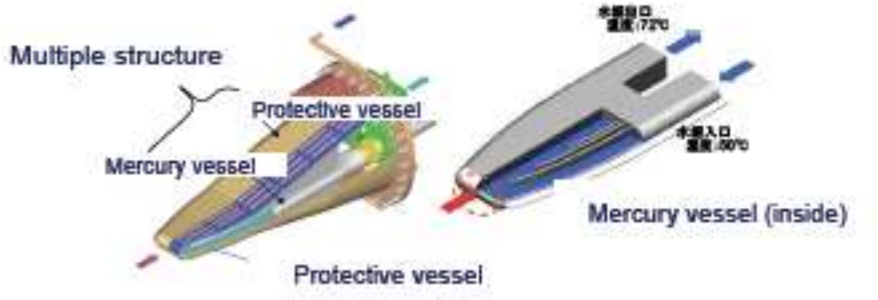

Figure 2.4: Structure of the multi-layer protective vessel for the Neutron Target. The target vessel consists of a container for mercury and a protective vessel. The protective vessel has two layers of metal walls interleaved with a helium gas layer, which is continuously monitored to detect any leakage of radioactive material and/or mercury.

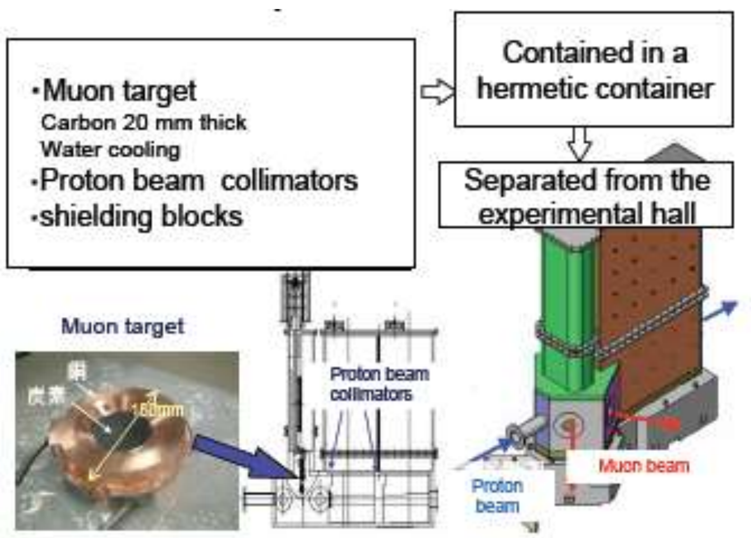

Figure 2.5: Muon Target and its protective container. The target is placed in a hermetic protective container with its temperature and the flow rate of its cooling water being monitored to detect anomaly.

The Muon Target shown in Fig.2.5 is made of a 2cm thick carbon block which is placed 30 m upstream of the Neutron Taret. The Muon Target is contained in a hermetic container and is completely separated from the experimental hall by airtight partitions placed in the beam ducts that lead muon beams to the experimental hall side.

2.1.3 Neutrino Experimental Facility

As for the Neutrino Experimental Facility, all of its underground area, where the beam goes through, is of the class 1 category. The surface areas that belong to the class 1 category are the zone control building, the target station building, Neutrino Utility building No.2 (NU2), a machine room, and Neutrino Utility building No.3 (NU3). The vicinities surrounding these class 1 areas on the surface belong to the class 2 category.

All of the equipment for secondary beam production such as the target and the electromagnetic horns of the Neutrino Experimental Facility is sealed in a hermetic iron vessel filled with helium gas (Helium Vessel) and is placed at the underground level of the target station building. Even if the target or the components close to it were damaged, or melted down, or even evaporated in an incident, radioactive material would remain inside the Helium Vessel. Moreover, the underground and the surface parts of the facility are separated by a hermetic sheet, etc., and its surface portion is maintained at a negative room pressure and its air exhausted through a filter to an exhaust chimney, with the concentration of radioactive material being continuously monitored. This negative room pressure control ensures the containment of radioactive material within the class 1 radiation controlled areas. The same design concept applies to the Neutrino Utility building No.3 (NU3) under which the end part of the Helium Vessel lies.

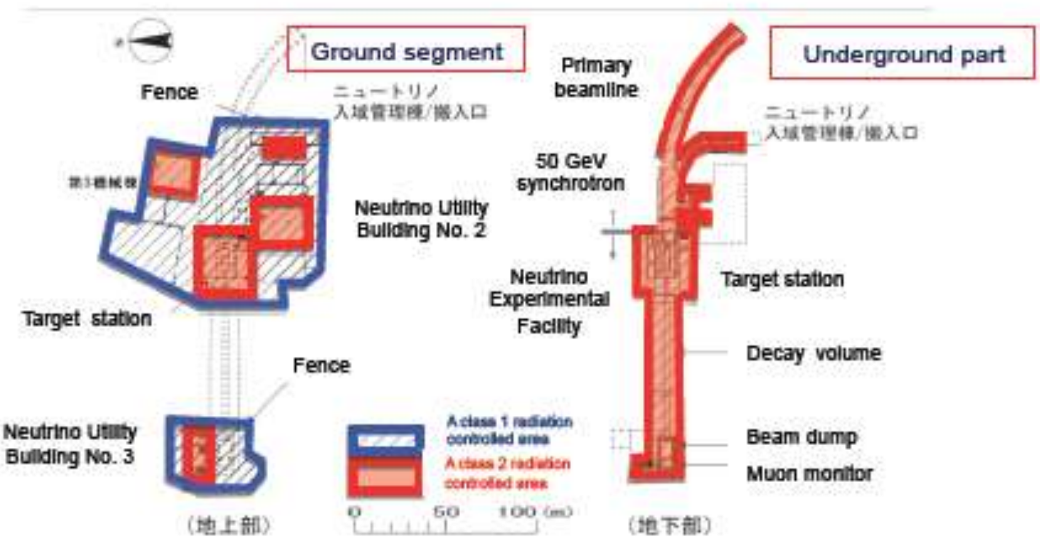

Figure 2.6: Radiation controlled areas of the Neutrino Experimental Facility

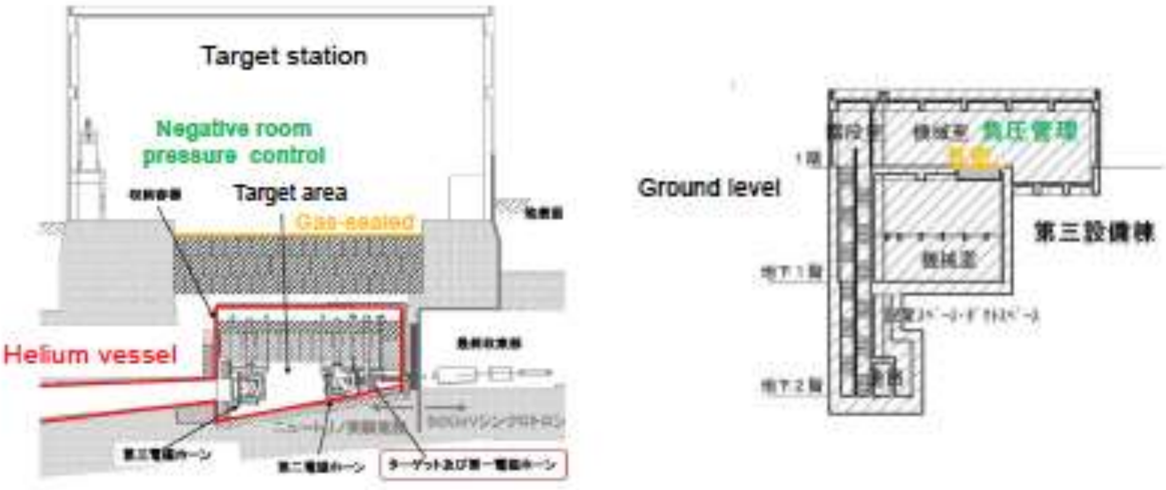

Figure 2.7: Target station (left) and Neutrino Utility building No.3 (right)

In an event when a target damage takes place, the yield of secondary particles would change In the case of the Neutrino Experimental Facility, the muons from the decays of secondary particles are monitored on a shot-by-shot basis. Any changes in the yield can hence be detected promptly. Depending on the state of the damage, there would be variations in the flow rate, temperature, and pressure drop of the cooling helium gas. These parameters are also continuously monitored.

2.1.4 Accelerator Facility

The Accelerator Facility comprises the Linac, the 3 GeV Synchrotron, and the 50 GeV Synchrotron. For all the accelerators their tunnels are air-tight and radiation-controlled as the class 1 controlled areas. In addition, an intermediate exhaust system is set up at the boundaries to the radiation uncontrolled areas. Figure 2.8 shows the present configuration of the class 1 radiation controlled areas for the Linac, Fig. 2.9 for the 3 GeV Synchrotron, and Fig.2.10 for the 50 GeV Synchrotron. The areas labeled in red are of class 1 and those in blue are of class 2.

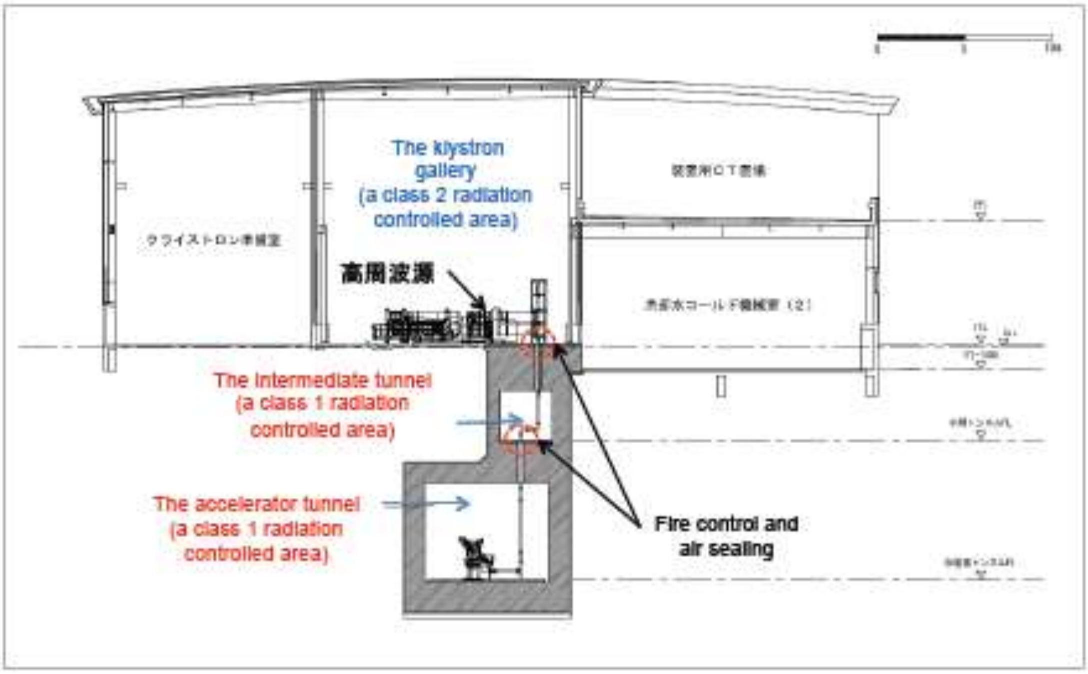

Figure 2.8: Cross-sectional view of the Linac building. The accelerator tunnel is defined to be a class 1 radiation controlled area and is gas-sealed, while the klystron gallery is a class 2 radiation controlled area. The intermediate tunnel that separates them is kept at a negative room pressure.

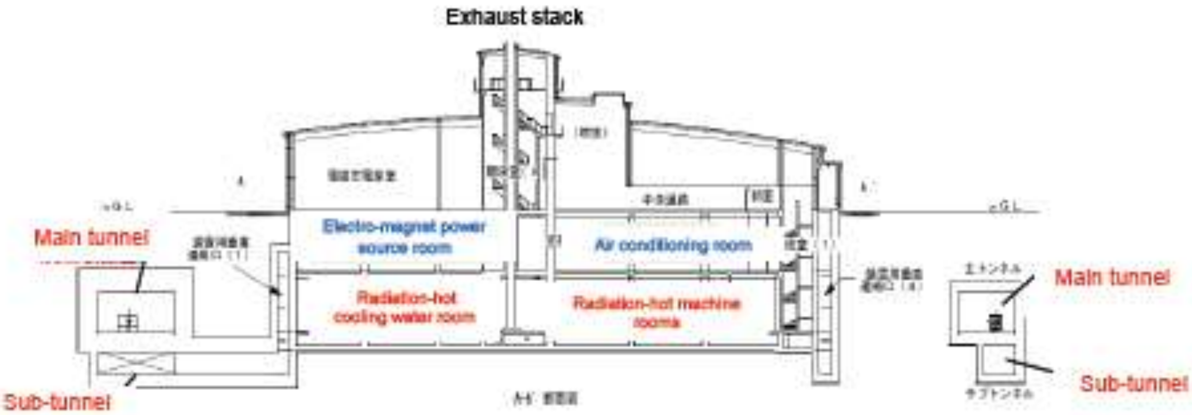

Figure 2.9: Cross-sectional view of the 3 GeV Synchrotron building. The main tunnel, the sub-tunnel, and the radiation-hot machine rooms for air conditioning and the cooling water are class 1 radiation controlled areas and the main tunnel is gas-sealed and the others are subject to negative room pressure control.

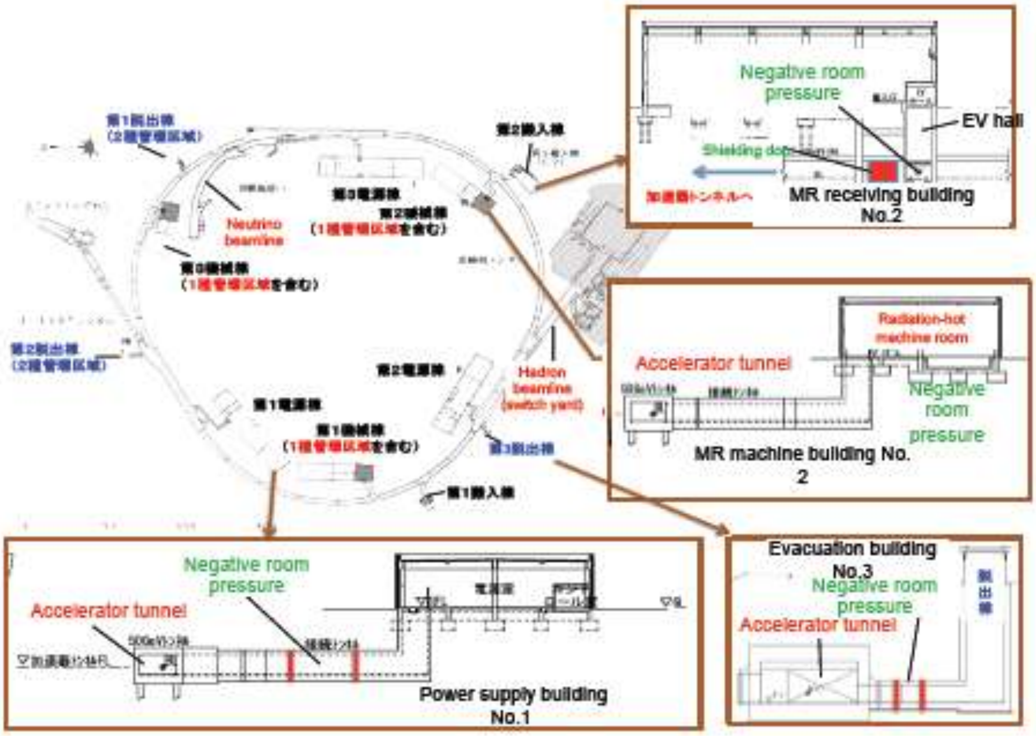

Figure 2.10: Plan view of the 50 GeV Synchrotron building and cross-sectional views of its annexes. The accelerator tunnel is a class 1 radiation controlled area and is air-tight. The radiation-hot machine rooms are also of the class 1 category, and are maintained at a negative room pressure. The evacuation buildings are of class 2. The power supply buildings are not controlled areas, but they are equipped with double-entry doors to the accelerator tunnel, so that the door-to-door gaps are exhausted and kept under a negative room pressure control. In each service entry building, an inspection room is placed for checking possible contamination between a sealed door and an EV (elevator) hall (a class 2 radiation controlled area). The interior of inspection rooms is regulated at a negative room pressure. The beam lines (the switch yard and the primary beam line for the Neutrino Experimental Facility) for extracting the beam for delivery to the experimental facilities from the 50 GeV Synchrotron are defined to be a class 1 radiation controlled area in ways similar to the accelerator tunnel.

2.2 Perspective for review of radiation controlled areas in provision against anomalous leak of radioactive material

Considering that the J-PARC is an experimental facility which handles unprecedentedly high intensity proton beams, we are considering the following possibilities.

2.2.1 Hadron experimental hall

In this accident radioactive material dispersed in a class 1 radiation controlled area leaked into the hadron experimental hall that is designated as class 2, from which the radioactive material leaked out into the surrounding space (class 1) and also released into an uncontrolled area due to operation of ventilation fans. In response to this accident, we reexamine the present sate of the radiation controlled areas in the Hadron Experimental Facility and develop plans for necessary reviews of the facility and equipment based on the following policy:

(1) Confinement of radioactive material in the primary beam line area of the hadron experimental hall, and
(2) Strictly controlled exhaust of air from the hadron experimental hall.

Figure 2.11 shows a schematic of these points. At present, a single-layer bulkhead is set up near the boundary of the primary beam line corridor for air isolation. We will replace it with a double-layered barrier so as to enforce hermeticity around the target assembly. At present the air inside the single-layer barrier is not monitored for possible contamination with radioactive material. Our proposal includes monitoring of radioactive material in the air within each layer.

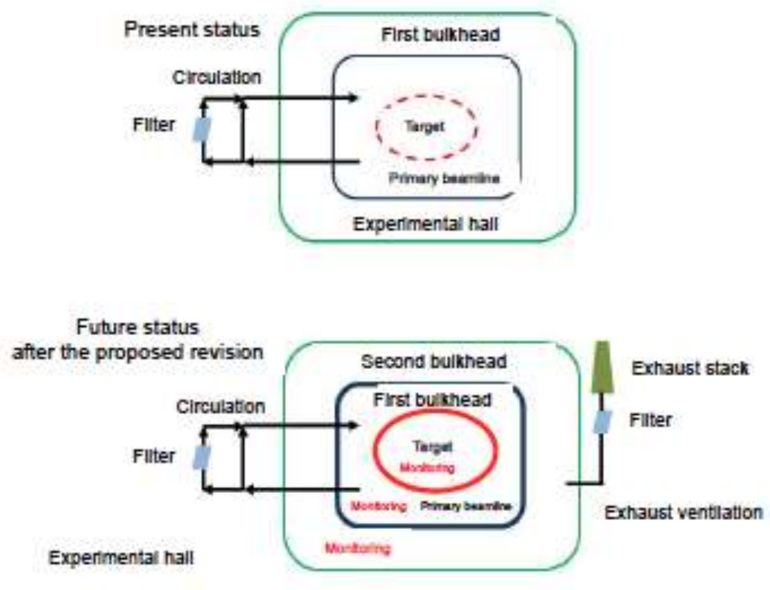

Figure 2.11: Schematic for revision of the facility and equipment. Present state (top), and after the proposed revision (bottom)

In addition to implementing these measures, we will reexamine the configuration of the radiation controlled areas in the hadron experimental hall. Figure 2.12 shows the extent to which the review for possible revision is to be considered.

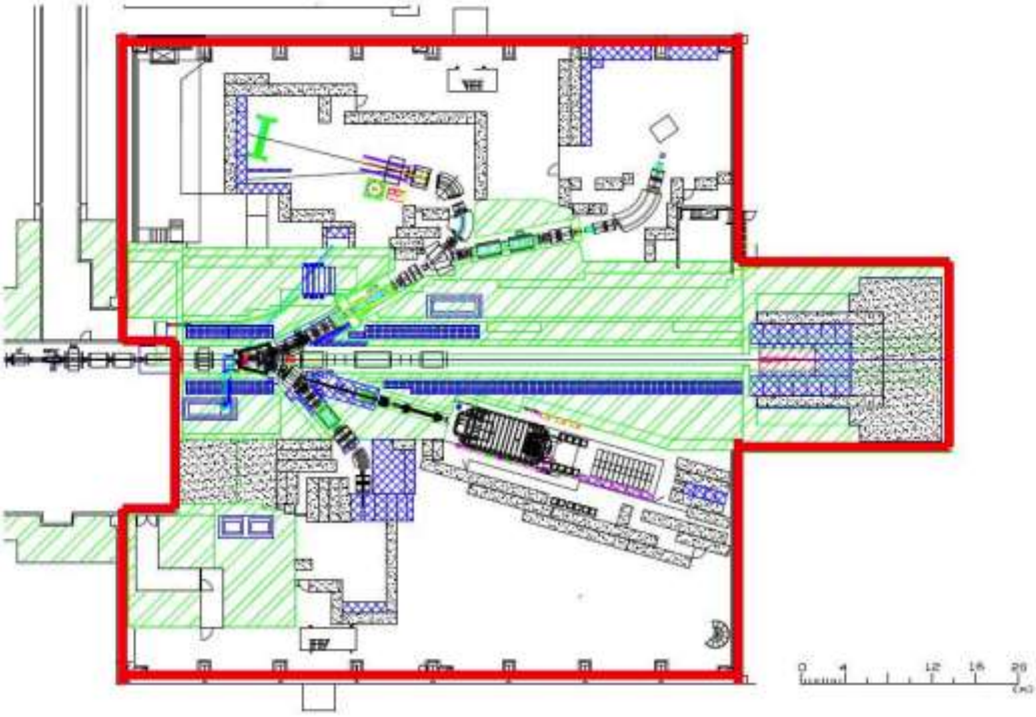

Figure 2.12: The extent which is subject to possible revision of the radiation controlled areas in the hadron experimental hall.

2.2.2 MLF

The facility is ensured to be capable of containing radioactive material inside the radiation controlled area. No problems are recognized in its management.

2.2.3 Neutrino Experimental Facility

The facility is ensured to be capable of containing radioactive material inside the radiation controlled area. No problems are recognized in its management.

2.2.4 Accelerator Facility

The facility is ensured to be capable of containing radioactive material inside the radiation controlled area. No problems are recognized in its management.

3. Issues regarding the safety management system and emergency procedures, and basic policy for countermeasures

In this chapter, based on the compilation shown in “the timeline table of judgments and actions”, we analyze issues in each entry of the table and summarize them in the following four points.

(1) Delay of the statutory reporting and judgment criteria related to it
(2) Leakage of radioactive material to the radiation controlled area
(3) Response to radiation exposure for workers
(4) Release of radioactive material to the environment surrounding the radiation controlled area

We then summarize our proposal of basic policies for countermeasures against these issues from the view points of restructuring our safety management system, revising the internal regulations, manuals and related matters, improving the education and training, etc.

3.1 Delay of the statutory reporting and judgment criteria related to it

3.1.1 Issues

(Interpretation of statute)

Responsible persons, including facility managers and the radiation protection supervisor, had interpreted “the law and ordinance about statutory reporting not applicable to a leak of radiation material to the radiation controlled area as long as the amount is below its prescribed limit”, and hence judged the reporting unnecessary.

(Related event sequence numbers (hereafter, No.) in “the timeline table of judgments and actions”: 15, 20, 25, 26, 27, 30, 31, 33, 38, 39, 48, 49, 52, 55)

(Information gathering)

Data and information necessary for proper assessment of the situation were not compiled adequately, which in turn delayed the judgment for reporting.

(No.: 15, 20, 25, 26, 27, 30, 31, 33, 38, 39, 48, 49, 52, 55)

(Criteria for the judgment for reporting)

Dissemination of our “manual for reporting on an accident, etc.” was insufficient. The description in the manual about conditions that calls for a statutory reporting was unclear for anomalous leak of radioactive material.

(No.: 15, 20, 25, 26, 27, 30, 31, 33, 38, 39, 48, 49, 52, 55)

(Management system in the absence of managers)

Managers were away from the scene of the accident and were unable to appropriately assess the situation, which in turn delayed the judgment.

(No.: 20, 31, 48, 52)

3.1.2 Basic policy for countermeasures

- We will revise the internal regulations, manuals, etc., and clarify criteria for judgment.
- We will ensure prompt reporting and information sharing.
- We will clarify the line of management in cases of absence of managers.
- We will implement appropriate programs for safety education and exercises.

3.2 Leakage of radioactive material to the radiation controlled area

3.2.1 Issues

(Expected events and measures)

- Experimental Facility, though its performance goal is to utilize an unprecedentedly high intensity proton beam, the assumptions about anomalous generation of radioactive material and its subsequent leak as well as our examinations of measures for such an incident were not thought out accordingly. Consequently, the possibility that radioactive material produced at the target would leak could anomalously into the radiation controlled area was not part of the consideration, and no countermeasure had been prescribed in "the operation manual" against such a leak.

(No.: 1, 2, 3, 4, 5, 6, 7, 22)

(Procedure for resumption of operation)

- Operation was resumed before the causes of MPS trips were thoroughly examined.

(No.: 2, 3, 4, 5, 22)

3.2.2 Basic policy for countermeasures

- With respect to all the J-PARC facilities, we will reexamine the measures to prevent radioactive material from leaking into radiation controlled areas. As for the Hadron Experimental Facility, we will enforce our certification protocol so as to ensure any possibilities of anomalous events are well taken into account from the view points of both design and operation.

- We will prescribe the procedure and measures for events accompanied by leakage of radioactive material into and/or out of radiation controlled areas and let all the relevant people be familiarized with these procedures through education and exercises.

3.3 Response to radiation exposure for workers

3.3.1 Issues

(Criteria for evacuation)

Although many individuals at the scene of the accident had various pieces of information, they were not shared at large, resulting in a delay of evacuation.

(No.: 10, 11, 12, 13, 14, 16, 22, 23, 24, 35, 64)

(Management system on radiation exposure)

Information and results of (radiation (dose)?) measurements that are needed for assessment of the risk of radiation exposure for workers were not suitably conveyed to managers.

(No.: 10, 11, 12, 13, 14, 16, 22, 23, 24, 35, 64)

3.3.2 Basic policy for countermeasures

・ We will clearly prescribe the procedure and practices on notification/reporting and evacuation in events which may cause radiation exposure. We will implement necessary programs for related education and exercises.

・ We will restructure our management system so as to ensure prompt implementation of appropriate measures including evacuation order to protect users, researchers, and workers, etc, in case of anomalous situations.

3.4 Release of radioactive material out of radiation controlled area

3.4.1 Issues

(Exhausting radioactive material out of radiation controlled area)

・ Based on an inadequate judgment that radioactive material in the contaminated air would decay in a relatively short time and that it would disperse in the atmosphere so that there would be no effect at all to the environment outside the radiation controlled area, we started operating ventilation fans.

(No.: 18, 20, 31, 34)

(Area monitors left unchecked)

・ We did not confirm the leakage of radioactive material out of the radiation controlled area by checking the area monitors.

(No.: 18, 20, 31, 34)

3.4.2 Basic policy for countermeasures

・ We will reexamine the configuration of our radiation controlled areas and will develop robust confinement measures with can withstand anomalous conditions.

・ We will incorporate the prescribed measures for events accompanied with leakage of radioactive material as well as descriptions on radiation monitoring in our operation manual. We will improve the sharing of these measures through education and exercises.

4. Further Studies

4.1 Investigation of facilities and equipment

As described above, after our 1st report we have been so far investigating the underlying causes of the accident and preventive measures against its recurrence. For the next step we will examine the target assembly and its vicinity in the hadron experimental hall as well as of the power supply that was suspected to have malfunctioned, and will deepen our understanding of the hardware aspects of the causes of the accident and their countermeasures.

4.2 Estimate of the amount of radioactive material released

We will evaluate the total amount of radioactive material released from the experimental hall to the environment which surrounds the radiation controlled area. This will be done by (1) estimating the amount of released radioactive material consistent with the data from area monitors in the hadron experimental hall, and by (2) periodically analyzing the amount of radioactive nuclei and by examining their half lives in the air sample that was collected on the day of the accident.

4.3 Exposure within the radiation controlled area

In the 1st report we have reported on the results of internal dose measurements for 100 out of 102 individuals who entered the area. With regards to the remaining two persons from overseas that were left out in the 1st report, they took whole body counter measurements in their home countries. We have received a report of "Not Detected" based on a preliminary result from one of them, and are expecting more detailed results to arrive. The measurement has been conducted also for the other, but the results are yet to be delivered.

5. Summary

This report summarizes the results from our investigations on the following two points.

(1) Review of radiation controlled areas in the J-PARC facilities in provision against possible anomalous leak

(2) Issues regarding our safety management system and emergency procedures, and basic policy for countermeasures

As for the point (1), “review of radiation controlled areas in the J-PARC facilities in provision against anomalous leak taken”, we have shown the present configuration of the radiation controlled areas in the entire J-PARC facilities and then discussed our basic considerations for revision of the radiation controlled areas so as to prevent leakage to the environment surrounding the radiation controlled areas.

As for the point (2), “issues regarding our safety management system and emergency procedures, and basic policy for countermeasures”, we have presented a “timeline table for judgments and actions” about the accident and clarified issues involved by comparing the actual events and the current judgment criteria. We then referred to possible preventive measures that are derived from the analysis.

In order to proceed further, it is necessary to continue investigations on the equipment and the facility thereby thoroughly unveiling the causes of the accident. Development of preventive measures against recurrence of similar accidents from hardware point of view will follow. It is also essential to develop preventive measures in software aspects by elaborating the analysis that is presented in this report on the safety management system and emergency procedures.

We will further scrutinize and update the contents of this report and will put them into our final report, taking inputs from the External Expert Panel into account.