# Contamination at Plutonium Fuel Research Facility of Oarai Research and Development Center

September 29, 2017

Japan Atomic Energy Agency

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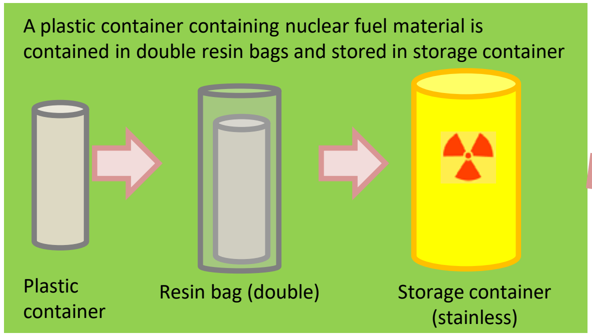
# Outline (1)

## Outline

Around 11:25, June 6, 2017 (Tue), in Room No. 108 of Plutonium Fuel Research Facility (PFRF) (controlled area), resin bags ruptured and contamination occurred when five workers were inspecting a storage container containing plutonium and uranium with a hood H-1).




The storage container was uncovered to check the storage situation in a hood.

## Background

PFRF was constructed in FY 1974 for the research on advanced fuel etc. of fast reactors, and the policy to decommission the facility was issued in FY 2013.
Check of the empty capacity etc. of existing storage containers (80 units) started in February 2017 as part of efforts to improve the management condition of nuclear fuel materials.
The accident occurred while checking the 31st container.

## Events in chronological order

June 6 (Tue)
Accident occurred around 11:15
June 7 (Wed)
It was judged that reporting of the accident was required by the law
June 19 (Mon )
Report was submitted to Nuclear Regulation Authority (NRA) in accordance with the Article 62-31 of the Nuclear Reactor etc. Regulation Law
June 21 (wed), 23 (Fri), 28 (Wed), 30 (Fri)
On-site inspection of NRA based on the paragraph 1, Article 68 of Nuclear Reactor etc. Regulation Law.
June 23 (Fri)
Report was submitted in response to the request from Ibaraki Prefecture.
July 4 (Tue)
Restoration of the accident site started.
・Route to the hood was secured.
July 5 (Wed)
The result of on-site inspection was reported at NRA by the Secretariat of NRA.

## Events in chronological order

July 7 (Fri)
Slight contamination was confirmed at the corridor of PFRF (Work was temporarily suspended).
July 10 (Mon)
The Radiological Science Research and Development Directorate of the National Institutes for Quantum and Radiological Science and Technology (hereinafter NIRS) released the result of the dose evaluation.

| Committed effective dose | Number of people |
|---|---|
| 100mSv or higher and less than 200mSv | 1 |
| 10mSvor higher and less than 50mSv | 2 |
| Less than 10mSv | 2 |

July 20 (Thu)
Moving out the storage container (the hood in Room No. 108 → the glove box in Room No. 101)
July 21 (Fri)
Report (second report) was submitted to NRA based on the Article 62-3 of Nuclear Reactor etc. Regulation Law.
July 24 (Mon)
Situation of the response to the incident thus far was reported at Ibaraki Nuclear Safety Response Commission.

# Outline (2)

## Events in chronological order

July 28 (Fri) Decontamination and paint fixation of the hood of Room No. 108 (H-1 was completed.

August 1 (Tue) Contamination test and decontamination of the floor of the Room No. 108 started.
Observation of containts of the storage container and scattered materials started.

August 2 (Wed) The Secretariat of NRA reported on the report required by the law (2nd report) to the NRA. The incident was temporarily evaluated as level 2 "Incident" of the International Nuclear Event Scale (INES).

August 8 (Tue) Ibaraki Tokai Area Environmental Radiation Monitoring Commission

August 14 (Mon) "Report on laborers' number per effective dose category (quarterly regular report)" was submitted to the labor standards inspection office

August 22 (Tue) Contamination test and decontamination of the floor of the Room No. 108 was completed.

August 23 (Wed) Contamination test and decontamination of the walls of the Room No. 108, ceiling, glove box, structure, etc. started.

September 8 (Fri) Contamination occurred in Room No. 101 of PFRF (Work suspended)

* Evaluation standard of INES (level) and example

| | | |
|---|---|---|
| 7 | Major Accident | Chernobyl disaster<br>Accident at Fukushima Daiichi NPP |
| 6 | Serious Accident | Kyshtym disaster |
| 5 | Accident With Wider Consequences | Three Mile Island Nuclear Power Plant Accident |
| 4 | Accident With Local Consequences | JCO nuclear criticality accident |
| 3 | Serious Incident | Asphalt facility fire and explosion accident |
| 2 | Incident | Damage to the heat exchanger tube of steam generator of KEPCO's Mihama reactor unit 2 |
| 1 | Anomaly | "Monju" sodium leak accident |
| 0 | Deviation | Damage to secondary piping causing fatal accident at KEPCO's Mihama unit 3 |

## Events in chronological order

September 8 – 15 Emergency inspection of the documents of response, treatment and planning concerning the contamination that occurred in Room No. 101

September 19 (Tue) Contamination test and decontamination of the walls of the Room No. 108, ceiling, glove box, structure, etc. restarted.

September 29 (Fri) Report (3rd report) was submitted to the NRA based on the Article 62-3 of Nuclear Reactor etc. Regulation Law.

## Situation of the workers

Below is the situation of the hospitalization of the workers in NIRS.

| Period of hospitalization | Number of people | Period of hospitalization | Number of people |
|---|---|---|---|
| June 7 - 13 | 5 | August 21 - 25 | 1 |
| June 18 - 26 | 5 | September 4 - 8 | 1 |
| July 3 - 7 | 3 | September 11 - 12* | 4 |
| July 24 - 28 | 3 | September 25 - 29 | 1 |
| August 7 - 11 | 2 | | |

*: Regular check-up

※The workers' hospitalization is because injection of chelate agent has effect on their condition.
※No abnormality with regard to the physical condition of the five workers
※The industrial doctor, health nurse and care team of the workers interview and provide care to the workers.

# Outline of Plutonium Fuel Research Facility and contents of work

## Outline of PFRF

- PFRF was constructed with the purpose of conducting R&D on advanced fuel etc. for fast reactors and completed in 1974.
- Experiment using plutonium started in 1977.
- fabrication and research on physical property of new fuels such as uranium-plutonium mixed oxide fuel, nitride fuel, long-lived minor actinide nuclear transmutation fuel and metallic fuel for fast reactors, fabrication of fuel pins for irradiation test aiming for verification of fuel soundness and research concerning dry type separation using electrolysis of molten salt were conducted in this facility.
- R&D ended in 2015. In accordance with the policy for decommissioning issued in FY 2013, nuclear fuel materials used for experiment was being processed for stabilization and the decommissioning plan was being examined.

Facility outline:
Two-story building, fire-resistive construction with reinforced concrete,
1518 $m^2$ of total floor space (controlled area is 570 $m^2$)
Main equipment:
Main facility
glove box: 36 units, argon circulation generator: 4 units, hood 4: units


## Outline of work

- In February 2017, correction of the below situation was ordered by NRA.
  - Nuclear fuel materials used in the past R&D were stored for a long period of time at a use facility of application for a use license, instead of a storage facility, under the excuse of being in use.
- In response to this order, work was planned to process these stored nuclear fuel materials etc. for stabilization, and store them additionally in 80 storage containers in the storage.
- In the storage container, the material is contained in a container and sealed in double resign bags. The purpose of the work is to open the storage container with the hood in Room No. 108 and check if there is a vacant space inside.
- The work started in February 2017, and have been completed for 30 of 80 storage containers, which contained items of which chemical form and physical property were clear. The accident occurred during opening work of the 31st storage container, which contained materials used experiment with various chemical compounds.

# Situation of radiation and contamination at the work site and contamination/exposure of the workers

## Situation of radiation and contamination at the work site

- There was no change in the indication values of the monitoring posts and ventilation dust monitor of PFRF before and after the accident.
- With regard to the concentration of radioactive materials in the air of the accident site, the indication value of the Pu dust monitor No. 2 inside the room (Room No. 108) at the time of the occurrence of the accident was within the normal fluctuation range
- The indication value of the Pu dust monitor No.2 rose to $5 \times 10^{-8}$Bq/cm$^3$ (average concentration of a week) at 13:55, June 6, 2017, but there was no rise of the value after that. This value is lower by one digit than the level of Pu-239 designated by the law ($7 \times 10^{-7}$Bq/cm$^3$). Later, as a result of replacing dust filter Pu dust monitor, it was confirmed that the indication value dropped to the normal fluctuation range. Since then, the indication value is within the normal fluctuation range.
- With regard to the surface concentration of Room No. 108, as a result of the measurement of the floor on June 7, 2017, contamination at the levels up to 55Bq/cm$^2$(α ray) and 3.1Bq/cm$^2$(β(γ) ray) were confirmed at 18:55. The maximum dose equivalent rate was 2μSv/h.
- It was confirmed that there was no contamination at the corridor to Room No. 108 and outside of the emergency exit of the room.
- Particles assumed to have scattered from the storage container were confirmed on the floor in front of the hood (H-1).

## Exposure of the workers

- As a result of the physical contamination test conducted in the green house, contamination was confirmed on the special cloths of the five workers (more than 322Bq/cm$^2$ (α ray)) and on the skin of the four workers, and among three of the four workers, contamination in nasal cavity (up to 24Bq(α ray)) was confirmed.
- The workers with skin contamination underwent decontamination in the shower room, and left the controlled area after confirming that the level is lowered than the detection limit (0.013Bq/cm$^2$(α ray)). When the decontamination for the first worker started, the flow of the shower water decreased in one or two minutes. The decontamination was restarted by bringing the industrial water with a hose from the machine room of the fuel research building.
- Three of the five workers wore individual dosimeters, and their values were 2μSv, 3μSv, and 60μSv.
- As a result of transporting the five workers to Nuclear Fuel Cycle Engineering Laboratories and conducting lung monitoring, the levels were evaluated as 22,000Bq and 220Bq with regard to Pu-239 and Am-241, and accordingly injection of chelate agent (Ca-DTPA) was administered.
- The five workers were transported to NIRS on June 7, 2017, and medical treatment including lung monitoring were administered.

# Situation of report concerning report required by the law

- 13:00, June 7, 2017, the accident was judged as an accident for which reporting is required by Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors

【Reason for the judgement】
  - As the measurement results showed the levels up to 22,000Bq and 220Bq with regard to Pu-239 and Am-241 due to the lung monitoring of the five workers conducted at Nuclear Fuel Cycle Engineering Laboratories, the levels of exposure exceed, or it is possible to exceed, the standards of reporting in the event of unplanned exposure of radiation workers entering controlled areas, which is 5mSv.
  - Judging from the contamination situation of the five workers, the surface concentration of the floor of Room No. 108 etc. exceeds, or it is possible to exceed, the standards for designating restriction area provided in the operational safety program（α nuclide：4Bq/$cm^2$）.

- The above matters were reported to the Secretariat of NRA at 13:27.

Reports based on the law was submitted to NRA on June 19 ($1^{st}$ report), July 21 ($2^{nd}$ report) and September 29 ($3^{rd}$ report).

# Impact on the environment



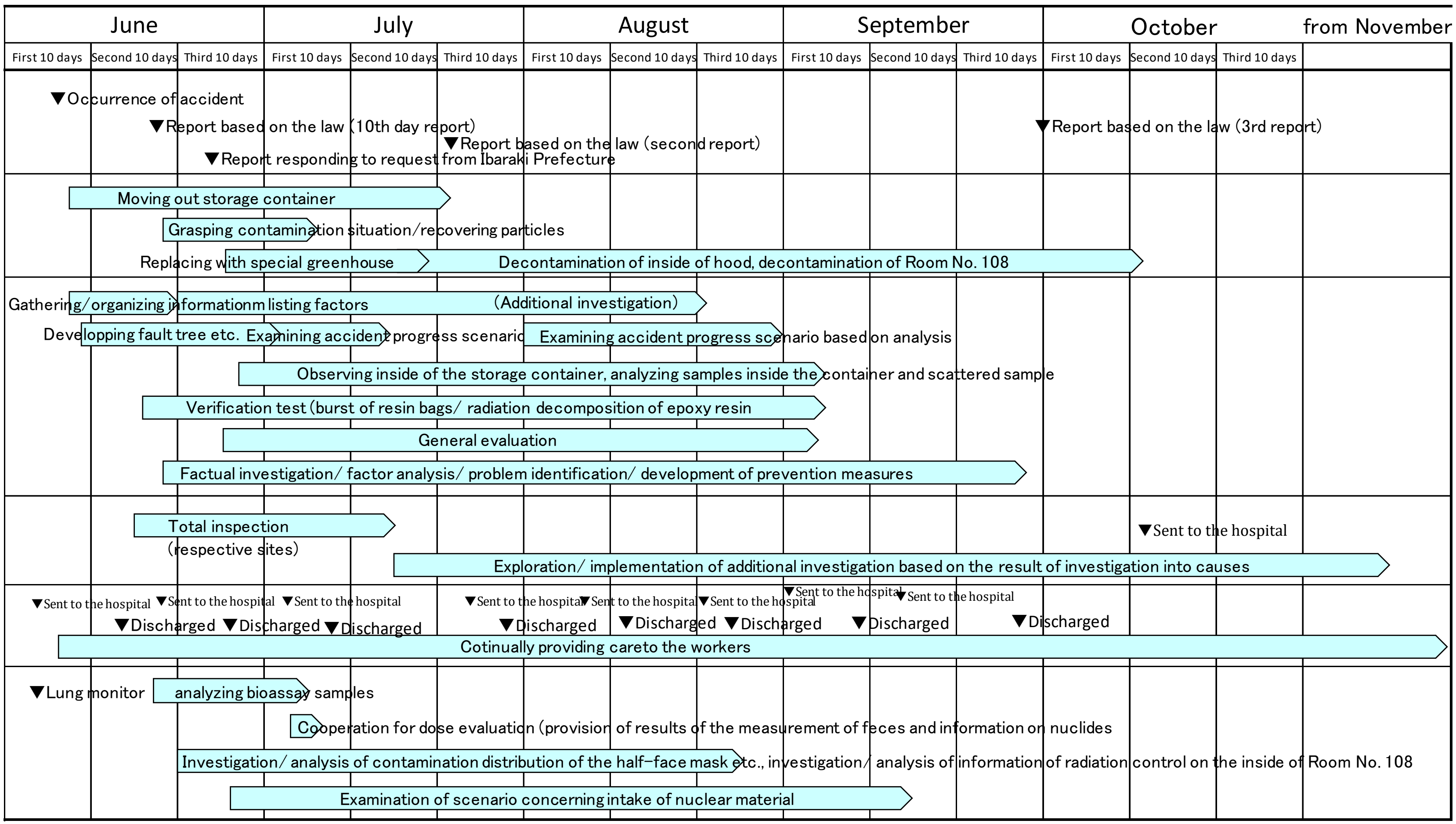
- At the time of the occurrence of the accident, the ventilation system of PFRF continued operation to maintain the normal negative pressure in the controlled area, and values indicated by the monitoring posts and the ventilation dust monitor of PRFR were within the normal fluctuation range. Therefore, there was no impact on the environment caused by this accident.

- Operation of the ventilation system of PFRF continues after the occurrence of the accident, and the normal negative pressure outside the controlled area is maintained. The indication values of the ventilation dust monitor and Pu dust monitor of PRFR and monitoring posts at the site borders shifted within the normal fluctuation range. Therefore, there is no impact on the outside of the facility.

# Schedule of response to contamination accident at PFRF（As of September 29）

## Schedule for restoration of the site and investigation into the cause

September 21, 2017



# Measures taken after the incident

## Restoration of the incident site

(1) Transportation of the storage container in the glove box

- Recovered the scattered particles and carried out the storage container where the accident occurred and recovered scattered particles from Room No. 108 to the glove box in Room No. 101

(2) Enhancement of contamination management

- Replaced the greenhouse set immediately after the occurrence of the accident with a greenhouse meeting the requirements of more strict contamination management

(3) Contamination test and decontamination of the hood (H-1)

- With regard to the hood inside, conducted decontamination using strippable paint (apply strippable paint to the contaminated locations and remove it after it became solidified) and confirmed decrease in the surface density after wiping with wet waste cloth. Applied strippable paint again and fixed the remaining contamination.
- With regard to the outside of the hood, confirmed decontamination to the level lower than the detection limit of the surface density.

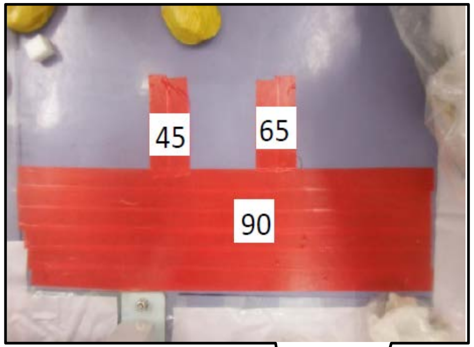
(4) Contamination test and decontamination of the floor of Room No. 108

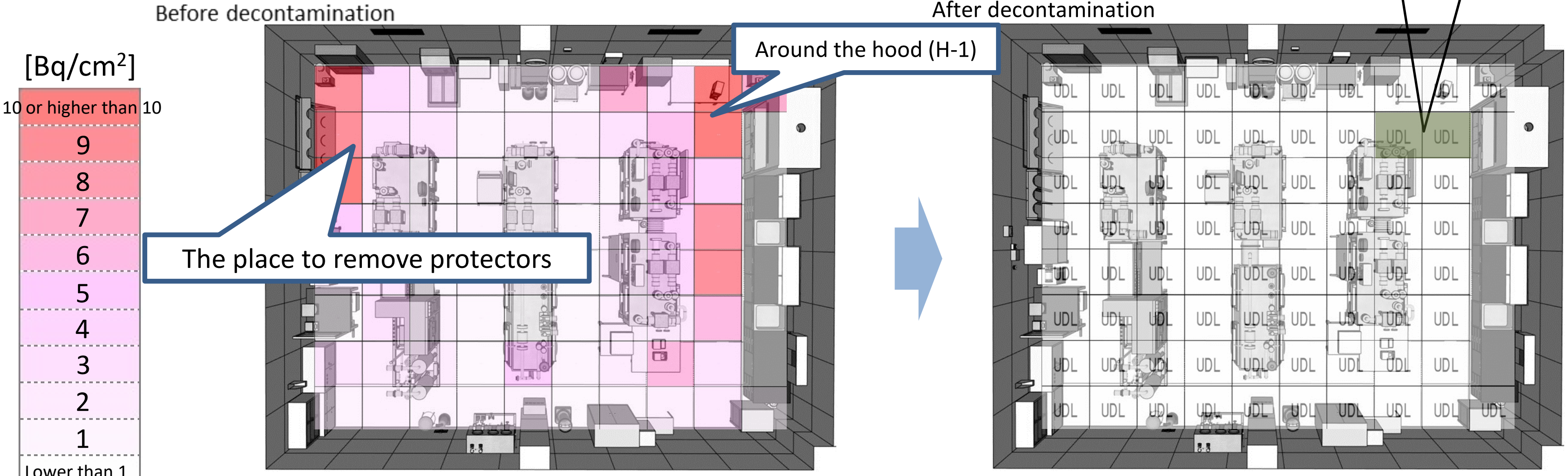
- Confirmed contamination with high density around the hood (H-1) and the place to remove protectors.
- Decontaminated with wet waste cloth etc. Fixed the remaining contamination with adhesive tape (right photo) and cured with plastic sheets.

(5) Contamination test and decontamination of the walls, ceiling, glove box, etc. of Room No. 108

- Contamination test and decontamination are currently being conducted (entrance restriction to Room No. 108 will be lifted by the middle of October).

Remaining contamination fixed with adhesive tape (figures show the surface density [cpm])




Distribution of average contamination density of the floor of Room No. 108

UDL: under detection limit

# Exposure evaluation of workers (1)

## Evaluation result concerning external exposure

(1)Evaluation of effective dose due to external exposure

- Measurement by optically stimulated luminescence (OSL) dosimeter
  - Worker A,B,C,D: Lower then the lower detection limit (0.1mSv)
  - Worker E: Evaluation is not possible due to the contamination which adhered to the surface of the dosimeter.
- Measurement by electronic personal dosimeter（EPD）(Three of the five workers wore the dosimeters)
  - Worker B: 2μSv, Worker D: 3μSv, Worker E: 60μSv
- Based on the above result, the exposure levels of the five workers were evaluated as lower than the record level (0.1mSv）.

(2)Evaluation of skin exposure dose by body surface contamination

- As contamination was confirmed of the special cloths of all the workers and of the skin of the four workers, skin exposure dose due to such contamination was evaluated under conservative presumption.
- From the occurrence of the accident to the exit from the controlled area
  - It is presumed that skin exposure continued for the longest possible period of time (7.67 hours) which is between the occurrence of the accident and exit of all the workers after completing decontamination, with radiation of contamination density at 1,000Bq/$cm^2$（in the case of the surface of the OSL dosimeter with the highest contamination density）directly adhering to the skin.
  - Result of evaluation: at maximum 83μSv
- From the exit from the controlled area to the completion decontamination at NIRS
  - It is presumed that the skin contamination at the time of hospitalization into NIRS (at maximum 140cpm, equivalent 0.44Bq/$cm^2$）continued from the time of the exit from the controlled area to the time when the contamination information was released (about 22 hours).
  - Evaluation result: at maximum 0.11μSv
- Based on the above result, with regard to all the five workers, contamination was evaluated as lower than the record level (0.1mSv）.

# Exposure evaluation of workers (2)

## Evaluation result concerning internal exposure

(1) Measurement/evaluation of internal exposure dose

- The workers were hospitalized into NIRS for examination of internal exposure and treatment.
- JAEA cooperated with NIRC for measurement/evaluation of internal exposure dose carried out as part of examination and treatment. Sample of bioassay (feces) was analyzed.
- Subsequently, necessary information is obtained from NIRS, and exposure doses were recorded based on the law. Below is the result.

| Committed effective dose* | Number of people |
|---|---|
| 100 mSv and higher and lower than 200 mSv | 1 |
| 10 mSv and higher and lower than 50 mSv | 2 |
| Lower than 10 mSv | 2 |

*Committed effective dose of 50 years

- It was confirmed that the level of one of the five workers exceeded the dose limit designated in the law (100 mSv for 5 years and 50 mSv for 1 year), and accordingly measures were taken to restrict the radiation work of this person.

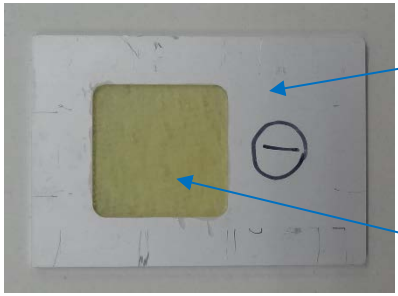
# Investigation result of contents of the storage container (1)



## Investigation result of contents of the storage container based on the documents

According to the result of inspection of the accounting record note, documents such as PFRF's monthly report, technical report, and inspection record, and interview with the staff (including retired staff), the following facts have become clear.

- Nuclear materials in the storage container were natural uranium（U）and plutonium（Pu）. With regard to Pu, five different isotopic compositions were mixed and their average isotopic composition were estimated.
- The nuclear materials in the storage container were gathering of the samples used for X-ray diffraction measurement.
- As characteristics of epoxy samples for X-ray diffraction measurement used at PFRF, method to mix the powder of nuclear fuel material and epoxy adhesive (mixture of main agent and curing agent) and fix it to aluminum sample holder was used. The size of the square part of the solid material was 20×20mm with the depth of 1.5 mm. The nuclear materials in the storage container were gathering of the samples used for X-ray diffraction measurement.
- This nuclear fuel material (resin solidified material) was put in the storage container in October 1991 in a state contained in a polyester container and then in double resin bags.
- When the lid of the storage container was opened in July 1996, inflation of the bag and damage to the bottom of the polyester container were confirmed, and therefore the packaging was redone. Since then, no document on inspection of the inside of the storage container was found until June 2017.



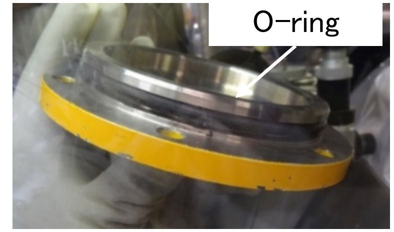

X-ray diffraction sample

# Investigation result of contents of the storage container (2)

## Observation result of contents of the storage container

- Interior surface of the storage container Ⓐ
  - No entrance of foreign substances. O-ring of the lid has cracks.
- Resin bags Ⓑ
  - The inside resin bag which is longer than the outside resin bag protruded from the outside resin bag.
  - The inside resin bag was cracked longitudinally along the side welded part.
- Polyester container Ⓒ
  - Change in color and embrittlement. No damage.
  - The lid and the container body were fixed with paper tape, which was broken at the boundary.
- Contents of the polyester container Ⓓ
  - Samples used for X-ray diffraction measurement (resin solidified material) was contained, filling the container up to 2/3 of its height.
  - Some kept almost complete shape and others were broken pieces.
  - Small fragmentsⒺ and powders were observed at the bottom.

  →The amount of the powders screened by 300 μm mesh (aperture) were very small compared to that of the resin fixed material.
  - Dose equivalent per piece of sampled resin fixed material was 5～220 μSv/h.
- Scattered material collected from the floor in front of the hoodⒻ
  - Various size of resin fixed material




Ⓐ Interior surface of the storage container

Ⓑ Opening at the top of the outside bag


Ⓑ Resin bags after the burst

Ⓒ Outside of the polyester container

ⒹContaining situation inside the polyester container

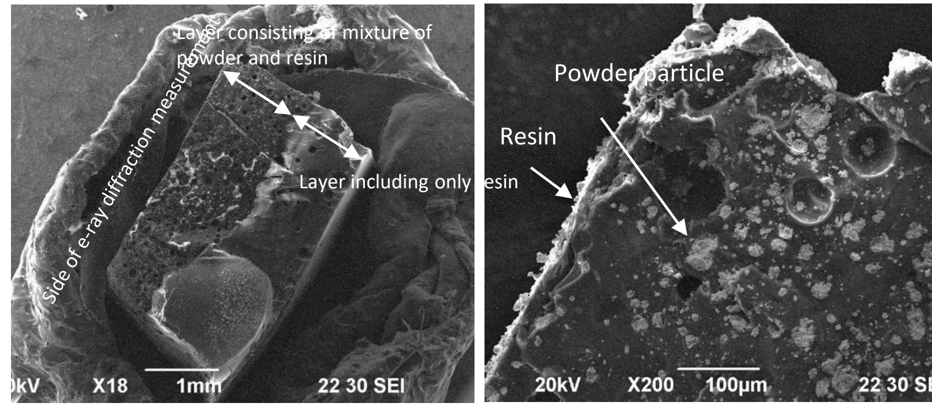
ⒺSmall fragments


ⒻScattered material collected from the floor in front of the hood

# Investigation result of contents of the storage container (3)

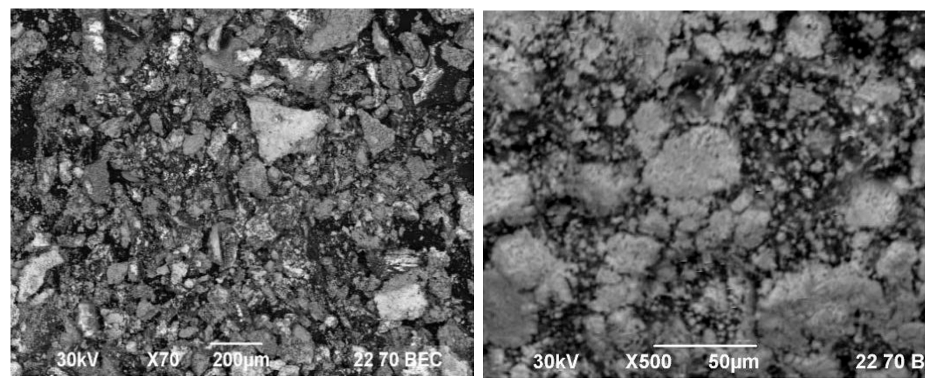
## Analysis result of contents of the storage container

- Resin fixed material Ⓖ
  - Resin fixed materials were observed and analyzed with an electron microscope and x-ray elemental analysis, dividing them in three levels of low, middle and high (range of 10 ～220μSv/h).
  - The cross-section shows two layers: a layer consisting of the mixture of resin and powder and a layer including resin only.
  - The size of the scattered powder particles spans from several micro meters to more than 50 μm (20 μm on average in the right image).
  - Low dose equivalent rate sample is almost only U.




ⒼCross-section of the resin fixed material（left） and magnified figure（right）
（Sample with high dose equivalent, about 220μSv/h）

- Screened powder component Ⓗ
  - The size of the powder particles expand from 1 μm to 300 μm.
    (Most of the components are more than several tens micro meters)
  - The ratio U/(U+Pu) is 0.8±0.1 at most analysis points.
  - By X-ray diffraction, carbide was confirmed in addition to oxide.
  - The powder components were presumed to be small elements breaking away from the resin fixed material, instead of resin fixed material treated with oxide heating, as the screened powders included resin and carbide.




Ⓗ Observation image of powder component (left: low magnification, right: high magnification)

- Scattered material
  - Powder particles were dispersed as well as resin fixed materials, and they were confirmed to be the pieces of the resin fixed materials.

- Other
  - Detected metal elements other than U and Pu are small amount of Ni added in the process of research, rare-earth Sm, etc.

# Investigation result of contents of the storage container (4)

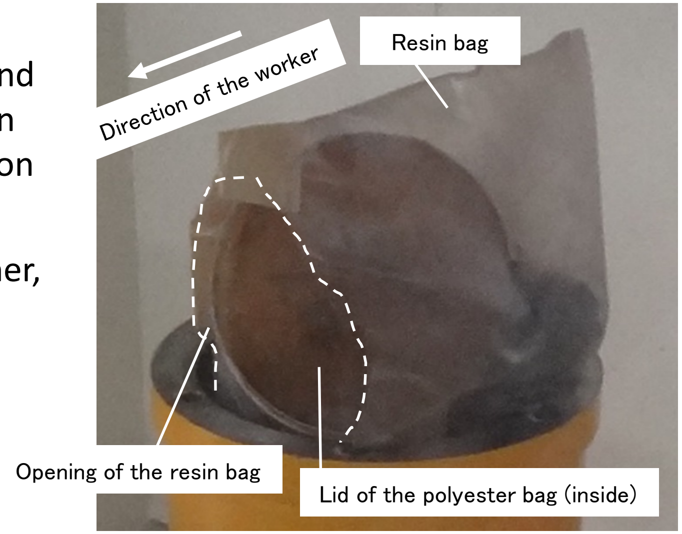
## Investigation result of the situation at the time of the burst

(1) Interview result

- The lid was rising up while the six bolt of the storage container were being loosened one by one. After six bolts were removed, there was a hiss of the inside gas coming out when lessening remaining two bolts. The sample of smear was collected from the space between the container and lid and confirmed there was no contamination.
- Holding the handle of the lid, a worker loosened the two bolts one by one, and when the two bolt were removed from the container the lid floated with a sound of burst. The sound the workers heard was one bang.
- Seeing the material scattered over the curing sheet after the burst, the worker “thought it was solidified with something.”

(2) Photo of the storage container taken by a worker

- The resin bag comes out from the top edge of the storage container, and opening of the bag is made along the side of the bag in a way to split in the vertical direction. The opening made by the burst faces the direction of the worker, and it is correspond with the statement of the worker.
- The cylindrical material seen in the bag is a lid of the polyester container, which is according to the worker upside down. The side visible is the inside of the lid.




Enlarged photo taken by the worker at the time of the burst of the resin bag

(The side of the bag was partially damaged in a way to split in the vertical direction)

# Contamination inspection of half-face mask（1）

## Measurement and analysis of half-face mask for investigating probable causes

Refer to the next page for the structure of the half-face mask and detailed measurement

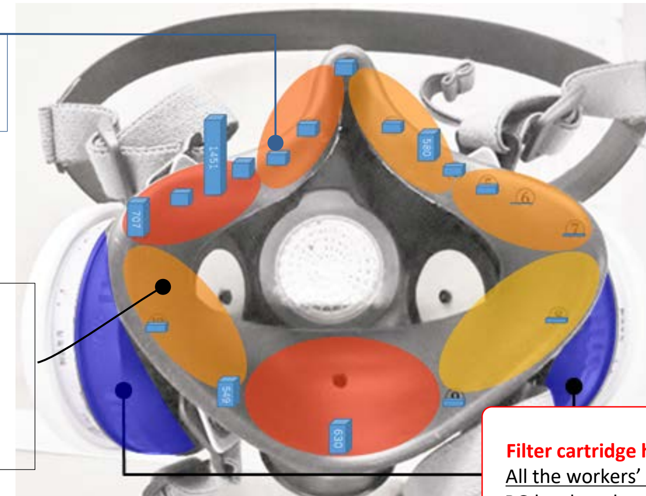
### ●Measurement result of mask **Worker E** wore during work

Result of measurement with a pencil type measuring instrument and smear measurement

Bar graph：measurement result of α ray with a pencil type measuring instrument (cpm)

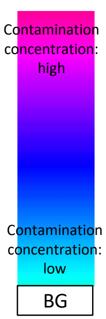
Measurement result of supply/exhaust valve

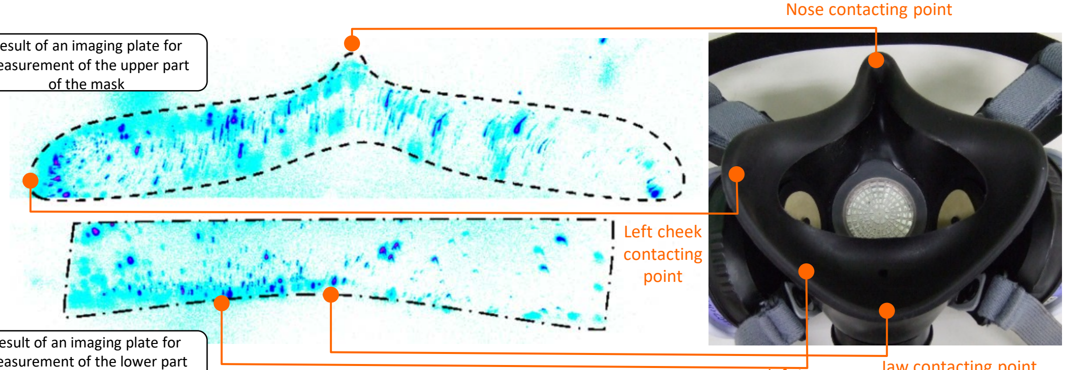
**Color chart**: result of smear measurement of mask surface and supply/exhaust valve

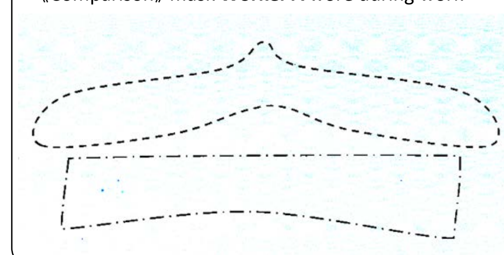
**Filter cartridge holder (inside)**
All the workers' masks were at BG level, and soundness of the filter was confirmed.

Measurement result of an imaging plate




《Comparison》mask **Worker A** wore during work



From the surface of the half-face mask Worker E was wearing during the work, highly concentrated contamination was detected at the points where the left cheek bone and lower left jaw contact. Also, the entire surface was widely contaminated, and intrusion into the inside of the half-face mask was confirmed of the contamination that had entered the face contacting points.

**Based on the interview with the workers and analyzation of the factors, it is presumed that Pu particles the workers got contact with at the time of the burst and contamination that had adhered to the face entered the gaps between the mask body and the face, and thus internal exposure was caused.**

# Contamination inspection of half-face mask（2）

## Measurement and analysis of half-face mask for investigating probable causes

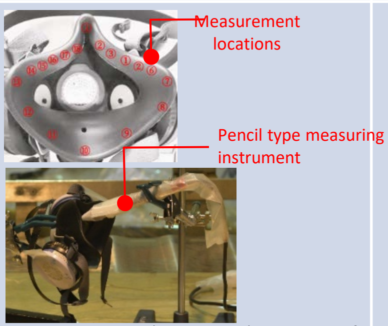
●Structure of the half-face mask

Front of the mask

Front of the mask (The filter cartridges are removed)

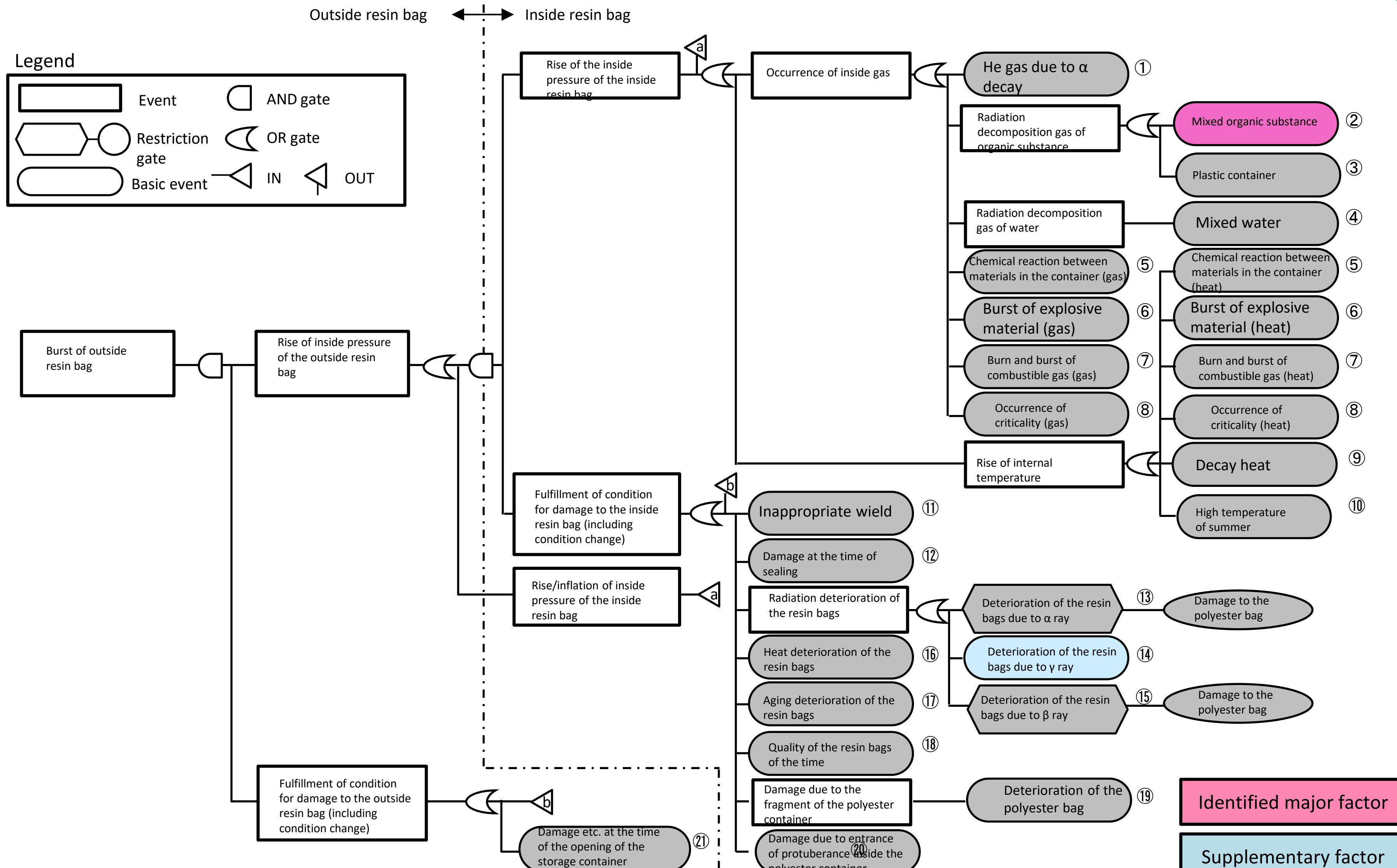
Contacting side

●Outline of the measurement

| Measurement items | α ray measurement using a pencil type measuring instrument of contamination of the mask at the part contacting with the face | α ray contamination distribution measurement of the mask (contacting side) using an imaging plate | α ray measurement of the smear sample collected from the filter cartridge holder (inside) | α ray measurement of the smear sample collected from the mask (contacting side) and the supply/exhaust valve |
|---|---|---|---|---|
| **Purpose** | Examination of the trace of contamination intrusion by measuring the distribution of relative intensity of the contamination of the mask at the contacting parts | Examination of the trace of contamination intrusion by measuring the detailed distribution of the contamination of the mask (contacting side) | Confirmation of the soundness of the filter | Examination of the trace of contamination intrusion by measuring the distribution of relative intensity of the contamination of the mask (contacting side) |
| **Method** | α ray direct measurement of contamination at 10 locations of the mask at the contacting parts using a pencil type measuring instrument | Measurement of location of contamination at the mask (contacting side) by α ray measurement using an imaging plate | Collection of smear sample of contamination of the both sides of filter cartridge holders (inside) and α ray measurement of the smear sample | Collection of smear sample of contamination of the seven locations of the mask (contacting side) and α ray measurement of the smear sample, and α ray measurement of the removed supply/exhaust valve |
| **Measurement situation** |   Measurement locations (18 locations) and image of the measurement |   Outline of the measurement |  Image of collecting smear sample |   Areas of collecting smear samples of the mask |
| **Result** | Through measurement of the masks Worker B, D and E wore during the work and Worker E's replaced mask, contamination was detected in all the masks<br>(〈Example〉The mask Worker E wearing during the work: refer to the page 8) | Contamination distribution was detected in the masks worn by the Workers other than A during the work and replaced mask<br>(〈Example〉The mask Worker E wearing during the work: refer to the page 8) | **All the Workers' masks were at the BG level, and the soundness of the filters were confirmed** | Smear：Through measurement of the masks Workers B, D and E wore during the work and Worker E's replaced mask, contamination was detected in all the masks<br>Supply/exhaust valve：Supply/exhaust valves of all the masks were measured and contamination was detected in the masks of Worker C, D and E.<br>(〈Example〉The mask Worker A wearing during the work: refer to the page 8) |

# Cause for the burst of the resin bags(1)　fault tree

## Result of observing/ analyzing the contents of the storage container was reflected




①～⑧: Factors relating to "internal gas occurrence", ⑤～⑩: Factors relating to "internal temperature increase", (⑤～⑧: Factors relating to "internal gas occurrence" and "internal temperature increase"), ⑪～㉑: Factors relating to "fulfillment of condition for damage to the inside resin bag (including condition change"

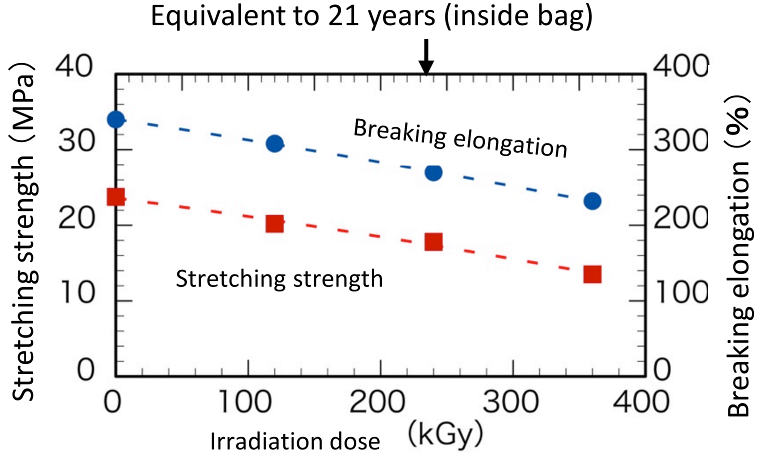
Identified major factor

Supplementary factor

Factors of which influence were evaluated as low

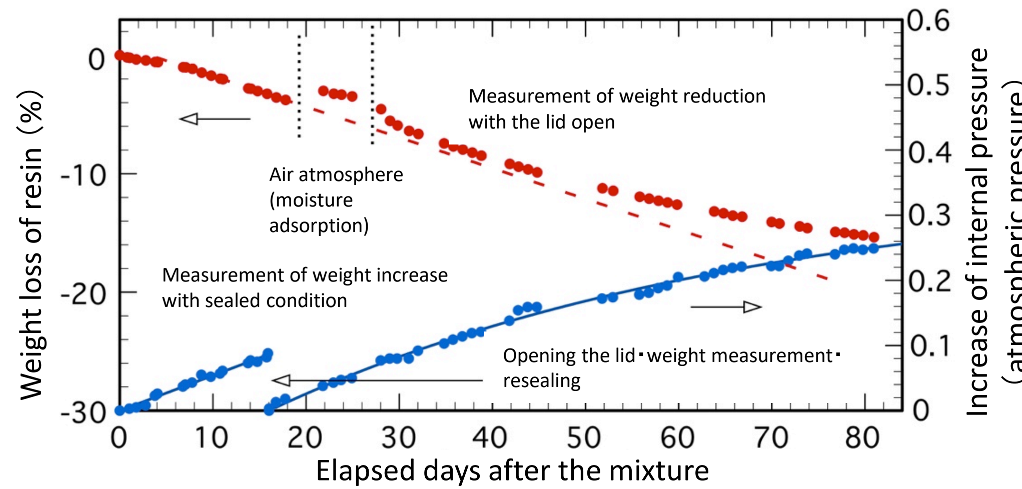
# Cause for the burst of the resin bags (2)　result of the verification test

## Deterioration of intensity by γ ray irradiation




・Stretching strength and breaking elongation of the resin bag deteriorates almost in proportion to the amount of irradiation dose.

## α ray decomposition of epoxy resin




- As a result of solidifying the mixture of Curium (Cm) with short half-life and epoxy resin and testing, the weight of the solidified mixture decreased due to α ray decomposition and gas was generated. The gas generation slowed down as the decomposition of resin proceeded. The result was reflected in the evaluation of generated amount of gas during storage period.

## Burst test of double resin bags

- In the test, pressure was applied to double resin bags contained in a metal container, and then the lid was opened. The process of burst and damage was observed. (Fig. 1)
- The damaged state of the resin bags deteriorated by γ ray irradiation was reproduced with the internal pressure at 2.5 atmospheric pressure or higher. (Fig. 2: Internal pressure was applied at 4 atmospheric pressure. The outside bag has opening at the top and the inside bag has one at the welded part.)

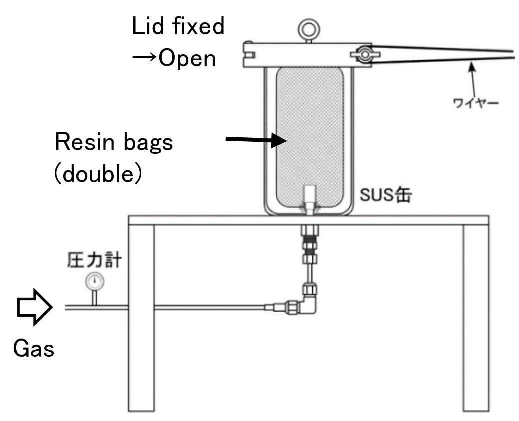



Fig. 1 Outline of the test

Fig.2 Resin bags after the test
(top: outside bag, bottom: inside bag)

# Cause for the burst of the resin bags (3) determination of the main factor of gas generation

## α ray decomposition of epoxy resin/polyester container/adsorption moisture

Based on the result of observation and analysis of the contents of the storage container and verification test, among the three probable causes for the rise of the internal pressure of the resin bags (α ray decomposition of epoxy resin/polyester container/adsorption moisture), gas generation due to α ray decomposition of mixed organic substance (epoxy resin) was determined to be the main factor.

Calculated value of gas generation due to α ray decomposition of epoxy resin
(21 years after replacement of packing)

| Pu isotopic composition | Average particle diameter of the powders in the resin*1 (μm) | Gas generation (L)*2 |
|---|---|---|
| Presumed average composition of mixed condition (without Am removal) | 10 | 79.5 |
| | 20 | 48.2 |
| | 35 | 26.2 |
| The same as above (with Am removal) | 35 | 22.4 |

Calculated value of gas generation due to α ray decomposition of polyester container
0.18 L

Calculated value of gas generation due to α ray decomposition of adsorption moisture
0.09 L

*1 Through observation with an electron microscope, two average particle diameters, 22 μmと36 μm, were confirmed. The particle diameters have substantial influence on gas generation. (α ray energy attenuation)

*2 Volume at an average condition (0℃, 1 atmospheric pressure)

# Cause for the burst of the resin bags (4) evaluation of shift in internal pressure of the bag

## Consideration on gas permeation of the bags and O-ring

### 【Main calculation conditions and gas generation】

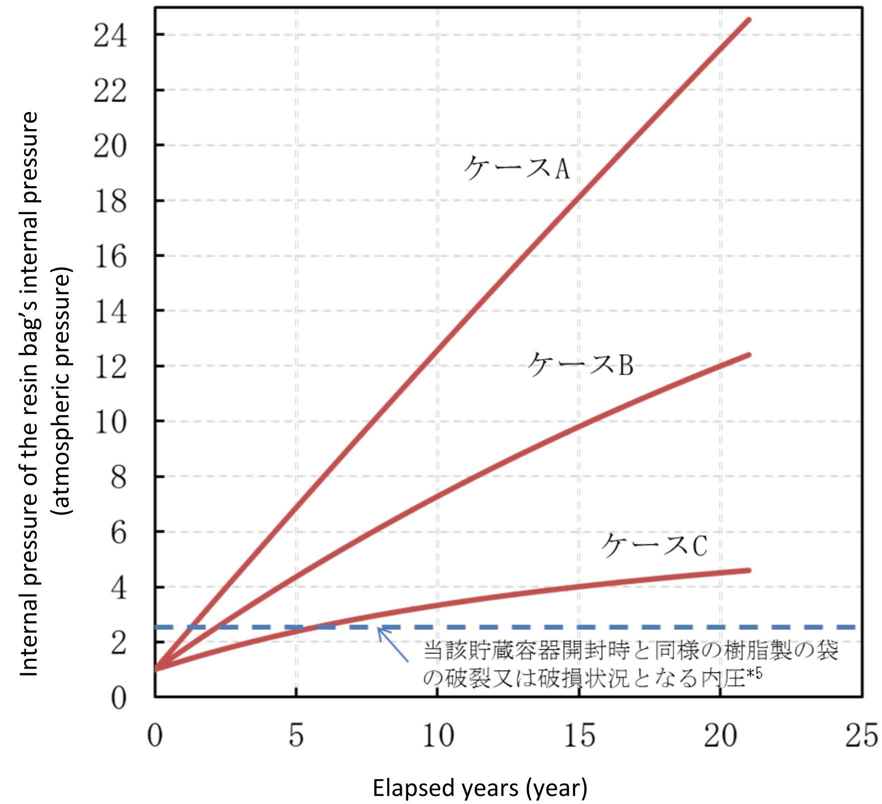
| Case | | A | B | C |
|---|---|---|---|---|
| Pu isotopic composition | | Average isotopic composition | | |
| G value of gas generation due to α ray[*1] | | 0.22 (based on the verification test) | | |
| Average particle diameter of the powders | | 10 μm | 20 μm | 35 μm |
| Resin bag | Gas permeability constant[*2] | $2.7 \times 10^{-10}$ (hydrogen)[a] | | |
| | | $3.0 \times 10^{-12}$ (methane)[a] | | |
| O-ring | Gas permeability constant[*2] | $1.4 \times 10^{-9}$ (hydrogen)[b] | | $3.9 \times 10^{-9}$ (hydrogen)[c] |
| | | $3.3 \times 10^{-10}$ (methane)[b] | | |
| | Leakage area[*3] | 1 mm width | 5 mm width | 5 mm width |
| Am removal[*4] | | No | No | No |
| Amount of gas generation in 21 years (25℃) | | 87.0 L | 52.8 L | 24.6 L |

【Data source】 a Technical Documents of Sumitomo Chemical Co., Ltd., http://www.sumitomo-chem.co.jp/acryl/03tech/b3_gas.html
T.D. Stark, et al., Geosynthetics International, 2005, 12, No. 1
b Technical Documents of Sakura Seal Co., Ltd., http://www.sakura-seal.co.jp/category/1981184.html
c Technical Documents of Packing Land Co., Ltd., https://www.packing.co.jp/GOMU/kitaitoukasei1.htm

### 【Calculation result】

- While evaluation values vary widely depending on the calculation condition, due to the generated gas, the internal pressure exceeds the breaking pressure of the resin bags (within the range of pressure that can break the bags)

### 【Calculation result of the shift of the bag's internal pressure】




*1 Number of generated gas molecule per unit absorbed energy (100 eV)
*2 Unit: cc/cm²/s/10mmHg. Gas permeability constant of O-ring differs depending on the source to a certain extent, and the difference regarding the gas permeability constant of the O-ring in this case is three times.
3* This means the contact area of the O-ring and sealed gas. The larger this area, the greater the gas permeation rate.
*4 Whether or not Pu purification (removal of Am, impurity) was conducted before sealing the container.
*5 In the burst test, the internal pressure that causes burst of or damage to a resin bag in the similar condition with the one in the storage container when it was opened was 2.5 atmospheric pressure or higher. It is considered that there is a margin of error due to similar condition etc., and burst is considered to occur at 2.5 atmospheric pressure or higher. This burst pressure is equivalent to the condition which simulates the deterioration of the bag through γ ray irradiation for 21 years.

# Result of analyzing the estimated factors causing intake of radioactive materials

## Result of analyzing factors concerning estimated exposure route

**Factors were identified with respect to each of the stages where exposure was suspected, and based on the result of interview, investigation of contamination situation, etc. possibility was determined.**

| Event | Cause for the intake of radioactive materials | | Investigation item | Investigation result |
|---|---|---|---|---|
| Internal exposure occurred in the circumstance where half-face masks were worn. | Intake of radioactive materials at the time of the resin bags' burst | Inhale at the time of the burst | Permeation of radioactive materials through the mask filter due to the concentration rise at the time of the burst | Not probable, because it was confirmed that as a result of the investigation of the half-face mask there was not permeation of radioactive materials through the filter. |
| | | | Inhale attributable to the lowered adhesion at the time of the burst | Worker A:× B:○ C:× D:△ E:◎ |
| | Intake of radioactive materials in Room No. 108 | Reduction in adhesion of the half-face mask | Inhale attributable to the lowered adhesion by conversation etc. | Worker A:△ B:○ C:○ D:○ E:◎ |
| | | | Inhale attributable to the lowered adhesion caused by perspiration | Worker A:△ B:○ C:○ D:○ E:◎ |
| | | | Oral intake associated with intrusion of contamination at the head etc. due to dripping sweat | Possibility of oral intake by drinking sweat having intruded is low, because the temperature of the room was not so high as sweat was dropping. (Worker A～E : × ) |
| | Intake of radioactive materials at the time of removal of clothes and decontamination | | Oral intake occurring at the time of changing half-face mask etc. | Worker A:× B:△ C:△ D:△ E:△ |
| | | | Oral intake at the time of body decontamination | Possibility of oral intake is low, because the Workers recognized the contamination at their head and face and paid attention not to take in contaminated liquid. ( Worker A～E: × ) |
| | | | Oral intake at the time of nasal cavity decontamination | Possibility of oral intake is low, because the Workers recognized the contamination at their head and face and paid attention not to take in contaminated liquid. ( Worker A～E: × ) |

○ : Factor evaluated as highly possible as exposure route
△ : Factor evaluated as possible as exposure route
× : Factor evaluated as unlikely as exposure route
◎ : Significant exposure route among factors marked with ○

**・It is highly possible that due to the reduction in adhesion of half-face mask caused by the burst of the bags, conversation, perspiration, etc., radioactive materials such as Pu that had adhered to the face etc. entered inside the mask through the part of the mask contacting with the face, and thus they took in radioactive materials by inhale.**

**・It is possible that the Workers took in radioactive materials such as Pu that had adhered to the head and face when changing the half-face mask at the time of removal of clothes.**

# Five problems and points needing improvement based on the operational safety program

Points needing improvement were picked out based on the requirements of the operational safety program regarding past storage of the fuel (in 1991) and inspection of the storage container (in 1996), recent safety activities concerning planning and implementing the improvement work, and the response after the occurrence of the incident that caused the five problematic events that were cleared through the cause analysis.

## 【Five problematic events and their relations with the operational safety program】

**(1)Epoxy resin was not removed at the time of encapsulation, and the information was not turned over**

→ A manual should have been made even though the operational safety program at the time did not provide specific requirements on it. Today, the subordinate rules are provided based on the "preparation of the manuals". However, as there is no provision on takeover of information, this manual needs to be improved.

→ The requirement of the subordinate rules concerning storage, "paying attention to the rise in gas pressure caused by radiation decomposition", was not considered. This infringes the provision on "storage of nuclear fuel material" in the then and present operational safety programs.

**(2)Technical information was not made use of for the storage of nuclear fuel material**

→ Preventive measures should have been included in the manual through collection of technical information even though the operational safety program at the time did not provide specific requirements on preventive measures. Currently, "preventive measures" and the subordinate rules have provisions on it, but as the technical information was eventually not reflected, the procedures need to be improved.

**(3)The possibility of the burst of the resin bags and contamination was not assumed at the time of planning the work**

→ The work schedule was developed based on the information at the time of planning, but the information was not correct and as a result, the procedures of "consideration of the place of work, detailed work and radiation protector" need to be improved.

→ Due to reasons such as failure to reflect information of the Nuclear Fuel Cycle Engineering Laboratories, the procedures of "preventive measures" should have been improved.

**(4)Work was continued without noticing the gas generation at the time of opening the lid of the storage container**

→ As the hold point was not set, contamination test of the storage container was conducted at the decision of the Workers. As a result, the work could not been suspended and the work schedule could not been reviewed, and therefore when "planning radiation work", procedures for "consideration of the work contents" need to be improved.

**(5)The Workers inhaled and took in nuclear fuel material scattered in the accident**

→ While improvement is necessary at the planning stage, there is a room for improvement regarding "removal of contamination" as nuclear fuel material entered inside the mask due to the failure to remove the contamination near the face immediately after the occurrence of the accident.

→ The subordinate rules provide implementation of inspection and maintenance of protection equipment and material in advance, but GH material was not covered. GH was built for the exit of the Workers, and therefore there is a room for improvement regarding the provisions concerning "emergency activities".

## 【Related provision】

**Part 7 Article 2 (preparation of the manuals)**

The Director shall prepare the manuals concerning the matters below.

(1) matters concerning management of the use or operation
(2) matters concerning the maintenance
(3) matters concerning management of nuclear fuel material
(4) matters concerning measures to be taken in an emergency

**Part 7 Article 19 (storage of nuclear fuel material)**

When storing nuclear fuel material, the General Manager of the Alpha-Gamma Section shall conduct it in the storage facility designated in the Appendix 9, (the rest omitted)

**Part 1 Article 18 (preventive measures)**

2. The Director of the Safety and Nuclear Security Administration Department, the Director Generals and the Directors shall take necessary measures in order to prevent the occurrence of potential non-conformity.

**Part 2 Article 16 (radiation work schedule)**

2. The General Manager shall consider the matters referred to in the items below and take safety measures.

(1) Place and time of work
(2) Details of work
(3) Use of personal dosimeters and radiation protectors
(4) Measures to lower the dose
(5) Dose associated with work

**Part 2 Article 19-2 (measures to be taken in the case abnormality is confirmed in the measurement of radiation workers etc.)**

4. The General Manager shall have contamination removed in the case of skin contamination, (the rest omitted)

**Part 1 Article 28 (activities in an emergency)**

The on-site emergency headquarters shall carry out preventive activities concerning life-saving, removal of causes for the state of emergency and prevention of accident expansion.

# Major measures to be taken (outline)

Twelve causes of the five problematic events were picked out. Measures to be taken for the grave ones are shown below. Also measures for the problems having emerged after the accident were explored.

【Grave ones of the causes for the five problematic events】

- When encapsulating in 1991, samples used for X-ray diffraction measurement (organic substance) was stored without oxidation heating.
  The provision in the "radiation safety handling manual" setting up that "attention should be paid to the rise in gas pressure due to radiation decomposition" was not considered.
- When the packaging was redone in 1996, measures such as change to a metal container was not taken and such information was not turned over.
  In 1996, damage to the polyester container and inflation of the resin bags were confirmed.

【Measures to be taken】

A) Improvement of the standards on storage and management for a stable storage of nuclear fuel material

B) Organization and clarification of the necessary information concerning storage of nuclear fuel material and improvement of method for long-term management of record

C) Ensuring training
Training on the causes and measures for this accident

- Detailed work schedule concerning contamination prevention was not mapped out in the work planning stage
  This is a result of an assumption that "it is stored in a stable condition".

D) Reviewing process of making work schedules
Formulation of the basic rules taking risk management into consideration in the event of handling unidentified material or in the situation where safety is not confirmed

- Abnormality could not been recognized during the work (opening the storage container) and the work could not be suspended
  Signs of abnormality such as unusual uplift of the lid and noise of the gas inside the container coming out were overlooked.

E) Clarification of hold point
Including suspension of work when signs of abnormality were confirmed

【Problems having emerged after the accident】

- In the work done after the accident, problem was found in the management of the cleansing facility in the controlled area.
- With regard to the work done after the accident, the fact that body contamination remained is a problem.

【Measures to be taken】

F) Inspection of the cleansing facility for decontamination and review of the management rule

G) Clarification of procedures concerning body decontamination method and measurement method

# Through inspection concerning storage and handling of nuclear fuel material and application of lessons learnt from this incident to other places (1)

## Confirmed situations after the submission of the legal report (second report) (1)

### 1. Identification by throughout inspection of storage containers etc. potential to cause the similar incident

Storage containers and safekeeping containers of nuclear fuel material in the JAEA were inspected and those potential to cause the similar incident by mixture of plutonium and organic substance were identified.

＜Summary of the legal report (second report)＞

① In total 13,878 units of the storage containers etc. were inspected.
（Excluding those at PFRF and Alpha-Gamma Facility of Oarai Research and Development Center）

② Among the above 13,878 units, 349 units containing plutonium were suspected of mixture with organic substance or encapsulation in resin bags or containers, and not had been inspected inside.

＜Additional inspection result of Oarai Center＞

③ By adding the inspection result of Oarai Center, the total number of units was 14,770, and the number of units with potential to cause the similar incident was 470.

### 2. Storage situation etc. of the identified units (470)

① Forty five containers at PFRF in the similar type with the one of the incident are labeled and kept safely in a designated storage. Records of these containers have been checked, and necessary measures will be taken based on the investigation into the causes and prevention measures.

② Among the storage containers etc. at facilities other than PFRF, 290 units kept in a cell or a glovebox were checked and evaluated from the perspective of risk in the event of burst, and it was confirmed that they are kept safety in the current situation.

③ Among the storage containers etc. at facilities other than PFRF, situation below was confirmed with regard to 99 units.

i) Nineteen units are free from risk of gas generation (nuclear fuel material and organic substance do not contact with each other).

ii) With regard to 41 units, gas generation was confirmed in periodic inspection etc. (the storage container etc. was encapsulated in a resin bag etc.)

iii) With regard to 39 units, because of low plutonium enrichment pellet, risk of gas generation is low.

④ Contents of 36 units are standard solution (marketed products bottled in ampoules etc.) including tiny amount of plutonium (lower than several tens μg).

## Confirmed situations after the submission of the legal report (second report) (2)

### 3. Additional investigation

① With regard to the storage containers etc. including α-ray emitting nuclides and uranium isotope U-233 (about six grams in the entire JAEA) other than nuclear fuel material, which were not subject to the throughout inspection as the handling amount was very small, check and evaluation were conducted and it was confirmed that they are kept safely in the current situation.

### 4. Application of lessons learnt from this incident to other places

① Current situation of the decontamination facilities, greenhouses and curing materials at respective research sites was checked. As the result, it turned out that in some cases the rules did not provide on the inspection of the decontamination facilities and setting on greenhouses. Also it was confirmed that emergency drills using these facilities that assumed the serious body contamination such as that occurred in the accident at PFRF were not carried out in many of the research sites. The review of the rules and implementation of the drills will be moved forward with in a structured way.

### 5. Measures to be taken

① With regard to matters concerning safe storage and keeping of nuclear fuel material such as stabilization treatment of nuclear fuel material and matters concerning prevention of interior exposure such as prompt exit from the incident site in the event of occurrence of serious body contamination, lessons learnt from this incident will be applied to respective research sites of the JAEA for improvement.

② The management standard (guideline) concerning storage and safekeeping of nuclear fuel material to prevent contamination caused by gas generation and burst will be developed, and improvement of management of nuclear fuel material in the JAEA will be achieved.

③ Correction measures for improvement will be proceeded with at Oarai Research and Development Center with regard to the organizational factors identified through the fundamental cause analysis of this accident, and based on the result, lessons learnt will be applied throughout the JAEA.

# Conclusion

- Efforts have been made after the occurrence of the incident for the investigation into the causes of the burst of the resin bags, evaluation of the workers exposure and restoration of the incident site.

- As the factors leading to the burst of the resin bags were determined, factors leading to the intake of nuclear material were assumed, preventive measures were formulated by analyzing the factors leading to the occurrence of the accident and restoration of the incident site was almost completed, the situation was compiled and reported as the third report.

- With regard to the preventive measures and application of lessons learnt to other places, correction measures will be implemented based on the result of the investigation into the causes as part of the non-conformity management.

- As the restoration of the incident site, contamination test of inside and outside of the hood of Room No. 108, decontamination and fixation of contamination have been conducted. Currently, contamination test and decontamination of Room No. 108 are ongoing. The designation of the entrance restriction area will be lifted by the middle of October 2017.

- The JAEA will take seriously this incident, and as an R&D institute handling nuclear fuel material, strive to ensure safety humbly without being conceited for all the previous achievements by thorough safety activities with profound attention that takes risks into consideration.