Appendix 2-2

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

Planning of safety measures
(Countermeasures against recurrence of similar accidents)

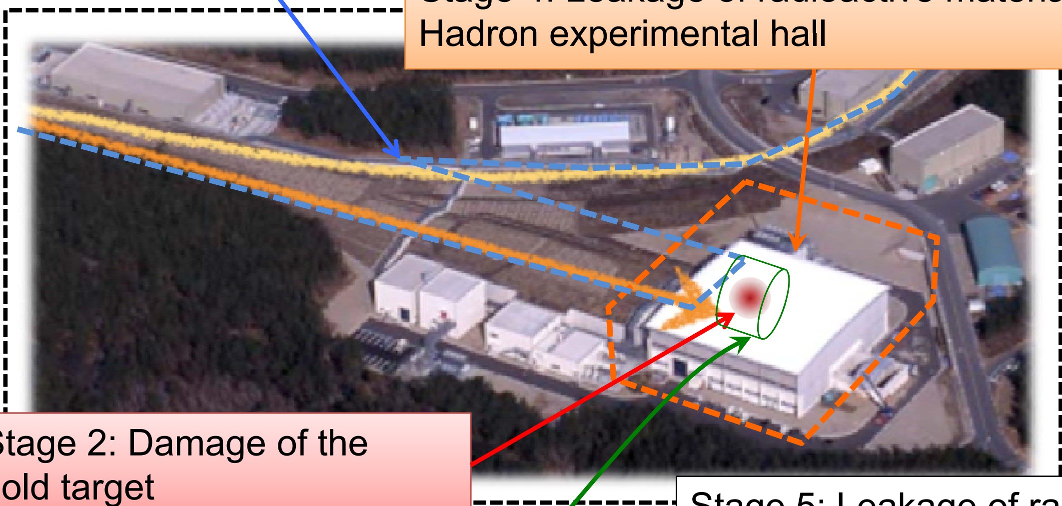
The 3rd External Expert Panel Meeting
to Review the Radioactive Material Leak Accident
at the Hadron Experimental Facility of J-PARC at
KKR Hotel Tokyo on 20 June 2013

Main causes of the radioactive material leakage and countermeasures against recurrence of a similar accidents

The accident is dissected in five stages for which preventive measures are developed.

Stage 1: Delivery of abnormal beam

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

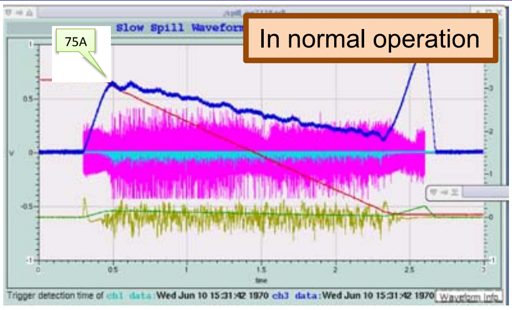


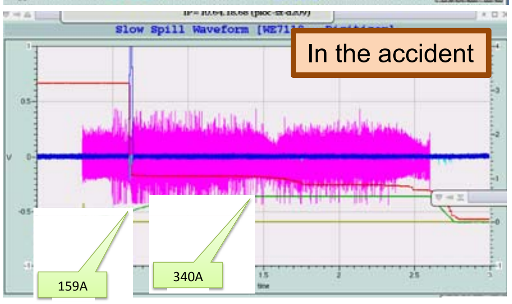
Stage 2: Damage of the gold target

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

Stage 3: Leakage of radioactive material into the primary beamline

Stage1: Preventive measures against recurrence of the malfunction of the EQ (extraction quadrupole) system





◆ Causes

The power supply for magnets, which control the slow beam extraction, did not properly respond to the command signal in the designated period of beam spill, and then it abruptly brought a large current to the magnets.

◆ Behavior of the EQ power supply in the accident

- It returned no response to the command signal for the first ~0.3 seconds of the intended beam extraction .
- While the response was restored in 0.3 seconds, the power supply control unit acted as if it was responding to an abrupt step command of 159 A. This set off alarms of an overvoltage condition and a tracking error.
- The investigation confirmed later that the power supply would behave in the way as it did in the accident, when a step command of 159 A is given.
- The reason for the lack of response in the first 0.3 seconds is still under investigation.

◆ Countermeasures against recurrence of similar accidents

Subject	Present	Future
Tracking error of magnet supply current	Display of the error status in the control system window.	Immediate shutoff of the power supply. Halting of continuous beam operation
Maximum current allowed on the EQ power supply	340 A	120 A
Response time to an emergency stop signal of the power supply	> 6 ms	< 1 ms

Tracking error：Excessive deviation of the measured current of a magnet power supply from its set value

Countermeasures against the risks of short pulse extraction

Possibilities	Measures
Continuous beam operation: Unintended firing of FX (fast extraction) kicker magnet	Rearrange the timing of the pulser charge-up, such that it is readied “right before completion of an SX (slow extraction)”, rather than “right before start-up of an SX”.
Continuous beam operation: Emergency stop of defocussing quadrupole magnets	Focusing quadruple magnets will be turned off when a signal for an emergency stop of defocussing magnets is detected.
Beam study of accelerators	Lead beam to a beam dump in the hadron hall directly, not go through a hadron target

FX kicker: A kicker magnet for fast beam extraction, which is used to dump left-over beam during slow beam extraction.

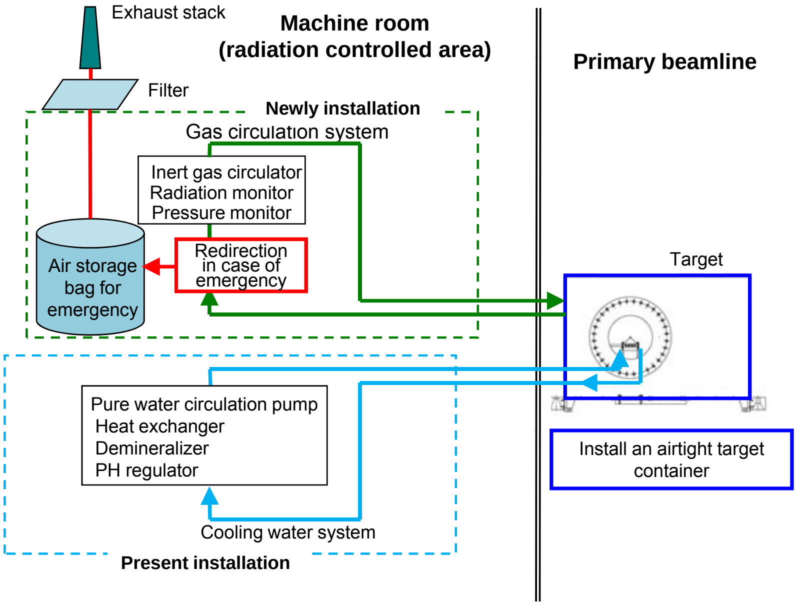
Stage 2: Damage of the gold target
Stage 3: Leakage of radioactive material into the primary beamline

Causes :

- The beam with a diameter of ~1mm deposited a large amount of energy when it penetrated through the target over a short period of 5 ms, locally heating up the gold target to a very high temperature.
- The gold target was not enclosed in a hermetic container.

Preventive measures against recurrences of the accident :

- An airtight target container.
- Fill the target container with an inert gas whose flow is controlled by a circulation system.
- Monitor the gas pressure and the concentration of radioactive material within the gas.
- Shorten the time interval of measurement of the target temperature and optimize the alarm threshold.
- Monitor the yield of secondary particles
- Take the target off the beam during accelerator studies.
- Improve the monitors and stop beam operation when an abnormal signal is detected.



Schematic of the new target system

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

Causes:

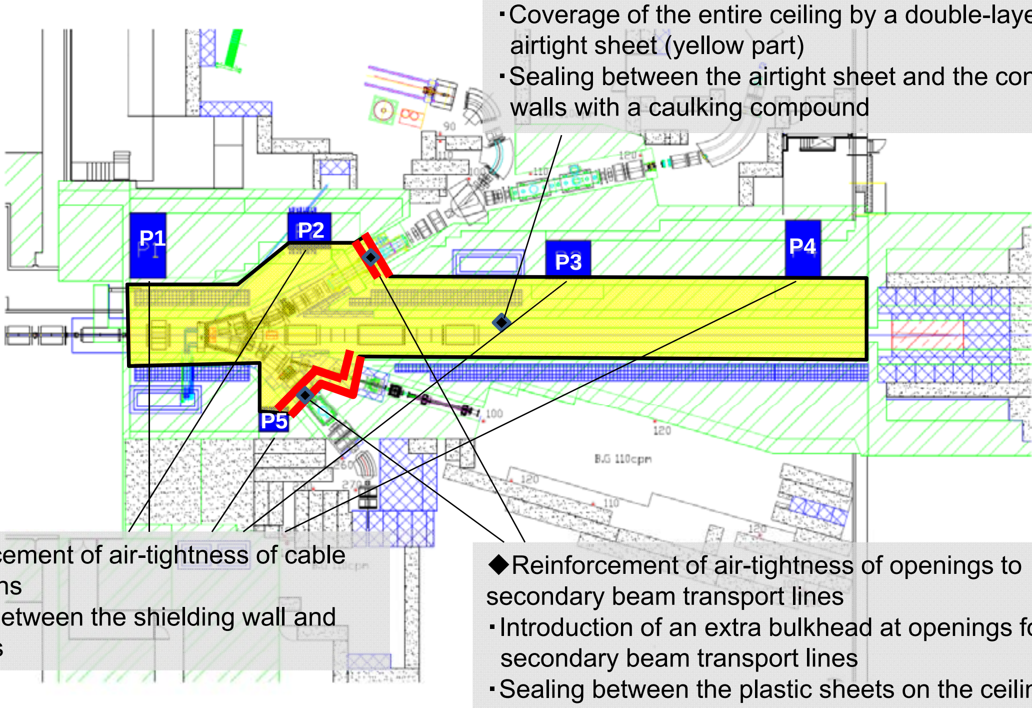
- Air-tightness of the radiation shielding wall was insufficient for containing the radioactive material released in this accident.

Preventive measures:

- Reinforcement of the air-tightness of radiation shields for the primary beamline
  - ✓ Cover widely two shielding-block layers of a ceiling of the primary-beamline with an airtight sheet
  - ✓ Introduction of an extra bulkhead at openings for secondary beam transport lines
  - ✓ Reinforcement of air-tightness of cable penetrations
- Install a radioactivity monitor for the air in the primary beamline area
  - ✓ Stop the beam operation when abnormal signatures are detected.

For stage4: Reinforcement of air-tightness of the primary beamline

- Plain view



◆Reinforcement of air-tightness of the ceiling area of the shielding blocks covering the primary beamline
・Coverage of the entire ceiling by a double-layered airtight sheet (yellow part)
・Sealing between the airtight sheet and the concrete walls with a caulking compound

◆Reinforcement of air-tightness of cable penetrations
・Sealing between the shielding wall and apertures

◆Reinforcement of air-tightness of openings to secondary beam transport lines
・Introduction of an extra bulkhead at openings for secondary beam transport lines
・Sealing between the plastic sheets on the ceiling and concrete walls with a caulking compound

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

Causes:

The leakage resulted from operations of ventilation fans

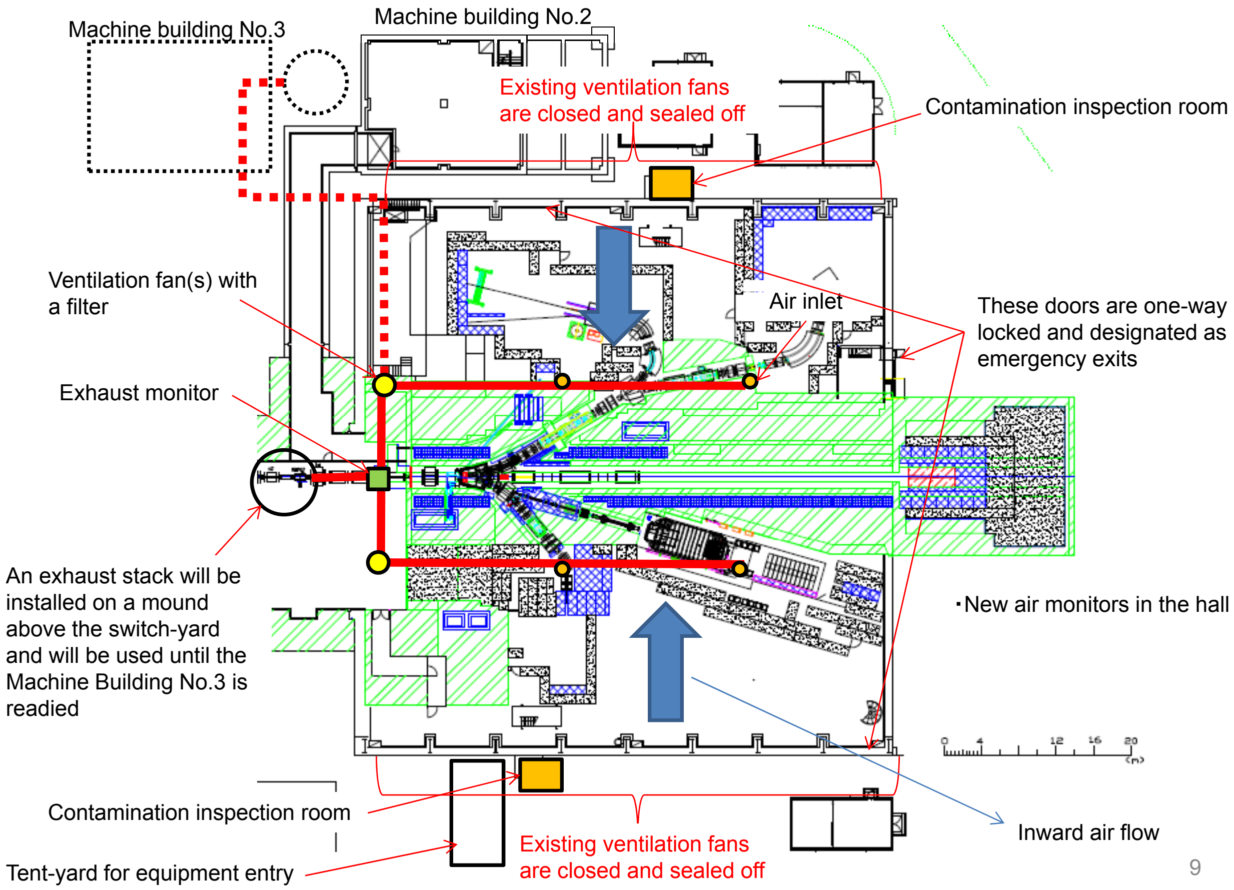
Preventive measures:

・Existing ventilation fans are to be closed and sealed off.

・Air ventilation from the hall will be done through an exhaust stack after filtering while monitoring the radiation level.

・Radiation monitors in the hall will be part of the protection system which stops beam operation when an abnormal radiation level is detected. (It is important to separate false alarms caused, for instance, by a radon isotope.)

For stage 5: Improvement of the Hadron experimental hall



Improvement of radiation safety management

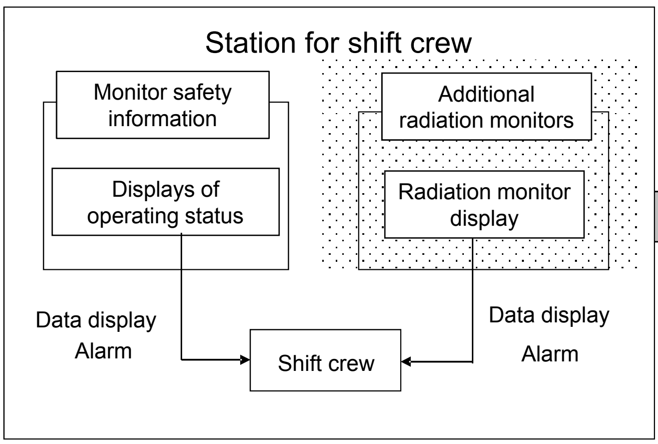
First step actions (draft)

・Add alarm functions on all monitors provided by KEK

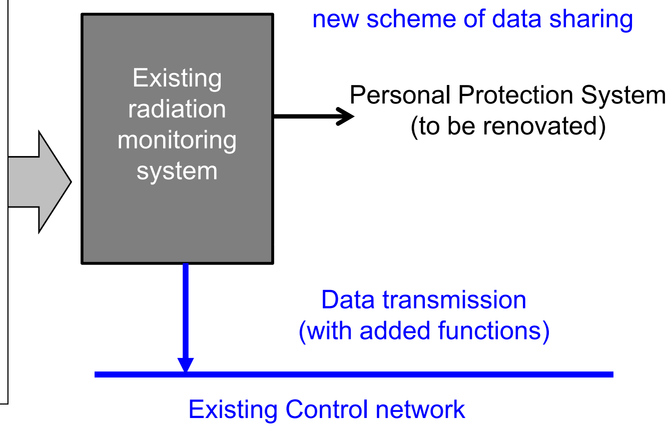
・Add status displays to provide the shift crew and relevant staff with monitor information

Second step actions (draft)

Enhanced sharing of monitoring information on the control system network, in close collaboration with each of the facilities at J-PARC



Schematics of the monitor system



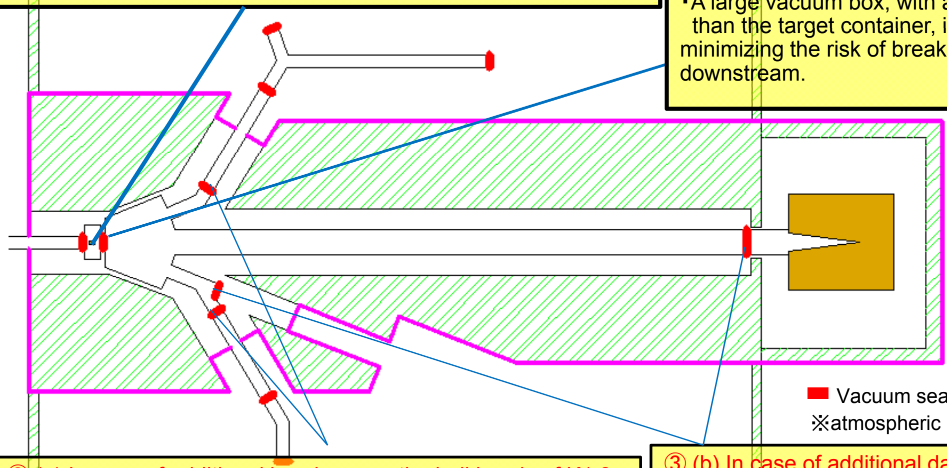
Case studies of heavy accidents at the Hadron Exp. Facility

① In case of melt or evaporation of the target metal due to an accidental, instantaneous exposure to a high-power beam

- An airtight target container to prevent leakage of radioactive material to the primary beamline area
- Integrity of the target container is to be maintained even in case the entire target material evaporates, since the maximum pressure rise in the target container will stay under 100 Pa.

② In case of additional breakage of the vacuum seal of the target container

- Radioactive material will leak into the vacuum duct of the primary beamline.
- Valves on vacuum valves are to be closed, minimizing the leakage of radioactive material leakage into the housing for the primary beam line. The primary beam line housing has an airtight structure to prevent leakage into the experimental hall.
- A large vacuum box, with a volume more than ten-fold larger than the target container, is placed immediately downstream, minimizing the risk of breakage of other vacuum seals further downstream.



Even if several vacuum seals are broken, radioactive material is confined to an inside of the primary beam line.

③ (a) In case of additional breakage on the bulkheads of K1.8 and K1.1

- Radioactive material will leak into a vacuum duct of the secondary beamline downstream
- Mitigate leakage to the experimental hall by returning exhaust air from the vacuum pump to the primary beamline area

③ (b) In case of additional damage on the vacuum seal in front of the KL or in front of the beam dump

- Radioactive material will leak into the primary beamline area or into the beam dump area
- Airtight structure of the primary beamline area and the beam dump area will prevent leakage into the experimental hall and into the environment

Summary of countermeasures against the recurrence of similar accidents

Safety measures developed in examination of each stage of this accident

- **Stage 1: Delivery of abnormal beam**
  - Measures taken on the EQ magnet
  - Prevent delivery of an excessively large current; Rigorously detect abnormal conditions, etc.
  - Countermeasures against the risks of short pulse extraction
- **Stage 2: Damage of the gold target**
  Stage 3: Leakage of radioactive material into the primary beamline
  - An airtight target container, Circulated inert gas to fill the container
  - Monitoring the gas pressure and the concentration of radioactive material
  - Shorten the time interval of measurement of target temperature, etc.
- **Stage 4: Leakage of radioactive material into the Hadron experimental hall**
  - Reinforcement of the air-tightness of radiation shields for the primary beamline
  - Install a radioactivity monitor of the air →Stop the beam operation when abnormal signatures are detected
- **Stage 5: Leakage of radioactive material into the environment outside the HD Facility**
  - Seal-off existing ventilation fans
  - Ventilation of the air of the hall will be through a stack after filtering and monitoring radiation level, etc.
- **Consolidation of status displays with improved radiation safety management system**

Appendix 2－3－1

Report from the Working Group

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

Problems in the safety management system and in the emergency procedures, etc.

The 3rd External Expert Meeting held at KKR Hotel Tokyo on July 20, 2013

Issues pointed out at the 2nd meeting of the External Expert Panel

- **Safety management system has to respond to symptoms before they turn into incidents.**
  - Actions to be triggered by symptoms
  - Symptoms to be identified by inquisitiveness
- **Well thought-out safety measures to minimize unanticipated problems**
- **Close sharing of information and judgment**
- **Authorization of facility operation belongs to the radiation safety management, not to the accelerator division**
- **Empowerment of on-site facility managers**
  - Keep in mind: Uniqueness of J-PARC, where a variety of visiting users conduct experiments
- **Protocol has to be clarified for delegation of responsibilities when the manager in charge is off-site.**

Problems in responding to the leak accident at the Hadron Experimental Facility

- **Many early symptoms did not lead to appropriate actions.**
  - Target damage and subsequent leak of radioactive material were not part of consideration.
  - No procedures were defined to respond to early symptoms.
  - No scheme for information sharing was in place for the pertinent people.
- **Delay in recognition of the accident led to late reporting.**
  - Ambiguous understanding of the criteria for issuing the statutory report.
  - Safety Division Head was solely responsible for judgment in issuing reports
- **Procedures for conducting user evacuation were incomplete.**
- **The facility manager in charge was off-site at the time of the incident.**

Appendix 2-4

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

Evaluation of the soundness of the other facilities of J-PARC
- Materials and Life Science Experimental Facility
- Neutrino Experimental Facility
- Accelerator Facility

The 3rd External Expert Panel Meeting to Review the Radioactive Material Leak Accident at the Hadron Experimental Facility of J-PARC at KKR Hotel Tokyo on 20 June, 2013

Materials and Life Science Experimental Facility (MLF)

- Area Classification

— Target area: Class 1 radiation controlled area
— Experimental halls: Class 2 radiation controlled area

- Prevention of leakage of radioactive material at area boundaries

—The target area is separated from the experimental halls by concrete walls, which are part of the building structure.
—Zoned pressure controls within the radiation controlled areas
—Air ventilation is done through filters with the radioactivity being monitored.

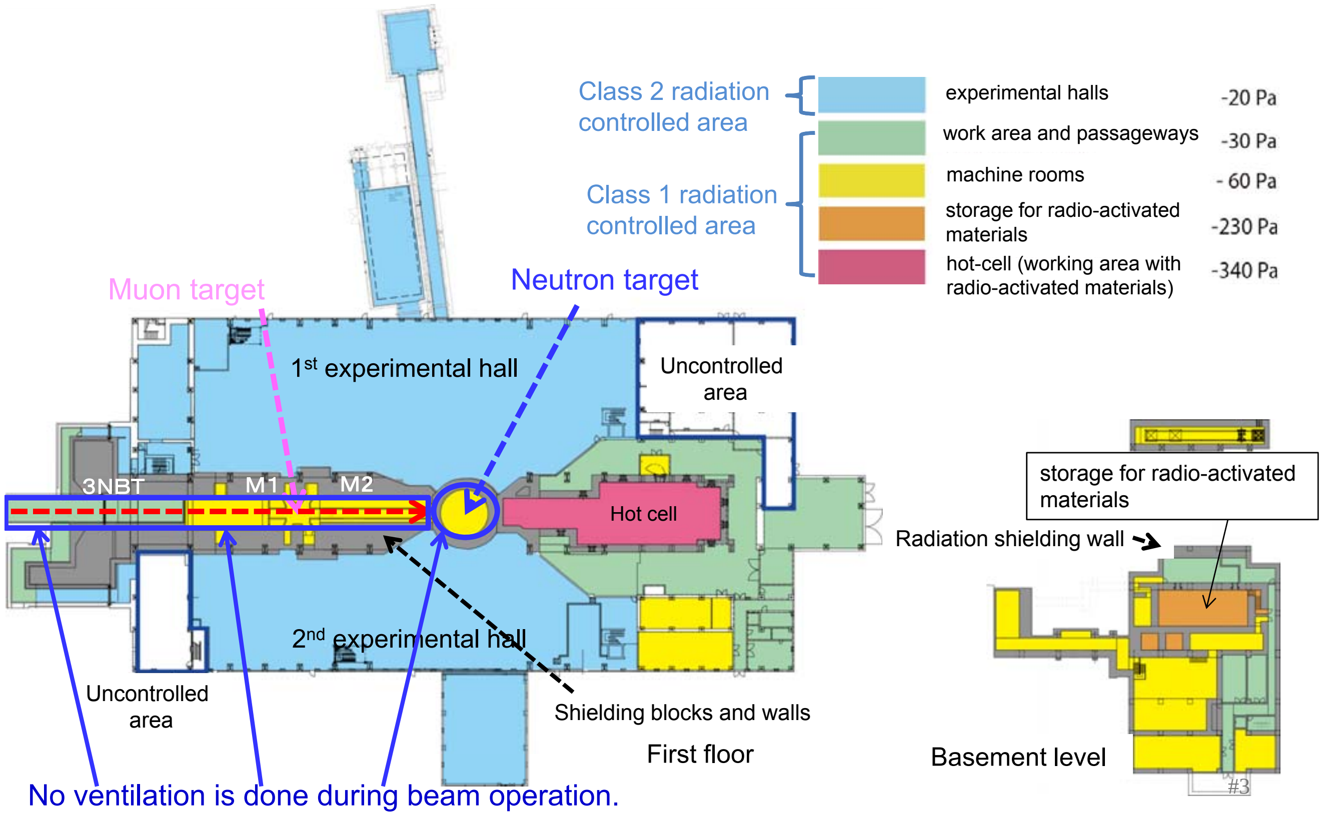
- Prevention of leakage of radioactive material due to damage on the neutron target

— Scheduled replacement before occurrence of damages
— Precautions against damages
  ･Multiple layers of protection against leakage of mercury and an early detection system.
  ･Shutting off the exhaust ventilation will confine the radioactive material

- Prevention of leakage of radioactive material due to damage on the muon target

—The target installed in a vacuum chamber for protection in worst-case scenarios
—Vacuum pump lines will be shut off and the pumps will be turned off, in case of emergency.

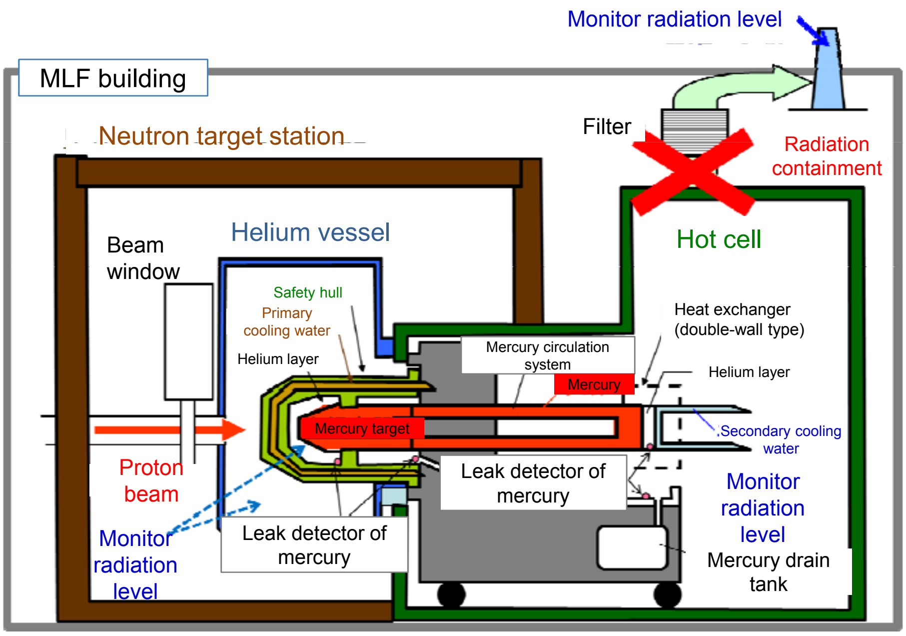
Zoned pressure controls in the MLF



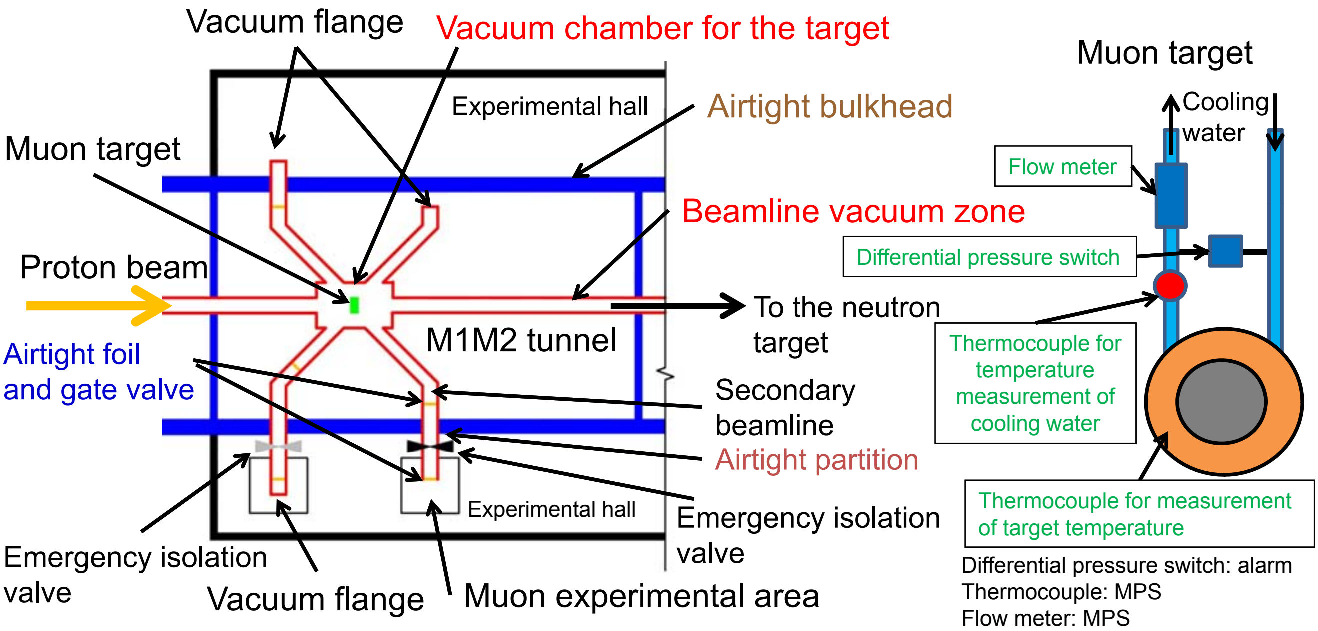
The similar zoned pressure control is arranged at the 2nd and 3rd floors

Multiple protection of the mercury target

- The mercury target vessel consists of a mercury vessel and a safety hull.
- The mercury target vessel is covered by a steel vessel filled with helium, which in turn is housed in a neutron target station consisting of an outer liner and hermetic plates, forming a multi-layered barrier.
- The mercury circulation system is placed in a hot cell under a negative room pressure.
- A multi-level detection system, including radiation monitors and leak detectors, is installed.
- radiation level in air ventilation is continually monitored before exhausting the air through a stack.



Multiple protection of the muon target



- Muon target (2 cm-thick graphite) is contained in a vacuum chamber.
- The emergency isolation valve and the gate valve will be shut off when the vacuum is deteriorated.
- The boundaries between the MLF experimental hall and the M1M2 tunnel are sealed airtight.

Neutrino Experimental Facility

- **Area classification**

—Target area, etc. (underground level): Class 1 radiation controlled area

—Utility and machine buildings (ground surface level): Class 1 radiation controlled area

- **Prevention of leakage of radioactive material at area boundaries**

—Underground level construction has a sealed structure

—Surface portion between the underground area and uncontrolled areas is under negative pressure control

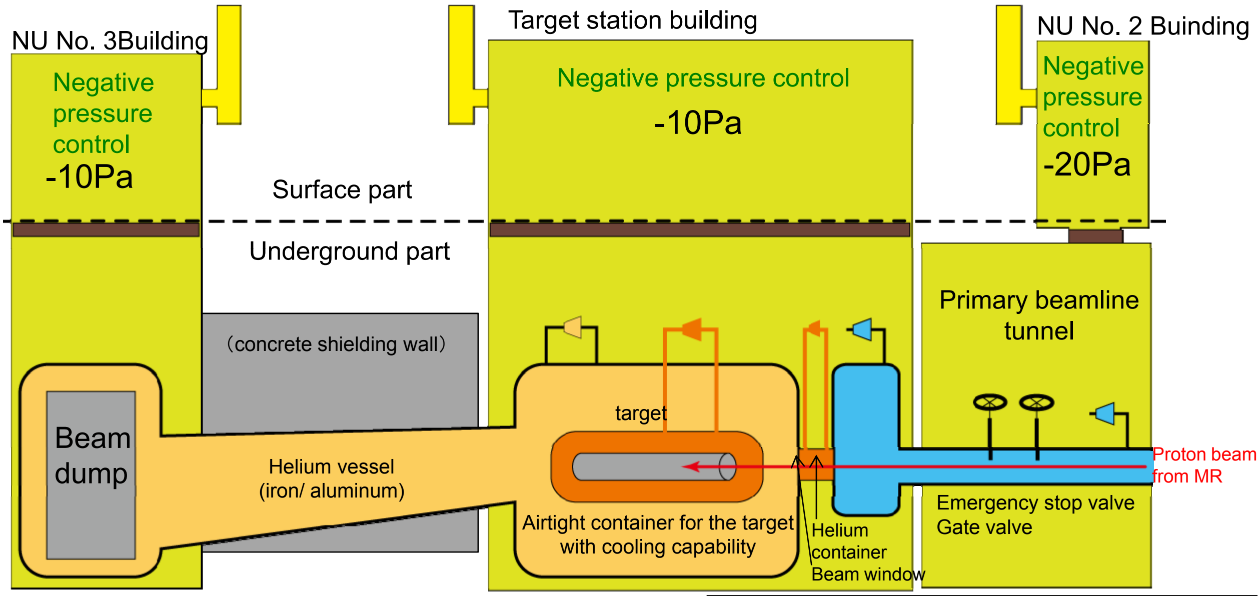
—Air exhaustion from the surface portion is done through filters and stacks with the radiation level continuously monitored.

- **Prevention of leakage of radioactive material due to damage of the target**

—The target is confined in a helium vessel.

—Watch any leak of radioactive material from the helium vessel

Multiple protection of Neutrino Experimental Facility



- Multiple-layered airtight systems:

—Both the target container and the helium container are helium–tight.

—Isolation of air between surface and underground levels

- Negative pressure control and controlled exhaustion at the surface level

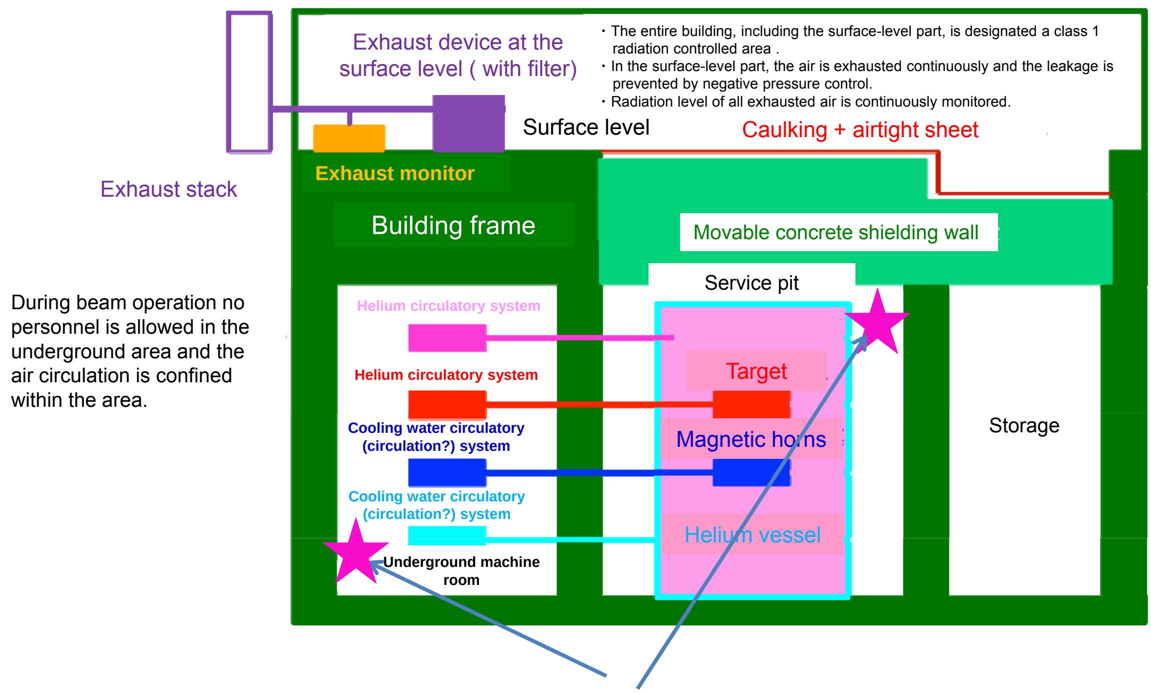
—Reference negative pressures: -10 Pa for TS/NU3 and -20 Pa for NU2

—The air is exhausted through HEPA filters from a stack, after checking the concentration of radioactive material.

- Protection system designed to prevent leakage of radioactive material in case of target of horn damages (worst case incident)

Target station and beam dump parts of the target vessel are a welded structure of 100-200 mm-thick steel plates. The decay volume part of the vessel is a welded structure of 16 mm-thick steel plates surrounded by 6 m-thick concrete walls. Earthquake-resistant structure is designed to withstand 650 Gal. No damage occurred in the Great East Japan Earthquake.

Prevention of leakage of radioactive material at the target station



During beam operation no personnel is allowed in the underground area and the air circulation is confined within the area.

Air monitor
(Capable of detecting leakage of radioactive material from helium vessel)

Accelerator Facility

- Area classification

— Accelerator tunnels: Class 1 radiation controlled area

  ･During beam operations the air dampers are fully closed.

  ･Air is recirculated within class 1 controlled area.

— Sub-tunnels: Class 1 radiation controlled area

- Prevention of leakage of radioactive material at site boundaries

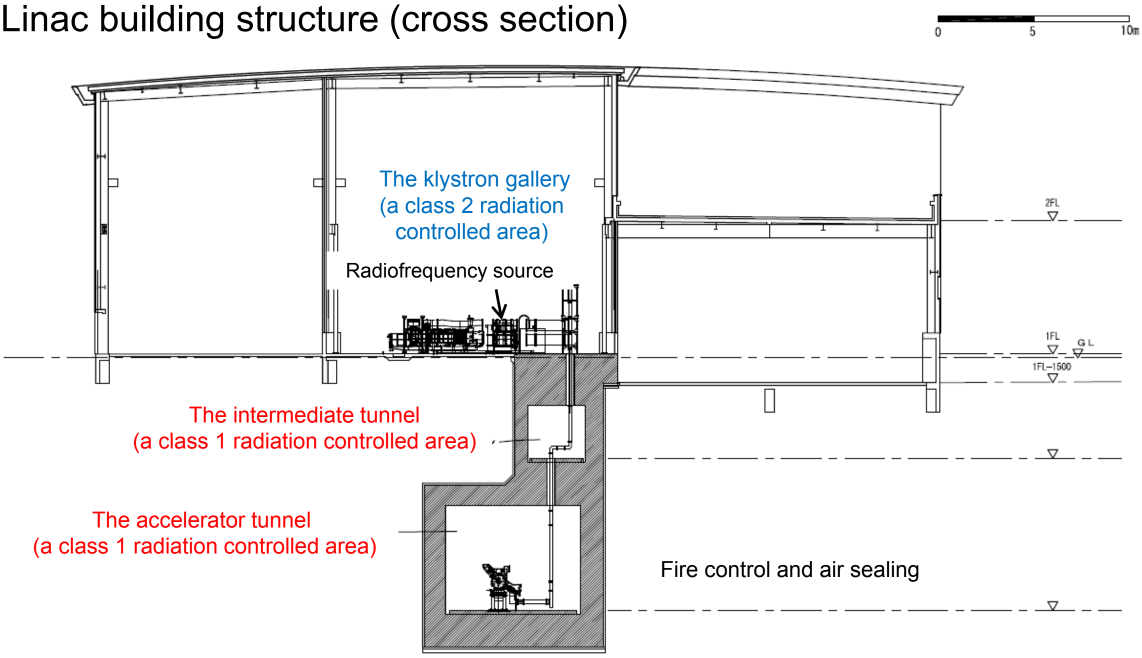
— Accelerator tunnels are air-tight.

— Interconnection areas between an accelerator tunnel and class 2 or uncontrolled areas are kept under negative room pressure and exhausted.

— The air is filtered and exhausted through a stack, with monitoring the radiation level.

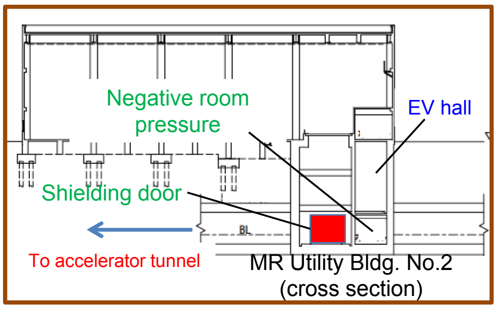
Prevention of leakage of radioactive material at Linac

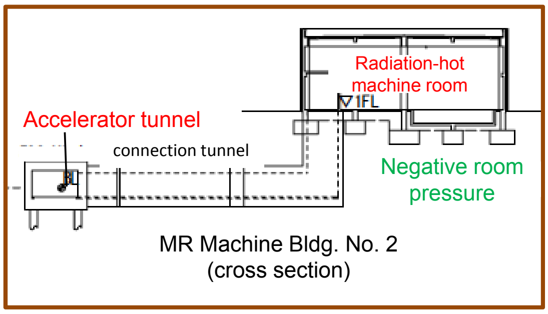
Linac building structure (cross section)

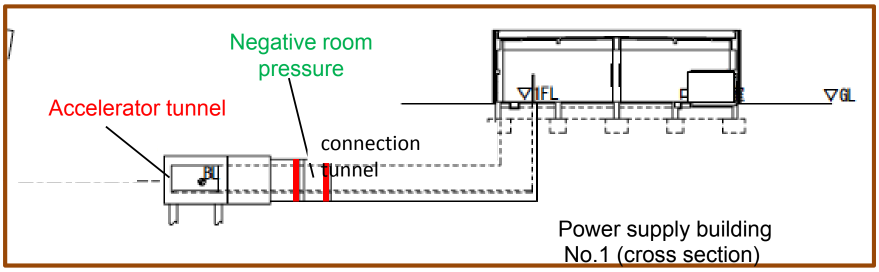


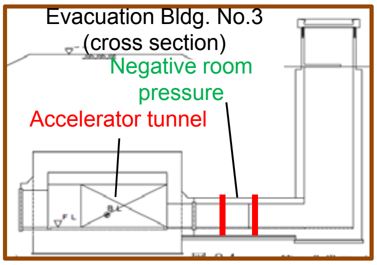
At 3 GeV synchrotron the zoned negative pressure control at the boundaries is conducted to prevent the leakage.

Prevention of leakage of radioactive material at 50 GeV synchrotron









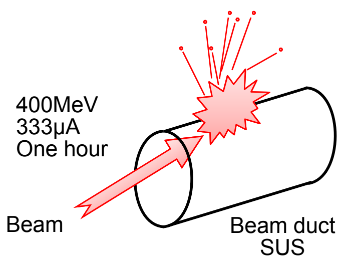
The same negative pressure control and exhaustion of interconnection areas are conducted at other boundaries.

An accident in worst-case scenario at Linac during beam operation

- Envisioned incident

A beam duct made of SUS was exposed to a continuous direct hit by the beam. A part of radio-activated beam duct was sublimed and was released in the accelerator tunnel. As no one noticed it, air exhaustion was started two hours after beam operation stopped.

Beam energy: 400 MeV
Average current: 333 μA
Period of beam exposure: one hour
Period of cooling down: two hours
Area of leakage: L3BT tunnel (2500 m^3)
Material of beam duct: SUS



Radioactive nuclides to be produced, their concentrations (absolute and relative values normalized by statutory limits), and their sum (two hours after beam irradiation)

Typical produced nuclide	Concentration (Bq/cc)	Ratio normalized by statutory limit	Total of the ratios
Mn 56	4.7×10^{-4}	4.7×10^{-1}	$7.0\times10^{-1} < 1$
Fe 52	7.1×10^{-6}	3.6×10^{-2}	
Mn 52	3.1×10^{-6}	3.5×10^{-2}	
etc.	–––	–––	

Even if all the radioactive material produced in this case was released to the environment (out of the radiation controlled area) through one-time exhaustion, the ratio of each nuclide concentration normalized by statutory limit stays less than 1.
The total sum of the ratios above is still less than 1.

Summary

➢ Materials and Life Science Material Experimental Facility

・Area classification: The areas for neutron and muon targets are classified to a class 1 radiation controlled area.

・Prevention of leakage of radioactive material at site boundaries
Zoned negative pressure control

・Prevention radioactive material leak due to the damage of the neutron target (worst-case scenario)

・Prevention radioactive material leak due to the damage of the muon target (worst-case scenario)

➢ Neutrino Experimental Facility

・Area classification: The target area is classified to a class 1 radiation controlled area

・Prevention of leakage of radioactive material at site boundaries

Underground level part is hermetic structure, and area between underground level and general area at surface level is exhausted continuously and controlled by negative pressure.

・Prevention radioactive material leak by the damage of the target (worst-case scenario)

➢ Accelerator Facility

・Area classification: Accelerator tunnels are classified to a class 1 radiation controlled area

・Prevention of leakage of radioactive material at site boundaries

Accelerator tunnels are air-tight. Interconnection areas between an accelerator tunnel and an unclassified general area are continuously exhausted and are controlled negative pressure

We conclude that the area classification, measures to prevent leakage of radioactive material at site boundaries and measures to prevent leakage of radioactive material due to the damage of a target at these facilities are maintained sound and healthy.

Appendix 2-5

Report from the Working Group

Working group of the Radioactive Material Leak Accident at the Hadron Experimental Facility of J-PARC

On observation of the target

- Reasons why direct observation of the target is needed
- Status of removal of iodine isotope in the air

The 3rd 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 20 June 2013

Reasons why direct observation of the target is needed

1. We would like to confirm our analysis on the cause of the accident which is presently presumed as follows: "The proton beam was extracted in a period much shorter than the normal operating condition and was delivered to the gold target. This caused partial melting or evaporation of the target, which resulted in release of radio-active material therein." For detailed designs of preventive measures, we would like to conduct direct observation especially taking heed on the following points:

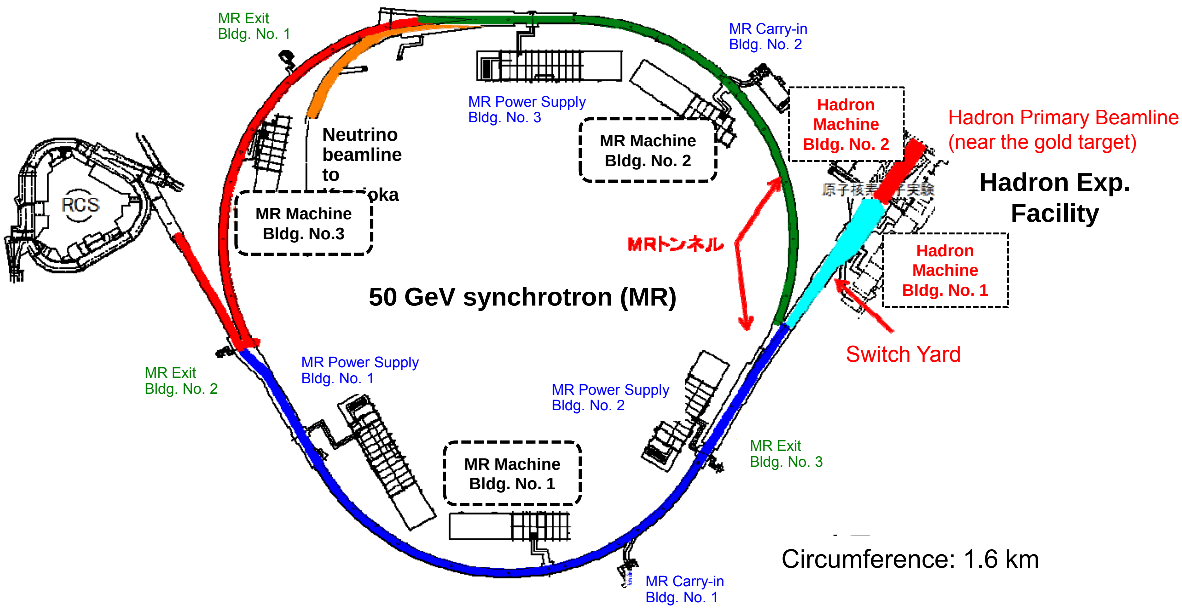
   – Condition of the target damage in its downstream part (determination of the extent of damage)
   – Slit condition between target gold blocks (emission pathway from the target)
   – Condition of bonding between gold and copper block
   – Condition of interior of the target container and the surrounding environment (lines of evidence for melting, vaporization and an emission pathway)
   – Status of beryllium film on the downstream side (possible damage)

2. We would like to investigate the extent of contamination in the area around the target and its neighborhood, learn the pathway for the leak and utilize the information for development of countermeasures.

Status of removal of iodine isotope in the air

Prior to investigation of the gold target, we have to reduce the concentration of radioactive material in the air to prevent spreading of the contamination. For this purpose the air in the tunnel was circulated through charcoal filters while the concentration was monitored.

Layout of machine buildings



- On July 11, 2013, HEPA filters were replaced by charcoal filters at the Hadron Machine Bldg. No. 1.
- On July 14, 2013, HEPA filters of other machine buildings were replaced by charcoal filters.

Radioactivity density in the sampled air (I-125, [Bq/cm^3])

	MR-M1	MR-M2	MR-M3	HD-M1
Before using charcoal filters	1.6×10^{-7} (July 10, 2013)	1.5×10^{-7} (July 9, 2013)	1.7×10^{-7} (July 9, 2013)	2.4×10^{-7} (July 8, 2013)
July 11, 2013	—	—	—	8.2×10^{-8} (3 hours circulation)
July 12, 2013	—	—	—	7.1×10^{-8} (11 hours circulation)
July 16, 2013	5.8×10^{-8} (3 hours circulation)	1.1×10^{-7} (5 hours circulation)	7.0×10^{-8} (5 hours circulation)	1.2×10^{-7} (14 hours circulation)
July 17, 2013	3.3×10^{-8} (7 hours circulation)	$<1.8\times10^{-8}$ (11 hours circulation)	4.0×10^{-8} (11 hours circulation)	4.4×10^{-8} (38 hours circulation)
July 18, 2013	1.6×10^{-8} (31 hours circulation)	1.9×10^{-8} (35 hours circulation)	2.2×10^{-8} (35 hours circulation)	2.8×10^{-8} (62 hours circulation)

・Charcoal filters have been found to be quite effective

* The numbers in parentheses indicate the total air circulation times after starting the use of charcoal filters