Outline of the 3rd report on the radioactive material leak at the Hadron Experimental Facility of the Japan Proton Accelerator Research Complex (J-PARC)

On August 12, 2013, the Japan Atomic Energy Agency (JAEA) and the High Energy Accelerator Research Organization (KEK), who are jointly operating the Japan Proton Accelerator Research Complex (J-PARC) in Tokai-Mura, Ibaraki Prefecture, submitted to the Nuclear Regulation Authority the 3rd statutory report on the radioactive material leak accident that occurred at the Hadron Experimental Facility (HD facility) of J-PARC on May 23. In addition to new findings which became available after submission of the 2nd report on June 18, this 3rd report discusses the preventive measures against recurrence of similar accidents from both the hardware and software aspects, which are under review by the External Expert Panel.

■Occurrence of the accident and progress of investigation (Chapter 4 of the text)

- Due to a malfunction of the slow beam extraction system of the 50 GeV synchrotron of J-PARC, 2×10^{13} protons were extracted in a very short period of 5 milliseconds (In normal operation 3×10^{13} protons should have been slowly extracted over 2 seconds.) and the proton beam was delivered to the gold target (6 mm × 6 mm × 66 mm) in the HD facility.
- While a cooling water system is implemented to remove the heat from the gold target, the simulation indicates that the center of the target was heated over 2000˚C by the instantaneous delivery of high intensity proton beam to the gold target (Chapter 7.1.2 of the text).
- It is presumed that part of the gold target was damaged and the radioactive material was dispersed from the target. Then it leaked into the primary beamline, because the target container didn’t have airtightness.
- Since the primary beamline room where the gold target was placed was not hermitically sealed, the radioactive material leaked into the Hadron experimental hall (HD hall) and workers were exposed to radiation. (see the table 5-1 for the list of nuclides and their radioactivity that leaked into the HD hall.)
- Due to operation of ventilation fans in the HD hall, the radioactive material was released into the environment outside of the radiation controlled area of the HD facility.
- It was erroneously considered that contaminations were contained within the radiation controlled area and the exposure dose was below the control criterion. Hence reporting and announcing were not made until the leakage of radioactive material into the environment out of radiation controlled area was acknowledged the next day. (Detailed descriptions are available in the attachment, “Timeline of incidents, judgments and actions”.)

■Leakage of radioactive material in the radiation controlled area and radiation exposure of workers (Chapter 5 of the text)

- The airborne sample that had been collected at the HD hall had been periodically measured and the compositions of radioactive nuclides were re-examined in detail assisted by the half-life analysis method. In addition, the total amount of the radioactive material that was released into the HD hall was estimated with a simulation based on actual data from the readings of the area monitors in the HD hall, and was found to be ~20 billion Bq (2×10^{10} Bq).

- A hundred two persons, including visitors, entered the radiation controlled area of the HD facility on the day of the accident. Out of these, 34 registered radiation workers were found to have received total (internal and external) radiation doses in the range of 0.1 and 1.7 mSv, all below the legal limit (Table 5-2). Medical examinations confirmed the absence of any adverse effects due to the radiation exposure.

■The leakage of radioactive material into the environment outside the radiation controlled area and an environmental impact (Chapter 6 of the text)

- On the site boundary the effective dose (the sum of internal and external radiation doses) at the location closest to the HD facility was revaluated. With a calculation using diffusion equations based on an analysis of nuclides and their ratios (Table 5-1), the estimate was found to be 0.17 micro Sv, a value below 0.29 micro Sv as reported in the first statutory report.

■ Analysis of causes (Chapter 7 of the text)

(1) Facilities and equipment

- The causes for and subject matters related to hardware aspects of the accident, including the facts that the gold target was not enclosed in a hermetic container and that the air-tightness of the primary beamline room was insufficient, were sorted out and analyzed (See Chapter 7.1 of the text for details).

(2) Safety management

- Various issues and subject matters related to management aspects of the accident, including the delay in statutory reporting, workers being exposed to radiation, and the leakage of radioactive material outside the radiation controlled area, were sorted out and analyzed. The outline is shown in the following table (See Chapter 7.2 of the text for details).

Table 7.2-1 Summary of the issues and subject matters based on the timeline table of judgments and actions

Issues	Causes	Subject matters
Delay in statutory reporting	・Incomplete collection of information ・Incorrect judgment ・Ambiguous criteria ・Absence of managers	・Establishment of the information management system ・Education on statutes and criteria ・Revison of criteria in internal regulations ・Delegation of managerial authority to be clarified in internal regulations ↓ Setup capable of responding to events which require difficult judgment. ↓ Setup, education and training which enable responding to incidents
Leakage of radioactive material into the radiation controlled area	・Beam operation was resumed while the analysis of causes was still incomplete.	・Revision of procedures in internal regulations to follow before resuming beam operation. ・Improvement of information management system ↓ Setup capable of responding to events which require difficult judgment. ↓ Setup, education and training which enable responding to incidents
	・Lack of thorough design considerations and lack of recognition on possibility of target damage	・Revision of the radiation safety evaluation system
Radiation exposure to workers	・Ambiguous criteria for evacuation. ・Lack of information sharing	・Revision of evacuation criteria in internal regulations ・Establishment of information management system ↓ Setup capable of responding to events which require difficult judgment. ↓ Setup, education, and training which enable responding to incidents
Leakage of radioactive material outside the radiation controlled area	・Ventilation by fans when radioactive material is present in the hall. ・Lack of close watching of area monitors	・Revision of procedures in manuals to follow ・Revision of internal regulations ↓ Setup capable of responding to events which require difficult judgment. ↓ Setup, education, and training which enable responding to incidents

■ Preventive measures against recurrence of similar accidents (Chapter 8 of the text)

- With the subject matters identified in the analysis of this accident, we examined the preventive measures against recurrence of similar accidents from the hardware standpoint (facilities and equipment) as well as from the software standpoint (safety management). In addition, we have decided to introduce a "warning status" between "the normal status" and "the emergency status" (Table 8.5-1) in facility operation. This will allow for responding to any anomalous symptoms for which clear judgment would be difficult, and for which tight information sharing would be required among multiple facilities. The outline is shown in Table 8.5.2 (Chapter-s 8.4 and 8.5 of the text for details).

Table 8.4-1 Correspondence between event and cause and preventive measures against recurrence

Events and causes	Preventive measures
Event: Anomalous beam extraction Cause: Malfunction of the beam extraction system	・Revision of the current limit setting of the power supply for the EQ magnet. ・Shutdown of the magnet power supply on detection of anomalous current deviation. ・Faster shutdown of the magnet power supply on detection of abnormality
Event: Damage to the target. Cause: The gold target was penetrated by intense short pulsed beam.	・More frequent monitoring of the target temperature (faster detection of target damage) ・Retract the target off the beam orbit during accelerator studies or shift the beam orbit
Event: Leakage of radioactive material into the primary beamline Cause: Gold target was not enclosed in a hermetic container.	・Make the target container air-tight ・Monitor the pressure and the concentration of radioactive material in the gas (enhancement of leak detection)
Event: Leakage of radioactive material into the HD hall Cause: Air-tightness of the primary beamline was insufficient.	・Make the boundaries of the primary beamline room air-tight ・Introduce airborne radioactivity monitors and shut down the beam upon detection of abnormal conditions(prevention of progress of abnormality)
Event: Leakage into the area outside the facility. Cause: Ventilation fans were operated to vent the hall.	・Existing ventilation fans will be sealed off. ・The air in the HD hall will be vented through filters, while monitoring the concentration of radioactivity in the air.
Event: Lack of sharing of radiation monitoring information Cause: Locations of the monitors were inappropriate. Alarm levels were inappropriate	・Improve recognisability of radiation monitoring information ・Set the alarm for warning level.

Table 8.5-2 Issues and measures from the viewpoints of safety management and procedures to be carried out in emergency situations

Subject matters derived from causes identified	Measures
Organizational setup for responding to incidents was incomplete. ・Prevention of delay in statutory reporting ・Prevention of extended leakage ・Prevention of radiation exposure	・Introduce three levels of status in response to incidents: “the normal status”, “the warning status”, and “the emergency status”. A uniquely identified commander to conduct information collection and sharing, statutory reporting, actions in incident site, and evacuation conduct.
Organizational set-up for safety review was insufficient. ・Thorough review of system designs and modifications ・Preventive measures against potential risks	・Assign field specialists, including external experts, as review committee members. ・More effective review in reference to pre-defined criteria. ・Task force(s) can be established, if necessary. ・Radiation Safety Meeting will be reorganized into the Radiation Safety Review Committee to reinforce safety evaluation processes.
Periodical reviews of education/training and safety standards were insufficient. ・Practical training for reacting to incidents ・Fostering safety culture	・Continual education and training for personnel, including the facility users ・Bidirectional education processes and exercises for radiation-related accidents ・Periodical reviews of the internal standards and procedures, etc. to prevent stereotypical responses

■ Safety assessment of facilities other than the HD facility (Chapter 9 of the text)

- Safety assessment was done on other facilities at J-PARC: the Materials and Life Science Experimental Facility, the Neutrino Experimental Facility, and the Accelerator Facility. Table 9.5-1 gives the summary.

Table 9.5-1 Actions taken regarding the accident risks in the Hadron Experimental Facility before and after implementing measures, and other facilities,

Potential risks of accidents	Hadron Experimental Facility (Before measures are taken) / (After measures are completed)	Materials and Life Science Experimental Facility	Neutrino Experimental Facility	Accelerator Facilities
Unexpected deliver of short pulse beam	Not taken into account	Since this facility utilizes the shortest pulse beam from the accelerator, incidents similar to the HD accident will not occur.	Same as on the left	The facilities always operate with the shortest pulse beam. Thus, no abnormal event similar to this accident would occur.
	Shut down the beam when symptoms of abnormality are identified or before abnormality is extended.			
Leakage of radioactive material into the class 1 radiation controlled area due to damage to target	Target container was not hermetic.	Target is enclosed in a hermetic container with a multi-layer protective structure.	Same as on the left	There is no target. (Beam is always confined in vacuum ducts.)
	The target will be enclosed in a hermetic container that confines the radioactive material even if the target is damaged.			
Leakage of radioactive material from the class 1 to the class 2 radiation controlled area	Air-tightness to confine radioactivated air	Pressure setting for the class 1 radiation controlled area is lower than the class 2 area.	The class 1 radiation controlled area is kept at negative pressure. (There is no class 2 radiation controlled area inside the building.)	A buffer area is set up between the class 1 and class 2 radiation controlled areas. The buffer area is kept under negative pressure control.
	Enhancement of air-tightness from the class 1 radiation controlled area to the HD hall			
Leakage of radioactive material from the radiation controlled area to outside.	Not taken into account.	The experimental halls are kept at negative pressure. The air is vented through filters while monitoring the radioactivity.	There is no experimental hall. The setup of machine rooms in the class 1 radiation controlled area are the same as described on the left.	There is no experimental hall. The setup of machine rooms in the class 1 radiation controlled area are the same as described on the left. A buffer area is kept under negative pressure control.
	The air from the HD hall is vented through filters while monitoring the concentration of radioactivity.			

Note: The class 1 radiation controlled areas along the proton beamlines are sealed off during beam operation, and the air in these areas is circulated through filters. The air in these areas is held for a period of time allowing radioactivity to decay after beam operation is halted and then it is vented through filters while the radiation level is monitored.