July 21, 2017

To Nuclear Regulation Authority

Toshio Kodama
President
Japan Atomic Energy Agency

Report on the contamination at Plutonium Fuel Research Facility (the second report)

With regard to the contamination at Plutonium Fuel Research Facility which we had reported on June 19, 2017, we formulated plans for restoration of the site of the occurrence of the event, investigation into the causes, etc. and have made effort for the investigation into the causes for the burst of the resin bags, evaluation of the workers' exposure and restoration of the site of the occurrence of the event based on the Article 62–3 of Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors. Recently, with regard to the investigation into the causes for the burst of the resin bags, probable causes were narrowed down, with regard to the evaluation of the workers' exposure, the result of the evaluation of the effective doses of external and internal exposure, and with regard to the restoration of the site of the occurrence of the event, the storage container in the hood was transferred to a glove box, and therefore, the progress is compiled and reported as the interim report as described in the Attached sheets.

The causes and measures to be taken will be subsequently reported based on the investigation that will continuously be made.

Attached sheets: Report on failure, etc. of a nuclear facility

Attached sheets

Report on failure, etc. of a nuclear facility

July 21, 2017

Japan Atomic Energy Agency

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| Title | Contamination at Plutonium Fuel Research Facility (PFRF) (second report) |
| Date and time of the occurrence of the event | Date and time: Tuesday, June 6, 2017; around 11:15<br>Date and time of decision: Wednesday, June 7, 2017; 13:00 |
| Place of the occurrence of the event | Analyzing room of PFRF (in a controlled area) |
| Name of the nuclear facility where the event occurred | Plutonium Fuel Research Facility<br>Oarai Research and Development Center (north zone)<br>Japan Atomic Energy Agency |
| Situation of the event | Around 11:15, June 6, 2017, in the hood (H-1) of the analyzing room of PFRF (hereinafter "Room No. 108"), during the inspection work of a storage container of plutonium and enriched uranium that contains nuclear fuel materials (hereinafter "storage container"), vinyl bags in the storage container encapsulating a container of nuclear fuel materials (hereinafter "resin bags") burst. As a result of a contamination check conducted in the Room No. 108 by the workers using surface contamination test meter of $\alpha$-ray, all the five workers were confirmed to be contaminated.<br>Below is the situation of the occurrence of the event revealed based on the interview with the workers.<br>When one of the workers was loosening the remaining two bolt of the storage container, after having removed four among the six bolts diagonally, they heard hiss of the inside pressure of the storage container leaking out. They collected samples of the smear of the entire circumference of the gap between the lid and storage container, and confirmed that there was no contamination. As leakage of the air from inside happened before when the room air was relatively high, and it was confirmed that there was no contamination by the smear of the entire circumference, they |

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| | decided to continue work. When the worker removed the remaining two bolts, holding the lid with the other hand, the resin bags burst. The lid was left in the hood then. The worker felt wind pressure at the abdomen, and all the workers heard the bang. Misty leakage from the inside of the storage container was confirmed. Though wearing the mask, they confirmed there was not abnormal odor. Though wearing rubber gloves, they touched the storage container, and confirmed that there was not rise of temperature.<br>After the occurrence of the event, for preventing the expansion of the contamination, a greenhouse was set at the entrance of Room No. 108, at the side of the corridor, and the gaps of the emergency exit of Room No. 108 to the outside of the building was sealed from the outside.<br>The workers' exit from Room No, 108 to the greenhouse was started at 14:30, June 6, 2017. By the body contamination test conducted in the greenhouse when they left the room, contamination was confirmed in the special work clothes, etc. of the five workers (more than 322 $Bq/cm^2$ ($\alpha$-ray) at a maximum). They carefully replaced the half-face masks and then undressed the special work clothes. Skin contamination and nasal cavity contamination (24 $Bq/cm^2$ ($\alpha$-ray) at a maximum) were confirmed respectively among four and three of the workers. Based on these result of body contamination test, Room No. 108 was designated as restriction area at 16:27.<br>The workers with skin contamination conducted decontamination using neutral detergent, solid and liquid soap, shampoo, nasal irrigation kit, etc. in the shower room dedicated for decontamination in the controlled area. If the contamination test conducted by the decontamination assistant detected contamination, the decontamination was repeated with the cooperation of the decontamination assistant. When contamination was not detected any more, the workers received the final confirmation test by the body survey conducted by the radiation control staff, and left the controlled area confirming that the level is lower than the detection limit (0.013 $Bq/cm^2$ ($\alpha$-ray)). |

Before using the shower room for decontamination, the availability of the shower was confirmed. However, when the first worker used the shower for one or two minutes, the flow rate dropped. By drawing industrial water (filtered water) from the machine room of PFRF, decontamination using water resumed.

The result of the lung monitor measurement conducted at Nuclear Fuel Cycle Engineering Laboratories to gain the information for the judgement concerning urgent medical treatment (injection of chelate agent etc.) was the evaluation of $2.2 \times 10$ Bq$^4$ and $2.2\times10$ Bq$^2$, respectively, with regard to Pu-239 and Am-241 at a maximum. Therefore, in cooperation of the National Institute of Radiological Science (hereinafter "NIRS"), injection of chelating agent was carried out aiming to prompt egestion of ingested Pu etc.

As based on the fact that $2.2\times10$ Bq$^4$ and $2.2\times10$ Bq$^2$ were confirmed, respectively, with regard to Pu-239 and Am-241 at a maximum through the measurement of the five workers using lung monitor, their levels of exposure exceeded or might exceed 5 mSv, the level at which report is required in the event of unplanned exposure of radiation workers entering a controlled area, and also there was a possibility that the surface density of the floor etc. of the Room No. 108 exceeded the level of the restriction area designated in the operational safety program (alpha nuclide: 4 Bq/cm$^2$), it was judged at 13:27, June 7, 2017 that this accident is an event of which report is required by laws and regulations based on the provision of the Article 62 – 3 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors. The report on the above was made to the Nuclear Regulation Authority at 13:27.

The surface density of the Room No. 108 was confirmed to be 55 Bq/cm$^2$ ($\alpha$-ray) and 3.1 Bq/cm$^2$ ($\beta$-ray ($\gamma$-ray)) at a maximum by the measurement of the floor carried out on June 7. 2017. Also, The maximum dose equivalent of the Room No. 108 was 2$\mu$Sv/h, and particles assumed to have scattered from the storage container were confirmed in front of the hood (H-1).

On June 7, 2017, the five workers were transferred to the

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| | NIRS and underwent treatment including decontamination of the body surface and measurement using lung monitor. JAEA received a report from the NIRS on June 12, 2017 to the effect that as a result of the measurement using lung monitor, no obvious energy peak was confirmed with regard to plutonium and that there were people with whom energy peak was confirmed with regard to americium based on the measurement data, but the level was declining.<br>After the occurrence of the event, the storage container was covered with the lid and placed in the hood (H-1) which was shut with sliding glass doors. Then, as part of the restoration work of the site, the storage container covered with the lid was removed from the hood (H-1) and transferred from Room No. 108 to the glove box in the adjustment room (Room No. 101) on July 20, 2017. As the measures for the full-scale site restoration, contamination test and decontamination of the hood (H-1) and Room No. 108 will be conducted.(for the details refer to Attachments)<br>(for the details refer to Attachments) |
| Cause of the accident | As effort for the investigation into the causes, the factors leading to the burst of the resin bags are presumed based on the interview with the workers, past records, etc., and investigation and analysis of the storage container, contents and scattered substance, and verification test relating to burst phenomenon of resin bags and radiation decomposition of resin are conducted.<br>The cause for the burst of the resin bags was presumed to be "inside gas generation", that is, the gas generation due to the interaction between $\alpha$ ray from Pu in the container and "mixed organic substance (epoxy resin)", "polyester container" and "mixed water". To determine the cause including the rate of contribution of the presumed causes to the gas generation, confirmation of the layout of the contents and clarification of the kind of nuclear fuel material fixed to epoxy resin, amount of the epoxy resin, particle diameter, amount distribution, etc. of the powder nuclear fuel material are necessary. Subsequently, the event progress scenario is explored after conducting analysis etc., and the causes for the burst of the resin bags will be determined by the end of August, |

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| | 2017.<br>To narrow down the direct factors leading to the occurrence of the accident, in addition to the analysis of the factors of the burst of the resin bags and evaluation of exposure, analysis and evaluation of the situation of the encapsulation, storage and safekeeping of the nuclear fuel material in the storage container, and succession of responsibility at the time when the two precedent organizations of the JAEA united are necessary. Probable items are already clarified at the moment. Subsequently, investigation of the relevant materials and interview with concerned people will be moved forward with, and the main factors will be clarified and measures will be formulated by the end of September 2017.<br>(for the details refer to Attachments) |
| Kind of safety devices and the state of their operation | No device. |
| Impact of radiation | At the time of the occurrence of the event, the ventilation system of PFRF continued operation and appropriately kept the negative pressure in the controlled area, and also the values indicated by the monitoring posts and ventilation dust monitors of PFRF were within the normal fluctuation range. Accordingly, there was no impact on the environment by this event.<br>After the occurrence of the event, the ventilation system of PFRF keeps operation and continues to maintain appropriately the negative pressure in the controlled area. Also, the values indicated by the monitoring posts, ventilation dust monitor and Pu dust monitor of PFRF shift within the normal fluctuation range, and there is no impact on the outside of the facility.<br>(for the details refer to Attachments) |
| Workers' exposure | With regard to the result of the evaluation of the workers' exposure, the all the workers' effective doses due to the external exposure were lower than the record level (0.1 mSv), and the effective doses (committed effective dose) due to the internal exposure were, according to the NIRS's announcement, within the |

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| | range 100 mSv and higher and lower than 200 mSv (one person), 10 mSv and higher and lower than 50 sSv ( two people), and lower than 10 mSv ( two people).<br>(for the details refer to Attachments) |
| Other damage | No. |
| Date and time of restoration | With regard to the restoration of the site of the occurrence of the event, a plan based on (i) approach for securing safety and (ii) approach for the full scale restoration was formulated, and efforts are being made.<br>Measures planned for (i) approach for securing safety, which are securing route to the hood (H-1), fixation of the lid of the storage container in the hood (H-1), moving out the storage container from the hood (H-1) and transfer it from Room NO. 108 to the glove box (123-D) of the adjustment room (Room No. 101), completed on July 20, 2017. As (ii) approach for the full scale restoration, contamination test and decontamination of the food (H-1) and Room No. 108 are planned. The restoration work is aimed to be completed by the end of September, with paying attention to prevent workers' exposure and expansion of contamination.<br>(for the details refer to Attachments) |
| Measures to prevent similar accidents | Efforts for the investigation into the causes are currently being made, and based on the clarified causes, recurrence prevention measures will be formulated, disseminated and shared throughout the organization. |

Attachment

# Report on

# Contamination at Plutonium Fuel Research Facility

July 2017

Japan Atomic Energy Agency

1. Title: Contamination at Plutonium Fuel Research Facility of Oarai Research and Development Center

2. Date and time of the occurrence of the event:

Date and time: Tuesday, June 6, 2017, around 11:15

Date and time of decision: Wednesday, June 7, 2017, 13:00

- Judgement that the workers' exposure levels exceed or may exceed the 5 mSv, the level at which report is required
- Possibility of the surface density of the floor, etc. of the analyzing room of PFRF (mentioned below) exceeding the level of the restriction area designated in the operational safety program ($\alpha$ nuclide: 4 Bq/cm$^2$)

3. Place of the occurrence of the event:

Plutonium Fuel Research Facility

Oarai Research and Development Center (north zone)

Japan Atomic Energy Agency

4. Situation of occurrence of the event

4.1 Background to the occurrence of the event

Research concerning nuclear fuel (carbide and nitride fuel, etc.) at PFRF (Fig. 4.1.1 and Attachment 4.1.1) started in May 1977. The storage container for plutonium and enriched uranium (hereinafter "storage container", Fig. 4.1.2) of the occurrence of this event contained samples used for X-ray diffraction measurement in October 1991.

In response to the requirement from the Nuclear Regulation Authority (NRA) to correct the long-term storage of nuclear fuel material using glove boxes ("Points confirmed in the safety inspection concerning long-term storage using glove box etc. of nuclear fuel materials in use facilities" dated February 15, 2017), the correction work (work to reposit nuclear fuel materials temporally stored in glove boxes in the storage facility etc., hereinafter "correction work") was being conducted. The planning and implementation of this correction work were based on the Nuclear Fuel Material Use Change Permission Application of Oarai Research and Development Center (North Zone) (hereinafter "Use Permission Application"), Operational Safety Programs of Nuclear Fuel Material Using Facility, etc., Oarai Research and Development Center (North Zone) (hereinafter "Operational Safety Programs"), Physical Protection Program, Accounting Provisions, Quality Assurance Plan and relevant programs and rules and their subordinate rules related to Industrial Safety and Health Act and other relevant laws and regulations (Fig. 4.1.3 and Fig. 4.1.4). As part of the correction work, inspection etc. of the storage container was being conducted with a hood (H-1) based on the Use Permission Application. A container encapsulated in resin bags (The work does not involve opening the bags) was stored in the storage container. The position of the inspection etc. work is shown in Attachment 4.1.2. During the work, necessary protection following the radiation work slip etc. which examined safety measures etc. (special work cloths, special work cap, cotton gloves, rubber gloves (double), half-face mask, shoe cover, RI work shoes, arm cover for those who work with a hood: Fig. 4.1.5) were worn. The situation of inspection work is shown in Attachment 4.1.3.

Among 80 units of storage containers, inspection etc. of 30 units had completed by the time of the occurrence of the event (Inspection of 28 units were implemented by the previous day. On the day of the occurrence of the event, which is June 6., inspection of four units including detailed check of vacant space of the two units of which inspection etc. had completed already had been implemented by the time of the occurrence of the event.), and the event occurred during the inspection etc. of the 31st unit.

## 4.2 Situation at the time of the occurrence of the event

### (1) The event

Around 11:15, June 6, 2017, in the hood (H-1) (Fig. 4.2.2) of an analyzing room in PFRF (in a controlled area) (hereinafter "Room No. 108" Fig. 4.2.1), resin bags encapsulating a container of nuclear fuel material in the storage container burst during the inspection work of the storage container. As a result of a contamination check conducted by the worker in the Room No. 108 using surface contamination test meter of $\alpha$-ray, all the five workers were confirmed to be contaminated. The location of the five workers (Worker A～E) at the time when the event occurred is indicated in Fig. 4.2.1.

When the Worker E slowly removed the four of the six bolts fastening the container diagonally and then loosened the other two, he heard hiss like the one made when gas comes out. He collected the smear from the lid and all the circumferences of the gaps and confirmed that there was no contamination. Because in the past air came out in the situation where the room temperature was high, and no smear contamination was confirmed, the Worker E decided to continue work. When the Worker E removed the remaining two bolts holding the lid with one hand, the resin bags burst. Then he put the lid in the hood. At the time of the burst, the Worker E sensed wind pressure in the stomach, and all the other workers heard the sound of burst. Mist-like leakage was observed coming from the burst container. Though wearing a mask, the Worker E confirmed no abnormal odor. Though wearing rubber gloves, he touched the metal container and confirmed no rise of temperature.

It became clear by the interview with the workers that they shot photos of the storage container in the hood before and after the event, the recording media of the digital camera (SD card) was taken from the controlled area on June 14, 2017, and the image was confirmed (Attachment 4.2.2)

(2) Situation of radiation and contamination at the site of the event

After the occurrence of the event, in order to prevent the expansion of the contamination, a greenhouse[1] (Fig. 4.2.4) was set at the entrance of the Room No. 108 to the side of the corridor and the gaps at the emergency exit of the Room No. 108 to outside of the building were sealed up from outside. The sealed place is shown in Fig. 4.2.5. The values indicated by the monitoring posts and the ventilation dust monitor of PFRF stayed unchanged before and after the occurrence of the event. The trend of the values indicated by the monitoring post nearest to PFRF (P-2) and the ventilation dust monitor of PFRF is shown in Fig. 4.2.6 and 4.2.7. With regard to the concentration of radioactive materials in the air of the site of occurrence, the value indicated by the dust monitor No.2 (inside the Room No. 108) (hereinafter "Pu dust monitor") at the time of the occurrence of the event was within the normal fluctuation range. At 13:55, June 6, 2017, the value indicated by the monitor rose to $5\times10^{-8}$ Bq/cm$^3$ (average concentration of one week)[2], but there was no rise in the value subsequently. This value is lower by one digit than the air concentration limit of Pu-239 designated by the law ($7\times10^{-7}$ Bq/cm$^3$). As a result of replacement of the dust filter of the Pu duct monitor, decline of the value to within the normal fluctuation range was confirmed. Since then the value has been within the normal fluctuation range. The trend of the values indicated by the Pu dust monitor is shown in Fig. 4.2.8. Based on the result of the body contamination test conducted when the workers moved from the Room No. 108 to the greenhouse, the Room No. 108 was designated as a restriction area at 16:27, June 16, 2027.

With regard to the surface concentration of the Room No. 108, levels of contamination of 55 Bq/cm$^2$ ($\alpha$ ray) and 3.1 Bq/cm$^2$ ($\beta(\gamma)$ ray) at a maximum (Fig. 4.2.9) were confirmed at 18:55 by the measurement of the floor conducted June 7, 2017. It was confirmed that there is no contamination in the corridor in front of the Room No. 108, which is in a controlled area, and the outside of the emergency exit of the Room No.

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[1] The greenhouse is a structure built at the work area in association with decontamination work for the purpose of preventing expansion of contamination. The frame of pipes are covered with plastic sheets or, as necessary, flame resistant sheets.

[2] Concentration limit in the air designated by laws and regulations (Pu-239): $7\times10^{-7}$ Bq/cm$^3$

108, which is exterior of the building.

The placement of radiation control monitors at PFRF, the system diagram of ventilation duct monitor and room Pu dust monitor, and the ventilation system at PFRF are shown, respectively, in Fig. 4.2.11, 4.2.12 and 4.2.13.

Photos of the hood (H-1) after the occurrence of the event (taken on June 7, 2017) are shown in Fig. 4.2.14. Particles assumed to have scattered from the storage container were confirmed on the floor in front of the hood (H-1). Immediately after the event, the storage container was covered with a lid and placed in the hood (H-1) shut with sliding glass doors. The storage container was monitored with TV camera through the glass doors of the hood (H-1). (Fig. 4.2.15)

(3) Situation of the workers' contamination and exposure

At 14:30, June 6, 2017, the workers started to exit the Room No. 108 to the greenhouse. By the body contamination test conducted in the greenhouse when they left the room, contamination was confirmed in the special work clothes, etc. of the five workers (more than 322 Bq/cm$^2$ ($\alpha$-ray) at a maximum), and undressing of the special cloth etc. was implemented, after carefully changing the half-face masks. Skin contamination and nasal cavity contamination were confirmed respectively among four and three of the workers (24 Bq/cm$^2$ ($\alpha$-ray) at a maximum, Table 4.2.1 and Attachment 4.2.3). The workers with skin contamination carried out decontamination in the shower room in the controlled area. The decontamination was conducted using neutral detergent, solid and liquid soap, shampoo, nose cleaning kit, etc. Decontamination was repeated if contamination was detected by the contamination check that a decontamination assistant conducted. When contamination was not detected any more, they received the final confirmation check by the body survey conducted by a stuff member of radiation control, and exited the controlled area confirming the level was lower than the detection limit (0.013 Bq/cm$^2$ ($\alpha$-ray) (Attachment 4.2.4).

Before decontamination in the shower room, the shower's availability was confirmed, but in one to two minutes after the first worker started decontamination, the flow of water dropped. Industrial water was drawn from the machine room of PFRF with a hose, and decontamination was restarted (Attachment 4.2.4). With regard to the introduction of hose, the door at the border of the controlled area was kept open, but, as the changing room where there is the shower room is connected to the exhaust system of PFRF, the air flows toward the inside of the controlled area even if the door is kept open. It is regularly confirmed that the air flows to the inside of the controlled area with the door at the border of the controlled area open. The containment function was confirmed to have been maintained by measuring the wind direction using a smoke tester, recreating the situation of the door at the time of using the hose later (Attachment 4.2.4).

With regard to the shower, the decompression valve was replaced on June 29, 2017, and it is returned to the state to supply water appropriately.

Three of the five workers wore pocket dosimeters, which are auxiliary dosimeters, and the values indicated by them were 2 μSv (Worker B), 3 μSv (Worker D) and 60 μSv (Worker E). The five workers were transferred to Nuclear Fuel Cycle Engineering Laboratories, and as a result of the measurement conducted there using lung monitor in order to contribute to the decision concerning medical treatment that should be administered urgently (injection of chelating agent: Ca-DTPA[3] etc.), $2.2 \times 10$ Bq$^{4}$ and $2.2 \times 10$ Bq$^{2}$ were confirmed, respectively, with regard to Pu-239 and Am-241 at a maximum (Table 4.2.2 and Attachment 4.2.5). Therefore, with cooperation of the National Institute of Radiological Science (hereinafter "NIRS"), injection of chelating agent was carried out aiming to prompt egestion of ingested Pu etc. On June 7, 2017, the five workers were transferred to the NIRS and underwent treatment including decontamination of the body surface and measurement using lung monitor. The JAEA received a report from the NIRS on June 12, 2017 to the effect that as a result of the measurement using lung monitor, no obvious energy peak was confirmed with regard to plutonium and that there were people with whom energy peak was confirmed with regard to americium based on the measurement data, but the level was declining.

Occurrence of the event in chronological order is shown in the Table 4.2.3.

### 4.3 Situation concerning report required by laws and regulations

As based on the fact that $2.2 \times 10$ Bq$^{4}$ and $2.2 \times 10$ Bq$^{2}$ were confirmed, respectively, with regard to Pu-239 and Am-241 at a maximum through the measurement of the five workers using lung monitor which was conducted at Nuclear Fuel Cycle Engineering Laboratories, their levels of exposure exceeded or might exceed 5 mSv, the level at which report is required in the event of unplanned exposure of radiation workers entering a controlled area, and also there was a possibility that the surface density of the floor etc. of the Room No. 108 exceeded the level of the restriction area designated in the operational safety program (alpha nuclide: 4 Bq/cm$^{2}$), it was judged at 13:00, June 7,

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[3] Chelating agent is a compound that can make coordinate bond holding a metal ion in the center. Pentetic acid calcium trisodium (Ca-DTPA) works to reduce body contamination by transuranic elements (Pu, Am, etc.).

2017 that this accident was an event of which report is required by laws and regulations based on the provision of the Article 62 – 3 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors. The report on the above was made to the Nuclear Regulation Authority at 13:27.

## 5. Environmental impact

At the time of the occurrence of the event, 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 PFRF were within the normal fluctuation range. Therefore, there was no impact on the environment caused by this event. (Fig.4.2.6 and 4.2.7)

The ventilation system of PFRF kept operating after the occurrence of the event, and the negative pressure of the controlled area was appropriately maintained. The indicated values of the monitoring posts, ventilation dust monitor and Pu dust monitor of PFRF shifted within the normal fluctuation range (Fig. 5.1, 5.2, and 5.3), and there was no impact outside of the facility.

## 6. Measures taken after the occurrence of the event

### 6.1 Plan concerning restoration of the site, investigation into causes, etc.

With regard to the response to the contamination in PFRF, strengthening the structure of the response headquarters of the Japan Atomic Energy Agency on June 8, 2017, activities for the restoration of the site, investigation into the causes, etc. which are shown below (1) – (4) are moved forward with.

Based on the effort for investigation into the causes made until now, completion of restoration of the site by the end of September, 2017 is aimed as shown in the schedule in Fig. 6.1.1.

(1) With regard to the effort concerning restoration of the site, as an emergency measures for securing safety, the lid of the storage container will be fixed and the storage container will be moved out from Room No. 108. As the full scale restoration of the site, decontamination of the hood and Room No. 108 will be conducted.

(2) With regard to the effort concerning investigation into the causes, based on the interview with the workers, past record, etc., factors leading to the burst of the resin bags will be presumed, and investigation and analysis of the contents and scattered subjects and verification test on burst of resin bags and radiation decomposition of resin will be conducted. Direct factors and background factors related to work management will be analyzed, and measures to prevent recurrence will be considered.

(3) With regard to total inspection and dissemination of information throughout the organization, total inspection concerning management situation etc. of nuclear fuel material in other centers based on this event, additional investigation based on the investigation into the causes, and dissemination of information to other centers will be conducted.

(4) With regard to the effort concerning exposure evaluation, the bioassay sample of the workers will be analyzed, cooperation will be provided to dose evaluation at the NIRS, half face masks the workers wore will be analyzed and exposure scenario will be developed. With regard to care for the workers, in cooperation with the NIRS, understanding of the health condition of the workers and provision of care to them will be proceeded with.

6.2 Restoration of the site of the occurrence of the event

(1) Basic approaches for restoration of the site of the occurrence of the event

The restoration will move forward based on two approaches: (i) approach for securing safety, (ii) approach for the full scale restoration. As an approach for securing safety, it is aimed to secure route to the hood (H-1), fix the lid of the storage container in the hood (H-1), move out the storage container from the hood (H-1) and move it from Room No. 108 to the glove box in the adjustment room (room No. 101). As an approach for the full scale restoration, contamination check and decontamination of the hood (H-1) and Room No. 108 will be conducted. Also, decontamination management will be strengthened by replacement of the greenhouse etc. With regard to the restoration of the site of the occurrence of the event, effort will be made for preventing workers' exposure and for keeping record of the site in order to hold the information on the situation.

Monitoring with TV camera of the storage container will be continued until it is moved out from the hood (H-1). The ventilation system of PFRF will continue operation and the negative pressure in the controlled area will be maintained (Attachment 6.2.1). Monitoring with the monitoring posts, ventilation dust monitor of PFRF and Pu dust monitor (Room No. 108) will continue to confirm that the indicated valued are within the fluctuation range.

Until now, (i) approach for securing safety was completed, and for (ii) approach for the full scale restoration, contamination management was strengthened. Restoration of the site of the occurrence of the event will be moved forward with based on the schedule shown in Attachment 6.2.2.

(2) Approach for securing safety

The storage container in the hood (H-1) of Room No. 108 was transferred to Room No. 101 and put in the glove box (123-D). Work in Room No. 108 which is contaminated was implemented with breathing equipment (work time was limited to 20 minutes per time), and following measures for securing safety were taken.

(i) Securing route to the hood (H-1)

With regard to the route from the entrance of Room No. 108 to the hood (H-1), the floor was wiped with wipe in order to prevent expansion and scattering of contamination by walking of the workers. After the wiping of the floor, the result the measurement of surface density of α nuclide dropped from 55 Bq/cm$^2$ (Fig. 4.2.9) at maximum to 5 Bq/cm$^2$ at maximum (designation standard of entrance restriction area (α nuclide :4 Bq/cm$^2$)) as shown in Fig. 6.2.1.

The particles assumed to have scattered from the hood (H-1) were collected in a vial container and contained in a metallic container after recording the information on the location (Fig. 6.2.1). They will be used for analysis for investigation into causes.

(ii) Fixation of the lid of the storage container in the hood (H-1)

The lid of the storage container was fixed with packing tape, opening the sliding glass window to the width enough to access to the storage container in the hood (H-1). After fixing the lid, fall prevention device was installed to the storage container, and the window in front of the hood (H-1) was closed. The situation of the storage container of which lid is fixed and to which fall prevention devise was installed was shown in Fig. 6.2.2.

(iii) Moving out the storage container from the hood (H-1) and transfer it from Room No. 108 to Room No. 101

Moving out the storage container from the hood (H-1) and transfer it from Room No. 108 to Room No. 101 were carried out using a container, curing with plastic bags as appropriate, and confirming that there was no abnormality by checking contamination on the surface. A special truck to transport plutonium and enriched uranium within the controlled area was used to transfer the storage container within Room No. 108, and the storage box was hand-delivered from Room No. 108 to the simple truck waiting near the greenhouse 1 (Fig. 6.2.3). The storage container was then moved into the glove box (123-D) in Room No. 101.The situation of the storage container moved into the glove box (123-D) is shown in Fig. 6.2.4.The storage container will be observed and analyzed for investigation into causes.

(3) Approach for the full scale restoration of the site of the occurrence of the event

(i)Strengthening contamination management

Slight contamination of the corridor was confirmed during moving out the smear filter used to check the contamination of the floor of Room No. 108 from PFRF (July 7, 2017. Therefore, measures to prevent expansion of contamination from Room No. 108 and the greenhouse and measures to strengthen area management were formulated to strengthen the contamination management.

As measures to prevent expansion of contamination from Room No. 108 and the greenhouse, the greenhouse set immediately after the occurrence of the event was replaced with the one having strengthened function of contamination management. The zippered structure is used for the entrance at the boundary of the greenhouse to improve the containment function. It was decided to implement the below items and started implementation.

- Change the shoes to the special ones for this area when entering and exiting the entry restriction area. In the case of taking out the RI boots used in Room No. 108 outside the entry restriction area, ensure to wear shoe cover and wear it on a curing sheet.
- With regard to greenhouse 2 and 3 after completing work, conduct contamination check of the sides in addition to the floor for strengthening contamination management.

As measures to strengthen area management, the below items were provided and started to be implemented.

- Set curing sheet on the floor of the corridor, set additionally a foot monitor around the center of the corridor and implement contamination check with foot monitor when moving to the side of the exit. People exiting from Room No. 108 and the greenhouse who may expand contamination will walk on the curing sheet, and contamination check will be implemented with the foot monitor.
- Before the contamination check with hand foot cross monitor in front of the airlock room, conduct contamination check with survey meter at self-survey area (ensure an item conducted from long time ago).
- With regard to the cleaning of the floor of the rooms with wipe which has been conducted during the inspection tour, change it to the method to wipe the floor in the direction of the greenhouse. Conduct wiping after work using Room No. 108 and the greenhouse in addition to the time of inspection tour.
- Change the adhesive sheets set at the corridor including the ones additionally set in front of the foot monitor and self-survey area before starting work in Room No. 108 and the greenhouse.

Outline of the strengthening of contamination management will be shown in Fig. 6.2.3.

To enable shift working of workers wearing breathing equipment or full face masks, the number of radiation workers was increased. Contamination management will continue to be strengthened in accordance with the situation of the restoration of the site of the occurrence of the event.

(ii) Plan of contamination inspection and decontamination of the hood (H-1) and Room No. 108

With regard to the work of the hood (H-1), unnecessary parts in the hood will be removed from the hood and stored in metallic containers. After removing contaminants from the inside and outside surface of the hood using seal as sample for analysis and evaluation, decontamination work and immobilization of fixed contamination will be implemented, while conducting contamination check of inside and outside surface of the hood.

With regard to Room No. 108, areas will be divided in meshes or by structure. First, the floor will be divided into the areas, and then the entire floor will be decontaminated by repeating contamination check and decontamination after removing contaminants using seal as sample for analysis and evaluation for each area, and the floor will be cured with plastic sheets. Also, the ceiling, walls, pipes and ducts, globe boxes, etc. will be decontaminated from top to down by area in the same procedures as the floor. The materials used for decontamination will be gathered by area and preserved.

As contamination check, direct survey method and smear method will be combined. Decontamination will be conducted until contamination is not detected by smear method. If contaminant is confirmed on the surface, immobilization or curing with plastic sheets will be conducted. Finally, contamination check of Room No. 108 will be conducted to confirm no contamination is detected by smear method.

6.3 Evaluation of workers' exposure

(1) Evaluation of effective dose due to external exposure (refer to Attachment 6.3.1 for the detail)

(i) Measurement with OSL (optically stimulated luminescence)

At Oarai Research and Development Center, the OSL dosimeter is used as basic dosimeter for daily monitoring of radiation workers. The OSL dosimeters worn by the workers were stored in the greenhouse as surface contamination was confirmed, and brought out on June 13, 2017. As a result of the inspection of the surface contamination conducted at the time of bringing out, with regard to the case of the dosimeters, contamination was confirmed at maximus $1.0 \times 10^3$ Bq/cm$^2$, but the dosimeters contained in the case was not contaminated.

As the result of the measurement of the OSL dosimeters conducted on Jun 15, 2017, 1 cm dose equivalent of the each of the Worker A, B, C and D was lower than the detection limit (0.1 mSV). However, the OSL dosimeter of the Worker E was determined not evaluable, as it is assumed that abnormal value was indicated due to long-hour of localized incidence of radiation which was from the contamination adhered to the surface.

Also, measurement was conducted with solid trace neutron dosimeter for neutron which was contained in the OSL dosimeter, and meaningful exposure by neutron was not confirmed.

(ii) Measurement with electronic personal dosimeter (EPD)

Three of the five workers wore EPD as auxiliary dosimeter, the read values were 2 μSv (Worker B), 3 μSv (Worker D), and 60 μSv (Worker E).

(iii) Evaluation of effective dose

As the result of the above measurements, the exposure of all the workers was evaluated lower than the record level (0.1 mSv) by evaluation of OSL dosimeters with regard to the Worker A, B, C, and D, and by evaluation based on EPD with regard to the Worker E (Table 6.3.1). Additionally, the dose equivalent of Room No. 108 that was measured on June 7, 2017 was 2 μSv/h at maximum (Fig. 4.2.10), and therefore the exterior exposure is evaluated lower than the record level (0.1 mSv) even if they stayed in the room for eight hours.

(2) Evaluation of skin exposure due to body surface contamination (refer to Attachment 6.3.1 for the detail)

By body contamination check conducted in the greenhouse at the time when the workers exited the controlled area, contamination was confirmed with the special cloths of all the workers and with the skin of four workers. Therefore, the dose of skin exposure caused by these contamination was evaluated (Attachment 6.3.1).

The skin equivalent dose was evaluated using the measurement result of the OSL dosimeter case which was the highest among the measurement data relating to the workers ($1.0 \times 10^3$ Bq/cm$^2$ by conservative measurement based on the smear method), under the presumption that the contamination at this level directly attached to the skin and exposure continued from the time of the occurrence of the event to the exit from the controlled area. The result was 83 μ  at maximum.

Based on these results, it is confirmed that skin contamination caused by body surface contamination was lower than the record level (0.1 mSv) for all the workers.

(3) Evaluation of effective dose due to internal exposure

It was decided based on the Operational Safety Program in the JAEA that internal contamination check and dose evaluation concerning internal exposure will be conducted when internal contamination is confirmed with radiation workers.

For examination and treatment concerning internal exposure of the workers, the JAEA hospitalized the workers in the NIRS on June 7, 2017, the following day of the occurrence of the event. The JAEA cooperated in the measurement and evaluation of internal exposure, which the NIRS conducted as part of examination and treatment. For this purpose, the JAEA conducted analysis of bioassay sample (feces) and reported the result to the NIRS on July 5, 2017.

The result of measurement and evaluation of the internal exposer dose is all medical information managed by the NIRS, and therefore the JAEA will obtain necessary information following appropriate procedures, and report and record the exposure dose of radiation workers based on laws and regulations such as the Nuclear Reactor etc. Regulation Act.

The NIRS examined the result of the bioassay examination etc. in the detail and evaluated internal exposure dose. The effective dose (committed effective dose) of the five workers that was released by the NIRS on July 10, 2017 is shown in Table 6.3.2.

By the lung monitor measurement conducted on June 6, 2017, the day of the occurrence of the event, $20^{2} \times 10^{4}$ Bq and $2.2 \times 10^{2}$ Bq at maximum were confirmed with regard to Pu-239 and Am-241,[4] but the lung monitor measurement conducted the following day at the NIRS did not confirm Pu-239. As body surface contamination at the level of 140 cpm at maximum was detected by the body surface contamination measurement conducted at the NIRS after the five workers were hospitalized, the cause of the difference confirmed in the lung monitor measurements is assumed that Pu-239 adhering to the skin had influence on the measurement of the JAEA. The relation between the value measured by the lung monitor and contamination adhering to the skin will be clarified.

## 6.4 Investigation result of contents of the storage container and situation at the time of burst

[4] On the presumption that all the amount is radiation in lung, the committed effective dose is equivalent to 12 Sv.

(1) Investigation result of contents of the storage container

With regard to the characteristics and history of the contents of the storage container, which contained the resin bags that burst, investigation of the account control record (Attachment 6.4.1), investigation of document such as the monthly report of PFRF, technical report and inspection record (Attachment 6.4.2), and interview with the employees concerning PFRF including the retired employees (Attachment 6.4.3) were conducted. The below are the findings.

(i) The contents of the storage container are natural uranium (U) and plutonium (Pu), and the Pu is mixture of five different isotope compositions (Table 6.4.1).

(ii) The nuclear fuel material in the storage container is gathered samples that were used for X-ray diffraction measurement.

(iii) As characteristics of X-ray diffraction measurement at PFRF, powder of nuclear fuel material was mixed with bond agent of epoxy resin (mixture of two agents: main agent and curing agent) and fixed to an aluminum sample holder. The solidified material in the sample holder is a flat square of about 20×20 mm with the depth of about 1.5 mm. A piece of this material includes 0.1 – 0.2 g of powdered nuclear fuel material and 0.7 – 1.0 g of epoxy resin.

(iv) Oxide, carbide and nitride have been confirmed as the kinds of the compounds of the nuclear fuel material. These compounds are mixture of those including only U or Pu and mixed compounds of U and Pu.

(v) In PFRF, samples were gathered in glove boxes after being used for X-ray diffraction measurement. Seventy-eight percent of the total amount of the samples stored in such glove boxes was moved to other glove boxes of air atmosphere in October 1989.

(vi) After being placed for two years in a glove box of air atmosphere equipped with a heating furnace for oxidation heating, the above nuclear fuel material was contained in the storage container in October 1991.

(vii) A relatively large cylindrical polyester container (hereinafter "polyester container") that was stocked in PFRF was used as an interior container. This polyester container was not for storing nuclear fuel material, but for temporarily containing burnable waste such as paper generated in a glove box and unburnable waste such as metal and glass.

(viii) With regard to the storage in the storage container, the nuclear fuel material, which was contained in the polyester container in a glove box, was taken out by bag-out method being put in a resin bag (polyvinyl chloride, inside one of the double bags), and was encapsulated in another resin bag (outside one of the double bags).

(ix) The existence of a record was confirmed on July 14, 2017, which was kept when the lid of the storage container was opened in July 1996, after the storage in the storage container started in October 1991, and the inside condition was inspected. In this inspection, the condition of the stored material of 64 storage containers containing Pu was inspected, and with regard to the ones of which abnormality was confirmed, their packing was redone (Table 6.4.2). In the record of the storage container, there is description that there was no abnormality after replacing the packing, in addition to that there was damage at the bottom of the polyester container and inflation of the resin bags (Attachment 6.4.2).

Below are the supplement and possible explanation relating to the above discovered matters.

With regard to (i) isotope compositions, it is assumed that some of Am-241 produced in Pu were removed during the use and others were not removed. Comparison of effective decay constants of $\alpha$ decay in Table 6.4.1 uses the values under the presumption that Am-241 was not removed. In the evaluation of influence by various factors which is described in 7.1 of this report, as a conservative evaluation, "A", of which effective decay constant is the largest of the five isotope compositions (high $\alpha$ decay), was used as representative composition.

With regard to (iv) and (v), as the glove box to which the nuclear fuel material was moved was equipped with a heating reactor called oxidation reduction reactor, it is assumed that it was moved there for oxidation heating of samples used for X-ray diffraction measurement. In a technical paper written by a researcher who worked in PFRF, which was published in 1989 and 1990, there is reference to a method to recover plutonium in organic substance by heating, and therefore it is assumed that they envisaged to reuse the nuclear fuel material in future by treating it with oxidation heating and storing it as scrap. It is presumed from the monthly work report of the time that there was recognition that among samples used for X-ray diffraction measurement, carbide and nitride were chemically active, and epoxy resin solids were removed from the sample holder and treated with oxidation heating using heating furnace in the glove box. In this treatment process, epoxy resin was decomposed and removed, and oxide powder of U and Pu remained. On the other hand, with regard to the oxide powder of epoxy resin solids, there is no description of heating treatment in the monthly report. It is probable that regarding it chemically stable, it was contained in the storage container without removing epoxy resin by heating.

With regard to (vii), also back then, using metallic containers was the general approach taken by the staff members engaged in the work in PFRF.

With regard to (ix), detailed record of the measures taken is not found, but it is presumed that after the contents of the storage container was put in the glove box and the nuclear fuel material was put in a new polyester container, it was encapsulated in resin bags again by bag-out method and contained in the storage container. Record that keeps following inspection of the state inside this storage container is not found at the moment.

Based on the information obtained at the moment, image of assumed state inside the storage container was developed by manufacture drawing of the storage container and measurement of the size of a polyester container of the size same as the one contained (Fig 6.4.1). The storage container is made from stainless steel (SUS 304) (hereinafter ""SUS 304 steal"), and a handle is fixed on the lid. The interior capacity of the storage container is 3.9 litters and substantially larger than that of the polyester container of which internal capacity is 1.5 litters. However, its diameter of the opening is 120 mm while the external diameter of the polyester container is 94 mm, and accordingly there is scarcely extra space after polyester container encapsulated in the double resin bags is contained. Air-tightness of the polyester container is low as the lid is just put on the container, and unless sudden change of pressure occurs, it is likely that the pressure inside the polyester container balances with that inside the interior resin bag. It is assumed that if the length of the outside resin bag was too long, its edge was folded at the top or bottom of the polyester container to be contained in the storage container. With an O-ring between the lid and container, air-tightness of the storage container was maintained. Also the air-tightness was tested under the condition pressured to three atmosphere when it was manufactured. The test does not expect the pressure from the inside of the storage container, and its design specification aimed to prevent entrance of water into the container from the standpoint of criticality management. The lid is fixed to the container with six bolds (M8, SUS304 steel).

As detailed situation of the inside storage container and amount of epoxy resin is not clear currently, necessary information will be obtained by observing the state inside the storage container which was moved into the glove box (123*D) in Room No. 101.

(2) Result of situation investigation at the time of burst

The situation at the time of the burst was constructed as below based on the interview with the workers on the event involving the burst of the inside resin bag during the work to open the lid of the storage container with the hood and the photo of Room No. 108 (Fig. 6.4.2 and 6.4.3).

The important points of the investigation by interview on the burst are as below.

(i) The lid rose in the process of loosening the six bolts of the storage container.
(ii) After removing four bolts, the workers heard noise of the pressured inside air coming out when loosening the remaining two bolts. They collected smear samples of the lid of the container and gaps and confirmed that there was no contamination.
(iii) One of the workers loosened the remaining two bolts one after another by fingers, holding the lid by the other hand. When the last bolt was removed from the container, the lid floated up with a bang.
(iv) The noise "ban" was heard only once.
(v) Looking at the substances scattered on the curing sheet, the workers thought it was solidified with something.

Based on (i) and (iii), rise in the pressure inside the resin bags during the storage period is obvious. As no contamination as confirmed in (ii), at least either of the inside or outside bag was not damaged. The noise of the pressured inside air coming out is assumed to have been made when pressured air between the internal surface of the storage container and the bag was released. From (iv), there is a possibility that the inside and outside bags burst at the same time, or either of them was already damaged during the storage period. In the latter case, as generally speaking the capacity of inside bag is smaller than the outside one, taking into consideration the expansion allowance, the inside bag should be considered to have been damaged. The outside bag is considered to have avoided burst or damage as it was restrained by the interior surface of the storage container and lid even though it inflated due to the rise of the inside pressure, until the lid was opened. It is presumed that when the bolts were removed from the storage container, the restraint from the lid was lost, and the bags burst by expanding rapidly beyond the limit of their intensity or by an exterior factor.

Below is the condition of the storage container that is derived from the photo taken by the workers (Fig. 6.4.2).

- The resin bag protrudes from the upper edge of the storage container, and it is observed that the bag splits along its side edge in the vertical direction. Assuming the situation of the encapsulation in the bag, the opening made in the bag coincides with the wielding part. Confirmation with the actual object is necessary.
- At the upper edge of the bag, there is not a wielding part.
- The opening of the bag made by the burst faces to the direction of the worker. This corresponds with the description of the worker that he felt a wind pressure at the left abdomen.

- The large cylindrical object observed inside the bag is the lid of the polyester container. According to the statement of the worker, the lid was upside down, and the inside of the lid is shown in the photo.
- The outside of the polyester container was originally white, but it changed greatly.
- A black substance is observed in the bag at the right of the lid. There is a possibility that nuclear fuel material in the polyester container flew out at the time of the burst.

Fig. 6.4.3 is a photo taken when they collected the particles scattered from the storage container at the time of the burst. The lower two photos are enlargement of the inside of the white doted lines. With regard to the black lumps, one of the worker stated that he thought they were solidified with something. Square shapes are confirmed among those that do not maintain their original shapes due to break or chipping. They are likely to be the part of epoxy resin solids used for X-ray diffraction measurement that was removed from an aluminum sample holder.

6.5 Investigation situation of radiation management information etc.

(1) Understanding of the slight radioactive material taken in by the workers

Assessment of radioactive nuclide is conducted in order to understand the characteristics of the slight radioactive material taken in by the workers such as the radioactive nuclide and the distribution of the particle diameter, using the filter of Pu dust monitor No. 2 that was replaced with the new one on June 6, 2017 and the smear filter of the contamination check of Room No. 108 that was conducted on June 7, 2017. The locations of the collection of the smear samples are shown in Fig. 4.2.9. With regard to the smear samples, photon energy spectrum could be measured of four among 14 samples. The result is shown in Fig. 6.5.1 – 6.5.4.

With regard to the samples of these filters, in addition to continual assessment of radioactive nuclide, clarification of the distribution of particle diameter etc. is planned. Also, investigation and assessment will be proceeded with concerning the radiation situation of Room No. 108, contamination situation of the half-face masks of the workers, etc.

(2) Investigation of factors leading to the intake of radioactive material

Based on the information on the situation of the event occurrence etc., factors that could have led to the intake of radioactive material were picked up and sorted out. The result is shown in Table 6.5.1. At the moment, possible factors at respective occasions of exposure are picked up as many as possible.

Subsequently, the possible factors will be narrowed down based on the result of investigation and assessment of the radiation situation of Room No. 108 and the greenhouse, and half-face masks of the workers as well as the interview with the relevant people (workers, staff of Facility Radiation Protection Section, etc.).

## 7. Causes for the occurrence of the event presumed based on the investigation result

### 7.1 Presumed causes for the occurrence of the event by analyzing the factors causing burst and exploration of prevention measures

Fault tree analysis was conducted for analyzing factors causing burst of the resin bags. The fault tree was formed based on "6.4 Investigation result of contents of the storage container and situation at the time of burst", setting "burst of the outside resin bag (the outermost layer of boundary)" as the incident whose causes should be identified (top incident), then breaking down factors causing the incident sequentially until reaching to basic factors that cannot be decomposed any more. Subsequently, the causes were presumed by evaluating the degree of influence by respective identified basic factors (basic incident), and prevention measures were examined.

(1) Formation of the fault tree chart for analyzing factors causing burst of the resin bag

The fault tree chart is shown in Fig. 7.1.1. The top incident "burst of the outside resin bag" was presumed to occur when "pressure rise in the outside resin bag" and "fulfillment of condition for damage to the outside resin bag (including condition change)" both occur. "Pressure rise in the outside resin bag" was presumed to be caused by burst of or damage to the inside resin bag or inflation of the inside resin bag due to rise in its inside pressure. "Burst of or damage to the inside resin bag" was presumed, the same as in the case of "burst of the outside resin bag", to occur when "pressure rise in the inside resin bag" and "fulfillment of condition for damage to the inside resin bag (including condition change)" both occur.

As a factor to burst or damage the inside resin bag concerning "pressure rise in the inside resin bag", "inside gas occurrence" and "inside temperature rise" were presumed.

With regard to "inside gas occurrence", eight basic factors shown in Fig. 7.1.1 as ① - ⑧ were presumed focusing on the interaction or chemical reaction between included Pu etc. and organic substance. Also, as causes for "inside temperature rise", six basic factors shown in Fig. 7.1.1 as ⑤ - ⑩ were presumed focusing on the rise in temperature due to the occurrence of chemical reaction heat etc.

As incidents bringing about "fulfillment of condition for damage to the inside resin bag (including condition change)", 11 basic factors shown in Fig. 7.1.1 as ⑪ - ㉑ were presumed focusing on deterioration of the quality and damage of the resin bag.

Thus, in total, 21 basic factors causing the top incident, "burst of the outside resin bag", were picked out to form the fault tree.

(2) Result of evaluation of influence degree of respective basic factors

With regard to the 21 basic factors composing the fault tree, degree of influence that respective basic factors have on the top incident, burst of the outside resin bag (degree of importance), was evaluated based on the information obtained from interview with the workers, checking ledger sheets and work record, site investigation, rough evaluation, and document investigation, in addition to the information by "6.4 Investigation result of contents of the storage container and situation at the time of burst". Before the evaluation, the below three items were set as the premise of the evaluation.

1) The rate of gas generation against 2.3 litter which is obtained by subtracting 1.6 litter, the exterior content of the polyester container, from 3.9 litter, the content of the storage container, was defined as "rate of inside pressure rise".

2) Irradiation dose (absorbed dose) to the resin bags in $\gamma$ ray irradiation test was determined by simulating the behavior of $\gamma$ ray using PHITS, a particle and heavy ion transport code system (Attachment 7.1.1).

3) By evaluating the pressure resistance of the resin bags through a test to apply pressure to unirradiated and irradiated resin bags with restraining force from outside by a metallic container and lid simulating the storage container, the rate of the inside pressure rise that causes burst or damage of the resin bags was determined 90 - 300 % (Attachment 7.1.2).

The result of the evaluation of influence on "burst of the outside resin bag" is shown in Table 7.1.1. The detailed evaluation is shown in Attachment 7.1.3. Below is the result of the evaluation.

1) With regard to the "inside temperature rise" which has influence on all the "inside gas occurrence" factors among factors to raise inside pressure of the inside and outside resin bags, the rate of inside pressure rise was calculated as temperature rose by 22 ℃ to which maximum rise of temperature in the two basic factors, ⑨"decay heat" and ⑩ "high temperature of summer" is added. The resulting rate of inside pressure rise was 7.8 %. As the rate of inside pressure rise that causes burst or damage of the resin bags is 90 - 300 %, the influence by "inside temperature rise" is small. However, in the more accurate evaluation that will be conducted for identifying the causes, the influence by

“inside temperature rise” is considered.

2) As the result of the evaluation, the basic factors having meaningful influence over the rate of inside pressure rise of the resin bags are ②mixed organic substance, ③plastic container and ④ mixed water. The burst of the resin bags is considered to have been caused by a compound incident of three factors from ② - ④ or a single incident of either of them.

(3) Presumed causes of the burst of the resin bags and prevention measures

By analyzing the fault tree, the burst of the resin bags was presumed to have been caused by a compound incident of three basic factors, ②mixed organic substance, ③ plastic container and ④ mixed water. In summary, gas was produced due to a compound incident mainly of ② - ④ or a single incident of either of them, and the rise of the inside pressure exceeded the rate of inside pressure rise causing burst of the resin bags during the 21-year storage period, but the bags avoided burst or damage because of the restraint by the storage container. The restraint from the storage container was gone when it was opened, and the balance of pressure between inside and outside of the resin bags was lost. Part of the resin bags which was not constrained by the container nor lid burst open linearly splitting, with the influence of the deterioration in intensity and flexibility of the resin bags due to radiation irradiation.

Based on the above presumed causes, prevention measures were considered.

First of all, to prevent excessive increase in the inside pressure of the resin bags, Pu and organic substance that produces radiation decomposition gas must avoid contact during storage. On the other hand, degradation of resin bags, polyester containers, etc. by radiation etc. cannot be prevented in the case of long storage, even if Pu and organic substance, which produce high energy $\alpha$ ray by contacting with each other, are separated, as there will be an influence of $\gamma$ ray. Therefore, taking below measures is considered to be necessary.

1) Remove epoxy resin etc. that produce a large amount of gas by thermal treatment etc. before the storage

This thermal treatment of nuclear fuel material is considered to be effective for preventing generation of radiation decomposition gas of adhered water, another factor causing inside pressure rise.

2) Store in metallic containers to prevent contact between powder nuclear fuel material and organic substance such as polyester container

By storing in a metallic container, a certain level of effect to block low energy $\gamma$ ray generated by Pu is expected, and accordingly storage in a metallic container is considered to have effect as measures to prevent radiation degradation of the resin bags to a certain degree, as described below.

3) With regard to nuclear fuel material stored in polyester containers, measures should be taken such as visual inspection and replacement at an appropriate interval based on the estimation of the length of time causing inflation and change of color to occur.

Among the basic factors ② - ④, the presumed main causes, ②"mixed organic substance" and ③"polyester container" are attributable to the interaction between α ray from Pu and organic substance. Taking the short α ray range into consideration, in order to improve the precision to evaluate the degree of influence of these basic factors, analysis etc. of the following items is necessary.

1) Layout etc. of the nuclear fuel material and organic substance in the storage container
2) Kinds of nuclear fuel material adhered to epoxy resin
3) Mount of epoxy resin
4) Particle diameter, amount and distribution of powder nuclear fuel material
5) Degradation, break, flaw, etc. of resin bags and polyester container
6) Additional analysis required by the result of investigation of the storage container

7.2 Presumed factors leading to the intake of radioactive material and prevention measures

With regard to the presumption of factors leading to the intake of radioactive material, probable incidents will be clarified based on "6.5 Investigation situation of radiation management information etc." and reflected in the measures to be taken.

8. Analysis of causes

Analysis of direct factors related to work management including safety management that led to the occurrence of the event is in progress, based on the analysis of the causes of the burst of the resin bags and result of exposure evaluation as mentioned above. The "team to analyze causes of the contamination accident at PFRF" (hereinafter "Cause Analysis Team") was set up under the committee of quality assurance promotion of Oarai Research and Development Center based on the Article 4 of "Rules on the committee of quality assurance promotion" (subcommittee).

8.1 Selection of analysis objects

Based on the relevant documents (documents of Japan and other countries), records, interview, etc. in addition to the information mentioned above, analysis objects are selected as below.

(1) Encapsulation, storage and safekeeping of nuclear fuel material in the storage container (by the time of starting the correction work)

Focusing on the procedures at the time of encapsulation and storage of nuclear fuel material in the storage container and following situation of safekeeping, potential problematic items were selected. For the selection of the problems, transport slips of nuclear fuel material in PFRF, past inspection situation, etc. were focused on, and information available at that time was examined. Also, the below items of which current situation should be analyzed were based on interview with the people concerned including staff members who belonged to PFRF at the time of the work to encapsulate nuclear fuel material in the storage container in 1991, rules relating to work contents and work implementation (both documented and not documented), etc. Shift of management organizations and relevant rules from 1991 through 2005 when the JAEA's two precedent organizations were united, to present, and facts related to the succession of information, training for workers, etc. were focused on, too, and investigated to pick out problems.

- Following description on the conditions for storage in the guide to safe handling of radiation used in 1989: "Adequate attention must be paid to the rise of gas pressure caused by radiation decomposition."

  ⇒ Facts will be clarified by means of interview with the people concerned at the time etc., and problems will be picked out.
- Matters relating to the method to store nuclear fuel material in the storage container in 1991 and recordkeeping.

  ⇒ Facts will be clarified on the matters such as whether or not the selection of the inside container (polyester container) was appropriate by checking the contents, and whether or not the conditions for storage in the guide to safe handling of radiation used in 1989 was considered, and problems will be picked out.
- The storage container of the occurrence of the event was inspected in 1994 and break at the bottom of the inside container (polyester container) and inflation of the resin bags were confirmed.

  ⇒The existence of the record describing that the inspection of the storage container of the occurrence of the event was conducted in 1994. In it, there was a description that broken polyester container and the resin bags were replaced. Facts will be clarified on the matters such as whether or not the information on the facts that damage was observed in about five years was transmitted to the people succeeded the responsibility and whether or not measures to improve the situation was taken, and problems will be picked out.

- Matters relating to adoption of technical information concerning plutonium storage mentioned in IAEA Safety Report[5] (1996) and DOE-STD[6] (1992 and 2012)

  ⇒IAEA and DOE have compiled reports concerning storage of plutonium. Facts will be clarified on whether or not the information was reflected in the management at PFRF, and problems will be picked out.
- Matters relating to handling of information on the inflation of the resin bags encapsulating nuclear fuel material in the Plutonium Fuel No. Development Room of Nuclear Fuel Cycle Engineering Laboratories, which was reported to NRA on January 26 and February 9, 2017

  ⇒ Management of nuclear fuel material at Nuclear Fuel Cycle Engineering Laboratories was reported to NRA on January 26 and February 9, 2017, and on this occasion, "the inflation of resin bags" in the Plutonium Fuel No. 1 Development Room was referred to. Facts will be clarified on whether or not this information was reflected in the work plan for the check of the storage container in PFRF, and problems will be picked out.

(2) Planning and implementation of the correction work, and accident response

With regard to the respective stage of planning and implementing the correction work and the accident response, analysis objects relating to the causes of the occurrence of the event (burst of the resin bags) and causes of the exposure of the workers were picked out as below based on the relevant documents, record and events in chronological order and interview with the five workers and radiation workers including the radiation management staff who responded to the accident in the early stage and conducted decontamination.

- Matters concerning planning the work schedule for inspection of nuclear fuel material of which situation of storage is not clear (including the predictability of the burst of resin bags).

  ⇒Based on the work flow in the stage of planning the correction work as shown in the Fig 4.1.4, the work schedule was formulated, and for the formulation of the schedule, risks of work were confirmed by checking on various aspects. Facts will be

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[5] In this material there are descriptions on physical and chemical characteristics, handling and points to note on storage of plutonium, as well as medical treatment for the intake of plutonium.

[6] In this material standards for stabilization, packing and storage for long-term storage of plutonium (metal, oxide, etc.) are provided.

clarified relating to the stage of planning the work schedule including how “nuclear fuel material of which situation of storage was not clear” was checked and reflected in the work schedule, and problems will be picked out.

- Matters relating to having continued work when the lid of the storage container was uplifted by loosening the bolts of the lid
  ⇒Uplift of the lid was confirmed when the storage container was being opened. Facts will be clarified on the implementation of the work and the recognition of the workers in this situation, and problems will be picked out.
- Matters relating to the time taken for the workers to start exit from the time of the occurrence of the event (about three hours)
  ⇒Between the time of the occurrence of the event and the workers' starting exit, there were checking of situation of the event and setting of a greenhouse for their exit. Facts will be checked again on the procedures taken then, in the light of the designated emergency measures, and problems will be picked out.
- Matters relating to the management of equipment for accident response at PFRF
  ⇒After the occurrence of the event, there were setting of a greenhouse and body decontamination using a decontamination shower. Facts will be checked again on the maintenance and management of the equipment for accident response, and problems will be picked out.

8.2 Planned actions

Analysis of causes (picking out problems and determining direct factors) will be moved forward with, based on the objective facts such as relevant documents and record from 1991 to the time of responding to the accident, as well as recognition and decision of the people concerned on each occasion and how they were transmitted to the following people in charge in the sift of organization.

Especially, with regard to the fact that nuclear fuel material was encapsulated in the storage container in 1991 in response to the detailed inspection of the contents of the storage container, and the fact that the existence of a record describing that the storage container was inspected in 1996, facts and problematic incidents will be clarified, and direct factors concerning storage, safekeeping, etc. of nuclear fuel material will be determined.

Also, after problematic incidents were picked out from each of the analysis object, direct factors and organization factors that lie behind them will be analyzed, and improvement measures will be formulated.

The analysis in this section is based on the facts clarified until now by investigation and interview with people concerned, and there will be addition and change appropriately when the analysis of the causes for the burst of the resin bags and result of the exposure evaluation are obtained and new facts are clarified.

## 9. Measures to prevent recurrence, and dissemination of information throughout the organization

In response to the occurrence of this event, currently ensuring safety first is emphasized all over the JAEA and similar work handling nuclear fuel material is all suspended (Attachment 9.1). As preparation for disseminating information throughout the organization aiming to prevent similar events, investigation and inspection was conducted in order to understand the management situation of nuclear fuel material. Also, investigation and inspection to confirm soundness of containers storing and safekeeping nuclear fuel material were conducted (Attachment 9.2).

Investigation into and analysis of the causes are currently in progress. Recurrence prevention measures will be formulated based on the clarified causes, and relevant information will be disseminated and shared throughout the organization.

## 10. Conclusion

Since the occurrence of the event on June 6, 2017, efforts have been made for investigation into the causes, evaluation of workers' exposure and restoration of the event site. With regard to the restoration of the event site and investigation into the causes, each work was conducted based on the plans prepared for the work. As the probable causes were narrowed down, evaluation result of the effective dose of the exterior and interior exposure of the workers were obtained, and the storage container in the hood (H-1) was transferred to the glove box, such progress was decided to be reported as the second report.

The cause for the burst of the resin bags is presumed to be "inside gas generation" which was attributable to the $\alpha$ ray from Pu inside the container and gas caused by interaction between "mixed organic substance (epoxy resin)", "polyester container" and "mixed water". Determination of the cause including attributable proportion of the presumed causes requires to confirm the layout of the contents etc. and to clarify the kind of nuclear fuel material fixed to epoxy resin, amount of the epoxy resin, particle diameter, amount and distribution of the powder nuclear fuel material, etc. Accordingly, after conducting analysis etc., the cause for the burst of the resin bags and the event progress scenario will be determined by the end of August 2017.

With regard to the evaluation of the workers' exposure, the effective doses of the five workers due to external exposure were lower than the record level (0.1 mSv), and the effective doses due to internal exposure (committed effective dose) were, according to the announcement of the NIRS, within the range of 100 mSv and higher and less than 200 mSv (one person), 10 mSv and higher and less than 50 mSv (two people), and less than 10 mSv (two people). As the result of measurement and evaluation of the internal exposure dose is the medical information managed by the NIRS, the JAEA will obtain the information following appropriate procedures and report and record the radiation workers' exposure doses based on the Nuclear Reactor etc. Regulation Act.

For narrowing down the direct factors causing the accident, not only the result of analyzing the causes for the burst of resin bags and evaluating the workers' exposure, but also the situation of encapsulation, storage and safekeeping of nuclear fuel material in the storage container (including the items concerning the record of the inspection conducted in 1996) and analysis and evaluation concerning succession of responsibility at the time of the integration of the precedent organizations in 2005. Potential problems are already determined. Subsequently, by investigation of relevant materials and interview with people concerned, major causes will be clarified and measures will be formulated by the end of 2017.

With regard to the restoration of the site of the event, as contamination of the corridor in PFRF was confirmed on July 7, 2017, the contamination management in the controlled area will be strengthened, and in order to proceed with decontamination work carefully, restoration of the site of the event will be conducted by the end of September 2017 based on the result of the work conducted at the site.

The final report of the report required by the laws and regulations will be submitted by the end of September 2017, based on the above results.