Appendix 2

# Report from the Working Group

Working Group for the External Expert Panel
on the Radioactive Material Leak Accident
at the Hadron Experimental Facility of J-PARC

1. Progress report
2. Main causes of the radioactive material leakage
3. Problems in the safety management system

The Second External Expert Panel Meeting to Review the Radioactive Material Leak Accident at the Hadron Experimental Facility of the J-PARC at KKR Hotel Tokyo on July 5, 2013



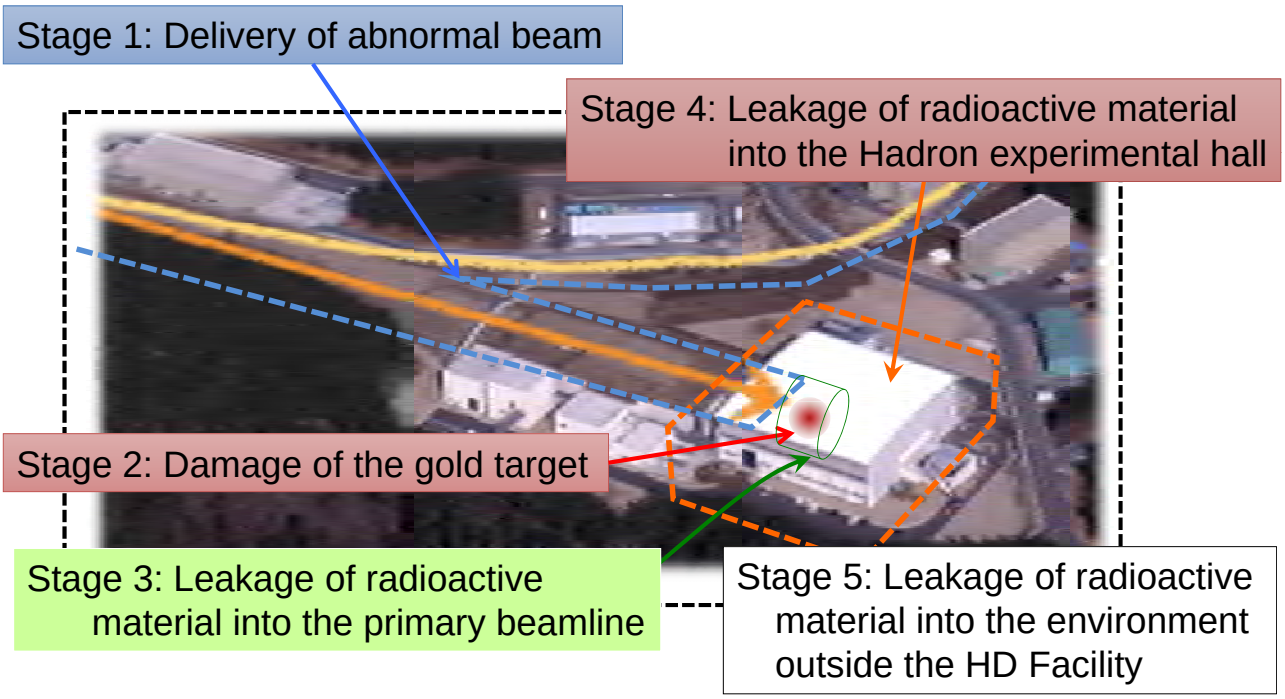
# 1. Progress report

Subjects of discussion at the 1st and 2nd Working Group meetings

- Safety management system
  Extraction of issues and problems, causes for the delay in the statutory report, procedures for reporting, user support, safety training, etc.
- Experimental facilities:
  (1) accelerators and beam transport system, (2) detailed investigation of the malfunction of the power supply system, (3) gold target: design specifics and history, (4) plans of site investigation for the gold target, (5) present set-up of radiation controlled areas, integrity of air-tightness and air exhaustion and (6) overall monitoring and control systems for managing unusual situations
- Countermeasures against recurrence of similar accidents
- Review of the integrity of other facilities at J-PARC

# 2. Main causes of the radioactive material leakage

The sequence of the accident is dissected into five stages where the causes therein are analyzed

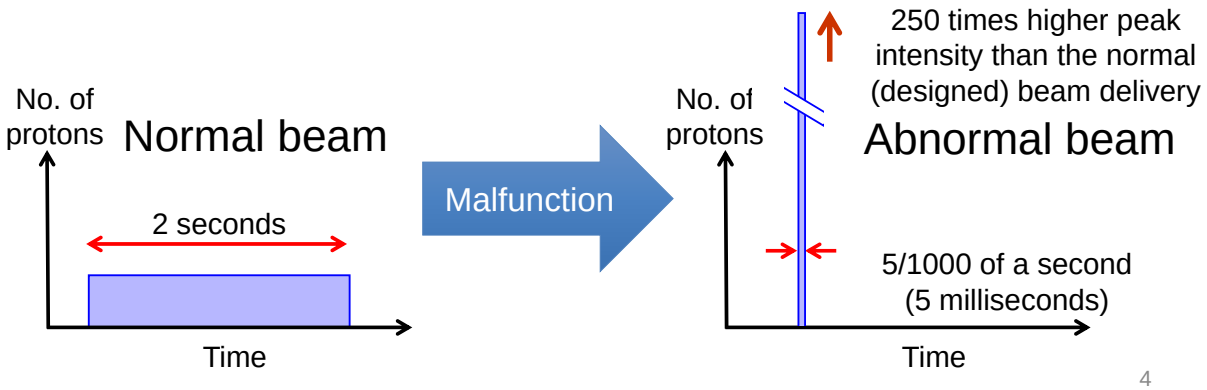





## 2. Main causes of the radioactive material leakage

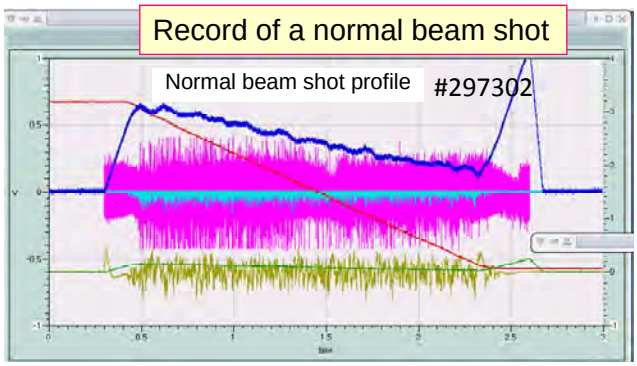
# Stage 1: Delivery of abnormal beam

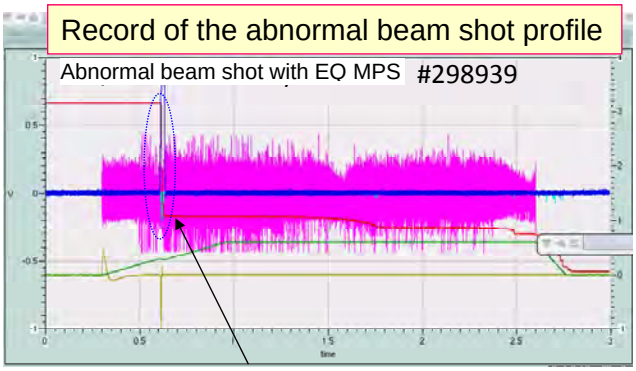
- At around 11:55 of May 23, 2013, due to a malfunction of the slow extraction system of the 50 GeV Synchrotron (MR), a proton beam consisting of $2 \times 10^{13}$ protons was delivered to the gold target within a very short period (5/1000 of a second).
- Normally $3 \times 10^{13}$ protons are slowly and evenly extracted and delivered to the gold target over a period of 2 seconds.



## 2. Main causes of the radioactive material leakage

# Stage 1: Delivery of abnormal beam




EQ: instantaneous high current output

The monitor display for beam extraction

Cause:
A power supply for driving a magnet, which controls the slow beam extraction, did not properly respond to the control signal during the first fraction of a second in the period of beam spill, and then it abruptly brought a large current to the magnet.

- The accelerator operation was automatically stopped by detecting the malfunction of the power supply and the signals from the beam loss monitors.
- While the operation staff of the accelerator misunderstood that it had been due to a malfunction of the fast extraction kicker. A large fraction of the proton beam in fact was delivered to the target in HD Facility.
- The accelerator staff did not recognize the incident as one that had led to any possibility of partial melting of the gold target.

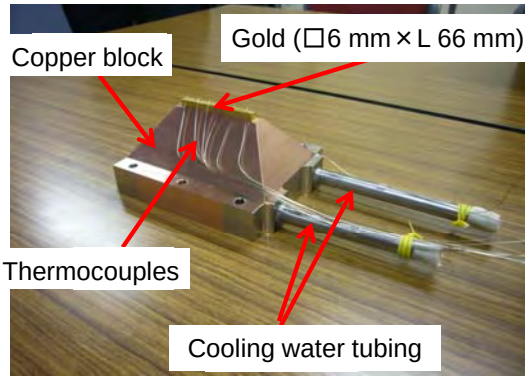
red line: intensity monitor for the circulating-beam
light blue line: beam spill monitor
green line: preset value for the EQ power supply
blue line: output current of the EQ power supply
pink line: preset value for the RQ power supply
olive-green line: output current of the RQ power supply

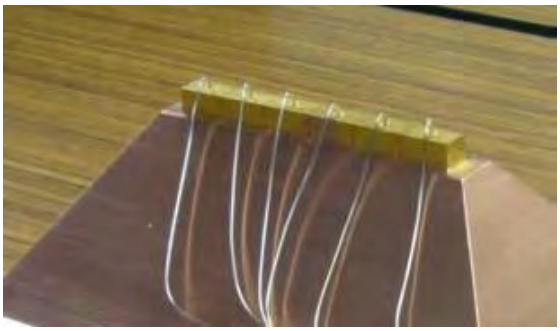


## 2. Main causes of the radioactive material leakage

# Stage 2: Damage of the gold target

The target was instantaneously heated up to a very high temperature and was partially damaged, causing dispersion of radioactive material in the air of the target container.



Close-up of the gold target

Cause:
When the beam with a diameter of ~1mm penetrated the target, a large amount of energy was deposited within a short period of 5 ms, resulting a very high temperature within the gold.

- A volume of ~1 mm in diameter and ~40 mm in length is presumed melted. The estimate above is based on simulation, which needs to be verified with site investigation that requires reduction of ambient dose rate in the neighborhood of the target as well as understanding of local authorities and local residents.
- Leak of radioactive material has not been aggravated by subsequent operation of the accelerator.

## 2. Main causes of the radioactive material leakage

# Stage 3 : Leakage of radioactive material into the primary beamline

Radioactive material was released from the damaged target spread into the space of the primary beamline surrounded by concrete shielding blocks.

Cause:

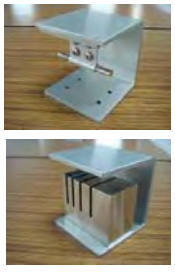
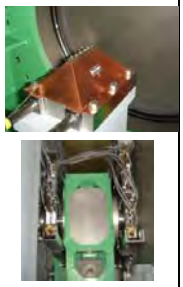
- The target container was not hermetically sealed.
  - Operation with the designed proton beam power assumed use of a water-cooled rotating nickel disk in a container that can be hermetically sealed.
  - In present operation with the beam power lower than the original design, the target design was revised to use platinum or gold for increasing the yield of secondary particles such as K-mesons. The target was stationary and air-cooled or water-cooled, and is placed in an non-hermetic atmospheric environment where no specific considerations were given for possible damages in abnormal beam conditions that had occurred in this accident or alike.
- Use of unsealed targets is not uncommon at high-energy proton synchrotron facilities, while risk hazards associated with beam-incurred target damages are a shared notion at cyclotron facilities and high-intensity electron accelerators.



## 2. Main causes of the radioactive material leakage

# Stage 3 : Leakage of radioactive material into the primary beamline

History of the T1 target at the HD Facility

| Beam power | 1.2 kW | 5 kW | | 50 kW | | |
|---|---|---|---|---|---|---|
| Operation period | Jan. 7 to Feb. 28, 2009 | Oct .1, 2009 to Mar. 2, 2010 | Oct. 1 to Nov. 16, 2010 | Jan. 7 to Jul. 2, 2012 | Dec.14, 2012 to Jun. 28, 2013 | |
| Target material | nickel (54 mm) | platinum (60 mm) nickel (54 mm) | platinum (60 mm) nickel (54 mm) | platinum (60 mm) | gold (66 mm) | nickel (54 mm) |
| Cooling method | Air-cooled rotating disk | Air-cooled (convection) | Air-cooled (convection) | Indirectly water-cooled | Indirectly water-cooled | Directly water – cooled rotating disk |
| Appearance |  |  |  |  |  |  |
| Airtight structure | yes | no | no | no | no | yes |

## 2. Main causes of the radioactive material leakage

# Stage 4: Leakage of radioactive material into the Hadron experimental hall

Radioactive material in the target assembly area leaked into the Hadron experimental hall.

Cause:

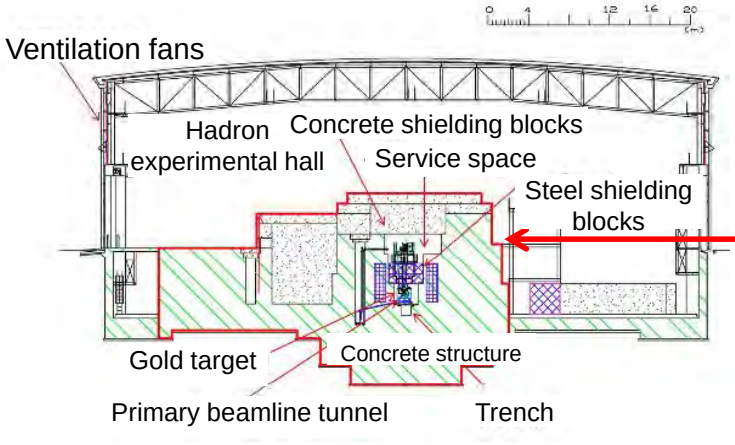
- Air tightness of a radiation shielding wall, made of concrete or steel shielding blocks, was insufficient for this incident.
  - Rubber sheets are inserted in space between the blocks. Putty filling is applied in gaps at penetrations of ducts and tubes.
  - The provisions above are sufficient for containing Argon-41 that is produced from radioactivation of the air during normal operation.
  - The provisions above could prevent radioactive material leakage due to the target damage if the target were hermetically sealed.
  - The provisions above are not sufficient in case of an accident involving damages to the non-sealed target as in this accident.



## 2. Main cause of the radioactive material leakage

# Stage 4: Leakage of radioactive material into the Hadron experimental hall

The radiation shielding walls in the HD hall



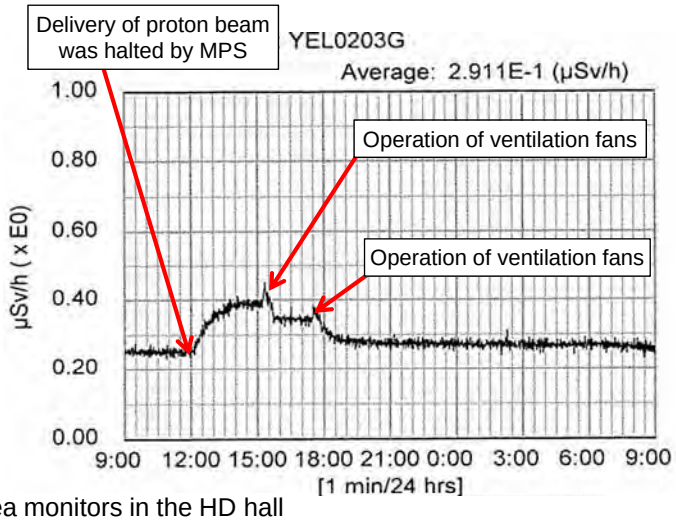

Cross section


Exterior view of the radiation shielding wall

## 2. Main causes the radioactive material leakage

# Stage 5: Leakage of radioactive material into the environment outside the HD Facility

Radioactive material leaked out to the environment outside the building.


Cause: The leakage is resulted from operations of ventilation fans

- Operation of ventilation fans
  - 1st instance: to confirm the soundness of area monitors in the HD hall
  - 2nd instance: to reduce radiation exposure to users
- Since the radiation dose rate in the HD hall was below the legal limit, the environmental effect associated with operation of ventilation fans was considered negligible.
- Lack of integration of information including data from radiation monitors in the hall and those at other facilities for adequate assessment of the situation.
- Failure in making rational and logical judgment, leading to personnel's radiation exposure and delays in reporting.



## 3. Problems in the safety management system:

# Human factors

- ✓ When the interlock alarm went off, the persons in charge considered it as a hardware issue, not as a potential radiation safety issue.
- ✓ Insufficient communication among the persons in charge caused a disorganized response to the accident.
- ✓ It was not clearly understood among the persons in charge as to "who is responsible for reporting the accident and for initiating the responding process".
- ✓ The Safety Division Head, who is responsible for decision making on a safety issue, was not available on-site to make suitable decisions.
- ✓ The safety manual was not sufficiently specific and the organization for facility-wide information sharing and decision-making procedures were not clearly laid out.
- ✓ Emergency drills did not include case studies of radioactive material leakage.

## 3. Problems in the safety management system:
## Monitoring devices

- ✓ The radiation monitoring system was not available in ways to allow sharing of all the information among the personnel at distributed locations.
- ✓ The layout of the radiation monitoring screen did not deliver information in straightforward ways to use in intermediate situations between hardware alarms and radiation alarms.(Difficulty in transition of recognition from hardware alarm situations to radiation alarm situations.)
- ✓ Not a sufficient number of radiation monitors were available at locations with possible leakage of radioactive material.



## 3. Problems in the safety management system:
## Accident of radiation exposure and accident of radioactive material leakage

- ✓ Safety management of accelerator-related facilities, such as at KEK, have been stipulated in accordance with Radiation Hazard Prevention Act.
- ✓ Facilities of JAEA have been managed in accordance with Nuclear Reactor Regulation as well as Radiation Hazard Prevention Act, and a stricter law (i.e., Nuclear Reactor Regulation) is applied in case of accidents.

***J-PARC under joint management of KEK and JAEA***

- ✓ Combination of the experiences and expertise of the two organizations could result in a more effective safety management system.
- ✓ Information sharing and work coordination between the two organizations were insufficient, leading to inappropriate judgment and actions taken in response to the radioactive material leakage in J-PARC.
- ✓ We expect reconsideration of the organizational relation between both parent organizations and the J-PARC Center concerning the radiation safety management.