The Series of Environmental Radioactivity Measuring Methods

AD-N・E

(No.36)

Method for Measurement of Radioactive Materials in the Air

Published in June 2022
Radiation Monitoring Division
Radiation Protection Department
The Secretariat of
Nuclear Regulation Authority

NRA JAPAN
Nuclear Regulation Authority

Introduction

The measurement of radioactive materials in the air plays an essential role in the early detection of radioactive materials released from nuclear facilities, confirmation of the spread of radioactive materials to the environment, and evaluation of exposure doses due to inhalation of the air. The Series of Environmental Radioactivity Measuring Methods No. 36, "Method for measurement of radioactive materials in the air", is a manual for measuring the "concentration of radioactive material in the air" stipulated in Nuclear Emergency Response Guidelines (Nuclear Regulation Authority, partially amended on April 6, 2022) [1].

The measurement of radioactive material in the air uses dust monitors and air monitors for continuous measurement of airborne dust containing particulate radioactive materials, dust samplers for collecting airborne dust, iodine samplers for collecting radioactive iodine (particulate and gaseous) in the air, and gas monitors for continuous measurement of gaseous radioactive materials such as radioactive noble gases in the air.

Dust monitor is a name for generic equipment. However, in principle, this report on the measurement method defines the equipment for use in normal times as dust monitors and the equipment only for use during emergencies as air monitors. The measurement principles are common for both. Air monitors are the equipment added for emergencies. Their specifications include the prompt, short-interval measurement of radioactive material concentrations in the air. In principle, the dust monitor is a device used in normal times. However, in an emergency, it will be additionally operated in emergency mode, which has the same functions as the air monitor, to strengthen the monitoring system.

This measurement method specifies the measurement procedures in normal times and emergencies.

In normal times and emergencies, the basic objective of measuring radioactive material concentrations in the air and the equipment for use includes common parts. However, there are different parts to the purpose of monitoring and the concept of data evaluation. Thus, this report consists of two parts: Part 1 discusses radioactive material measurements in the air in normal times, and Part 2 discusses radioactive material measurements in the air in emergencies. Each part is designed also for use as an independent manual.

Radioactive material measurements in the air in normal times (Part 1) describe measurement procedures for continuous monitoring with dust monitors, collecting and analyzing air samples with dust samplers and other equipment, collecting and analyzing air samples with iodine samplers, and continuous monitoring with gas monitors.

Radioactive material measurements in the air in emergencies (Part 2) describe measurement procedures of continuous measurements with air monitors, analysis of air samples collected with air monitors, collection and analysis of air samples with iodine samplers, and collection and analysis of air samples with dust samplers.

The Series of Environmental Radioactivity Measuring Methods presents standard measuring methods to assist each organization in producing reliable measurement data. These measurement methods reflect technical levels and knowledge updated at the time of formulation. However, it does not preclude the possibility of more reliable and adequate measurements by considering new techniques that are developed daily. We hope the use of these measurement methods assists in selecting optimal methods for adequate implementation of the radioactive material concentration measurements in the air, considering the aims of The Series of Environmental Radioactivity Measuring Methods based on their descriptions.

Configuration

Part 1 Measurement of Radioactive Materials in the Air in Normal Times

Part 2 Measurement of Radioactive Materials in the Air in Emergencies

Common to Part 1 and Part 2

Part 1 Measurement of Radioactive Materials in the Air in Normal Times

Table of Contents

Chapter 1 Introduction

The “Monitoring in Normal Times (Supplementary Reference Materials for the Nuclear Emergency Response Guidelines)” (Nuclear Regulation Authority, Radiation Protection Department, Radiation Monitoring Division, revised on Dec. 21, 2021)[2] defines monitoring in normal times as monitoring for preparing the monitoring in emergencies by grasping the air dose rates and radioactive material concentrations in the environment of nuclear facilities in normal times, and for early detection of an abnormality of nuclear facilities and evaluation of its impacts on nearby residents and environments.

The purpose of the radioactive material concentration measurements in normal time monitoring is (1) estimation and evaluation of exposure doses to nearby residents, etc., and (2) early detection of unexpected releases of radioactive materials from nuclear facilities and evaluation of environmental impacts.

Part 1 describes the procedures of continuous measurement with dust monitors, collection and analysis of air samples with dust sampler and other equipment, collection and analysis of air samples with iodine sampler, and continuous measurement with gas monitor, which are implemented as normal time monitoring.

Chapter 2 Basics and Scope of Application

2.1 Purpose

Normal-time monitoring measures radioactive material concentrations in the air for the following two purposes based on the Normal Time Supplementary Reference Materials.

(1) Estimation and evaluation of exposure doses to nearby residents, etc.

To protect the health and safety of nearby residents and other people of nuclear facilities, normal-time exposure doses to nearby residents and other people due to radioactive materials in the environment caused by the nuclear facilities are estimated and evaluated.

(2) Detection of the unexpected release of radioactive materials and evaluation of environmental impacts in early stage.

Detection of the unexpected release of radioactive materials from nuclear facilities outside the premises contributes to early detection of the abnormality of nuclear facilities. The results of normal-time monitoring are examined to adequately and promptly evaluate the impact in the case of unexpected releases of radioactive materials from nuclear facilities.

2.2 Equipment and flow

This section indicates equipment used for normal-time monitoring. Refer to the respective chapters for details on each piece of equipment.

2.2.1 Dust monitor

(1) Outline of equipment

A dust monitor is an equipment for continuously measuring radioactivity concentration in airborne dust while collecting airborne dust with filter paper as radioactive material concentrations in the air. Dust monitor is a name for generic equipment. This report on the measurement methods defines the equipment for use as dust monitors in normal times. However, to strengthen the monitoring system in an emergency, dust monitors will be additionally operated in emergency mode.

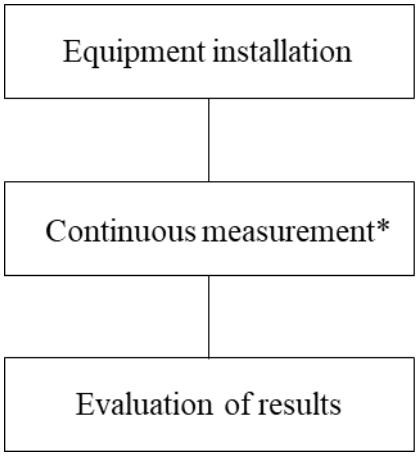
The use of dust monitors as dust samplers (refer to 2.2.2) is included in the scope of this measurement method.

Figure 2-1. Examples of dust monitors

(2) Flow of use

The flow of use of the dust monitor is shown below. The main Series of Environmental Radioactivity Measuring Methods for reference are also shown.

(a) Continuous measurement of radioactive material concentration in the air

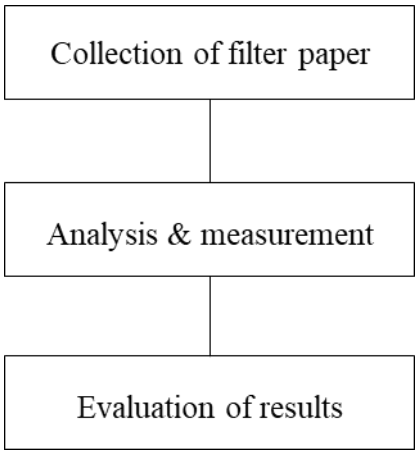


<Measurement targets>

- Gross α radioactivity, gross β radioactivity, etc. (Discriminative evaluation of facility contribution)
  (Selected according to the nuclear facility)

*The purpose of collecting airborne dust is also included if the dust monitor is also used as a dust sampler.

(b) Analysis of air samples (if necessary)



<Analysis and measurement targets>

- γ-ray emitting nuclides, α-ray emitting nuclides, β-ray emitting nuclides (Selected according to the nuclear facility)

<The Series of Environmental Radioactivity Measuring Methods for major reference>

- No. 4, " Radioactive iodine analysis method "
- No. 7, "γ-ray spectrometry using germanium semiconductor detector"
- No. 12, "Plutonium analysis method"
- No. 13, "Sample pretreatment method for instrumental analysis using germanium semiconductor detectors, etc."
- No. 14, "Uranium analysis method"

2.2.2 Dust samplers

(1) Outline of equipment

A dust sampler collects airborne dust on filter paper.

Dust monitors can also be used as dust samplers in terms of equipment that can collect airborne dust.

High-volume air sampler

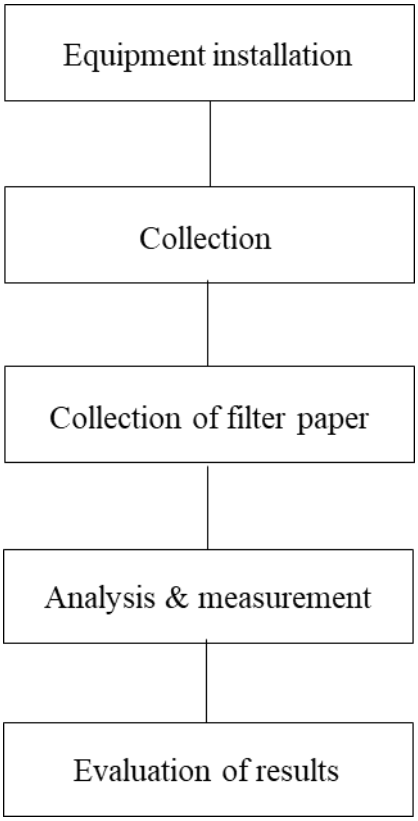
Low-volume air sampler

Figure 2-2. Examples of dust samplers

(2) Flow of use

The flow of use of dust samplers is shown. The main Series of Environmental Radioactivity Measuring Methods to be referenced are also shown.

・From collection to analysis of air samples in the air



<Analysis and measurement targets>

・ γ-ray emitting nuclides, α-ray emitting nuclides, β-ray emitting nuclides (Selected according to the nuclear facility)

<Major Series of Environmental Radioactivity Measuring Methods for reference>

・ No. 4, "Radioactive iodine analysis method"
・ No. 7, " γ -ray spectrometry using germanium semiconductor detector"
・ No. 12, "Plutonium analysis method"
・ No. 13, "Sample pretreatment method for instrumental analysis using germanium semiconductor detectors, etc."
・ No. 14, "Uranium analysis method"
・ No. 16, "Environmental sampling method"

2.2.3 Iodine sampler

(1) Outline of equipment

Iodine samplers collect radioactive iodine (particulate and gaseous) from the air on filter paper and activated carbon cartridges.

Transportable type

Installed type

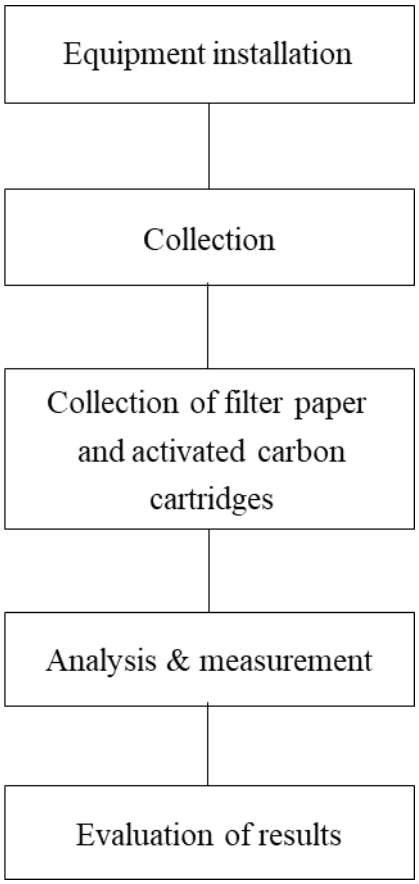
Figure 2-3. Examples of Iodine Sampler

(2) Flow of use

The flow of use of iodine samplers is shown.

The Series of Environmental Radioactivity Measuring Methods is also shown for major reference.

・ From collection to analysis of radioactive iodine



<Analysis and measurement targets>

- Radioactive iodine

<The Series of Environmental Radioactivity Measuring Methods for major reference>

- No. 4, "Radioactive iodine analysis method"
- No. 7, " γ -ray spectrometry using germanium semiconductor detector"
- No. 16, "Environmental sampling method"

2.2.4 Gas monitor

(1) Outline of equipment

Gas monitors continuously measure the gaseous radioactive material concentration of radioactive noble gases, etc., in the air.

Figure 2-4. Examples of gas monitor

(2) Flow of use

The flow of gas monitor use is shown.

・Continuous measurement of the concentration of gaseous radioactive materials in the air

<Measurement targets>

・Gaseous radioactive materials

Equipment Installation

Continuous measurement

Evaluation of results

Chapter 3 Continuous Measurement with Dust Monitor

The principle of the continuous measurement with dust monitors is to measure the count rates of α-, β-, and γ-rays emitted from airborne dust without energy discrimination* and promptly evaluate the radioactivity concentrations in the airborne dust as radioactive material concentrations in the air for the early detection of the unexpected release of radioactive materials from nuclear facilities.

Refer to Explanation A for the effectiveness of the radioactive material measurement in the air.

Quantitative determination of the concentrations of radioactive nuclides in airborne dust involves collecting paper filters from dust monitors and precise analysis with γ-ray spectrometry or radiochemical analysis. Refer to Chapter 5 for the procedures of precise analysis.

*Excluding cases of spectrum analysis using silicon semiconductor detectors, etc. (all treated the same from 3.1 onward).

3.1 Equipment

The basic information on dust monitors described in this section is based on JIS Z 4316:2013 "Radioactive dust monitors"[4].

3.1.1 Classification of equipment

Dust monitors are classified into (1) – (5), shown in Table 3-1.

Table 3-1. Classification of Dust Monitors

Classification	Definition
(1) α-ray dust monitor	Dust monitor to measure α radiation from airborne dust
(2) β-ray dust monitor	Dust monitor to measure β radiation from airborne dust
(3) γ-ray dust monitor	Dust monitor to measure γ rays from airborne dust
(4) α- and β-ray dust monitors	Dust monitor that simultaneously measures α- and β-rays from airborne dust using a single detector
(5) Dust monitor into which (1) – (4) are combined	Dust monitor in which at least any two detection parts of (1) – (4) are installed

3.1.2 Scope

(a) Gross α radioactivity concentration

α-rays from α-ray emitting nuclides in airborne dust are measured without energy discrimination and calculated as the radioactivity concentration (Bq/m^3) evaluated with one type of α-ray standard source used in the efficiency calibration of the dust monitor (refer to 3.3.2).

(b) Gross β radioactivity concentration

β-rays from β-ray emitting nuclides in airborne dust are measured without energy discrimination and calculated as the radioactivity concentration (Bq/m^3) evaluated with one type of β-ray standard source used in the efficiency calibration of the dust monitor (refer to 3.3.2).

(c) Total count rates of γ rays

Measure the γ-ray gross count rate (s^{-1}) from airborne dust.

Dust monitor measurements include contributions from natural radioactive materials (mainly radon-thoron decay products), and those fluctuations at normal background levels can greatly affect the measurements, thus hindering early detection of unexpected radioactive releases from nuclear facilities. Refer to Explanation E for the effects of radon/thoron decay products.

A combination of (a) – (c) or spectral analysis may evaluate the contribution of radioactive materials from nuclear facilities that are included in measurements. For an evaluation of the measurement results, refer to 3.5. For the discrimination method for the facility-induced portion, refer to Explanation F.

Note that continuous measurement with dust monitors can evaluate the contribution from facility-induced radioactive materials. However, it isn't easy to quantify the concentration of each radionuclide.

3.1.3 Equipment selection

Refer to Table 3-1 and select a dust monitor appropriate for the type of radiation to be measured. Table 3-2 shows the measurement targets of dust monitors according to the nuclear facilities listed in the Normal Time Supplementary Reference Materials.

In the Normal Time Supplementary Reference Materials, for all nuclear facilities in Table 3-2, the contribution of facility-induced radioactive materials in dust monitor measurements is to be discriminatively evaluated for early detection of unexpected releases of radioactive materials from nuclear facilities.

Considering this purpose, this measurement method is based on selecting α- and β-ray dust monitors.

Table 3-2. Targets of dust monitor measurements according to nuclear facilities

Nuclear facility	Measurement target
Nuclear power reactor facilities (PAZ and UPZ settings required)	Facility-induced artificial radionuclides
Reactor facilities for power generation as specified in the Cooling Notice	Facility-induced artificial radionuclides
Nuclear power reactor facilities (UPZ setting not required)	Facility-induced artificial radionuclides
Nuclear reactor facilities for testing, research, etc. (UPZ setting required)	Facility-induced artificial radionuclides
Uranium processing facility* (UPZ setting required)	Gross α
Processing facility for handling plutonium*	Gross α
Reprocessing facility*	Gross α, gross β

*The measurement targets are gross α for uranium processing facilities (requiring UPZ setting) and processing facilities that handle plutonium, and gross α and β for reprocessing facilities. However, it is necessary to discriminate and evaluate facility-induced radioactive materials at any facility.

3.1.4 Equipment configuration

The dust monitor consists of a sampler, detection unit, indicator, alarm section, and data transmission unit, as shown in Figure 3-1. The configuration and functions of each part are shown in (1) – (6).

General matters

(a) To withstand continuous operation, the equipment shall be robust and easy to operate and maintain.
(b) The structure shall resist vibration, impact, corrosive gases, etc.
(c) The structure shall not be susceptible to electromagnetic induction, static electricity, etc.
In addition, the structure shall be designed to have little or no electromagnetic induction or other effects on other devices.
(d) The equipment desirably has a self-diagnostic function in case of any failure.

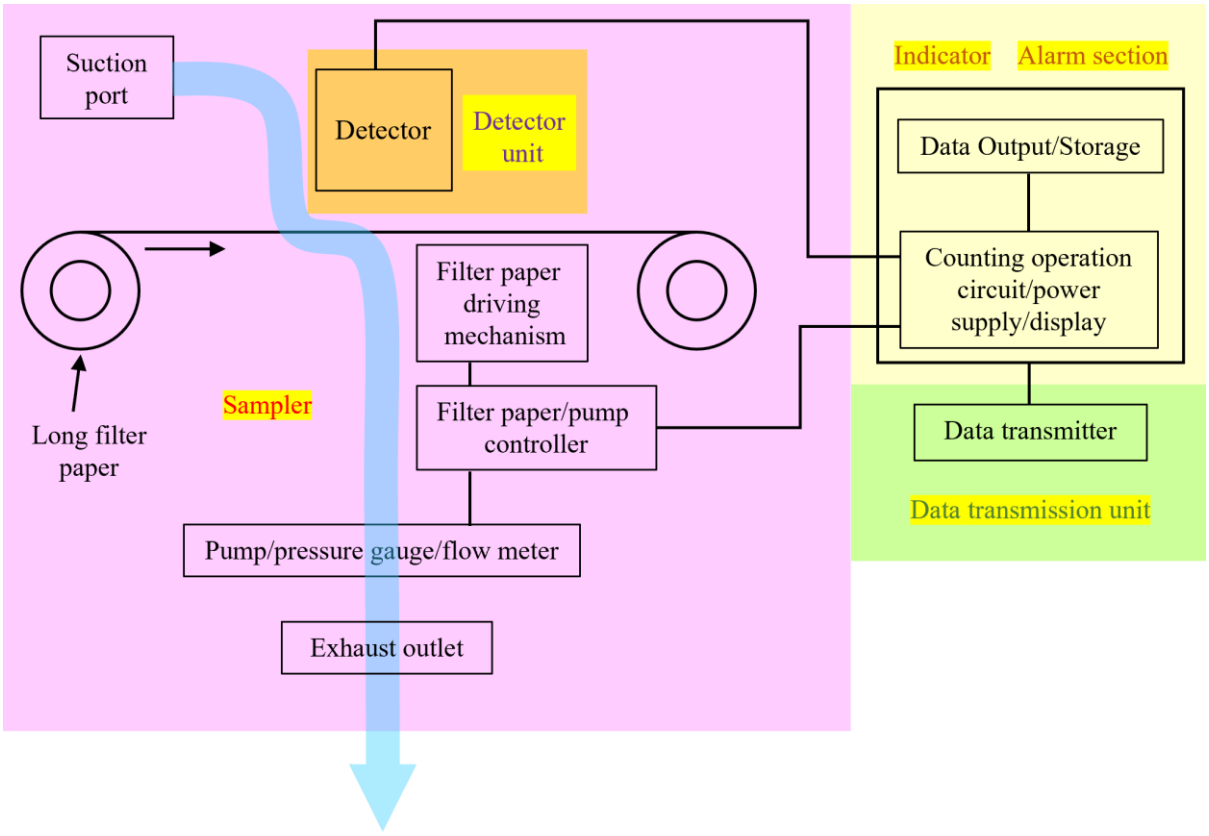


Figure 3-1. Example of dust monitor equipment configuration

(1) Sampler

The sampler consists of a pump that draws air, a flow meter, and an air sampling unit that collects airborne dust with attached filter paper.

Refer to Chapter 4 for pump and flow meter specifications, etc.

(a) Air sampling unit

The air sampling unit shall be airtight and constructed to measure the radiation emitted from the collected airborne dust properly.

The relationship between air sampling time and the required lower detection limit determines the flow rate. Use a pump whose flow rate can be set to 100*-250 L/min for airborne dust only, approximately 50 L/min for radioactive iodine only, and approximately 50 L/min for both airborne dust and radioactive iodine. Mass flow meters capable of compensating for pressure fluctuations are recommended for flow meters. Refer to 3.4(3) for setting measurement conditions.

* It is acceptable to set the flow rate smaller than 100 L/min if it is possible to properly discriminate facility-induced radioactive materials and ensure the detection limit in the precise analysis after filter paper collection.

Examples of specifications for an air sampling unit and points to be considered are shown in Table 3-3.

Table 3-3. Examples of specifications and notes for an air sampling unit

Item	Example specifications and notes
Air sampling method	Air sampling shall be continuous, and the filter paper collection method shall be used. The air sampling unit shall start suctioning from the startup moment and, after that, repeatedly measure the integrated flow volume at set intervals.
Flow rate adjustment range	50 to 250 L/min approx.
Flow meter	10 to 300 L/min
Pressure gauge (Vacuum gauge)	-101.3 to 0 kPa[gage]
Suction port	The height of the suction port should be about 1 m above the ground to match the height at which the radiation dose rate in the air is measured. However, this does not preclude the installation of a suction port higher than 1 m above the ground if there is a special reason, such as to prevent suction due to the uplift of surrounding soil, etc., or to prevent the suction port from being buried in snow, making it impossible to suction the air. Install on the side of the wall, etc. The structure should be designed to prevent intrusion of water, garbage, insects, etc. (e.g., with wire mesh, etc.).
Exhaust port	The exhaust shall be vented outside the station through the wall surface of the station building, etc. Exhaust should be expelled as far away from the suction port as possible to avoid re-suction of exhaust from the suction port.
Humidity and condensation control	To avoid the influence of condensation on filter paper, it is desirable to reduce the relative humidity of the air using a heating tube or insulation materials. The heating control system shall be equipped with a temperature monitor to prevent high-temperature runaway and with a safety device to stop the heating control system in the event of a high-temperature runaway.

(b) Filter paper

Examples of filter paper specifications are shown below. Refer to 3.2 for the material of filter paper, etc.

- For fixed filter paper samplers, circular or square filter paper is used, and for mobile filter paper samplers, rolled (long) filter paper is used.
- The quantity of filter paper should allow continuous measurement for at least one month.
- The filter paper shall be of a structure that can be replaced safely, quickly, and easily.
- Prevent contamination of the filter paper due to surrounding air by covering the filter paper with a cover, etc., or by making the area airtight.

(c) Filter paper feeding method

The filter paper of the dust monitor needs to be replaced or moved at regular intervals to prevent clogging.

With mobile filter paper samplers, there are two types: intermittent feeding, in which the filter paper is moved at regular time intervals, and continuous feeding, in which the filter paper is moved continuously at a fixed speed. This measurement method employs an intermittent feed method (Refer to 3.4(3)).

An example specification of the filter paper feeding system is shown below.

- The filter paper feeding can be remotely controlled, and it can be set to any time.
- To shorten the blank time of continuous measurement due to filter paper feeding, the time of filter paper feeding operation should be kept as short as possible.
- The filter paper can be fed automatically when the concentration of radioactive materials in the air exceeds the set value, when the flow rate falls below the set value, or when the pressure difference between the front and back sides of the filter paper exceeds the set value.
- It is also desirable to manually feed filter paper (on-site operation and remote control).

(2) Detector unit

The detector unit is the part that detects radiation emitted from airborne dust.

The following are points to be noted in the detector unit.

- The structure shall have a small gap near the detector unit so that the measurement is not affected by radioactive noble gases in the collected air that remain near the detector unit during measurement.
- The structure shall be resistant to contamination and easy to decontaminate or replace.

An example of detector specifications is shown below.

- The shape of the effective surface of the detector should be the same as or larger than the shape of the air sampling surface.
- The surface of the detector (the part in contact with the aspirated air) should be made of a material that is difficult to adsorb, etc., to prevent the adsorption of radioactive materials.
- The detector should be shielded by a lead shield that is approximately 3 – 5 cm thick to reduce background radiation from the outside.

Refer to 3.1.5 for details on the measurement principle of the detector.

(3) Indicator

The indicator is the part that measures signals from the sampler and detector, displays the indicated values, and outputs them to the data transmission section.

The main body of the dust monitor does not necessarily need to have the functions of calculating the concentration of radioactive materials in the air in the indicator and issuing an alarm in the alarm section, as long as the telemeter system, etc., has such functions. Table 3-4 shows an example of specifications for the indicator.

Table 3-4. Example of indicator specifications

Item	Example specifications
Measurement item	Radioactivity concentration (Bq/m^3) *Only the count rate shall be used if the radioactivity concentration cannot be evaluated.
	Count rate (s^{-1}), integrated count (count)
	Flow rate (L/min), Integrated flow volume (L)
	Measurement time (sec)
Display items	Date and time of measurement: XX year, XX month, XX day, XX hour, XX minute, XX second
	Nearest radioactivity concentration (Bq/m^3)
	Count rate (s^{-1}), integrated count (count)
	Flow rate (L/min), Integrated flow volume (L)
	Measurement time (sec)
	Pressure (kPa)
Data storage function	The measurements, etc., and status signals can be stored in a data recorder.
	(A) Measurements, etc. (a) Location name, (b) Device number, (c) Location information, (d) Date and time of measurement, (e) Radioactivity concentration, (f) Count rate, (g) Integrated count, (h) Integrated flow volume, (i) Measurement time
	(B) Status signals (including alarms) (a) Under measurement, (b) Under calibration, (c) Under adjustment, (d) Communication error, (e) High radioactivity level, (f) Sampler error, (g) Detector error, (h) HV power failure, (i) LV power failure, (j) Pressure is high, (k) Pump flow rate is low, (l) Filter paper is out, (m) Filter paper is being fed, (n) Filter paper remaining low
	(C) Storage capacity (A) must be able to save every hour (or every 10 minutes in case of emergency), (B) Record the event when it occurs. The number of stored cases should be secured in the unit for at least one month. In addition, the stored data shall be outputted by connecting a USB memory stick or PC, etc., to the main unit.
External output	The measurements, etc., and status signals shall be able to be output to a telemeter system, etc., via a data transmission device.
Control input	Control signals can be input from telemeter systems via data transmission devices. Control signals: start (measurement start), stop (measurement stop), filter paper feed, changing paper feed interval (switch to emergency mode)
Time synchronization	The time server of the telemeter system or other systems shall be accessed at startup to synchronize the time, and the time shall be synchronized at least once daily regularly.

(4) Alarm section

The alarm section detects and notices that the indicated value exceeds a certain set value, etc. Depending on the alarm's content, the system should be set up to issue a warning to the indicator or telemeter system, etc.

Examples of specifications for the alarm section are shown below. Examples of alarm events are shown in Table 3-5.

- When the measurement exceeds the alarm setpoint, an alarm shall be issued using a lamp, buzzer, etc.
- When an alarm occurs, the alarm contents shall be displayed on the display screen of the main body or telemeter system, etc.
- Alarms shall be maintained until reset or the cause is eliminated, and the alarm shall be recorded.
- The user shall be able to check the alarm setpoints and confirm that the alarms usually operate.
- It is desirable to be able to display failures or abnormalities separately for each cause.

Table 3-5. Examples of alarm events

	Item
Alarm event	Radioactivity concentration is high; the detector is abnormal; the sampler is abnormal; the power supply is abnormal; the pressure is high; the pump flow rate is low; the filter paper is out; the filter paper feed is abnormal.

(5) Data transmission section

This part outputs the data collected in the indicator to the telemeter system and other devices via communication devices. It controls the dust monitor by receiving control signals from the telemeter system and other devices.

Refer to 3.4(5) for examples of data transmission items.

For data communication, the communication lines used by the facilities in the monitoring station building, if any, should be used. Communication lines are desirably multiplexed to prevent data communication outages.

(6) Other

If necessary, a heating pipe or water trap should be installed on the intake side to prevent condensation on the airflow path and filter paper, and a silencer on the exhaust side to prevent noise generated by the pump.

3.1.5 Detector types and measurement principles

The types of detectors used for dust monitoring are listed in Table 3-6.

However, these apply to any detector with performance equivalent to or greater than the listed types and are not limited to them. For detector performance, refer to the detection limit in Explanation B.

Table 3-6. Types of Detectors Used in Dust Monitors

	Detector type
α-ray detector	ZnS(Ag) scintillation detector
	Silicon semiconductor detector
β-ray detector	Plastic scintillation detector
	Silicon semiconductor detector
γ-ray detector	NaI(Tl) scintillation detector
α- and β- ray detector	ZnS(Ag) scintillation detector +Plastic scintillation detector
	Silicon semiconductor detector

(1) α-ray detector

(a) ZnS(Ag) scintillation detector

Light generated from the ZnS(Ag) scintillator upon radiation incident is converted to photoelectrons by a photomultiplier tube, amplified, and output as a pulse signal for measurement.

ZnS (Ag) scintillators are made of ZnS (Ag) particles of about 0.1 mm diameter coated on the surface of a transparent glass plate, etc. Since ZnS is a white powder, light transmission is low. However, the emission intensity of short-range α-rays is higher than that of β-rays and γ-rays, so the α-ray output pulse is discriminated, and detection is easy.

ZnS (Ag) is one of the inorganic crystal scintillators and has the following physical properties.

- It is a white powder sensitive to α-rays.
- The mainly emission wavelength is at 450 nm, close to the maximum sensitivity wavelength of general photomultiplier tubes.
- The decay time of 200 ns is comparable to that of NaI (Tl) at 230 ns.
- Coating the surface of a plastic scintillator sensitive to β-rays enables simultaneous measurement of α- and β-rays.

(b) Silicon semiconductor detector

Secondary electrons are generated due to the interaction between the incident radiation and the silicon crystal.

The ionizing action of these secondary electrons produces electron-hole pairs. Applying a high voltage allows the anode to collect electrons and the cathode to collect holes, and an electric current through them. The signal is output as a pulse.

(2) β-ray detector

(a) Plastic scintillation detector

The principle of measurement of a plastic scintillation detector as a scintillation detector is the same as that of the ZnS(Ag) scintillation detector. A plastic scintillation detector measures α- and β-rays and fast neutrons. However, because of its low luminous efficiency for radiation with high ionization density, such as α-rays, it is used in dust monitors for measuring β-rays. Plastic scintillators are made by dissolving organic scintillators in a solvent and then polymerizing them into a solid plastic. Base materials include polystyrene, polyvinyl toluene, and polymethyl methacrylate.

(b) Silicon semiconductor detector

Same as (1) α-ray detector

(3) γ-ray detector

(a) NaI (Tl) scintillation detector

Excitation luminescence (fluorescence) generated in the NaI(Tl) crystal upon radiation incident is converted to photoelectrons in a photomultiplier tube, amplified, and output as a pulse proportional to the intensity of the light. Since the output pulse signal's magnitude is proportional to the incident radiation's energy, analyzing the γ-ray spectrum enables qualitative or quantitative determination of radionuclides.

The detector is characterized by not directly measuring the absorption reaction of radiation in the form of ionization or energy but indirectly by light. The low photoelectron conversion efficiency results in a small number of photoelectrons generated, which does not allow for high energy resolution. On the other hand, the photomultiplier tube's extremely high electron multiplication factor allows the pulse height discriminator to distinguish and separate signal from noise even in extremely low-level signals, thus enabling high and stable radiation detection.

For details, refer to the Radioactivity Measurement Methods Series No. 6 "NaI (Tl) scintillation spectrometer instrumental analysis method".

(4) α- and β-ray detectors

(a) ZnS (Ag) scintillation detector + plastic scintillation detector

To detect α- and β-rays simultaneously, an integrated detector with a ZnS(Ag) scintillator coated on a plastic scintillator is used. The measurement principle is the same for each of the detectors described above. There is also a method to evaluate the contribution from facility-induced radionuclides using the α and β simultaneous measuring function (refer to Explanation F).

(b) Silicon semiconductor detector

Same as (1) α-ray detector and (2) β-ray detector

3.1.6 Example of equipment specifications

An example of dust monitor equipment specifications is shown in Table 3-7. Refer to 3.2 for air absorbent. Equipment not listed in the example specifications may be used if it meets the required performance. For the performance of dust monitors, refer to the detection limit in Explanation B.

Table 3-7. Examples of dust monitor equipment specifications

Item	Type A	Type B	Type C	Type D	Type E
Measurement target	α-ray	β-ray	α- and β-rays		γ-ray
Detector	ZnS(Ag) scintillator	Plastic scintillator	ZnS(Ag) Scintillator + Plastic scintillator	Silicon semiconductor	NaI(Tl) scintillator
Air absorbent	Membrane filter paper	Cellulose/ Glass fiber filter paper	Membrane filter paper, or, Cellulose/glass fiber filter paper[*1]		Cellulose/ Glass fiber filter paper
Detector size	50 mm ϕ	50 mm ϕ	50 mm ϕ	25 mm ϕ	2 inch ϕ × 2 inch
Flow rate	50 to 250 L/min				
Filter paper feed method	Intermittent feed or exchange at a fixed time[*2]				

*1 Use membrane filter paper, etc., when measuring mainly α-rays, and cellulose/glass fiber filter paper, etc., when measuring mainly β-rays.

*2 Intermittent feeding for long and fixed filter paper is changed at a fixed interval.

3.2 Air absorbent

3.2.1 Selection of air absorbent

Dust monitors are based on using long filter paper because of the need to change the air absorbent at regular time intervals automatically. If circular or square filter paper is used, the air absorbent should be changeable automatically at regular intervals.

When α-rays are measured, membrane filter paper or the like should be used to avoid underestimating measurement results due to airborne dust entering the filter paper. When β- and γ-rays are measured, cellulose/glass fiber filter paper should be used, prioritizing the pressure loss and strength of the filter paper because the effect of airborne dust entering the filter paper is small, as is the case with α-rays.

In the radiochemical analysis of α-ray emitting radionuclides described in Chapter 5, if it is challenging to analyze membrane filter paper, use filter paper that can appropriately perform radiochemical analysis, such as cellulose/glass fiber filter paper. It may also be done by analyzing cellulose/glass fiber filter paper from dust or iodine samplers collected separately.

Examples of air absorbents to be selected according to the classification of dust monitors are shown in Table 3-8. Refer to 4.2 and Reference A for the characteristics of each air absorbent.

Table 3-8. Examples of air absorbent selection

Classification	Example of selection of air absorbent
α-ray dust monitor	Membrane filter paper
β-ray dust monitor	Cellulose/glass fiber filter paper
γ-ray dust monitor	Cellulose/glass fiber filter paper
α- and β-ray dust monitor	Membrane filter paper (when α-rays are measured primarily) Cellulose/glass fiber filter paper (when measuring mainly β-rays)

3.2.2 Examples of specifications for air absorbent

Table 3-9 shows an example of specifications for air absorbents used for dust monitors. If the required performance is met, using air absorbents not listed in the example specifications is acceptable.

Table 3-9. Examples of air absorbent specifications

Item	Type A	Type B	Type C
Material	Cellulose/glass fiber		Membrane
Shape	Rolled (long)	Circular form	Rolled (long)
Hole diameter	——		3.0 μm
Thickness	0.41 mm		0.13 mm
Dimension	75 mm×10 – 90 m	60 mm ϕ	35 mm×12 m
Collection efficiency	99.7% or more (0.31 μm polystyrene latex particles, ventilation rate 55-135 cm/s)		99.7% (> 0.15 μmϕ particles, ventilation speed 878 cm/s)
Pressure loss	0.27 kPa		8 to 15 kPa
Physical properties	Lined with cloth (cold gauze) for strength, Water repellent		PTFE lined with polyethylene, etc., for strength
Heat-resisting property	130 ℃		130 ℃

3.3 Installation, calibration, and inspection

To obtain measurements representative of the installation site, it is essential to install dust monitors in appropriate locations and to ensure the integrity of the equipment through calibration and inspection.

3.3.1 Installation

(1) Selection of installation site

The following items (a) to (c) should be considered when selecting the installation site.

In principle, dust monitors should be fixedly installed in the monitoring station building where monitoring posts, etc., are installed. However, the selection conditions are shown below, considering the case where new dust monitors will be built.

(a) Social environment

Item	Selection criteria
Distance from nuclear facilities	Locate within a 5 km radius[*1].
Direction from nuclear facilities	The installation site should be centered on the nuclear facility so that the orientation of the installation site is unbiased.
Population distribution	Priority will be given to areas with large populations.

*1 The Normal Time Supplementary Reference Materials states that “In the application for the establishment permit of a nuclear facility based on the Reactor Regulation Act, etc., the dose received by the public around the facility due to radioactive materials released into the environment during normal operation is evaluated as follows depending on the facility characteristics. The effective dose from radioactive rare gases is evaluated where the dose is maximum. The effective dose from radioactive iodine and particulate radioactive materials is evaluated where the concentration is maximum. Because the points are set within a 5 km radius from the facility, the normal monitoring necessary for early detection of the unexpected release of radioactive materials or radiation from the nuclear facility and for assessing the impact on the surrounding environment is conducted within a 5 km radius from the nuclear facility, and appropriate points within this radius are selected and implemented”.

(b) Natural environment

Item	Selection criteria
Terrain	・ Select a location with open surroundings and easy access. ・ Ideally, the site should be flat and surrounded by at least several tens of meters of open space. Even if dust monitors are located in an existing monitoring station building, avoid locations where trees, cliffs, or other influences may interfere with the suction of airborne dust.
Past wind conditions record	・ To facilitate early detection of the release of radioactive materials from nuclear facilities, the past wind condition record, such as prevailing winds, should be investigated, and priority should be given to the location in the downwind direction of nuclear facilities. ・ In addition to past wind condition records, it would be helpful to understand the diffusion trends specific to the vicinity of nuclear facilities based on long-term air diffusion calculations using past meteorological data, etc.
Other	・ Avoid places with high temperatures, high humidity, and different adverse environments. ・ In the Great East Japan Earthquake, the damage caused by the tsunami after a large-scale earthquake was enormous. Therefore, when installing at a point close to the sea, it is necessary to consider installing on higher ground where there will be no tsunami impact. On the other hand, however, if a community is located along the coast, it must be installed at a point close to the sea. Therefore, if the equipment becomes unusable, it is necessary to respond to the event, including substituting transportable type equipment.

(c) Other and local condition

Item	Selection criteria
Power supply	Select a location where a stable power supply is available from the station building or other facilities.
Communications network	Select a location where multiple means of data communication can be constructed in consideration of a disaster.
Access to the installation location	Avoid locations that are difficult to access, as periodic filter paper changes and equipment adjustments must be performed. In addition, since it may be used for emergency monitoring, it is necessary to consider road disruptions during disasters.
Other	In roadsides with heavy traffic, places close to factories, or other places, select a location where the dust monitor’s filter paper is less likely to be impacted since the effects of exhaust gases and dust may clog the filter paper in a short period.

(2) Indoor installation condition

For indoor installation, the following items (a) – (i) should be considered before selecting the installation site.

Item		Installation conditions
(a)	Station building	・ The monitoring station desirably has a wide entrance to allow equipment delivery. ・ The space and ceiling height should allow enough space for the equipment to be installed to facilitate maintenance and inspection. ・ It is desirable to apply a dust-proof coating to the floor. ・ A piping pit is needed on the floor to accommodate cables and other wiring.
(b)	Suction port	・ The height of the suction port should be basically about 1 m above the ground, in accordance with the height at which the air dose rate is measured. However, this does not preclude the installation of a suction port higher than 1 m above the ground if there is a particular reason, such as to prevent suction due to the uplift of surrounding soil, etc., or to prevent the suction port from being buried in snow and making it impossible to draw in air. ・ Do not install a suction port on the same side as the air conditioning blower. ・ The direction of the fence should be downward or oblique downward to prevent rain and snow from getting in, and a wire mesh or similar matter should be provided in order to avoid the entry of insects and other foreign matter. ・ Minimize obstructions around air suction ports. ・ In the piping from the suction port to the air sampling unit, considering the reduction of deposition of particulate matter in the piping, it is desirable that the piping should be as short as possible, curved pipes (elbows) be avoided, and corrosion-resistant metals such as stainless steel being used.
(c)	Exhaust port	・ To prevent the exhaust air from being sucked back through the suction port, the positional relationship to be kept in mind between the suction port and exhaust port includes avoiding installation on the same wall surface as the suction port as much as possible.

(d)	Power supply	Supply power and other infrastructure may be cut off in a nuclear disaster accompanied by a large-scale natural disaster. In anticipation of such a case, the power supply method is multiplexed using private generators, batteries, solar power generation equipment, etc. However, for the generator, securing fuel that can be supplied continuously (light oil, LPG, etc.) is necessary. ・ The structure desirably facilitates maintenance. ・ The power supply circuit shall have a protective device or protection circuit. ・ Switching sections, connections, etc., shall maintain electrical performance even after being operated repeatedly. ・ Unexpected lightning strikes can cause the instrument's electrical system to fail via AC power. It is advisable to install arrestors to avoid this situation. ・ Grounding for noise reduction.
(e)	Air condi−tioning	Provide air conditioning in the station building for stable operation of equipment ・ Maintain a range of temperature and humidity within which the manufacturer guarantees normal operation of the dust monitor. ・ To maintain a constant room temperature, it is effective to insulate the interior walls of the station building.
(f)	Conden-sation Preven-tive measure	Take measures to prevent condensation to avoid the effect of condensation on the filter paper. ・ A heating tube with a built-in heater is installed between the suction port and the air sampling unit to heat the suctioned air and reduce relative humidity. Heating the room by about 10 ℃ can reduce the relative humidity from 90% to 35% - 55%. ・ Cover the piping and air sampling unit with heat-insulating material.
(g)	Earth-quake-resistance	Earthquake countermeasures, including the station building, equipment, and piping, shall be taken to have earthquake resistance at Class S or equivalent grade to Class S in the earthquake resistance standards of the Building Standards Act.
(h)	Commu−nication	Assuming that the means of data transmission may be cut off, it is desirable to have multiplex communication methods, including the construction of satellite communications, etc., which are relatively unaffected by disasters.
(i)	Other	Enclose the area around the installation site with a fence, etc., and take measures to prevent intrusion from outside, tampering, etc..

3.3.2 Calibration

The calibration of detectors used in dust monitors is described here. Flow meters are desirably calibrated periodically for proper evaluation of air suction volume.

(1) Standard sources for calibration

Use the standard sources listed in Table 3-10 depending on the type of radiation to be measured.

The standard source should be a plane source, as shown in Figure 3-2, with the same shape as the air sampling surface. The traceability to national standards shall be clear, and the relative expanded uncertainty U of the surface emission rate or radioactivity shall be below 10% (k = 2).

Table 3-10. Standard sources for calibration

Radiation type	Standard source
α-ray	Am-241
β-ray	Cl-36 or Tl-204
γ-ray	Cs-137

Figure 3-2. Example of standard source (Cl-36, 2-inch ϕ)

(2) Calibration method

To ensure that the geometric relationship between the air absorbent and the detector is the same, a standard source is installed at the position of the air absorbent, as shown in Figure 3-3; calibration is performed, and the instrument efficiency is measured according to Equation 3.1. Instrument efficiency is the ratio of the net count rate of the instrument that is measured under defined geometric conditions to the surface emission rate of the radiation source (the number of rays per unit time emitted from the surface of the standard source).

A special jig for source installation should be prepared in advance to ensure that the installation conditions do not change each time calibration is performed.

$E = N/\phi$ (Equation 3.1)

ε: Equipment efficiency
N: Net count rate (s^{-1}) (Calculated by subtracting the pre-measured background count rate.)
ϕ: Surface emission rate of radiation source (s^{-1})

The concentration of radioactive materials in the air measured by the dust monitor is calculated as the radioactivity concentration evaluated by one standard source used for efficiency calibration and is the total radioactivity concentration.

Refer to Explanation D for details on the efficiency of dust monitors.

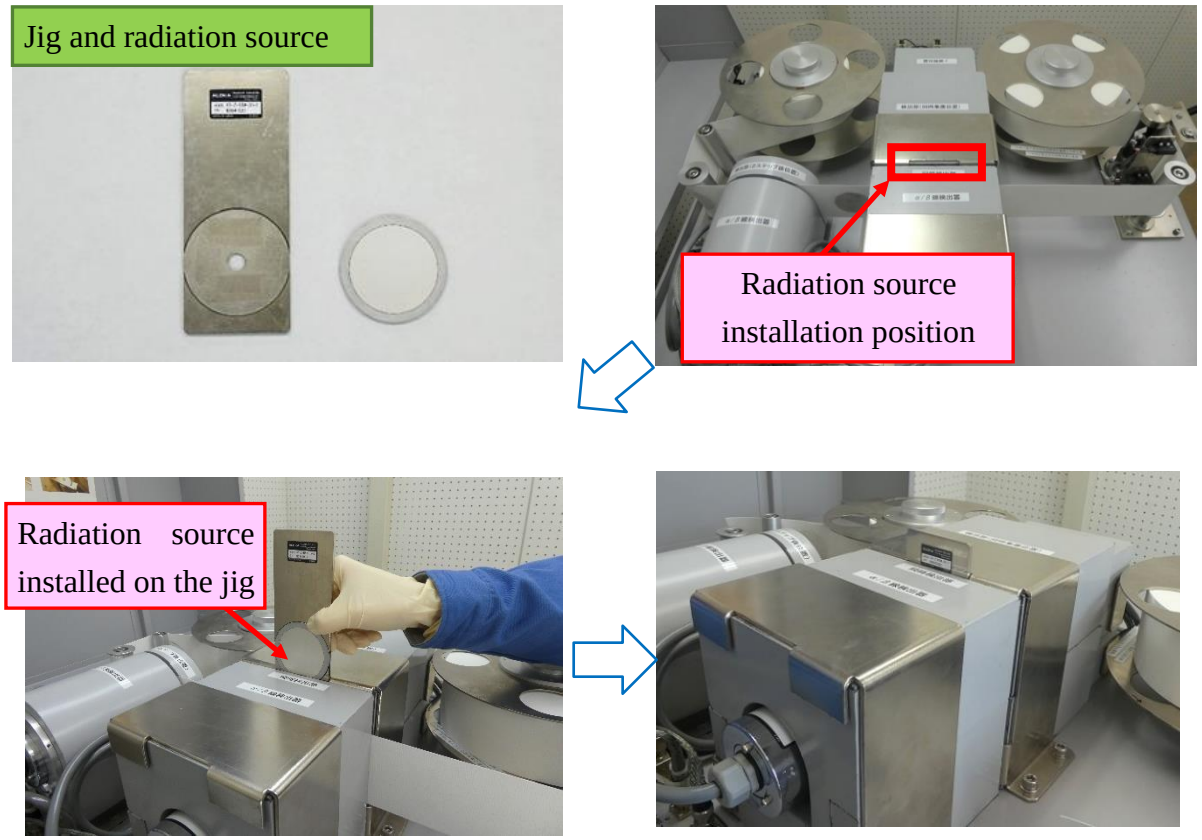


Figure 3-3. Example of standard source installation during calibration

(3) Calibration frequency

Calibration shall be performed at the installation site at the time of equipment installation.

After that, the equipment efficiency should be checked about once a year during inspections, etc., using a standard source to confirm that there is no change in equipment efficiency.

If the equipment efficiency deviates from the range of ±(10+U)% with respect to the equipment efficiency used in the calculation, recalibration should be performed to change the equipment efficiency, or if there is a possibility of equipment abnormality, an equipment inspection should be performed, focusing on the detector. U is the relative expanded uncertainty (k = 2) associated with the calibration work.

3.3.3 Inspection

(1) Daily inspection

Daily inspections include items to be conducted remotely by telemeter systems, etc., and items at the installation site.

Examples of daily inspection items are shown below.

(a) Examples of items to be conducted remotely by telemeter systems, etc.

Example of daily inspection items	
Operation check	Is it operating and communicating normally?
	Is there any anomaly in flow rate or integrated flow volume?
	Are the pressure values within the normal range?
Abnormal values	Is the alarm not triggered?
	Is there any anomaly in radioactivity concentration or count rate?

(b) Example of items at the installation site

Example of daily inspection items	
Operation check	Is it operating and communicating normally?
	Is there any anomaly in flow rate or integrated flow volume?
	Is there any abnormality in the operating noise of the pump?
	Is the filter paper being fed properly?
	Is the suction port clogged?
	Whether the pressure values are within the normal range
Abnormal values	Is the alarm not triggered?
	Is there any anomaly in radioactivity concentration or count rate?
Operating environment	Is the air conditioning in the station building working properly?
Remaining amount of filter paper	Is enough filter paper remaining (until the next inspection, etc.)?

(2) Periodic inspection

Examples of periodic inspection items by the manufacturer are shown below.

Example of periodic inspection items		
(a) Visual inspection		Sampler
		Detection unit
		Indicator
		Data transmission unit
		Cable and connector
(b) Unit operation and performance test		
Sampler		External output signal check
		Leak test
		Power failure countermeasure operation check
	Filter paper	Confirmation of filter paper feed operation
		Confirmation of control operation
	Flow meter	Operation check
		Flow rate indication accuracy
	Pump	Operation check (heat generation, unusual noise, vibration, odor, etc.)
		Periodic replacement of worn parts
	Condensation prevention unit	Confirmation of heating control
		Temperature indication accuracy
Detector		Equipment efficiency check
Indicator		Operation check
		External output signal check
		Count rate indication accuracy
		Flow indication accuracy
		Scaler operation check
		Recorder indication accuracy
Alarm section		Alarm operation check
Data transmission unit		Data transmission check

(3) Inspection frequency

For routine inspections, inspections should be conducted daily by the telemeter system, etc, and about monthly at the installation site.

Periodic inspections shall be conducted at least once a year.

3.4 Measurement

(1) Start-up of equipment

The system should be activated at all times to perform continuous measurements from normal times.

(2) Installation of air absorbent

Install the air absorbent according to the dust monitor's user manual.

* Avoid mistaking the filter paper's front and back when installing the air absorbent. Also note that if the long filter paper is loosely installed, the filter paper feeding may not work properly, and the equipment may stop.

(3) Setting of measurement conditions

The measurement conditions should be set based on early detection of the effects of unexpected releases of radioactive materials from nuclear facilities.

Examples of measurement conditions are shown in Table 3-11, and the points to be considered for each item are described in (a) – (e).

Changes in measurement conditions shall be feasible by remote control using a telemeter system or other means.

Table 3-11. Primary measurement conditions for continuous measurement with dust monitors

Item	Measurement condition
(a) Sampling flow rate	Approximately 50 to 250 L/min.
(b) Filter paper feeding method (long filter paper case)	Intermittent feeding
(c) Sampling time (filter paper feed time)	Six hours
(d) Measurement position	Air sampling position
(e) Measurement time	Continuous (measurement at least every one hour)

(a) Sampling flow rate

The flow rate should be approximately 50 to 250 L/min.

When collecting filter paper from dust monitors for precise analysis of radionuclide concentrations, the flow rate should be set considering the detection limit shown in Explanation B.

* A flow rate of approximately 230 L/min is required to obtain a sample amount of 10,000 m^3 for one month (30 days), described as the detection limit in Table B-2 of Explanation B. A flow rate of approximately 70 L/min is required to obtain a sample of 3,000 m^3 in one month (30 days). When radioactive iodine is sampled simultaneously, the collection rate should be about 50 L/min to maintain the collection efficiency of iodine.
* Make sure that the flow rate does not drop by more than 10% due to clogging of the filter paper. Refer to Explanation C for an example of evaluating flow reduction.

(b) Filter paper feeding method

An intermittent feeding method shall be used when long filter paper is used. The continuous feed method is not employed in this measurement method.

(c) Sampling time (filter paper feed time)

As a general rule, the sampling time shall be 6 hours long. However, this does not preclude a sampling time longer than 6 hours if it does not affect the early detection of facility-induced radioactive materials released from nuclear facilities. The longer the filter paper feeding time is, the greater the amount of airborne dust collected, and the natural radioactive materials contained are, which is likely to make it more challenging to detect facility-induced radioactive materials.

The Normal Time Supplementary Reference Materials also describes a method of continuous sampling for one hour and measurement for about 10 minutes after sample collection. In this case, the filter paper is fed every hour. However, in this method, the filter paper must be replaced more frequently*, so the remaining filter paper must be carefully monitored. It should also be noted that as the amount of filter paper required increases further, more time and labor are required to replace the filter paper.

In an emergency, the filter paper feeding time shall be able to be switched every hour by switching to the emergency mode, etc., because hourly filter paper feeding is required in accordance with the air monitor.

* If a 90 m long filter paper is used and the filter paper feeding distance is 20 cm, the filter paper needs to be replaced at intervals of approximately 112 days for a filter paper feeding every 6 hours or 18 days for a filter paper feeding every hour.

(d) Measurement position

While collecting airborne dust, the radiation emitted from the collected airborne dust is measured with a detector installed at the air sampling location.

(e) Measurement time

In principle, the measurement shall be consecutive, but measurements shall be taken at least once per hour. If the filter paper feeding time is set to 6 hours, 6 measurements are taken at least once per hour during one filter paper feeding interval.

In case of emergency, it shall be possible to switch to the emergency mode, obtaining measurements every 10 minutes since measurements taken every 10 minutes are required in accordance with the air monitor.

(4) Start of measurement

Start measurement by pressing the start button, etc.

To facilitate evaluating the measurement data, it may be designed to set the filter paper feeding at times such as 0:00, 6:00, 12:00, and 18:00 and to obtain the hourly measurement values every hour.

It is desirable to remotely control the start and stop of measurement by the telemeter system or other means.

(5) Data transmission

Data should be transmitted to the telemeter system at least once per hour. In an emergency, the system can switch to data transmission at an interval of every 10 minutes. Alarms and other monitoring information shall be transmitted to the telemeter system rapidly after an abnormality occurs. An example of data transmission items is shown in Table 3-12.

Table 3-12. Example of data transmission items to telemeter system

Classification	Component	Output item	
Measurements	Indicator	Date and time of measurement	
		Measurement point	
		Measurement time	
		Radioactivity	Count rate (s^{-1})
			Integrated count (count)
			Radioactivity concentration (Bq/m^3)
	Sampler	Flow rate	Average flow rate (L/min)
			Integrated flow volume (m^3)
Status signal	Indicator	Detector abnormal	
		Measurement unit abnormal	
		High radioactivity level	
		Low radioactivity level	
		High count rate	
		Low count rate	
	Sampler	In the process of air sampling	
		Filter paper is being fed	
		Abnormal pump flow rate	
		Abnormal pressure	
		Abnormal filter paper feed	
		Out of filter paper	
		Abnormal air sampling unit	
		Pump overload	
		Sampler power failure	
		Abnormal heating unit	
Control signal (Received information)	General	Start or stop	
	Indicator	Under adjustment	
		Reset during adjustment	
	Sampler	Filter paper feed	

(6) Calculation of radioactivity concentration

(a) Dust monitors that measure α or β radiation

The hourly gross α or β radioactivity concentration (Bq/m^3) is calculated as the average radioactivity concentration up to the elapsed time from the filter paper feeding using Equation 3.2. If necessary, correction is made, considering factors affecting the measurements, such as collection efficiency.

Figure 3-4 shows the hourly net count rate and integrated flow volume for calculation in a 6-hour filter paper feed.

$$C_t = \frac{N_t}{(\epsilon \times V_t)} \quad \text{(Equation 3.2)}$$

C_t: Gross α or β radioactivity concentration at t hours after filter paper feeding (Bq/m^3)

N_t: Net count rate at time t hours after filter paper feed (s^{-1})

ε : Equipment efficiency

V_t: Integrated flow volume from filter paper feed to t hours later (m^3)

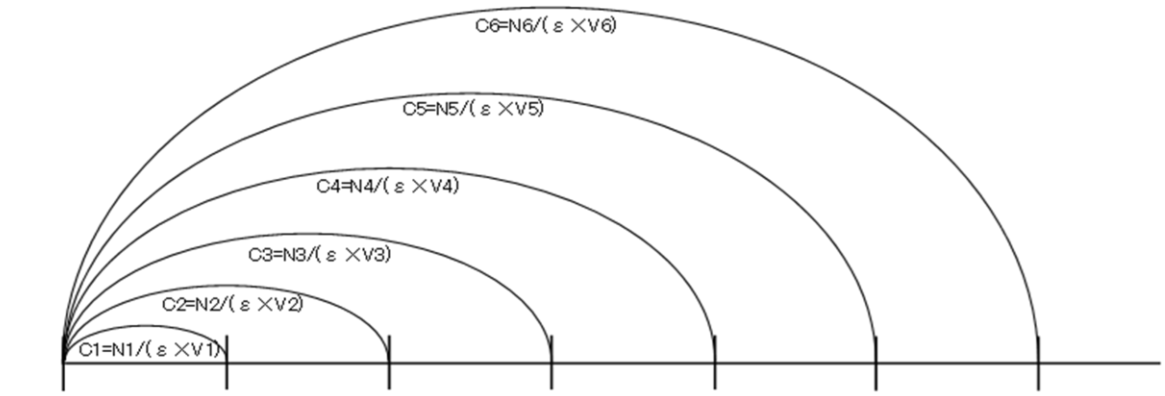
Supplementary information on how to obtain the net count rate

The net count rate is calculated by subtracting the pre-measured background count rate.

In principle, the net count rate at t hours after filter paper feeding should be evaluated as precisely as possible.

Since this method is based on measurement during air sampling, a count rate meter is used fundamentally to obtain the count rate (instantaneous value) of airborne dust collected on filter paper at the time of t hours after the filter paper is fed.

Note that care should be taken when the count rate is calculated from the integrated counts measured by the scaler. Refer to Explanation C for the concept.



Radioactivity Concentration Ct	C1	C2	C3	C4	C5	C6
Net count rate Nt	N1	N2	N3	N4	N5	N6
Integrated flow volume Vt	V1	V2	V3	V4	V5	V6

Figure 3-4. Net count rate and integrated flow volume used in calculations (for 6-hour filter paper feed)

Dust monitor measurements are calculated as the average concentration from the filter paper feeding. But for air monitors used in an emergency, the average concentration per 10 minutes evaluated from the difference in the count rate (count rate from the radioactivity in airborne dust collected on the filter paper at each 10-minute time starting from the filter paper feeding) is used. Refer to Explanation C for the difference between the two calculation methods.

If the evaluation of the average concentration per unit time is used in normal times, it is difficult to properly evaluate the difference due to the short half-life of radon/thoron decay products. However, if it is feasible to conduct a reliable evaluation, we do not reject the evaluation based on the average concentration per unit time to evaluate the contribution of the facility-induced radioactive material.

(b) γ-ray dust monitors

Record all hourly counts. If radionuclide concentrations can be quantified, hourly concentrations of facility-induced γ-ray emitting radionuclides (Bq/m^3) should be calculated.

Refer to the Radioactivity Measurement Method Series No. 6 "NaI(Tl) scintillation spectrometer instrumental analysis method" for the analysis method.

(7) Collection of filter paper

If the filter paper of the dust monitor is subjected to precise analysis, collect the filter paper periodically.

Care must be taken to prevent abnormal filter paper feeding caused by the improper installation when long filter paper is cut off in the middle and reinstalled.

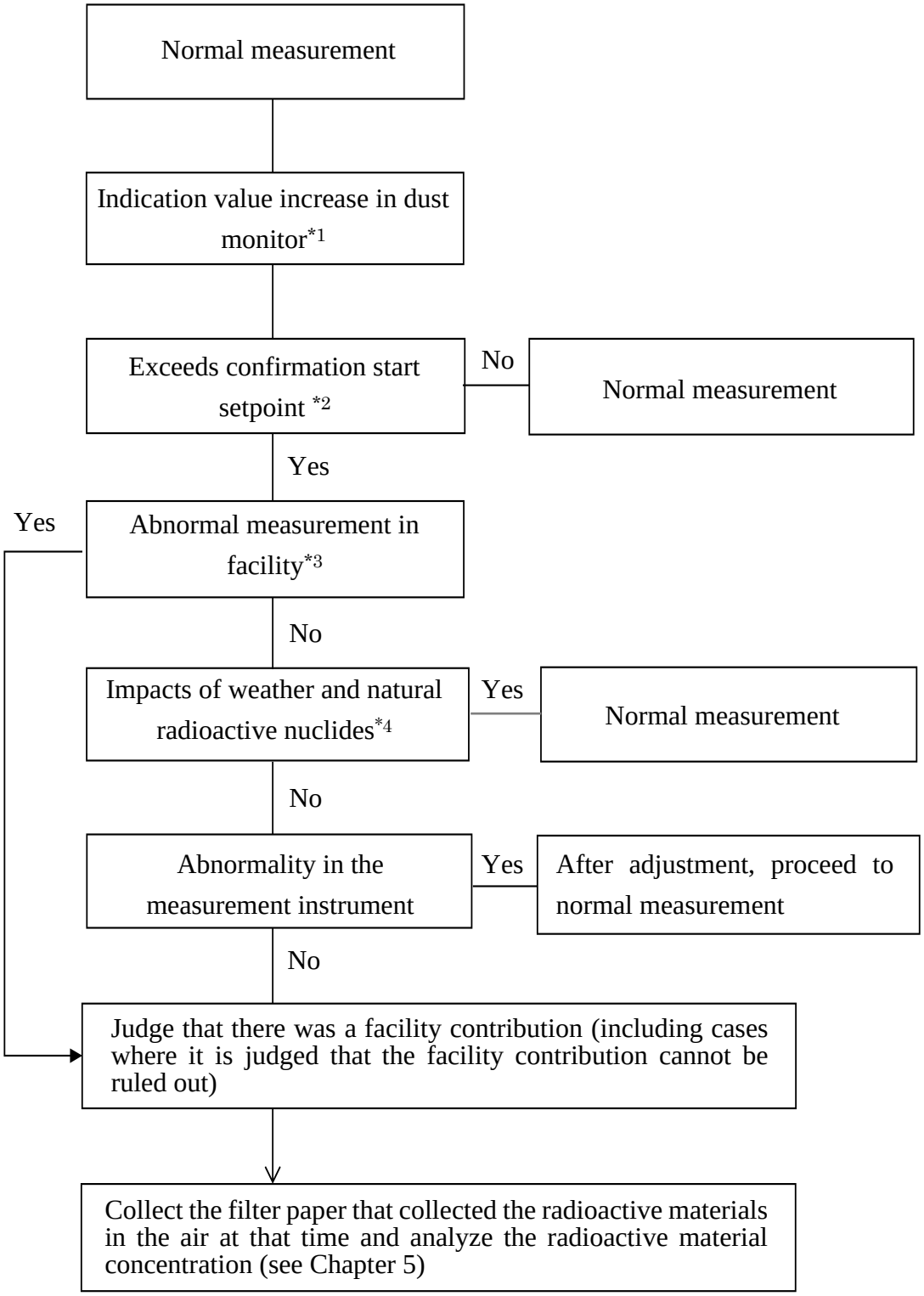
Refer to Section 4.4 for the filter paper collection procedure and Chapter 5 for the subsequent analysis procedure.

3.5 Evaluation of measurement results

3.5.1 Evaluation flow

The purpose of evaluating dust monitor measurements is to provide early detection of the effects of unexpected releases of radioactive materials from nuclear facilities. For this purpose, it is necessary to establish an appropriate confirmation start setpoint and initiate a factor investigation to determine if the facility contribution is present or not when that value is exceeded. An example flowchart for discriminating facility contributions is shown in Figure 3-5.

The Normal Time Supplementary Reference Materials states that the confirmation start setpoint should be set considering the variation of individual devices and the maximum value in the past. In light of the current technical standards, the maximum value should be approximately 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting radionuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration) for the measurement after facility contribution discrimination. Measurements also vary with natural factors (refer to 3.5.3). Thus, measurements can exceed the confirmation start setpoint even without a facility contribution. Since the confirmation start setpoint triggers the confirmation action, the facility contribution of the above level must at least be detectable in light of the current technical level. However, a lower value may be used as the confirmation start setpoint considering equipment performance, natural variations, administrative requirements, and other factors.



*1 Measurement after facility contribution discrimination

*2 After evaluating the facility contribution in the dust monitor measurements, the confirmation start setpoint should be set considering the variation of individual equipment and the past maximum value. The maximum value for the confirmation start setpoint should be 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting radionuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration). Refer to 3.5.2 for setting the confirmation start setpoint.

*3 Abnormal values of area monitoring equipment, etc., in the facility or status of releases (including controlled releases) outside the facility

*4 Analysis of β/α ratio (ratio of gross β radioactivity concentration divided by gross α radioactivity concentration), spectrum, etc. (Weather data such as rainfall, snowfall, and lightning are also considered.)

Figure 3-5. Example of a flowchart for discriminating facility contribution to the results of continuous measurement of airborne radionuclide concentrations (including cases where the possibility that it is a facility contribution cannot be ruled out)

3.5.2 Monitoring for exceeding the confirmation start setpoint

(1) Evaluation method

The confirmation start setpoint is for initiating a factor investigation to determine whether there was a facility contribution to the dust monitor measurements (including cases where the possibility of a facility contribution cannot be ruled out) when the dust monitor measurements increase after discriminating the facility contribution.

The Normal Time Supplementary Reference Materials states that the confirmation start setpoint should be set using measurements after facility contribution discrimination, considering individual device fluctuations and the maximum values in the past. Its maximum value should be set at approximately 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting radionuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration) in light of the current technical standards.

Since the confirmation starts setpoint triggers the confirmation action, at least the above level of facility contribution must be detectable in light of current technical standards. However, a lower value may be used as the confirmation start setpoint considering equipment performance, natural variations, administrative requirements, and other factors.

The data used to set the confirmation start setpoint shall be the measurement after facility contribution discrimination, and the maximum value shall be the confirmation start setpoint. If the maximum value is greater than 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting nuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration), the confirmation start setpoint shall be set at 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting nuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration).

The following are some notes on the data used for the above setup.

- Use the hourly measurements taken over the past 3 to 5 years. If no data is available over the past three years, use hourly measurements from at least the past year.
- The data should not include abnormal values such as equipment errors.
- The data should not include measurements determined to have been contributed by the facility.

The confirmation start setpoint should be reviewed periodically in accordance with updates to the normal time monitoring plan, equipment upgrades, changes in the surrounding environment, etc.

The alarm level should be set so that the person in charge is notified in real time when a measurement value exceeds the confirmation start setpoint.

Various methods have been put into practical use to discriminate facility contributions. However, it is necessary to select an appropriate method according to the characteristics of the facility to be monitored. It is also essential to fully understand the principles of each method and the meaning of the measurements before evaluation.

In this section, we show how to use the β/α ratio (ratio of gross β radioactivity concentration divided by gross α radioactivity concentration) when α- and β-ray dust monitors are used. It should be noted that this method is based on the fact that the β/α ratio is generally constant when there is

no influence from nuclear facilities and thus can only be used to estimate the facility contribution to the gross β radioactivity concentration when the major release from nuclear power reactor facilities, etc., results from β-ray emitting nuclides. There is no influence from α-ray emitting nuclides.

In cases where facility-induced α-ray emitting radionuclides are released at uranium processing facilities or plutonium processing facilities, or both α-ray and β-ray emitting radionuclides are released at reprocessing facilities, it is necessary to discriminate and evaluate the facility contribution by the method using the αβ coincidence counting or spectral analysis as described in Explanation F.

Refer to Explanation F for the discrimination evaluation method for the facility-induced portion in the gross α radioactivity concentration and the discrimination evaluation method other than the evaluation method using the β/α ratio in the gross β radioactivity concentration.

(a) Method using β/α ratio

Due to the influence of radon/thoron decay products, the gross α and β radioactivity concentrations fluctuate to a large extent over time. However, the ratio of the two, the β/α ratio, remains almost constant. Using this property, estimating the total beta radioactivity concentration from natural radioactive materials and subtracting it from measurements allows for evaluating the gross β radioactivity concentration derived from facility-induced radioactive materials.

This method is effective when the gross β radioactivity concentration from facility-induced radioactive materials is dominant and is not applicable when the ratio of the gross β radioactivity concentration to the gross α radioactivity concentration from facility-induced radioactive materials is comparable to the ratio from natural radioactive materials (radon/thoron decay products).

It should be noted that the β/α ratio may be calculated higher for the data immediately after the filter paper is fed because the gross β radioactivity concentration is apparently higher than the gross α radioactivity concentration due to airborne dust penetrating the filter paper, and that small radiation counts may make the β/α ratio vary widely. If this results in a higher frequency of exceeding the confirmation start setpoint, it is recommended that an evaluation is performed for each elapsed time since the filter paper was fed (refer to Explanation F.3 for an example of evaluation).

1) Setting the standard β/α ratio

Calculate the average value of β/α ratio from hourly measurements for the past several years without influence from nuclear facilities at the target measurement points and set the standard β/α ratio. The standard β/α ratio may also be determined from the slope of the correlation between the gross α and gross β radioactivity concentrations. An example evaluation is shown in Figure 3-6.

2) Calculating the estimation of facility-induced gross β radioactivity concentration

The natural gross β radioactivity concentration is estimated from the product of the hourly measurement of the gross α radioactivity concentration and the standard β/α ratio. The facility-induced gross β radioactivity concentration is estimated by subtracting the estimated natural gross β radioactivity concentration from the hourly measurement of gross β radioactivity concentration.

<u>Evaluation formula</u>

Measurement of gross α radioactivity concentration × Standard β/α ratio = estimated value of natural gross β radioactivity concentration

Measurement of gross β radioactivity concentration – estimated value of natural gross β radioactivity concentration = estimated value of facility-induced gross β radioactivity concentration

3) Determination of confirmation start setpoint

The maximum value of the estimated facility-induced gross β radioactivity over the past several years is set as the discrimination level. The evaluation example of Figure 3-7 shows 0.78 Bq/m^3.

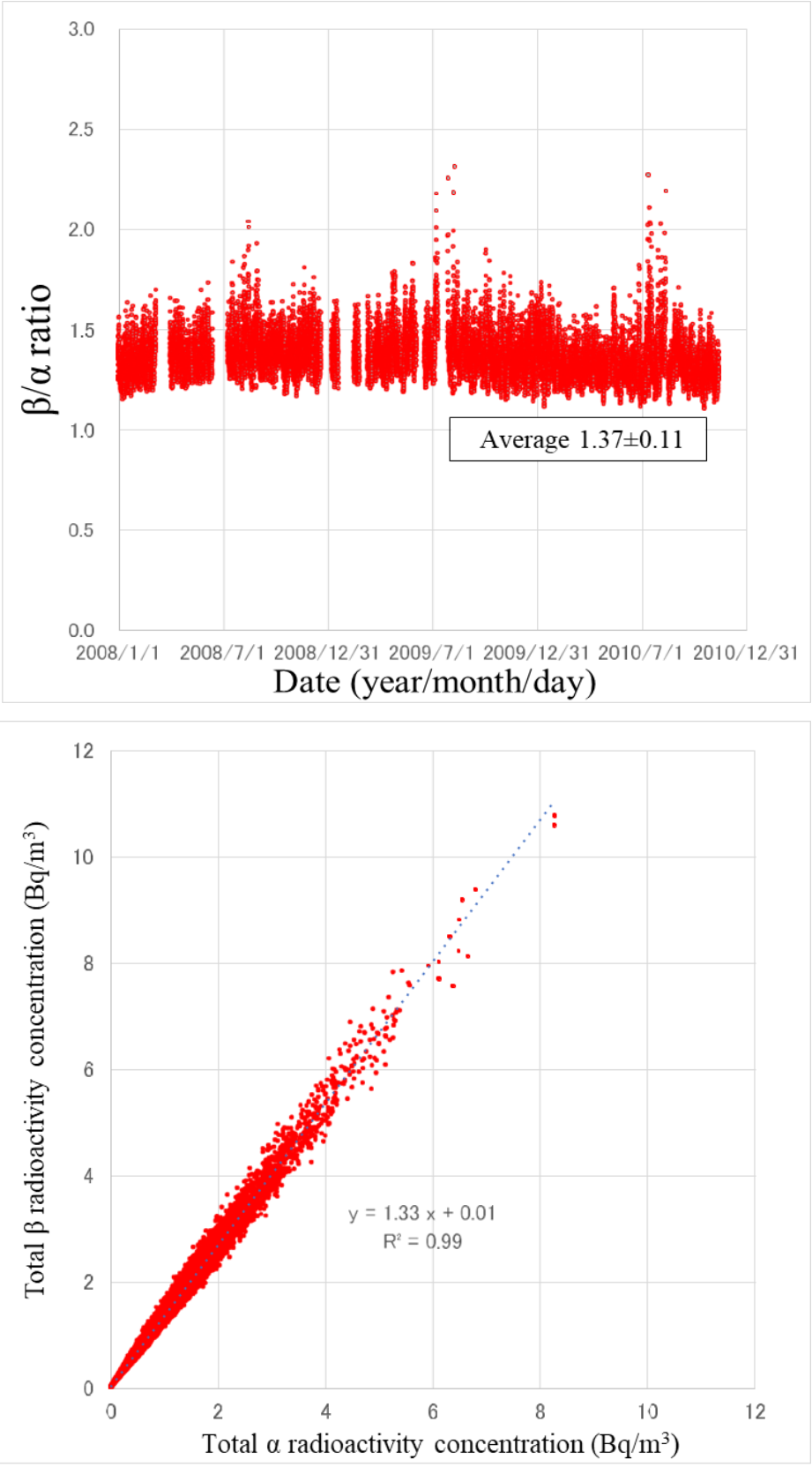


Figure 3-6. Example of evaluation of standard β/α ratio
(Top: Example of evaluation by average value. Bottom: Example of evaluation by the slope of correlation)

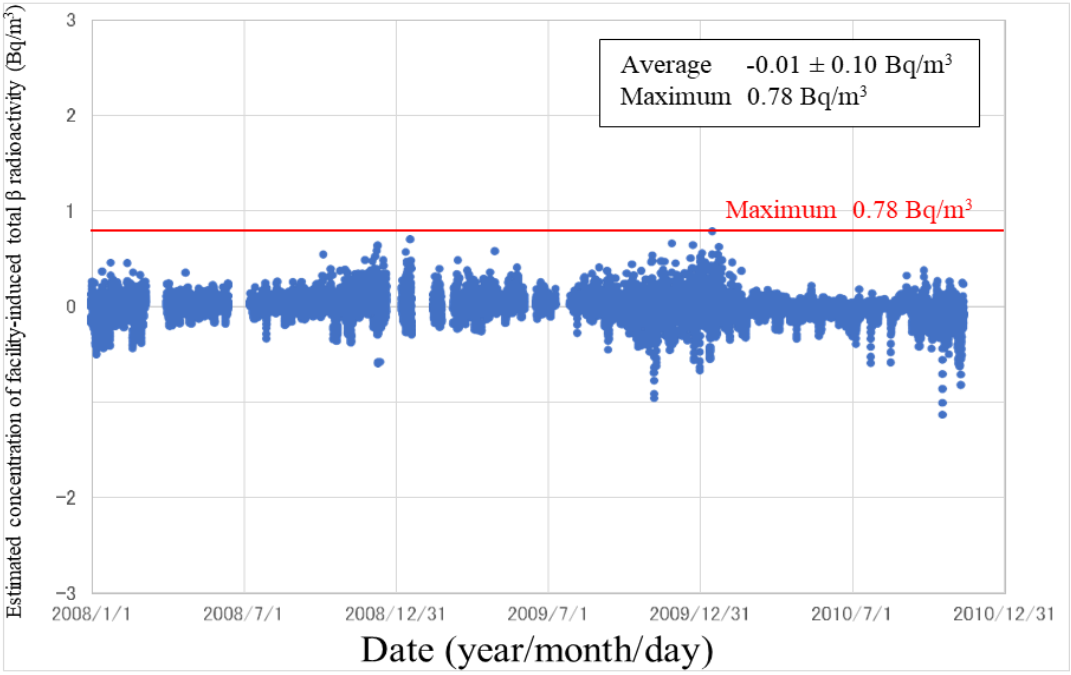


Figure 3-7. Example of evaluation of estimated facility-induced gross β radioactivity concentration

Figure 3-8 shows an example of evaluating the facility-induced contribution of radioactive materials based on dust monitor measurements in Chiba City, Chiba Prefecture, during the TEPCO's Fukushima Daiichi Nuclear Power Plant (hereinafter referred to as "Fukushima Daiichi NPP") accident in March 2011. The increase in the gross β radioactivity concentration since March 15 can generally be evaluated as an estimate of the facility-induced gross β radioactivity concentration.

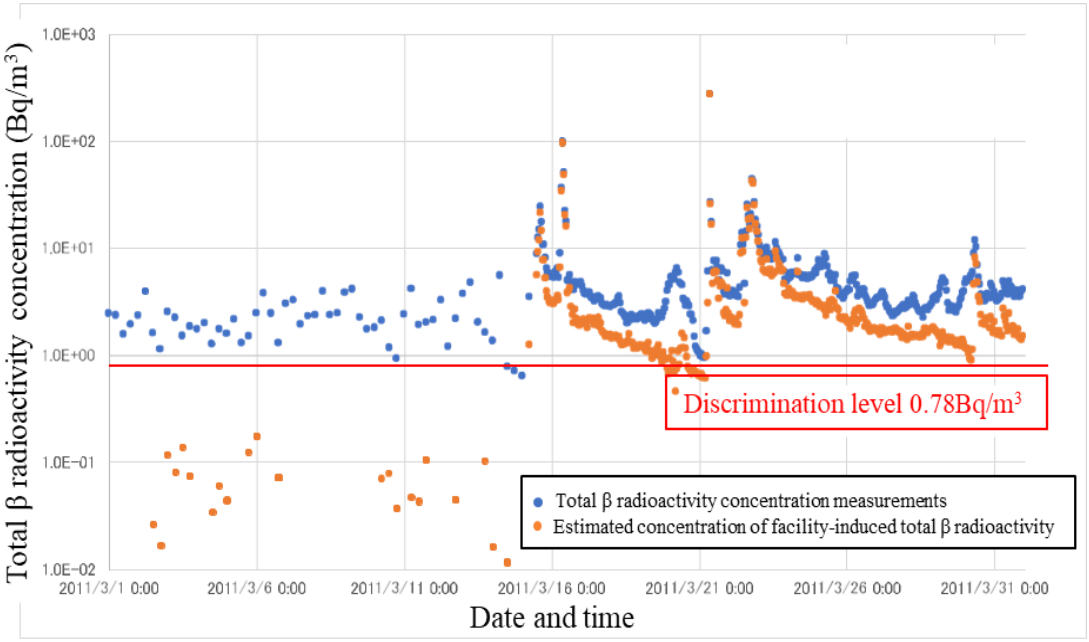


Figure 3-8. Example of evaluation of estimated facility-induced gross β radioactivity concentration at the time of the TEPCO's Fukushima Daiichi NPP accident

*Before 12:00 on March 15, 2011, the measurements are shown for the first hour of every 6 hours of filter paper feeding, and after that, the measurements are shown hourly for every hour of filter paper feeding. Only positive values are shown for the estimated values of facility-induced gross β radioactivity concentration.

(2) Actions to be taken when the confirmation start setpoint is exceeded, etc.

If the hourly measurement exceeds the confirmation start setpoint, check abnormalities or effects in (a) – (d) below.

(a) Abnormalities in facility measurements, etc.

- Releases outside nuclear facilities (including controlled releases)
- Abnormal values of area monitoring equipment, etc., in nuclear facilities
- Release and diffusion of artificial radioactive materials into the air due to the effects of nuclear explosion tests, etc.

(b) Effects of weather, natural radioactive materials, etc.

- Weather factors such as rainfall, snowfall, snow accumulation, etc.
  - Washing away of airborne dust from the air by rainfall or snowfall

- Suppression of resuspension of airborne dust from the ground surface due to rainfall, snowfall, and snow accumulation, and suppression of emission of radon/thoron decay products.
- Increase in airborne dust due to natural phenomena such as soil uplift during high winds and yellow sand
- Increase in near-surface radon/thoron decay product concentrations associated with stabilization of the air at dawn
- Noise caused by lightning

・ Changes in geography, topography, and other natural conditions due to natural disasters, etc.
・ Changes in the surrounding environment due to human factors, such as civil engineering works in the neighborhood

(c) Abnormality of measuring instruments, etc.

・ Failure of measuring instrument
・ Changes in measurement conditions such as sampling method, the performance of measuring instruments, measurement method, etc.
  - Change in measurements due to contamination around the detector
  - Fluctuations in measurements due to changes in air sampling flow rate
  - Fluctuations in measurements due to improper grounding or unstable voltage
  - Variation in performance of air absorbents

(d) Variation of measurements due to counting uncertainty

3.5.3 Management of dust monitors by normal variation range

Dust monitor measurements before facility contribution discrimination include the contribution from natural radioactive materials and will vary even in the absence of facility contribution. This is induced by changes in the concentration of radon/thoron decay products in the air due to natural factors such as rainfall, snowfall, wind strength, seasonal wind effects, etc. Therefore, it is effective from a management perspective to ascertain the normal fluctuation range and to check for any abnormalities in the equipment if the measurement exceeds this range. If necessary, investigating the frequency of exceeding the normal fluctuation range due to natural variations may also be available to set a confirmation start setpoint. The normal fluctuation range is the certain range within which measurement fluctuations are generally considered to fit under normal operation of nuclear facilities and when measurement conditions are appropriately managed.

(1) Calculation method of the range of normal fluctuation

The same data used for setting the confirmation start setpoint (refer to 3.5.2(1)) should be used to calculate the normal fluctuation range. Data including the contribution of natural radioactive materials without discriminating facility contribution shall be used.

The normal fluctuation range is calculated from the arithmetic mean of hourly measurements of gross α radioactivity concentration or gross β radioactivity concentration for the past several years + (3 x arithmetic standard deviation), etc.

Fluctuations in dust monitor measurements in normal times are due to changes in the concentration of radon/thoron decay products and often include seasonal variations, as shown in Figure 3-9, due to natural factors such as wind strength, seasonal wind effects, rainfall, and snowfall. The variation in measurements also varies with the time elapsed since air sampling.

If the frequency distribution of individual measurements, as shown in Figure 3-9, can be regarded as a log-normal distribution, as shown in Figure 3-10, it is better to calculate the range of normal variation using the geometric mean instead of the arithmetic mean, as shown in Figure 3-11*. Using the geometric mean, the normal fluctuation range is the geometric mean value of hourly measurements of gross α or β radioactivity concentrations for the past several years × (the cube of the geometric standard deviation).

*The arithmetic mean is the average value obtained by dividing the sum of all measurements by the number of measurements and is commonly used.
The geometric mean is the average value obtained by multiplying all the measurements and taking the radical root of the power of the number of measurements. It is used, for example, to obtain the average value of the rate of change.

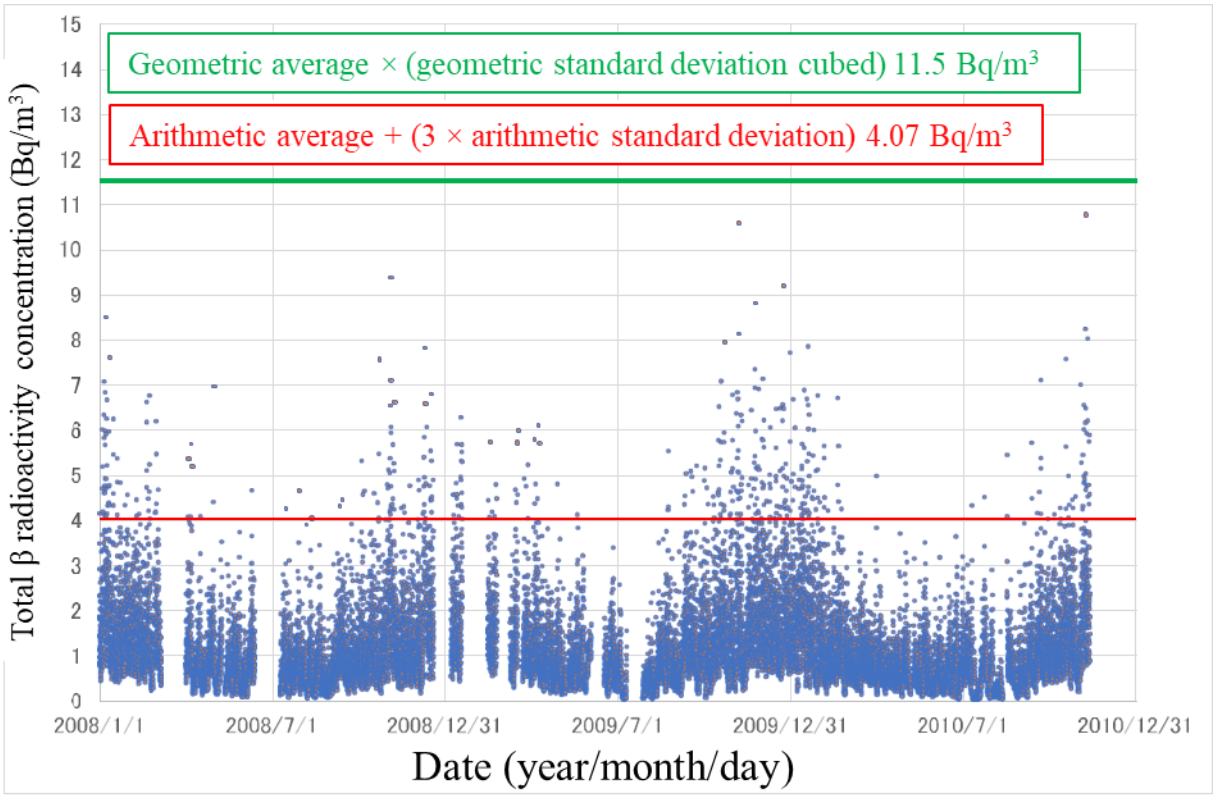


Figure 3-9. Example of change over time in dust monitor measurements (gross β radioactivity concentration)

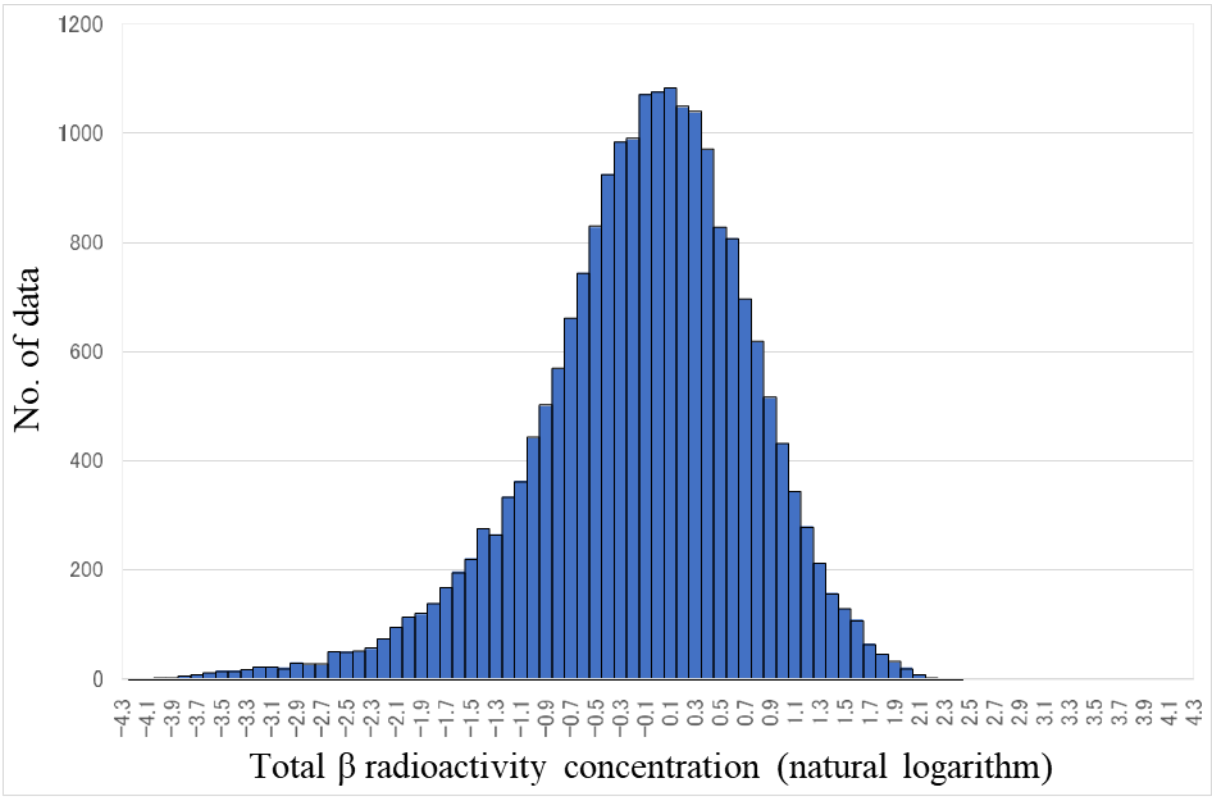


Figure 3-10. Frequency distribution of dust monitor measurements (log-normal distribution)

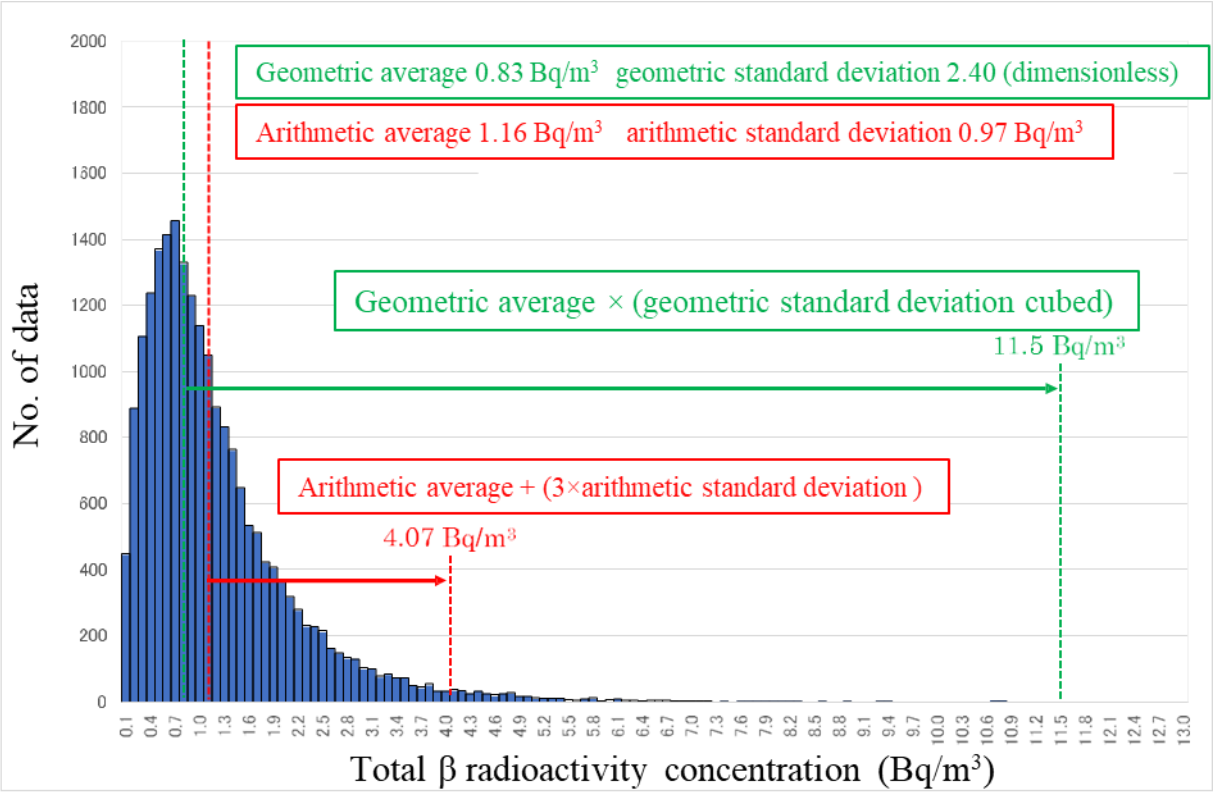


Figure 3-11. Setting an example of the normal fluctuation range of dust monitor measurement values

(2) Confirmation of exceeding the normal fluctuation range

If the normal fluctuation range is exceeded, it is effective for management to check whether the cause is due to natural fluctuations or any abnormalities in the equipment.

If the frequency of exceeding the normal fluctuation range increases during periods when the dust monitor measurements are high due to natural fluctuations, it is recommended to use the maximum value of gross α or β radioactivity concentration over the past several years or to make an evaluation by setting the normal fluctuation range for each elapsed time since filter paper feeding or for each season.

However, it should be noted that if the maximum value over the past several years is used, it will be larger as a normal fluctuation range and looser as a criterion for judgment.

3.5.4 What to do when it is determined that there has been a facility contribution

If the confirmation start setpoint was exceeded and a factor investigation determined that there was a facility contribution (including cases where the possibility of a facility contribution cannot be ruled out), collect filter paper containing airborne dust collected at the time in question, and conduct a precise analysis of radionuclide concentration to estimate and evaluate the exposure dose to nearby residents, etc.

If a dust sampler is installed, collect its filter paper.

The measurement targets for precise analysis according to the nuclear facilities listed in the Normal Time Supplementary Reference Materials are shown in Table 3-13. The procedure for precise analysis is described in Chapter 5.

Table 3-13. Measurement targets for precise analysis when it is determined that there was a facility contribution

Nuclear facility	Measurement target
Nuclear power reactor facilities (PAZ and UPZ settings required)	γ-ray emitting nuclides, radioactive iodine
Nuclear power reactor facilities as specified in the Cooling Notice	γ-ray emitting nuclides, radioactive iodine
Nuclear power reactor facilities (UPZ setting not required)	γ-ray emitting nuclides, radioactive iodine
Nuclear reactor facilities for testing and research, etc. (UPZ setting required)	γ-ray emitting nuclides, radioactive iodine
Uranium processing facility (UPZ setting required)	Uranium
Processing facility to handle plutonium	Plutonium
Reprocessing plant	γ-ray emitting nuclides and plutonium

Chapter 4 Collection of Air Samples by Dust Samplers, etc.

Collecting air samples by dust samplers, etc., and analyzing air samples as described in Chapter 5 should be conducted to estimate and evaluate the exposure doses to nearby residents, etc.

The procedures for collecting air samples are based on the description in The Series of Environmental Radioactivity Measuring Methods No. 16, "Environmental sampling method".

4.1 Equipment

Dust samplers or iodine samplers are used to collect air samples. There are two types of dust samplers: low-volume air samplers and high-volume air samplers, and the difference between them is based on suction amount, with no big difference in configuration. The equipment configuration of the dust sampler is shown in (1), and the features of each sampler are shown in (2) and (3). The dust monitor described in Chapter 3 can also be used as a dust sampler.

The relationship between the air sampling time of filter paper and the required detection limit concentration, etc., determines the flow rate for collecting air samples. However, a flow rate of 100 to 250 L/min is suitable for airborne dust only, and approximately 50 L/min is suitable for iodine.

(1) Dust Sampler Equipment Configuration

Figure 4-1 shows that a dust sampler consists of a particle separator, filter medium holder, flow controller, and suction pump. The functions of each part are shown in (a) through (d).

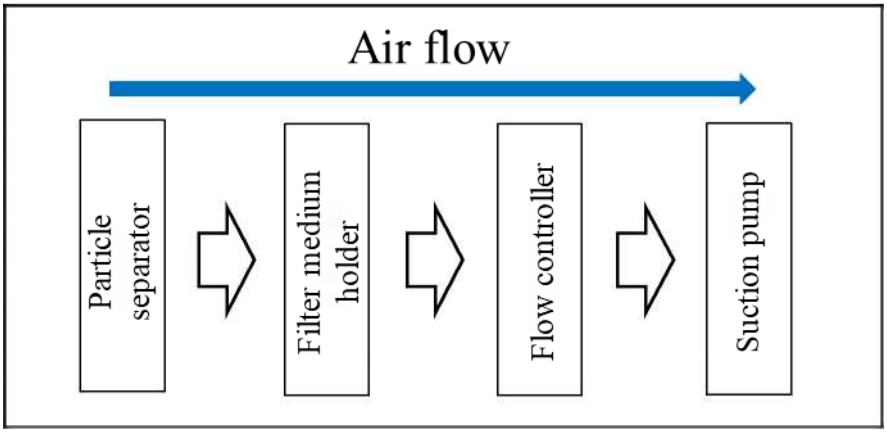


Figure 4-1. Configuration of a dust sampler

(a) Particle separator (particle size sorting unit)

A particle separator separates airborne dust of the required particle size from the collected airborne dust. There are three types according to screening methods: gravity settling type (multi-stage parallel plate type particle separator), inertial collision type (inertial collision type particle separator), and centrifugal sedimentation type (cyclone type particle separator). Particle-size sorting of airborne dust is not performed when monitoring nuclear facilities. Therefore, as a general rule, using a particle separator is unnecessary. However, particle separators effectively obtain radioactivity concentration for each particle size of airborne dust.

(b) Filter medium holder (mounting unit of absorbents (filter paper))

The filter medium holder has a structure that facilitates replacing the filter medium (a device such as a filter paper that filters and collects particulate matter. In this measurement method, it is referred to as an air absorbent.) and prevents filter medium damage and air leaks.

(c) Flow controller (suction amount adjusting unit)

The flow controller is structured to control the actual flow rate through the particle separator to a predetermined flow rate based on air temperature and air pressure.

The method of controlling the actual flow rate depends on the flow meter used (see JIS Z 8814:2012 "Low-volume air samplers" Annex A [6] for the method of correcting the actual flow rate).

Flow meters widely used are area-type, differential pressure-type, volume-type, and mass-type.

(d) Suction pump

A suction pump suctions air at a predetermined flow rate through an air absorbent and includes linear motor-driven, rotary, and diaphragm types. The rotary type has a high flow rate and low fluctuation. Diaphragm and piston types have moderate flow rates and fluctuations, while the turbo type has a high flow rate and fluctuation.

Fluctuations in flow rate due to changes in pressure drop of filter paper, etc., depend on the type of pump.

(2) Low-volume air sampler

It is designed for continuous air sampling and can withstand approximately several days to a week of use. The suction amount is approximately from 20 to 100 L/min. Filter paper of approximately 5 cm in diameter is attached to the filter paper holder, and activated carbon cartridges are also attached for collecting radioactive iodine.

An example of equipment specifications of a low-volume air sampler is shown in Table 4-1. Note that equipment not listed in the example specifications may be used if it performs well.

For the performance of the dust sampler, refer to the detection limit in Explanation B.

Table 4-1. Example of equipment specifications of a low-volume air sampler

item	Type A	Type B	Type C	Type D
Rated suction amount	40 L/min or more	50 L/min or more	120 L/min or more	20 to 120 L/min
Variable flow range	30 to 50 L/min	50 L/min	-	20 to 120 L/min
Air absorbent	Cellulose and glass fiber filter paper 60 mm ϕ (activated carbon filter paper or activated carbon cartridges can be attached)	Cellulose and glass fiber filter paper 60 mm jig (activated carbon filter paper or activated carbon cartridges can be attached)	Cellulose and glass fiber filter paper (105-110 mm ϕ)	Cellulose and glass fiber filter paper 60 mm (activated carbon filter paper or activated carbon cartridges can be attached)
Measurement Information	Flow rate, integrated flow volume			
Portability	Yes			
Weight	Approx.* 6 kg	Approx. 15 kg	Approx. 3 kg	Approx. 8 kg
Dimensions W×D×H(mm)	150×205×177	260×260×1000	200×162×262	190×323×285
Power	AC100 V 1.5 A	AC100 V 300 VA	Battery DC7.4 V 3200 mA	AC100 V
Other	Continuous operation: up to 99 hours	-	Continuous operation More than 60 minutes	Continuous operation: Approx. 1 week

*Approx.=Approximately

(3) High-volume air sampler

It is unsuitable for continuous air sampling over a long period because it collects airborne dust by suctioning a large amount of air in a short time.

The suction amount should be approx. 200-2000 L/min. Attach the large filter paper with approx. 10 cm in diameter or approx. 8 inches (203 mm) x 10 inches (253 mm) square.

There are two types of equipment: transportable type and large installed type equipment.

An example of equipment specifications of a high-volume air sampler is shown in Table 4-2. Note that equipment not listed in the example specifications may be used if it performs well.

For the performance of the dust sampler, refer to the detection limit in Explanation B.

Table 4-2. Example of high-volume air sampler equipment specifications

item	Type A	Type B	Type c
Rated suction amount	650 L/min	500 L/min	1000 L/min
Variable flow range	-	100 to 800 L/min	100 to 1200 L/min
Air absorbent	Cellulose and glass fiber filter paper 105 to 110 mm ϕ	glass fiber filter paper 110 mm ϕ	silica filter paper 8 ×10 inch
Measurement Information	Flow rate, integrated flow volume		
weight	Approx. 4 kg	Approx. 8 kg	Approx. 31 kg
Dimensions W×D×H (mm)	165×169×165	425×200×270	575×575×1420
Power	AC100 V 580 W	AC100 V 10 A	AC100 V 10 A

4.2 Air absorbent

Filter papers for collecting airborne dust include cellulose and glass fiber filter paper, and activated carbon filter paper and activated carbon cartridges are used for collecting gaseous radioiodine. Their intended uses differ.

In JIS Z 4601:2009 “Radioactive dust samplers” [7], the performance of filter paper is described as “The collection efficiency should be 95% or more for particles of 0.3 μm in diameter”. The filter paper used has a collection efficiency of approximately 99% for particles of 0.3 μm in diameter. However, some cellulose and glass fiber filter paper does not necessarily have sufficient collection efficiency for particles of 0.1 μm or lower in diameter, and caution should be exercised when collecting samples in an environment dominated by particles of 0.1 μm or lower in diameter*.

* See Reference A Characteristics of air absorbent.

(1) Air absorbent for low-volume air sampler

(a) Cellulose and glass fiber filter paper

This filter paper is made of cellulose and fine glass fibers, with a cloth backing and water-repellent treatment for reinforcement.

It conforms to the filter paper specified in JIS Z 4601: 2009 “Radioactive dust samplers” [7].

(b) Glass fiber filter paper

It is made of ultra-fine borosilicate glass fibers with low hygroscopicity. It is also characterized by high collection efficiency.

(2) Air absorbent for high-volume air sampler

(a) Cellulose and glass fiber filter paper

Equivalent to (1)(a), circular (105 mm ϕ) and square (8 inches × 10 inches) types are available.

(b) Glass fiber filter paper

Equivalent to (1)(b) and square types (8 inch × 10 inch).

The collection efficiency, etc., of filter paper is shown in Table 4-3.

Table 4-3. Example of filter paper collection efficiency, etc.

Filter paper material	Cellulose and glass fiber				Glass fiber
Weight (g/m^2)	145			120	95
Thickness (mm)	0.41			0. 40	0. 38
Pressure drop (kPa)	0. 27			0. 32	0. 30
Water repellency (kPa)	4.9			4.9	-
Ventilation speed (cm/s)	55	80	135	20	-
Collection efficiency (%)	99. 7*[1]	99. 8*[1]	99. 9*[1]	99*[2]	99. 99*[3]

Pressure drop: The differential pressure between the upstream side (before passage) and the downstream side (after passage) of air as the air passes through the filter paper at a ventilation speed of 5 cm/s.

For the measurement method, refer to JIS K 0901: 1991, “Shape, dimensions, and performance test method of filter medium for collecting dust samples in gas” [8].

Water repellency: pressure required for water to pass through.

Ventilation speed: the speed at which air passes through.

*1 Collection efficiency: measured from particle concentrations upstream and downstream when 0.31 μm polystyrene latex particles were filtered at a ventilation speed of 55 to 135 cm/s.

*2 Collection efficiency: measured from upstream and downstream particle concentrations when 0.3 μm polyalphaolefin particles are filtered at a ventilation speed of 20 cm/s.

*3 Collection efficiency: value obtained when 0.3 μm dioctyl phthalate particles are filtered at a ventilation speed of 5 cm/s

4.3 Installation and inspection

This section describes the outdoor installation and inspection methods of dust samplers. For indoor installation, refer to 3.3, as it is common to dust monitors.

4.3.1 Installation

Select an installation location for a dust sampler that is a flat area (e.g., the center of a park or parking lot) without trees or buildings in the vicinity and where certain facilities do not strongly influence the dust sampler. In addition, select an installation location, considering the availability of a power supply and ease of maintenance and inspection. If no suitable location is available, it may be installed on a flat rooftop of a building.

The height of the suction port should be approx. 1 m above the ground to match the height at which the air dose rate is measured. It may be higher than 1 m if there is an effect of updraft from the ground surface, snow accumulation, etc. Install a rain shelter to prevent rainfall and snowfall from entering it and take a fall prevention measure.

When multiple dust samplers are used simultaneously, they should be arranged so that their exhaust does not affect each other. If a transportable type generator is used as a power supply, the suction of its exhaust is avoided.

4.3.2 Inspection

To maintain the performance of the dust sampler, it must be inspected on a regular daily basis, and the flow meter must be calibrated about once a year. Inspection and calibration are requested to a professional organization or manufacturer for proper maintenance and management.

An Example of daily inspection items is shown below. Refer to the dust sampler’s user manual for detailed inspection methods.

Example of daily inspection items	
(1) Visual inspection	There is no trace of a strong impact.
	No dirt (dust accumulation, etc.)
	No screw or part that is missing or broken
(2) Check of operation	There is no anomaly in the operation panel display and its operation.
	No leakages when filter paper is installed
	Flow rate setting and start/stop operation should be standard.
	The power anomaly recovery function and its recording should be expected.
(3) Check of temperature, air pressure, and flow rate	The displayed temperature is within the standard range of an ordinary thermometer
	The displayed air pressure is within the standard range of the atmospheric pressure gauge.
	The displayed flow rate (set flow rate) is within the standard range.

An example of the main regular inspection items performed by manufacturers and others is shown below.

Example of periodic inspection items		
(1) Visual inspection		Samplers, pumps, recorders, cables, and connectors
(2) Stand-alone operation · Performance test	Sampler	Check of control operation
		Check of alarm operation
		Leak test of air sampling unit
		Flow rate indication accuracy (maximum flow rate check)
	Pump	Operation check (heat generation, abnormal noise, vibration, unusual odor, etc.)
		Periodic replacement of worn parts
	Recorder	Indication accuracy

4.4 Collection

4.4.1 Collection Method

	Procedure
1	Conduct an operation test of the dust sampler to check its performance, then attach the specified filter paper.
2	Start air sampling and record the time and flow meter reading immediately after the start.
3	During air sampling, read the value of the flow meter at appropriate time intervals to obtain the total suction amount (Vt)* using the following formula. $Vt = V_1t_1 + V_2t_2 + \ldots\ldots\ldots + V_nt_n$ (L) V_1 to V_n: flow meter value (L/min) t_1 to t_n: time (min) corresponding to the flow rate readings
4	Read the value of the flow meter immediately before the end of air sampling and record the end time. Note that a dust sampler with an integrating flow meter reads the value of the integrated flow volume.
5	After the suction, place the filter paper in a designated storage container to prevent the collected airborne dust from falling out.

* The air suction amount during air sampling varies greatly depending on the amount of airborne dust. The collection time should be set within the range where the flow rate does not drop below 90% of the initial suction value due to clogging of the filter paper by collection.

4.4.2 Setting sampling conditions

The air suction amount is determined according to the purpose of γ-ray spectrometry and radiochemical analysis, etc.

Usually, continuous air sampling is conducted for approx. a week at approximately 50 to 100 L/min in case of using a low-volume air sampler fitted with a circular filter paper approx. 5 cm in diameter. If a high-volume air sampler is equipped with a large circular or rectangular filter paper, the sample for measurement is prepared by air sampling at 200-1000 L/min from several hours up to 24 hours.

4.4.3 Records of samples

An example of records during sample collection is shown in Table 4-4.

Table 4-4. Example of records during sample collection

Item	Example of records	
(1) Name of sampling institution		
(2) Name of sampler		
(3) Sample No.		
(4) Date and time of sampling	Start time - End time	
(5) Sampling location (latitude, longitude)	Installation location and surrounding circumstances, suction port height (latitude and longitude)	
(6) Sampling situation	Weather, etc., during the sampling period	
(7) Sampling method	Equipment used, type and size of filter paper, number of sheets, etc.	
(8) Flow rate	At the start L/min	At the completion L/min
(9) Suction amount	Integrated flow volume L	Suction time min
(10) Processing situation		
(11) Processor name		
(12) Transportation situation	Transportation method, sample shape, sample volume, etc.	
(13) Other reference items		

4.4.4 Sample transport

Filter paper that has collected airborne dust should be placed in a polyethylene bag or other storage container with the dust collection side folded inward, then sealed with tape, etc., for transportation. A copy of the sampling record should be attached to the transported sample.

Chapter 5 Analysis of Air Samples Collected by Dust Samplers, etc.

Air samples are analyzed either (a) by collecting filter paper from dust samplers, etc., at each continuous sampling for a certain period according to the nuclear facility or (b) by collecting filter paper from dust samplers urgently when continuous measurement by dust monitors or monitoring posts detects emitted radioactive materials or radiation (i.e., when the results of continuous measurement of the concentration of radioactive materials in the air or the air dose rate increase indicating the facility contribution to the increase (including cases where it is judged that the possibility of the facility contribution cannot be ruled out)), to estimate and evaluate the exposure doses to nearby residents, etc.

Analysis methods for filter paper collected from dust samplers, etc., can be broadly classified into analysis of γ-emitting nuclides by γ-ray spectrometry and analysis of α-emitting nuclides, etc., by radiochemical analysis. This chapter describes the pretreatment and analytical methods for both analyses on the collected filter paper.

The Normal Time Supplementary Reference Materials stipulates that at nuclear power reactor facilities, etc., γ-emitting nuclides in the air are measured by germanium semiconductor detectors approximate once a month, and at uranium processing facilities and processing facilities handling plutonium, uranium, or plutonium levels in the air are measured approximately once every three months by radiochemical analysis, etc., and further at reprocessing facilities, γ-emitting radionuclides and plutonium in the air are measured approximately once every three months by germanium semiconductor detectors or radiochemical analysis (see (a) above). When the contribution of a facility is recognized by continuous measurements using dust monitors or monitoring posts, samples are collected from dust samplers, etc., and the following measurements are conducted: the concentrations of γ-emitting nuclides, etc. are measured by germanium semiconductor detectors, etc. at a nuclear power reactor facility, etc.; the uranium concentrations are measured by radiochemical analysis, etc. at a uranium processing facility; at a plutonium processing facility, plutonium concentrations are measured by radiochemical analysis, etc.; and at a reprocessing facility, the concentrations of γ-emitting nuclides, radioactive iodine, and plutonium are measured by germanium semiconductor detectors or radiochemical analysis (see (b) above).

At a uranium processing facility and processing facility that handles plutonium, uranium or plutonium in environmental samples should be measured only when facility-derived uranium or plutonium is detected by the measurement described in (1) above. However, radiochemical analysis takes time, and there is a high risk that traces will be lost if environmental samples are collected after the final judgment has been made after the analysis. Therefore, it is necessary to collect and measure environmental samples promptly by measuring the gross α radioactivity concentration to determine early whether or not there is facility contribution and then to conduct a radiochemical analysis of collected filter paper.

To determine the presence or absence of facility contribution at an earlier stage than radiochemical analysis, in (a) and (b), a method should be adopted that can easily measure radiation from airborne dust on collected filter paper using a survey meter or the like. Measuring γ-rays of U-235 (186 keV) and Am-241 (60 keV) by γ-ray spectrometry is also effective for screening. In (b), it may also be effective to wait for the decay of natural radioactive materials (radon/thoron decay products) contained in airborne dust before making measurements. Since the apparent half-life of radon decay products is 37 minutes and that of thoron decay products is approximately 12 hours (Figure 5-1), measurement 72 hours (5 hours if radon decay products are predominant) after the stop of air sampling to remove

their effects may enable to determine the presence of facility contribution earlier than radiochemical analysis.

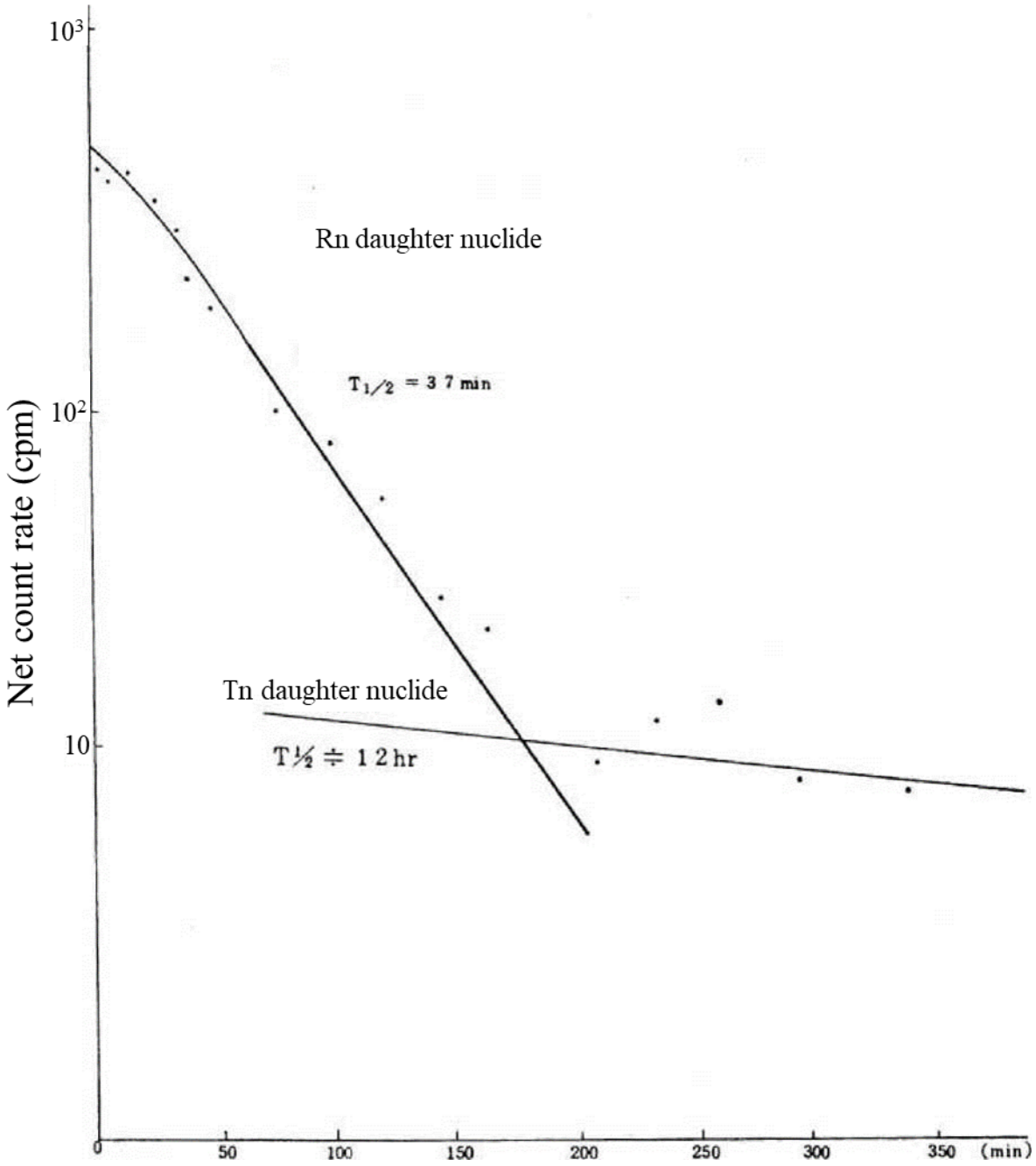


Figure 5-1. Radioactive decay of radon/thoron decay products
[Series of Environmental Radioactivity Measuring Methods No.1]

5.1 Pretreatment

When both γ-ray spectrometry and radiochemical analysis are conducted, the sample should be divided beforehand for each purpose, or radiochemical analysis should be conducted using the sample after the measurement by γ-ray spectrometry.

(1) Pretreatment for γ-ray spectrometry

As pretreatment method, filter paper may be filled directly into the measuring container, clipped and filled, and ashed and filled.

Considering the ease of making a standard radiation source, the highest possible counting efficiency, and good reproducibility, the filter paper is classified into four types according to shape: small circular, large rectangular, large circular, and extended filter paper, and each type is described below.

Since some types of filter paper may contain radioactive materials, a blank test using the same lot of filter paper should be conducted and corrected if radioactive materials are contained.

(A) For small circular filter paper

(a) Direct filling method

	Procedure
1	Carefully place the collected airborne dust into a plastic container that is slightly longer in diameter than the filter paper (measurement container).
2	Press it with a plastic disk or similar object to reach a specific volume and cover it (Figure 5-2).
3	Wrap the sample in polyethylene film to make a measurement sample.

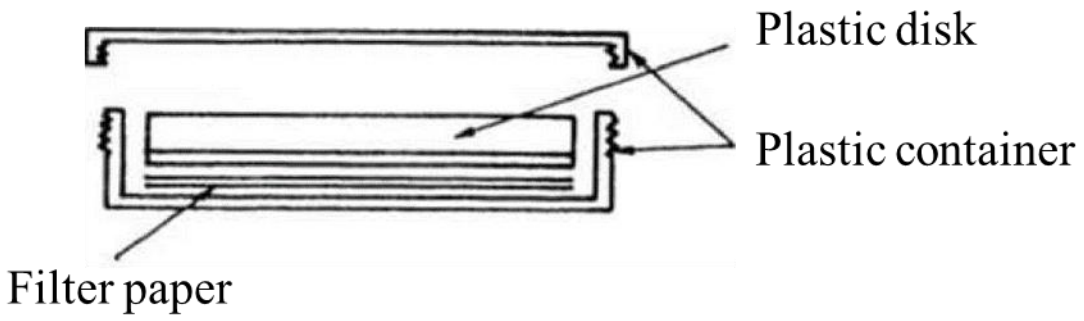


Figure 5-2. Example of filling a plastic container with a filter paper sample
[Series of Environmental Radioactivity Measuring Methods No.16]

(B) For large rectangular filter paper

(a) How to fold

	Procedure
1	Since the air sampling surface is discolored, use scissors to cut off the discolored part, paying attention to keep the collected airborne dust from falling out.
2	With the air-sampling surface facing inside, fold the sample to a specific size, and then wrap it in polyethylene film and seal it, or place it in a plastic container (measuring container) to make a measurement sample.

(b) Circular punching method

	Procedure
1	Punch out the air sampling surface into several circular shapes (Figure 5-3). Note: The diameter of the circle to be punched out is determined by considering the size of the plastic container (measuring container) and the size of the standard radiation source. This should be done on a wooden or lead board with a cork borer or stainless steel radioactivity measuring dish. When removing the punched filter paper, avoid dropping a part of the sample. For this reason, cover the surface of the filter paper with a thin plastic film in advance and punch out the covered film to avoid scattering the sample.
2	Pack the punched filter paper in a plastic container (measuring container) as in (A) to make a measurement sample.

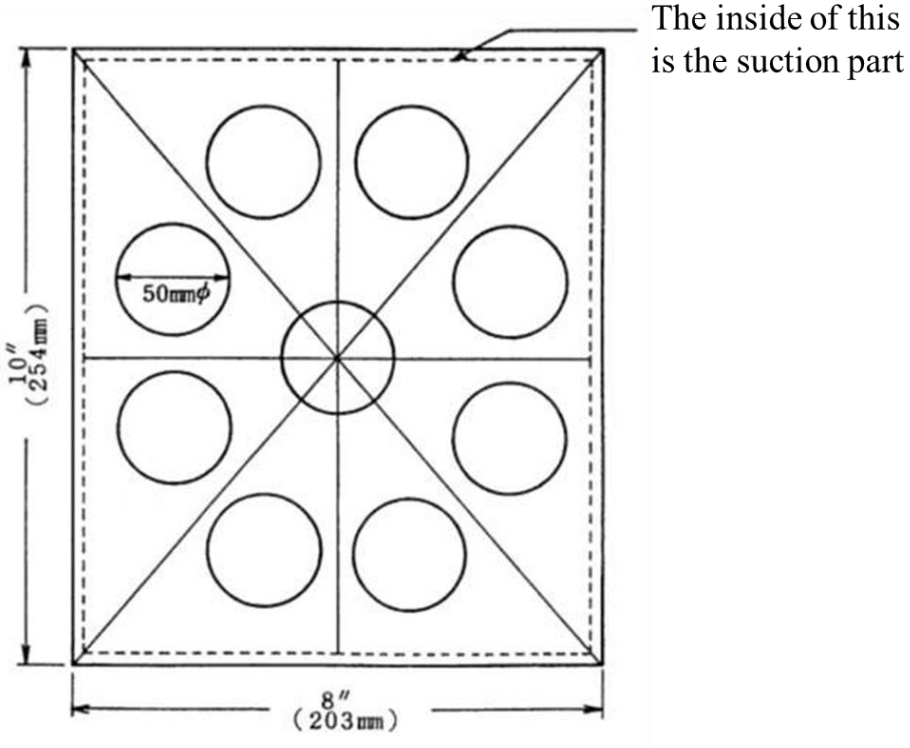


Figure 5-3. Example of punching out large rectangular filter paper
[Series of Environmental Radioactivity Measuring Methods No.16]

(c) Ashing

	Procedure
1	Fold the filter paper (cellulose and glass fiber filter paper, etc.) that has collected airborne dust with the air sampling surface facing inward or cut it into slices with scissors, etc., and place it in a porcelain evaporating dish. Note: Clean the scissors, etc., thoroughly after use.
2	Place it in an electric furnace and ash it at 500 ℃* for 4 to 5 hours. If volatilization of cesium at 500 ℃ is concerned, ashing at 450 ℃ or lower may be applied.
3	After open cooling, transfer the ashed sample to a plastic container (measuring container) using a paintbrush or similar tool.

* It is not applicable to some nuclides because they are volatile. It is noted that even applicable nuclides may be volatile when an electric furnace comes to a higher temperature than the set value due to an abnormal rise in temperature.

(C) For large circular filter paper

(a) How to fold

	Procedure
1	Since the air sampling surface is discolored, use scissors to cut off the discolored area, paying attention to keeping the collected airborne dust from falling out.
2	With the air sampling surface facing inside, fold the sample to a specific size, and then wrap it in polyethylene film, seal it, or place it in a plastic container (measuring container) to make a measurement sample.

(b) Circular punching method

	Procedure
1	To clearly distinguish the suction part of the filter paper, draw a frame on the sampler with the filter paper still attached to the sampler using a pencil or other tool, and then remove the filter paper.
2	Punch out the filter paper in the suction part to obtain one circular piece with a diameter of 5 cm or less or several smaller circular pieces, as shown in Figure 5-4.
3	Place the pieces in a plastic container (measuring container) in layers or wrap them in polyethylene film and seal them to make a measurement sample.

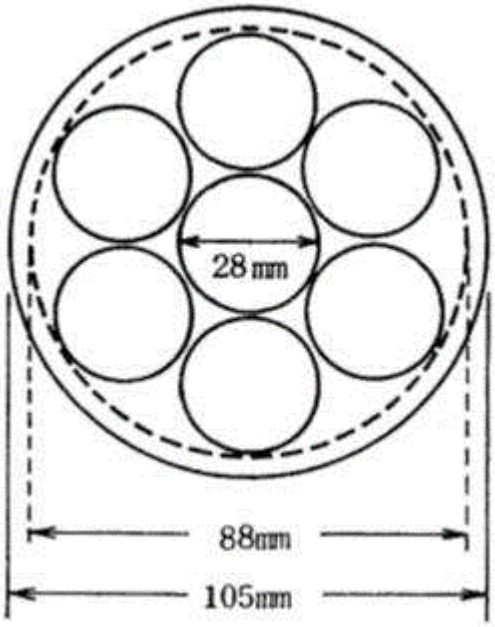


Figure 5-4. Example of punching out large circular filter paper
[Series of Environmental Radioactivity Measuring Methods No.16]

(c) Ashing

	Procedure
1	Fold the filter paper (cellulose and glass fiber filter paper, etc.) that has collected airborne dust with the air sampling surface facing inward or cut it into slices with scissors, etc., and then place it in a porcelain evaporating dish. Note: Clean the scissors, etc., thoroughly after use.
2	Place it in an electric furnace and ash it at 500 ℃* for 4 to 5 hours. If volatilization of cesium at 500 ℃ is concerned, ash it at 450 ℃ or lower.

*It is not applicable to some nuclides because they are volatile. It is noted that even applicable nuclides may be volatile when an electric furnace comes to a higher temperature than the set value due to an abnormal rise in temperature.

(D) For extended filter paper

(a) How to fold

	Procedure
1	Cut the part not covered with airborne dust at the appropriate size from the collected filter paper.
2	With the air sampling surface facing inward, fold the paper to fit the measuring container, and then wrap it in polyethylene film, seal it, or place it in a plastic container (measuring container) to make a measurement sample.

(b) Punching methods

	Procedure
1	After collecting the filter paper, cut out the air sampling surface with scissors or other means or punch it out with a specific apparatus. When cutting or punching out, matching the diameter of the surface with that of the measuring container facilitates filling. Note: Clean the scissors, etc., thoroughly after use.
2	Place the punched (cut out) filter paper in a plastic container (measuring container) in layers with the surface with airborne dust facing down, or wrap it in polyethylene film and seal it to make a measurement sample.

(c) Ashing

	Procedure
1	Roll up the filter paper (cellulose and glass fiber filter paper, etc.) that has collected airborne dust, fold it with the air sampling surface facing inward, or cut it into slices with scissors to place the treated paper in a porcelain evaporating dish. Note: Clean the scissors, etc., thoroughly after use.
2	Place it in an electric furnace and ash it at 500 ℃* for 4 to 5 hours if volatilization of cesium at 500 ℃ is concerned, ash it at 450 ℃ or lower.
3	After open cooling, transfer the ashed sample to a plastic container (measuring container) using a paintbrush or similar tool.

*Note that some filter paper, such as membrane filter paper, cannot be ashed.
It is not applicable for some nuclides because they are volatile.
It is noted that even applicable nuclides may be volatile when an electric furnace comes to a higher temperature than the set value due to an abnormal rise in temperature.

(2) Pretreatment for radiochemical analysis

Pretreatment for uranium or plutonium analysis by radiochemical analysis.

(a) Uranium analysis

In principle, the filter paper is ashed and analyzed.

If ashing membrane filter paper, etc., is not possible and uranium contained in airborne dust collected on the filter paper can be extracted with acid, etc., the extracted solution is used for analysis.

For cellulose and glass fiber filter paper, ash and analyze it.

Some types of filter paper may contain uranium, so unused filter paper from the same lot should be analyzed to obtain a blank value for correction.

For the pretreatment procedure, refer to The Series of Environmental Radioactivity Measuring Methods No. 1, "Uranium analysis method".

(b) Plutonium analysis

In principle, the filter paper is ashed and analyzed.

If ashing membrane filter paper, etc., is not possible and plutonium contained in airborne dust collected on the filter paper can be extracted with acid, etc., the extracted solution is used for analysis.

For cellulose and glass fiber filter paper, ash and analyze it.

For the pretreatment procedure, refer to The Series of Environmental Radioactivity Measuring Methods No. 2 "Plutonium analysis method".

5.2 Analysis

(1) γ-ray spectrometry

The measurement sample prepared in 5.1 is measured with a germanium semiconductor detector.

The detection limits are shown in Explanation B.

For detailed measurement procedures, refer to "γ-ray spectrometry using germanium semiconductor detector" in The Series of Environmental Radioactivity Measuring Methods No.7.

(2) Radiochemical analysis

(a) Uranium analysis

Separate and purify uranium in the ashed sample or uranium extract solution by solvent extraction, ion exchange separation, etc. Electrodeposit the uranium in the purified sample on a stainless steel plate to make a sample for α-ray measurement and quantify it by α-spectrometry with a silicon semiconductor detector.

Other measurement methods include absorption photometry, Fluorphotometry, and ICP mass spectrometry.

The detection limits are shown in Explanation B.

For detailed analysis procedures, refer to the "Uranium analysis method" in The Series of Environmental Radioactivity Measuring Methods No. 14.

(b) Plutonium analysis

Separate and purify the plutonium in the ashed sample or plutonium extract by solvent extraction, ion exchange separation, etc. Electrodeposit the plutonium in the purified sample on a stainless steel plate to make a sample for α-ray measurement and quantify it by α spectrometry with a silicon semiconductor detector.

Other measurement methods include ICP mass spectrometry and liquid scintillation measurement.

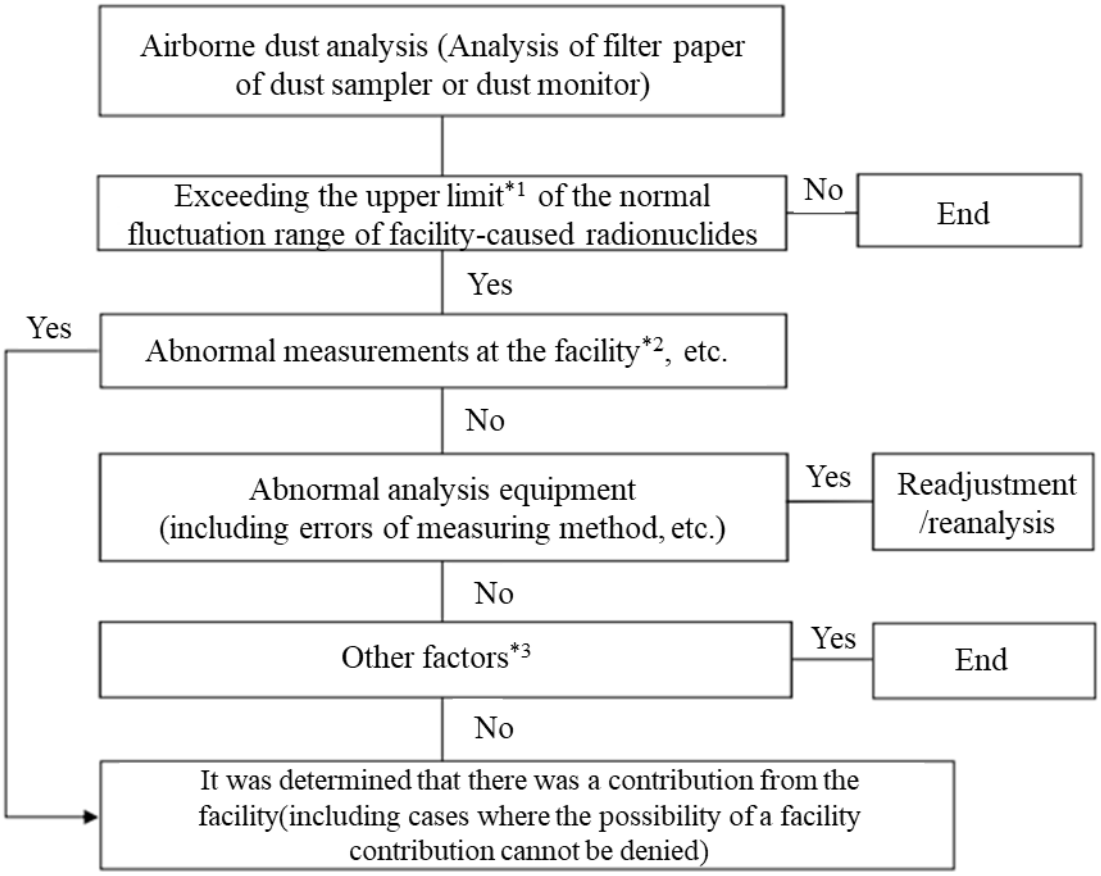
The detection limits are shown in Explanation B.

For detailed analysis procedures, see "Plutonium analysis method" in The Series of Environmental Radioactivity Measuring Methods No. 12.

5.3 Evaluation of analysis results

For the analysis results of airborne dust collected by dust samplers, etc., set the maximum measurement value for the past several years or since the start of measurement as the upper limit of the normal fluctuation range.

Figure 5-5 shows an example of a flowchart for discriminating facility contribution (including cases where the possibility of facility contribution cannot be ruled out).



*1 A maximum value measured over the past several years or since the start of measurement

*2 Abnormal values of area monitoring equipment, etc., in the facility or status of releases (including controlled releases) outside the facility

*3 An example of other factors search

- Contaminated samples may have been mixed in depending on the circumstances of sample collection.
- Caused by other than the facility subject to the study (including nuclear tests).
- There are no other radioactive materials that are expected to be detected at the same time due to the effect of the facility.
- Caused by radionuclides related to health.

Figure 5-5. Example of a flowchart for discriminating facility contribution (including cases where the possibility of facility contribution cannot be ruled out)

In cases where the measured values exceed the upper limit of the normal fluctuation range, etc., [*1] as a result of normal time monitoring, the cause of the excess is first investigated. If it is determined that there was a facility contribution (including cases where the possibility of a facility contribution cannot be denied), the exposure dose due to the facility contribution must be estimated and evaluated.

Estimating the exposure doses to nearby residents, etc., is usually done by separately calculating the effective dose from external exposure for a year and the committed effective dose from internal exposure from intake of food and drink, etc., over a year, and then synthesizing the results.

In this case, the former is calculated based on the measurement of air dose rate and the latter based on the concentration of radioactive materials in the air environmental samples, intake amount, etc.

The exposure doses to nearby residents, etc., are assessed by comparing the dose targets[*2] that are detected in the public in the vicinity of the nuclear power reactor facility and the estimated exposure doses.

Refer to the Normal Time Supplementary Reference Material for exposure dose evaluation.

*1 If the concentration of radioactive materials in the air exceeds the upper limit of the normal fluctuation range, etc., the concentration is thought to be caused by fallout from accidents at nuclear facilities other than those being monitored. Thus, the fallout needs to be verified as one of the causes.

Fully understanding the nature of fallout from past accidents at nuclear facilities, changes over time in the nuclides contained in the fallout, and continuous radiation measurements allows us to estimate whether the increase is due to facility contributions by comparing those data. So, an effort to obtain such data is created.

*2 The guidelines on target dose levels around light water reactor facilities for power generation recommend setting the target effective dose level that is detected in the public around a nuclear power reactor facility from radioactive materials released to the environment during normal operation at the effective dose of 50 μSv for a year.

In addition, in the Guidelines for Assessment of Target Dose Values around Light Water Reactor Facilities for Power Generation, effective doses are to be assessed as effective doses that result from γ-rays from radioactive noble gases in gaseous waste, from radioactive materials in liquid waste (effective doses from internal exposure due to ingestion of seafood containing radioactive materials), and from radioactive iodine in gaseous waste (effective doses from internal exposure due to inhalation, intake of leafy greens, and intake of milk).

5.4 Sample storage

When storing filter paper before analysis, store it in a desiccator to prevent hygroscopicity.

After analysis, store the filter paper (other than that used for radiochemical analysis) until the storage period is completed, keeping them ready for reanalysis.

Chapter 6 From Air Samples Collection by Iodine Sampler to Analysis

6.1 From collection to analysis

The Normal Time Supplementary Reference Materials stipulates that when a facility contribution is found in the measured values of dust monitors for a nuclear power reactor facility, etc. (including cases where it is judged that the possibility of a facility contribution cannot be ruled out), samples from iodine samplers should be collected. Radioactive iodine (particulate and gaseous) in the air should be measured.

In addition, radioactive iodine (in particulate and gaseous form) in the air should be collected and measured periodically at a reprocessing facility. Cellulose and glass fiber filter paper and activated carbon cartridges, etc., removed from the iodine sampler should be subjected to measurement of radioiodine using a germanium semiconductor detector.

For the measurement procedure, refer to The Series of Environmental Radioactivity Measuring Methods No. 4, "Radioactive iodine analysis method".

In this report, only an example of equipment specifications for an iodine sampler (Table 6-1) and an outline of air absorbents (Table 6-2) are presented. Note that equipment not listed in the example specifications may be used if it performs well.

For the performance of the iodine sampler, refer to the detection limit in Explanation B.

Table 6-1. Examples of equipment specifications for iodine samplers

	Type A	Type B	Type C	Type D
Flow rate (L/min)	40	Max. 30	25 or more	40 or more
flow rate range to be set (L/min)	5 to 40	-	0 to 50	-
Filter paper type and size	Cellulose and glass fiber filter paper 60 mm ϕ (Activated carbon filter paper and activated carbon cartridge can be attached.)			
Dimensions W × D × H (mm)	200 × 200 × 285	150 × 205 × 117	300 × 200 × 270	260 × 260 × 100
Weight (kg)	Approx. 5 kg	Approx. 5 kg	Approx. 8 kg	Approx. 15 kg
Power supply	AC100 V, 1 A, DC24 V	AC100 V, 1 A, DC24 V	AC100 V, 1 A, DC12 V, 6 A	AC100 V, 3 A
Function	Timer setting: 99 minutes or 99 hours	Timer setting: 99 minutes or 99 hours	Timer setting	Timer setting: From 1 minute to 1000 hours

Table 6-2. Air absorbents used in iodine samplers

	Outline
Activated carbon cartridge	50 mesh activated carbon is packed in a polyvinyl chloride or stainless steel container and covered with a non-woven fabric or stainless steel mesh on the front and back. Some cartridges have TEDA (triethylenediamine) impregnated* to the activated carbon to increase iodine collection efficiency.
Activated carbon filter paper	This is filter paper made from highly adsorptive activated carbon (50%) and cellulose fiber, etc., and used to collect radioactive iodine and volatile radioactive materials. Protective paper is attached to the front and back to prevent the activated carbon from falling out. Some are also impregnated with 5% or 10% TEDA (triethylenediamine). Equivalent to "filter paper type" specified in JIS Z 4336: 2010 "Radioactive iodine samplers" [9] Annex A [filter material for iodine collection].

*Impregnating activated carbon with TEDA (triethylenediamine) or potassium iodide, etc., enables efficient iodine collection. The collection efficiency varies depending on the amount of impregnated substances: above a certain amount, the collection efficiency decreases. Generally, from 1% to 10% is considered an appropriate amount [12]. However, there are also reports that from 0.1% to 1% is better for potassium iodide because it causes a decrease in the ignition point of activated carbon [13].

Chapter 7 Continuous Measurement with Gas Monitors

7.1 Equipment

A gas monitor continuously measures the concentrations of gaseous radioactive materials such as radioactive noble gases. It is mainly used for monitoring around a reprocessing facility releasing radioactive noble gases during normal operation. The basic information on gas monitors described in this section is based on JIS Z 4317:2008 "Radioactive noble gas monitors" [10].

7.1.1 Equipment configuration

The gas monitor consists of a detector unit, an indicator, an alarm section, and a data transmitter, as shown in Figure 7-1. The functions of each part are shown in (1) through (4).

General matters

(a) The equipment should be robust to withstand continuous operation and easy to operate and maintain.
(b) The structure should resist vibration, impact, corrosive gases, etc.
(c) The structure should resist electromagnetic induction, static electricity, etc. In addition, the structure should be designed to have little electromagnetic induction or other effects on other equipment.
(d) It desirably has a self-diagnosis function to detect failures.
(e) If the measured value is sensitive to the flow rate, the meter must have functions capable of measuring the flow rate of the sampling gas and controlling or adjusting it. The flow measurement device should be equipped with a flow rate display device.
(f) If the measured value is sensitive to pressure, as in the case of an ionization chamber, it is desirable to have a pressure gauge with an alarm and a function to control or adjust the pressure and to output a warning for excessive pressure fluctuations. In addition, pressure gauges must be calibrated under standard conditions.

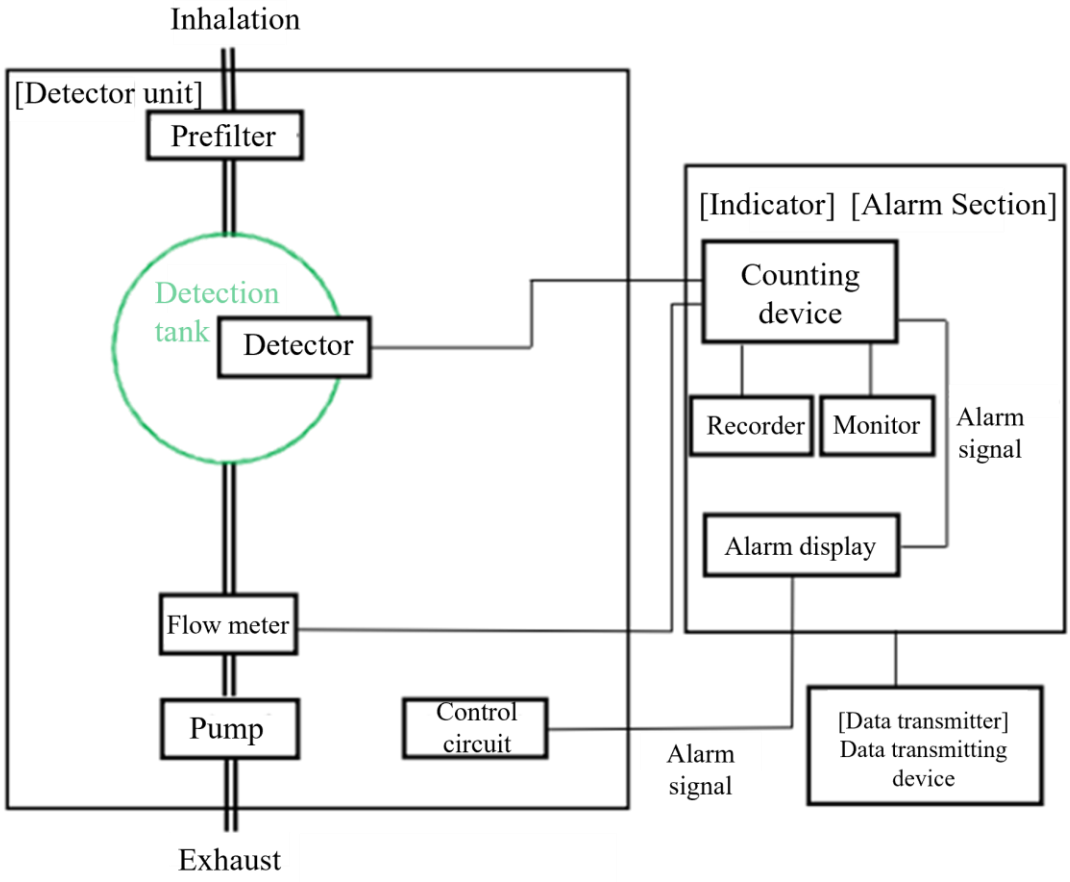


Figure 7-1. Example of equipment configuration

(1) Detector unit

The detector unit circulates the sample air from which particulate matter has been removed through the detection tank to detect radiation from gaseous radioactive materials. It is composed of a suction port, filter, detection tank, detector, flow meter, pump, and attached functional units.

The following are points to be noted in the detector unit.

- The structure should resist contamination and be easy to decontaminate or replace.
- The structure should allow a filter to be attached to the suction side of the sampler to remove the effects of particulate natural radioactive materials, and the filter should be of a structure that allows replacing without scattering the collected radioactive materials and does not collect or retain noble gases. A monitor that measures ionization current should be structured so that an ion removal device can be attached to the suction side of the sampler.
- Shielding elements, coincidence mechanisms, anti-coincidence mechanisms, etc., may be added as necessary to reduce the effects of external γ-rays and noise.

(2) Indicator

The indicator measures signals from the detector unit, displays the indicated values, and outputs them to the data transmitter.

An example specification of the indicator is shown below.

- An analog or digital count rate meter, ammeter, or scaler provides an indication.
- The units of the measured values are s^{-1}, A, kBq/m^3, etc., and the radioactivity concentration is calculated by multiplying the conversion constant according to the nuclide of interest.
- The unit of flow rate should be L/min, etc.
- Display with date and time in tabular or graphical format.

(3) Alarm section

The alarm section detects when the device is abnormal or the indicated value exceeds a specific set value. Examples of specifications for the alarm unit are shown below.

- When the indicated value exceeds the alarm set value, or in the event of equipment failure or abnormality, a warning is issued by a lamp, buzzer, or other means.
- The notice should be maintained until reset or the cause is eliminated.
- Provide a test function to check alarm operation. If the alarm setting is variable, it must be possible to set it within the effective measurement range and to check the alarm set value.

(4) Data transmitter

This part sends out the data collected by the indicator to the telemetry system, etc., via communication equipment and also controls the gas monitor by receiving control signals from the telemetry system, etc.

An example of data transmission items is shown in Table 7-1.

For data communication, the communication lines used by the facilities in the monitoring station building, if any, should be used. Communication lines are desirably multiplexed.

Table 7-1. Examples of data transmission items

	Data transmission item
(a) Measured value	Count rate, radioactivity concentration, flow rate, measurement time, date and time, and location information
(b) Status signal	High count rate, low count rate, detector reading anomaly, flow rate anomaly, power anomaly, adjustment in progress, measurement in progress
(c) Control signal (Received information)	Startup and stop

7.1.2 Detector types and measurement principles

The types of detectors used for gas monitoring are listed in Table 7-2.

Table 7-2. Types of detectors used in gas monitors

	Detector type
β-ray detector	Plastic scintillation detector
	GM counter
	Vented ionization chamber

(1) Plastic scintillation detector

Same as 3.1.5(2)(a)

(2) GM counter

This measures the number of output pulses due to electron avalanche caused by electrons generated by ionization of gas (Q gas, etc.) in the detector due to radiation incidence.

Since the output pulse height is independent of the initial ionization amount due to incident radiation and remains constant, the output pulse has no energy information.

(3) Vented ionization chamber

This measures the total ionization current generated by radiation emitted from gaseous radioactive materials released into the ionization chamber.

7.1.3 Example of equipment specifications

An example of gas monitor equipment specifications is shown in Table 7-3. Note that equipment not listed in the example specifications may be used if it has the required performance.

For the performance of gas monitors, refer to the detection limit in Explanation B.

Table 7-3. Example of gas monitor specifications

Item	Type A	Type B	Type C
Measurement target	β-ray		
Detector	Plastic scintillator	GM Counter	Vented ionization chamber
Flow rate	6.5 L/min	60 L/min	5 L/min
Detection tank volume	Approx. 30 L	Approx. 0.3 L	Approx. 14 L
Measurement method	Continuous measurement		
Elimination of external radiation effects*1	Lead shielding*2 , Pre-filter		
Power supply	100 V	100 V	100 V
Power consumption	500 VA	-	150 VA

*1 In addition to the functions described here, background reduction functions such as removal of cosmic ray effects by the anti-coincidence mechanism, noise reduction by the coincidence mechanism, and ion removal by the ion precipitator (ionization chamber only) are added as necessary.

*2 Add shielding of 2 to 5 cm thick, if necessary.

7.2 Installation, calibration, and inspection

7.2.1 Installation

Gas monitors should be fixed and installed indoors at the monitoring station building, etc.

Installation conditions should be the same as for dust monitors (3.3.1).

7.2.2 Calibration

The calibration of detectors used in gas monitors is described here. The flow meters are also desirably calibrated periodically for proper evaluation of air suction amount.

(1) Calibration method

When installed, an actual gas calibration test using Kr-85 should be conducted. During maintenance and inspection, sensitivity tests and plateau characteristic tests should use β and γ-ray sources (Cl-36, Ba-133, Cs-137).

(2) Standard radiation sources for calibration

The standard radiation sources used for calibration are listed in Table 7-4.

Table 7-4. Standard radiation sources for calibration

Radiation type	Standard radiation source
β-ray	Kr-85 (standard radioactive gas)

(3) Calibration frequency

Calibration is conducted at the time of installation.

After that, about once a year, during maintenance and inspection, the detection sensitivity should be checked with Cl-36, etc., and if it deviates from the true value by ±15% or more, an actual gas calibration test using Kr-85 should be conducted.

7.2.3 Inspection

(1) Daily inspection

Daily inspection is conducted remotely by telemetry systems, etc., and at the installation location, depending on the items.

(a) Contents are to be implemented remotely by a telemetry system, etc.

Example of daily inspection items	
Operation check	Are operation and communication proper?
	Is the flow rate normal?
Abnormal values	Is a warning being issued?
	Are there any pronounced changes in the count rate and radioactivity concentration?

(b) Contents are to be implemented at the installation location

Example of daily inspection items	
Operation check	Are operation and communication proper?
	Is the flow rate normal? (Adjust flow rate if necessary)
	Is the operating noise of the pump normal?
Abnormal values	Is a warning being issued?
	Are the count rate and radioactivity concentration normal?
Operating environment	Is the air conditioning in the station building working properly?

(2) Periodic inspection

An example of periodic inspection items by manufacturers is shown in Table 7-5.

Table 7-5. Example of periodic inspection items

Example of periodic inspection items	
(a) Visual inspection	Detector unit
	Indicator
	Cables and connectors
(b) Stand-alone operation and performance test	
Detector unit	Operation check
	Alarm operation check
	Count rate indication accuracy
	Flow rate indication accuracy
	Maximum airflow rate test
	Leak test
	Sensitivity test
	Plateau characteristic test
	BG check before and after nitrogen gas replacement
	Check for the lower limit of concentration for measurement
	Periodic replacement of consumables
Indicator	Recorder indication accuracy

(3) Inspection frequency

Daily inspections include once-a-day inspections by the telemetry system, monthly inspections at the installation location, etc.

Periodic inspections should be conducted approximately once a year.

7.3 Measurement

(1) Startup of equipment

The system should be activated at all times for continuous measurements at normal times.

(2) Setting of measurement conditions

Set the measurement conditions for continuous measurement.

An example of measurement conditions is shown in Table 7-6, and notes on each item are described.

Table 7-6. Example of gas monitor measurement conditions

Item	Measurement conditions
(a) Flow rate	This depends on the volume of the detection tank.
(b) Measurement time	Continuous (measurements should be made at least every hour)

(a) Flow rate

Set the flow rate so that the air suctioned into the detection tank is replaced in approximately 10 minutes, depending on the volume of the detection tank. The rate in a 30 L detection tank should be approx. 5 L/min.

(b) Measurement time

The measurement should be consecutive, and measurements should be made at least every hour. To conduct surveys with a higher time resolution when abnormalities, etc., occur, measurements may be obtained at shorter intervals, allowing us to calculate measured values every hour by using the actual measurements.

(3) Start of measurement

Start measurement.

Desirably, the telemetry system or other means can control the start and stop of measurement remotely.

(4) Data transmission

Data on measurement information should be transmitted to the telemetry system at least once an hour. Alarms and other monitoring information should be transmitted to the telemetry system as soon as possible after an abnormality occurs. An example of data transmission items is shown in Table 7-7.

Table 7-7. Example of data transmission items to telemetry system

Category	Component	Output item
Measurement information	Detector unit	Count rate (s^{-1})
		Radioactivity concentration (kBq/m^3)
		Average flow rate (L/min)
		Integrated flow volume (m^3)
Monitoring information	Detector unit	Under measurement
		Under adjustment
		Power anomaly
		Flow rate anomaly
	Indicator	Power anomaly
		High count rate
		Low count rate

(5) Calculation of radioactivity concentration

Calculate the hourly radioactivity concentration (kBq/m^3) using Equation 7.1.

$C = N \times K$ (Equation 7.1)

C: Radioactivity concentration (kBq/m^3)
N: Net count rate (s^{-1})
(Sample count rate - background count rate)
K: Concentration conversion constant ($kBq/m^3/s^{-1}$)

7.4 Evaluation of measurement results

Like other nuclear facilities, a reprocessing facility should investigate the cause when values exceeding the upper limit of the normal fluctuation range (e.g., the maximum value measured over the past several years) are measured. If a facility contribution is found or cannot be ruled out, the exposure dose due to the facility contribution should be evaluated.

However, since facility contributions to measured values may be recognized even when the reprocessing facility operates normally, and the upper limit of the normal fluctuation range may be exceeded, caution should be exercised in determining whether an increase in measured values constitutes an abnormal situation.

Therefore, criteria are required to indicate a situation beyond the normal range of fluctuation, justify the investigation of the cause, and determine if this is an abnormal situation. For example, one should set a range of recorded measurements (including measurements where facility contributions were recognized) obtained when the facility is under normal operating conditions and not under unusual weather conditions and evaluate the measurement results.

Explanation

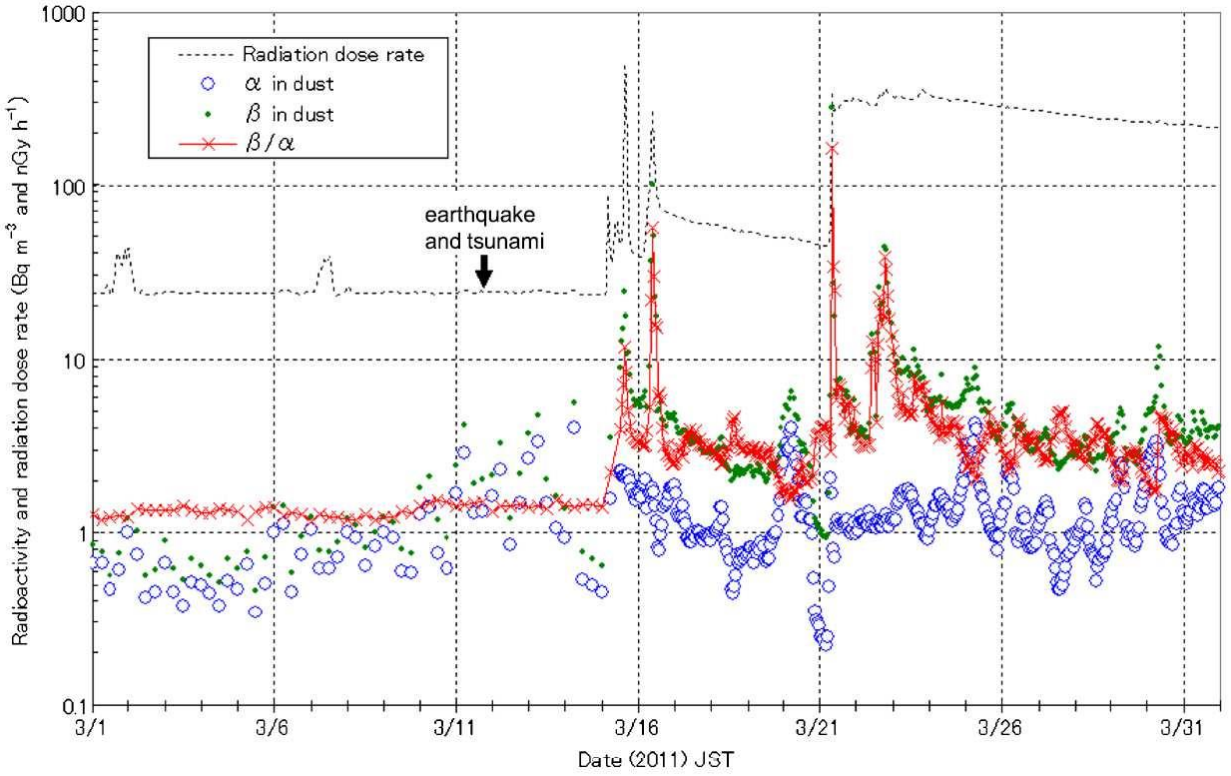
Explanation A Validity of Airborne Radioactive Material Measurements

The Normal Time Supplementary Reference Material stipulates that the concentrations of radioactive materials in the air should be measured to detect radioactive materials released from nuclear facilities early.

Examples of actual measurements and calculations on the effectiveness of measuring radioactive materials in the air are presented.

(1) Observation example during the accident at the TEPCO's Fukushima Daiichi NPP

In Chiba City, Chiba Prefecture, an increase in gross β radioactivity concentration and β/α ratio was found by dust monitors in the early morning of March 15, 2011. The increase in the air dose rate occurred almost simultaneously.



Unit: nGy/h (Radiation dose rate), Bq/m^3 (α in dust, β in dust)

Figure A-1. Observation example in Chiba City, Chiba Prefecture [14].

*The data after 6 hours of filter paper feeding until March 15, and data after 1 hour of filter paper feeding after that.

*The increased air dose rates on March 1 and 7 were attributed to the effects of natural radioactive materials from rainfall.

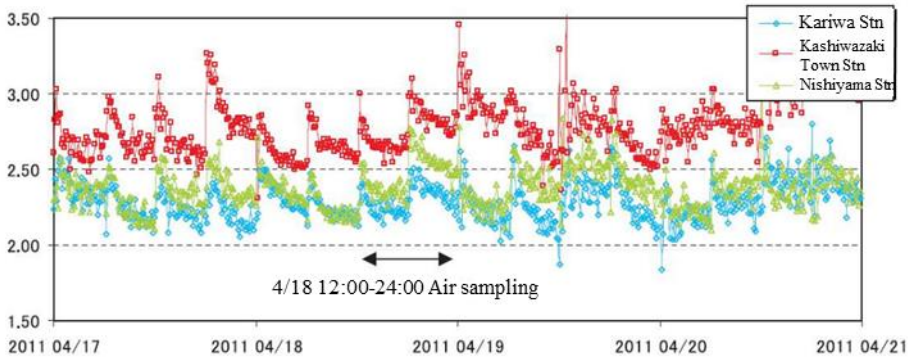
(2) Example of facility contribution detected after the decay of radon/thoron decay products

Although real-time observations could not be made as in (1), an example of detecting the presence of a facility contribution after the decay of radon/thoron decay products is shown in (2).

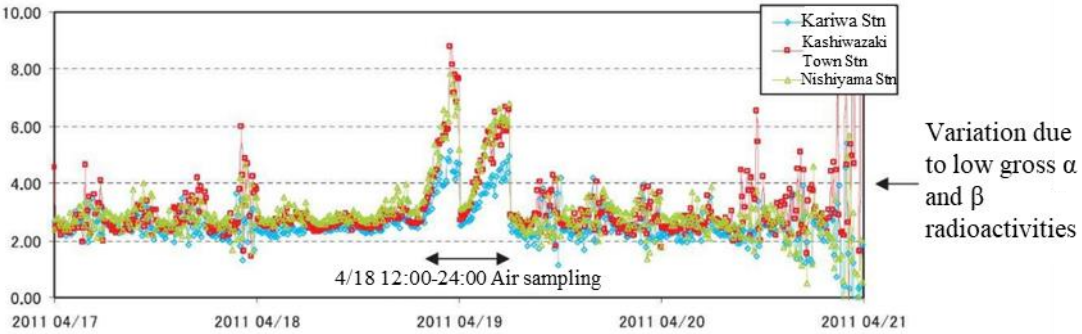
In Niigata Prefecture, no significant increase in the β/α ratio of airborne dust collected on April 18, 2011, from 12:00 to 24:00 was observed in the measurement at the air sampling location (Figure A-2(a)). However, a significant increase was observed in the β/α ratio 6 hours after air sampling (Figure A-2(b)). No significant increase was observed in the gross β radioactivity concentration after 6 hours of air sampling (Figure A-2(c)).

In addition, the air dose rate at monitoring posts only increased due to rainfall, and no increase was observed due to the TEPCO's Fukushima Daiichi NPP accident.

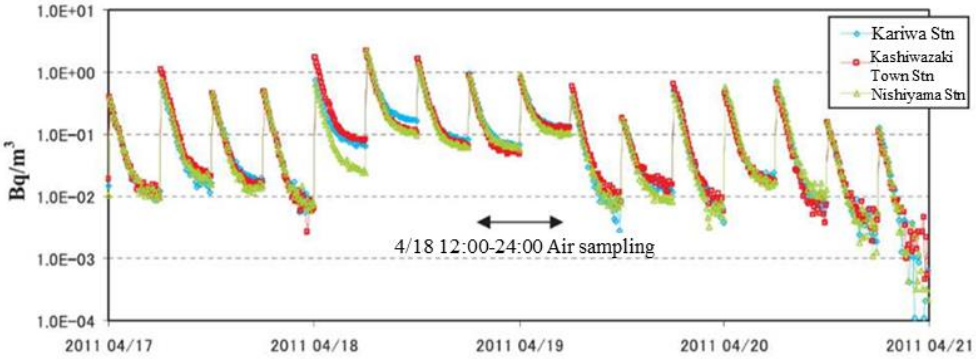
(a) β/α ratio (10-minute value) at air sampling location (real-time measurement)



(b) β/α ratio 6 hours after air sampling (10-minute value)



(c) Gross β radioactivity concentration 6 hours after air sampling (10-minute value)



*The horizontal axes in Figures (a), (b), and (c) are all measurement times. The data in the arrows indicate the measurement results at the same air sampling time, but the arrow locations of (b) and (c) are different from the arrow locations of (a) because they were the results of measurements 6 hours after air sampling.

Figure A-2. Observation examples in Niigata Prefecture [15].

(3) Effectiveness evaluation by calculation

IAEA-TECDOC-1162 [16] provides conversion factors for every radionuclide from radioactive material concentrations in the air-to-air dose rates (Table A-1).

Calculation using this conversion factor shows that an increase of 5 Bq/m^3 in the concentration of Cs-134 in the air would increase by 1.7 nSv/h in the air dose rate. However, the increase would be difficult to detect at monitoring posts that measure air dose rates because the background fluctuations would hide the increase.

Therefore, the dust monitors can discriminate and evaluate facility-derived radioactive materials of 5 Bq/m^3, thus enabling earlier detection than that of the monitoring post.

Table A-1. Conversion factors from radioactive material concentrations in the air to air dose rates [16].
(Only conversion factors for radioactive Cs are excerpted.)

Radionuclide	Conversion factor $(mSv/h)/(kBq/m^3)$
Cs-134	3.4E-04
Cs-136	4.8E-04
Cs-137/Ba-137m	1.3E-04
Cs-138	5.2E-04

Explanation B Detection Limit

Detection limits for measuring radioactive material concentrations in the air are shown in (1) through (3).

The detection limits listed here are values that can be reasonably achieved in light of current technical standards and should be used as a guide for introducing equipment and setting measurement conditions when measuring the concentration of radioactive materials in the air.

(1) Continuous measurement of radioactive material concentrations in the air using dust monitors

Table B-1. The detection limit of continuous measurement by dust monitor

Sample	Detection limit		Reference (measurement conditions)	
	Gross α radioactivity concentration	Gross β radioactivity concentration	Sample amount	Measurement time
Airborne dust	0.05 Bq/m^3	0.10 Bq/m^3	9 m^3	1 hour

Method of calculating the detection limit

The detection limit is the value overestimated from the maximum detection sensitivity specified in JIS Z 4316:2016 "Radioactive dust monitors" [5]. It is not a discrimination level for facility-derived radioactive materials. The assumptions are the following:

- Detectors: α-ray ZnS(Ag) scintillator, β-ray plastic scintillator
- Detector size: 50 mm ϕ
- Equipment efficiency approx. 49% (gross α approx. 35% (gross β)
- Background count rate: α-ray 2 cpm, β-ray 15 cpm
- Flow rate: 150 L/min, test volume: 1 hour of integrated flow volume, collection efficiency: 100%.

(2) Precise analysis table of radioactive material concentrations in airborne dust collected by dust samplers

Table B-2. The detection limit of γ-ray spectrometry

Sample	Detection limit				Reference (measurement conditions)		
	Co-60	I-131	Cs-134	Cs-137	Sample amount	Measurement time	Relative efficiency
Airborne dust, etc.	0.0074 mBq/m^3	0.0037 mBq/m^3	0.0074 mBq/m^3	0.0074 mBq/m^3	10^4 m^3	Approx. 80,000 sec.	Approx. 20 %
	0.037 mBq/m^3	0. 027* mBq/m^3	0. 035 mBq/m^3	0.030 mBq/m^3	Approx. 3000 m^3	Approx. 70,000 sec.	Approx. 40 %

- Measurements of samples that were pretreated in U-8 containers for nuclides except for I-131
- I-131 was measured in raw samples in 2 L Marinelli containers

*Measurement using a detector with a relative efficiency approx. 30%.

Method of calculating detection limit (Table B-2, lower part)

· The average value of the lower detection limit was obtained from the historical actual measurement data of a representative sample using a detector with a relative efficiency of approx. 40 % (2L Marinelli with a relative efficiency approx. 30%).

· In actual measurements, background and other conditions vary depending on the shielding material and installation environment, even when the same detector is used. Thus, the detection limit was calculated by tripling the above-average value, assuming measurement under high background data conditions, and calculating an overestimated value in the aspect of "the detection limit even in complicated conditions".

[The Series of Environmental Radioactivity Measuring Methods No.7]

Table B-3. The detection limit of uranium analysis

Sample	Measurement method	Detection limit	Reference (measurement conditions)	
			Sample amount	Measurement time
Airborne dust	α spectrometry	1 μBq/m^3	10^3 m^3	20 hours.
	ICP mass spectrometry	0.001 μBq/m^3	10^3 m^3	10 sec.

Calculation method of detection limit

(a) α spectrometry:

The detection limit was set to be three times the counting error associated with the net count rate when the collection efficiency was 80%, the counting efficiency was 20%, and the background count rate was 1 count/20 hours.

(b) ICP mass spectrometry:

The detection limit was defined as three times the standard deviation of the background counts when the background count rate was set to 5 s^{-1}.

[The Series of Environmental Radioactivity Measuring Methods No.14]

Table B-4. Detection limit of plutonium analysis

Sample	Measurement method	Detection limit	Reference (measurement conditions)	
			Sample amount	Measurement time
Airborne dust	α spectrometry	0.2 μBq/m^3	10^4 m^3	24 hours

Method of calculating the detection limit

Three times the counting error associated with a counting efficiency of 20% and a total count value of α-rays from the nuclides was set as the detection limit.

[The Series of Environmental Radioactivity Measuring Methods No.12]

(3) Continuous measurement of gaseous radioactive material concentrations by gas monitors

Table B-5. The detection limit for continuous measurement by gas monitors

Sample	Detection limit	Reference (measurement conditions)
	Gross β radioactivity concentration	Measurement time
Air	1 kBq/m^3	1 hour

Calculation method of detection limit

The value overestimated from the maximum detection sensitivity of the gas monitor using a plastic scintillation detector (detection tank approx. 1 L, conversion constant (Kr) 2.8×10^{-3} Bq/cm^3/s^{-1}, background count rate 14 s^{-1}) was used as the detection limit.

Explanation C Concept of Dust Monitor Measurement Condition Setting

The effects of differences in measurement conditions on measurement results are described to assist in setting up measurement conditions for dust monitors.

See Explanation E for the effects of radon/thoron decay products.

(1) Effects on measurement results due to differences in calculation methods for radioactive material concentrations in the air

If the concentration of radioactive materials in the air is constant at 10 Bq/m^3, the radioactivity on the filter paper changes, as shown in Figure C-1 for a radionuclide with a long half-life (no physical decay during air sampling time) and a radionuclide with a short half-life (assuming radon decay products, half-life: 30 minutes).

When collecting radionuclides with long half life, the radioactivity on the filter paper increases linearly if the concentration in the air is constant.

On the other hand, for radionuclides with a short half-life (half-life: 30 min), the radioactivity supplied on the filter paper increases linearly. However, the radioactivity on the filter paper becomes almost constant over time because the radioactivity decreases on the filter paper due to physical decay simultaneously. As a convenient assumption for interpreting Figure C-1, the radioactivity on the filter paper is calculated on a 10-minute basis, and the increase in radioactivity every 10 minutes does not consider the physical decay during the capture (during the relevant 10 minutes). For example, the radioactivity that is increased between 10 and 20 minutes after filter paper feeding is not corrected for decay at 20 minutes after filter paper feeding. However, at 30 minutes after filter paper feeding, the physical decay during 10 minutes between 20 and 30 minutes is considered.

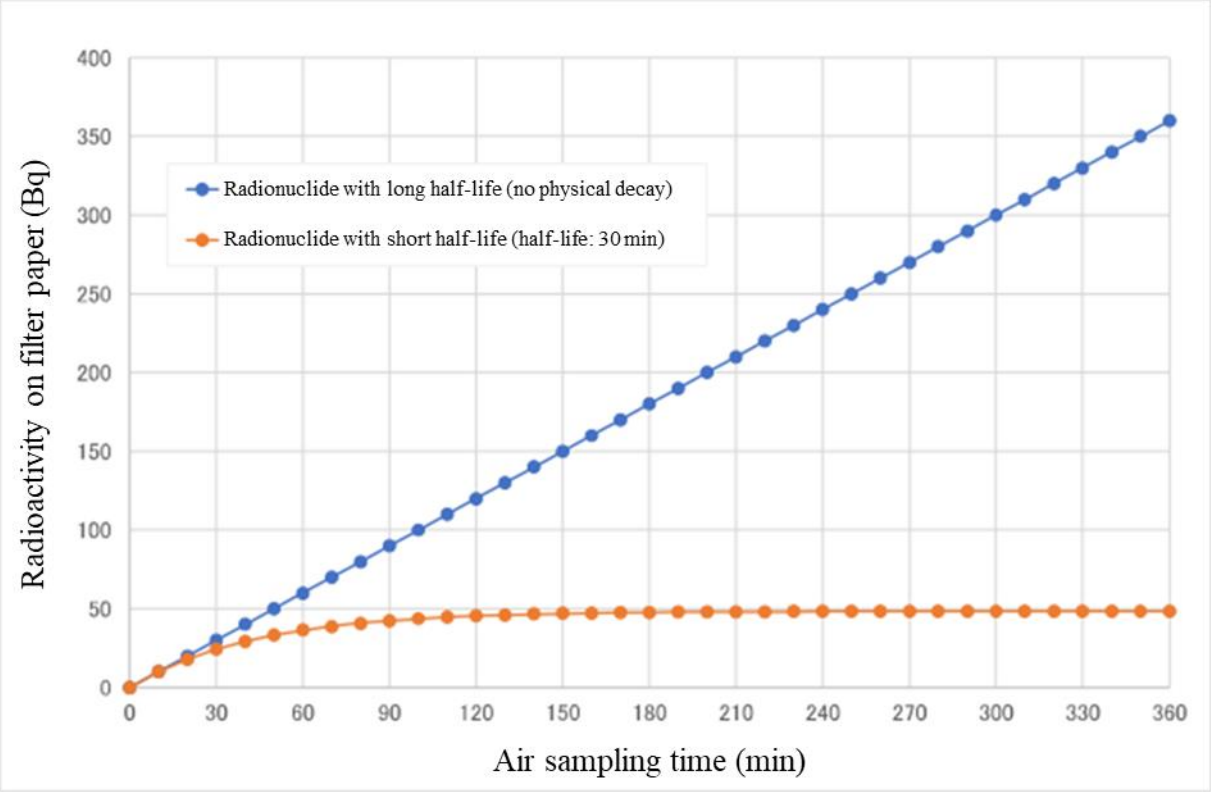


Figure C-1. Change in radioactivity on filter paper

Dust monitors and air monitors measure radioactivity in collected airborne dust in two ways: (a) measuring as the average concentration starting from the filter paper feeding and (b) measuring as the average concentration per unit time based on the difference in count rates per elapsed time. If the method described in (b) is used in normal times, it may be difficult to properly evaluate the difference due to the short half-life of radon/thoron decay products, but we do not deny its use if it can be used to evaluate the contribution of facility-derived radioactive materials.

As the basis of this measurement method, the dust monitor uses (a) the average concentration starting from the filter paper feeding, and the air monitor uses (b) the average concentration per unit time.

The calculation method for each is shown below.

(a) Method of calculating average concentration starting from filter paper feeding

$$\begin{aligned} &Radioactivity\ concentration\ (Bq/m^3) \\ &= \frac{Net\ count\ rate\ at\ elapsed\ time\ from\ filter\ paper\ feeding\ (s^{-1})}{Equipment\ efficiency\ \times\ integrated\ flow\ volume\ (m^3)\ up\ to\ the\ elapsed\ time\ from\ filter\ paper\ feeding} \end{aligned}$$

(b) Calculation method of average concentration per unit time (formula below is for 10 minutes)

$$\begin{aligned} &Radioactivity\ concentration\ (Bq/m^3) \\ &= \frac{Count\ rate\ at\ the\ current\ tens\ of\ minutes\ (s^{-1}) - \ Count\ rate\ at\ the\ previous\ tens\ of\ minutes\ (s^{-1})}{Equipment\ efficiency\ \times\ 10-minute\ integrated\ flow\ volume\ (m^3)} \end{aligned}$$

For cases where the radioactivity on the filter paper changes, as shown in Figure C-1, the results of calculating the average concentration starting from the filter paper feeding and the average concentration per unit time of radioactivity in the collected airborne dust are shown in Figure C-2 and Figure C-3, respectively.

In the case of a radionuclide with a long half-life, the average concentration starting from the filter paper feeding is not different from the average concentration per unit of time.

On the other hand, in the case of a radionuclide with a short half-life (half-life: 30 minutes), the average concentration starting from the filter paper feeding decreases over time because the radioactivity on the filter paper which is almost constant over time, is divided by the integrated flow volume which increases linearly.

The average concentration for each unit time approaches zero over time because it is calculated by dividing the difference in the count rates for each unit time by the integrated flow volume (constant value) for each unit time.

It should be noted that for radionuclides with short half life, this calculation method underestimates the actual concentration of radioactive materials in the air (10 Bq/m^3 in this case) in terms of both the average concentration starting from filter paper feeding and the average concentration per unit time.

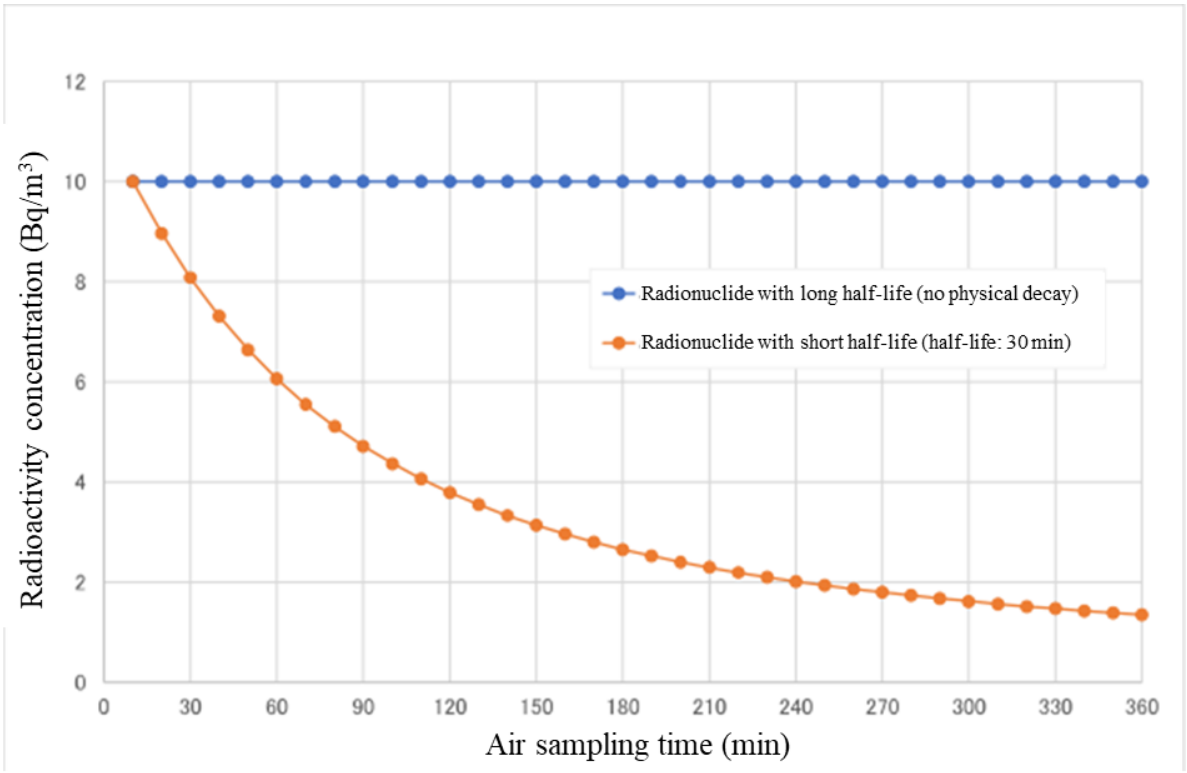


Figure C-2. Radioactivity concentration in collected airborne dust (average concentration from filter paper feeding)

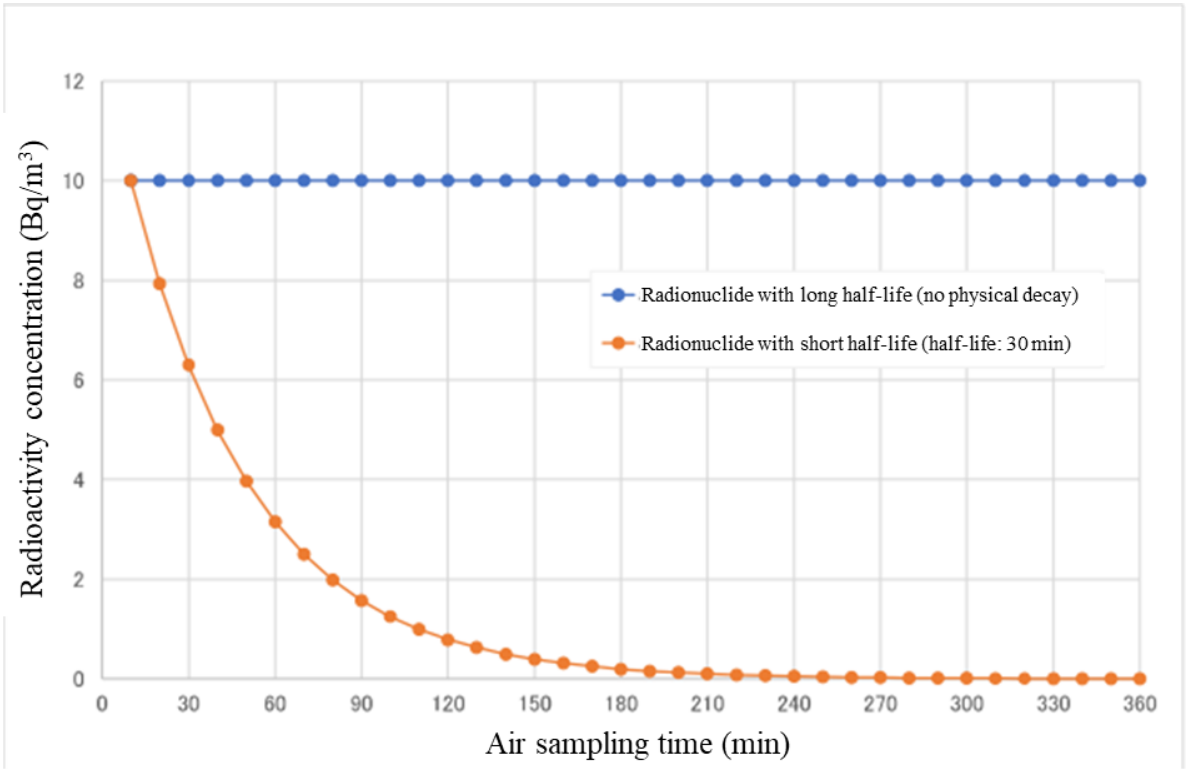


Figure C-3. Radioactivity concentration in collected airborne dust (average concentration per unit time)

(2) Notes on the evaluation of the count rate

In dust or air monitor measurements, air sampling collects particulate radioactive materials in a specific air volume on filter paper. The radioactivity concentration in the air (Bq/m^3) can be calculated by measuring the radioactivity of the radioactive materials on the filter paper (Bq) and the volume of collected air (m^3). The radioactivity on the filter paper is determined by dividing the count rate measured by the detector by the equipment efficiency.

JIS Z 4316:2013 "Radioactive dust monitors" [4] state that dust monitor indication should be made by a count rate meter or scaler.

Since this method is based on measurement during air sampling, a count rate meter is fundamentally used to obtain the count rate (instantaneous value) of airborne dust collected on filter paper at the time of t hours after the filter paper feeding.

When calculating the count rate from the integrated counts measured by the scaler, care should be taken when measuring during air sampling, so the points to be noted are shown separately for the calculation methods (1) (a) and (b).

(a) When measuring the average concentration starting from the filter paper feeding using a scaler

The measurement method of the concentration of radioactive materials in the air by dust monitors or air monitors does not describe the measurement after air sampling. However, it describes the relationship between measurement time and count rate for the measurement after air sampling, as shown in a) in contrast with b).

a) When the integrated counts are obtained by measurement after air sampling

When measuring the concentration of radioactive materials in the air after air sampling, the count rate is constant, as shown in Fig. C-4 top right, since changes in the radioactivity on filter paper during air sampling are irrelevant to subsequent measurements, and the radioactivity on filter paper during measurement is constant for radionuclides with long half life. The count rate n_a can be calculated by dividing the integrated counts by the measurement time t_a.

Even if the concentration of the target radioactive material in the air is the same, for a radionuclide with a short half-life relative to the measurement time, the count rate evaluated by dividing the integrated counts by the measurement time is underestimated because the radioactivity physically decays with time even during measurement. The count rate decreases, as shown in the lower right panel of Figure C-4.

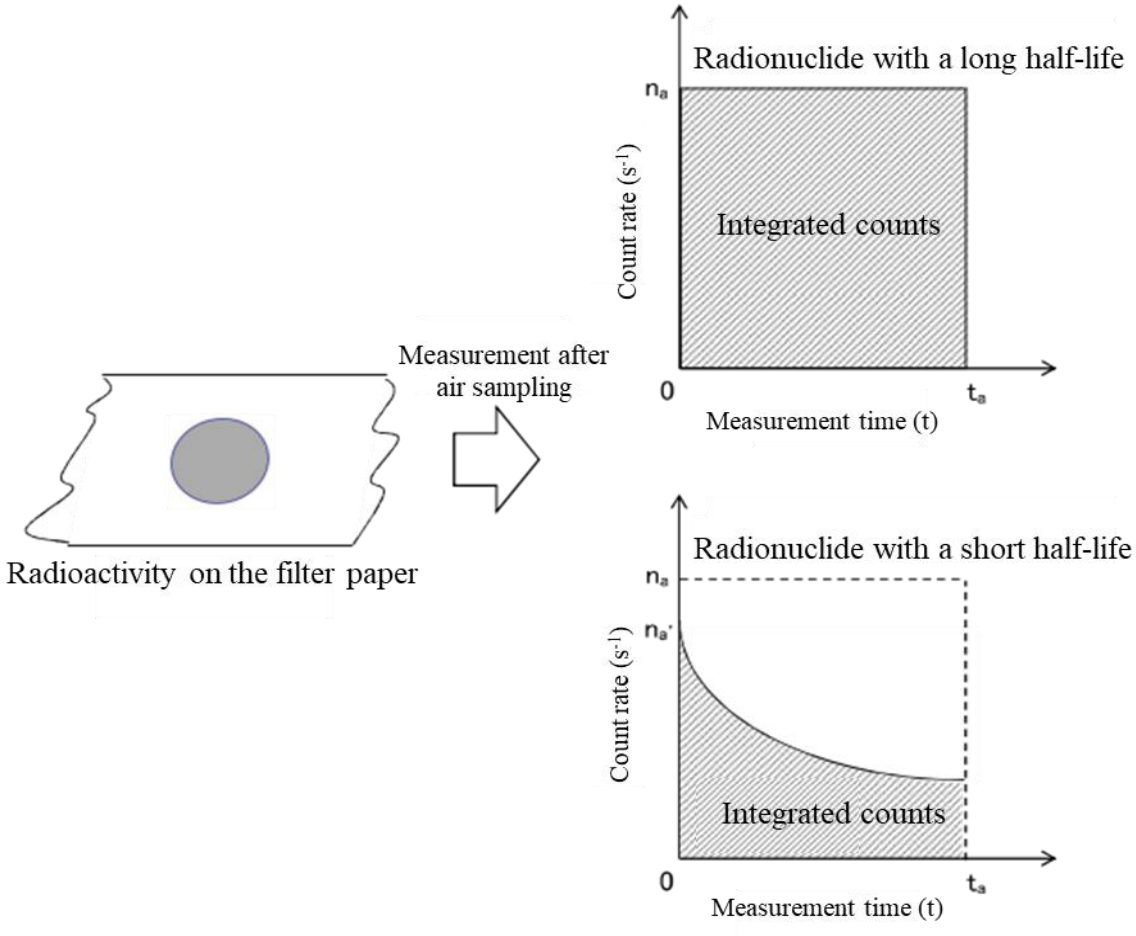


Figure C-4. Evaluation of integrated counts by measurement after air sampling

b) When the integrated counts are obtained by measurement during air sampling

When obtaining the integrated counts by measurement during air sampling, even if the total radioactivity collected is the same as in a), caution should be exercised when calculating the count rate because the radioactivity collected at a specific time does not contribute to the counts integrated over the measurement time up to the specific time, and the integrated counts may differ, depending on changes in the concentration of radioactive materials in the air during air sampling.

Assuming that the concentration of radioactive materials in the air is the same and constant as in a), when measuring during air sampling, the radioactivity on the filter paper during measurement increases linearly for radionuclides with long half life, and the count rate increases with measurement time, but the integrated counts are approx. a half of that of a), as shown in Figure C-5. Therefore, simply dividing the integrated counts by the measurement time underestimates the count rate n_a that should be obtained.

Radionuclides with short half life also cause underestimation of the integrated counts for the same reason as above, but on the other hand, the underestimation effect due to physical decay of radioactivity is smaller than that of a). The reason is that the measurement is performed during air sampling while the measurement of a) is performed after air sampling.

In actual measurements, changes in the concentration of radioactive materials in the air during air sampling affect the measurement of integrated counts, as shown in Figure C-6. Thus, it is necessary to note the trend of changes in the concentration of radioactive materials in the air when evaluating data. Figure C-6 left figure shows the case where the concentration of radioactive materials in the air tends to increase, and Figure ’-6's right figure shows the case where the concentration of radioactive materials in the air tends to decrease. The magnitude of the slope of the count rate is proportional to the concentration of radioactive materials in the air. The tendency to increase the concentration of radioactive materials in the air is likely to lead to underestimation, while the tendency to decrease is likely to lead to overestimation.

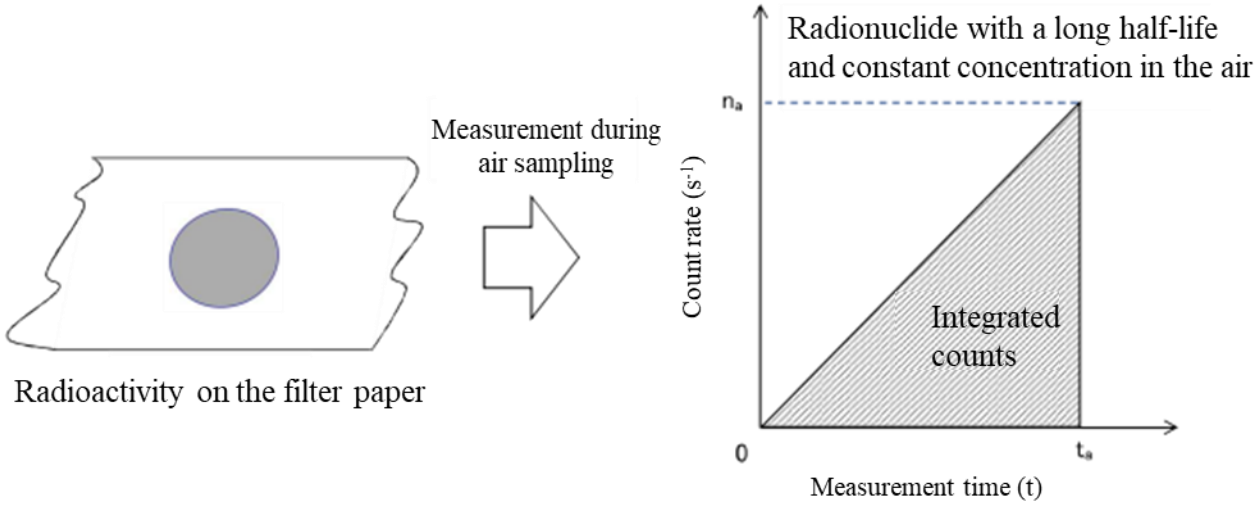
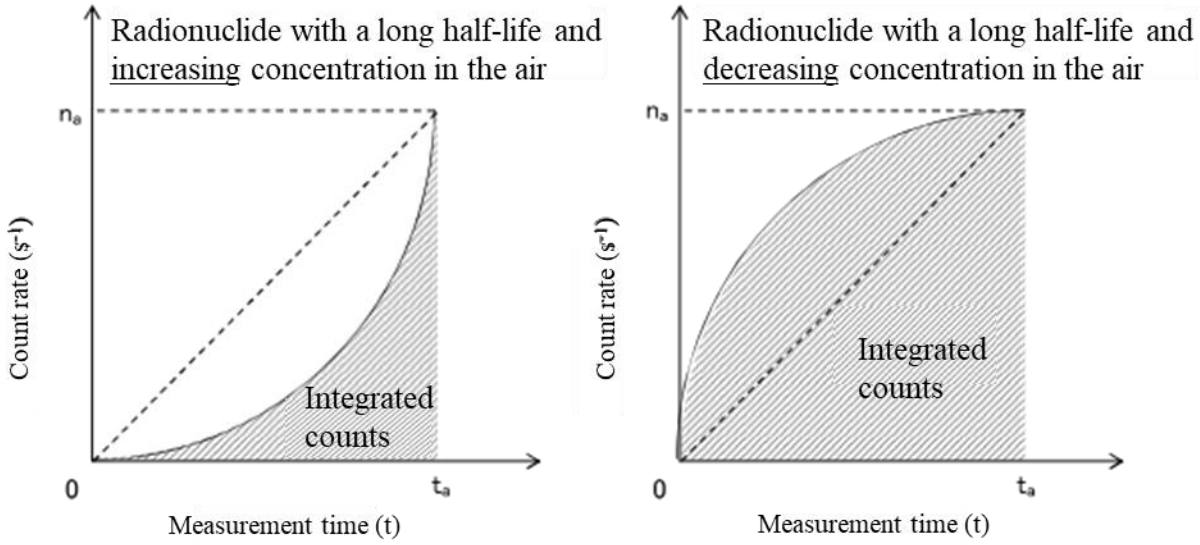


Figure C-5. Evaluation of integrated counts by measurement during air sampling



*The slope of the count rate represents the concentration of radioactive materials in the air.

Figure C-6. Effect of changes in the concentration of radioactive materials in the air on the integrated counts

(b) When the scaler measures the average concentration per unit time

The difference in count rates is based on the change in the count rate for each unit time, which is measured by the count rate meter from the previous time.

When the count rate is obtained by calculation from the integrated counts measured by the scaler, dividing the difference in the integrated counts (S1-S3) every 10 minutes by the measurement time (10 minutes) does not result in the count rate at the time of the tens of minutes, but in the count rate at that intermediate time as shown in Figure C-7, leading to an underestimate of the count rate.

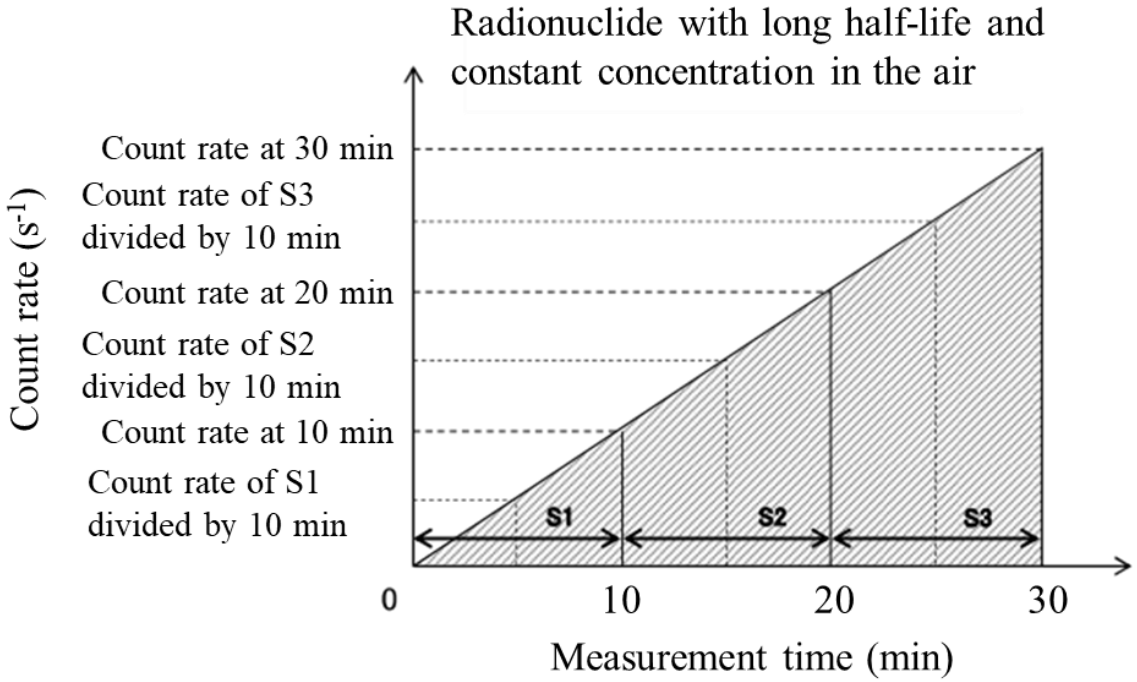


Figure C-7. Evaluation example of the difference in count rate calculated from the integrated counts-1

The following is a method for obtaining a count rate as close as possible to the actual count rate at tens of minutes from the integrated counts.

a. Method of estimating the count rate from the integrated counts for the relevant10-minute period

If the concentration of radioactive materials (nuclides with long half life) in the air during the relevant 10 minutes is constant, the count rate increases linearly. Thus, the count rate exactly at ten minutes can be estimated by considering the integrated counts as the area of the triangle (from 0 to 10 minutes) or trapezoid (from 10 to 20 minutes) shown in Figure C-8. However, in an emergency, the concentration of radioactive materials in the air is expected to change rapidly, as shown in Figure C-8, from 20 to 30 minutes. In this case, the change in concentration during this period cannot be known, so the count rate must be estimated by assuming a constant concentration. Therefore, the count rate exactly at 10 minutes can be calculated by considering the integrated counts for a 10-20 minutes period as the area of a trapezoid while retaining the integrated counts (equivalent to the area of the filled-in area for each period) for 20-30 or 30-40 minute periods. Therefore, it should be noted that when the count rate at exactly 10 minutes is calculated, the deviation from the actual count rate at exactly 10 minutes may be large, depending on the circumstances of concentration changes during the process.

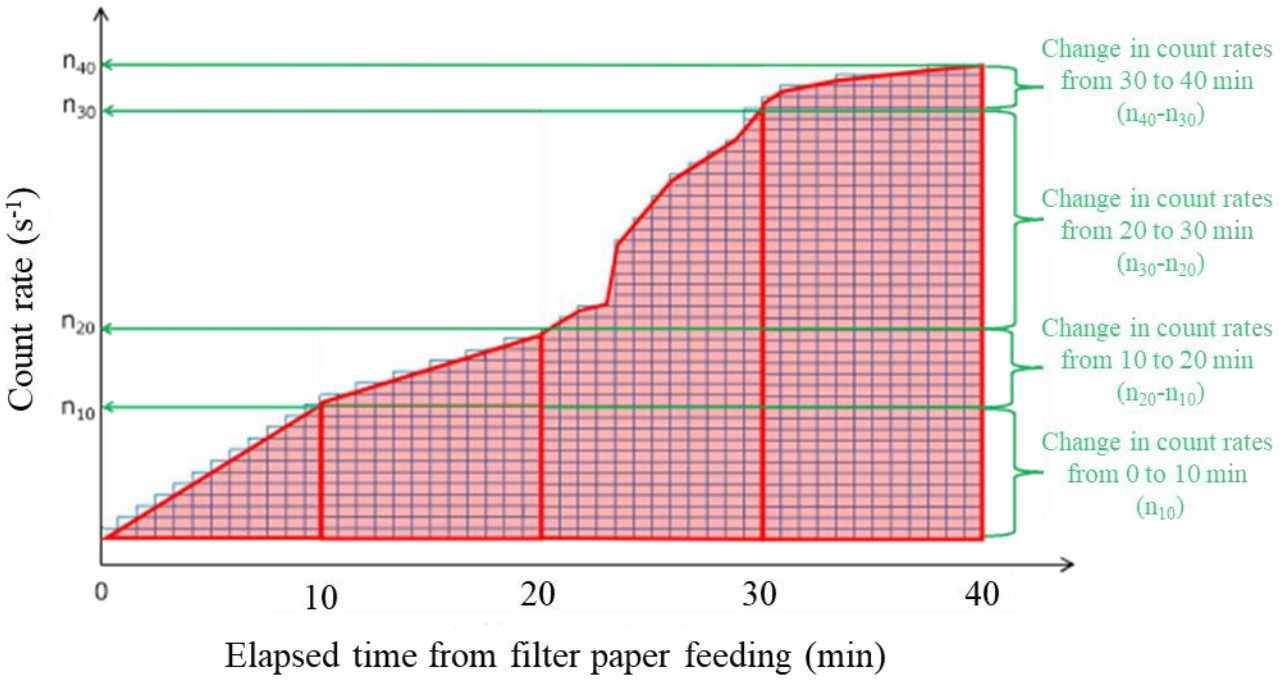


Figure C-8. Example of evaluation of difference in count rate calculated from the integrated counts-2

b. Method to evaluate the count rate by shortening the divided time of the measurement of the integrated counts

The shorter the time to measure the integrated counts, the closer the count rate at the end of the integrated counts can be to the count rate measured by the count rate meter, even when the integrated counts are simply divided by the measurement time. For example, the count rate obtained by dividing the integrated counts from 9 to 10 minutes by 1 minute (60 seconds) is close to the count rate obtained by the count rate meter at 10 minutes in Figure C-9. Another method uses the count rate calculated

from the 10 integrated counts for every minute for 10 minutes to obtain the count rate at 10 minutes exactly. It should be noted, however, that the uncertainty in the calculated count rate increases as the integrated counts become smaller.

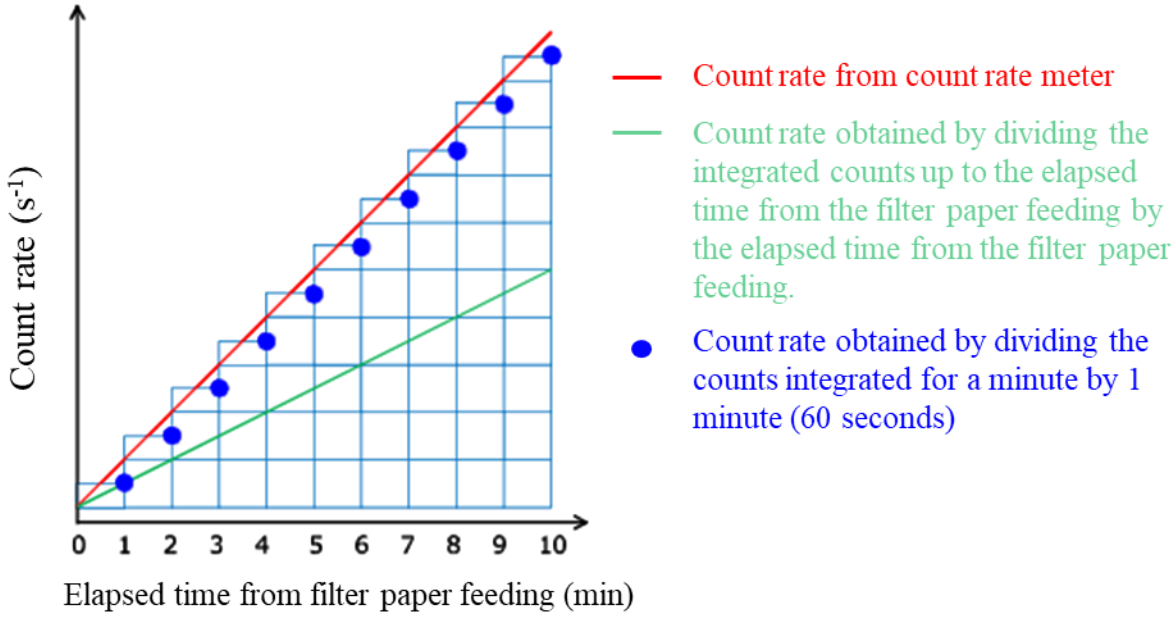


Figure C-9. Example of evaluation of difference in count rate calculated from the integrated counts-3

(3) Relationship between air sampling time and lower detection limit

Table C-1 shows an example of evaluating lower detection limits for α- and β-ray dust monitors.

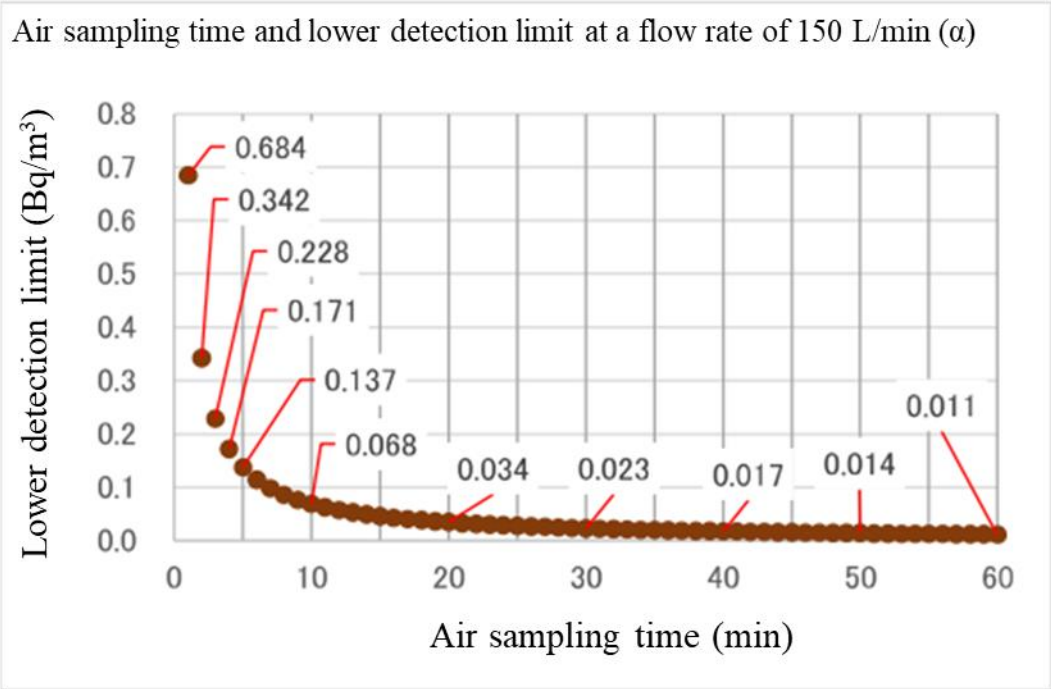
The maximum detection sensitivity (scalar method) described in JIS Z 4316:2006 "Radioactive dust monitors" [5] was calculated as the lower detection limit. This is not a discrimination level for facility-derived radioactive materials.

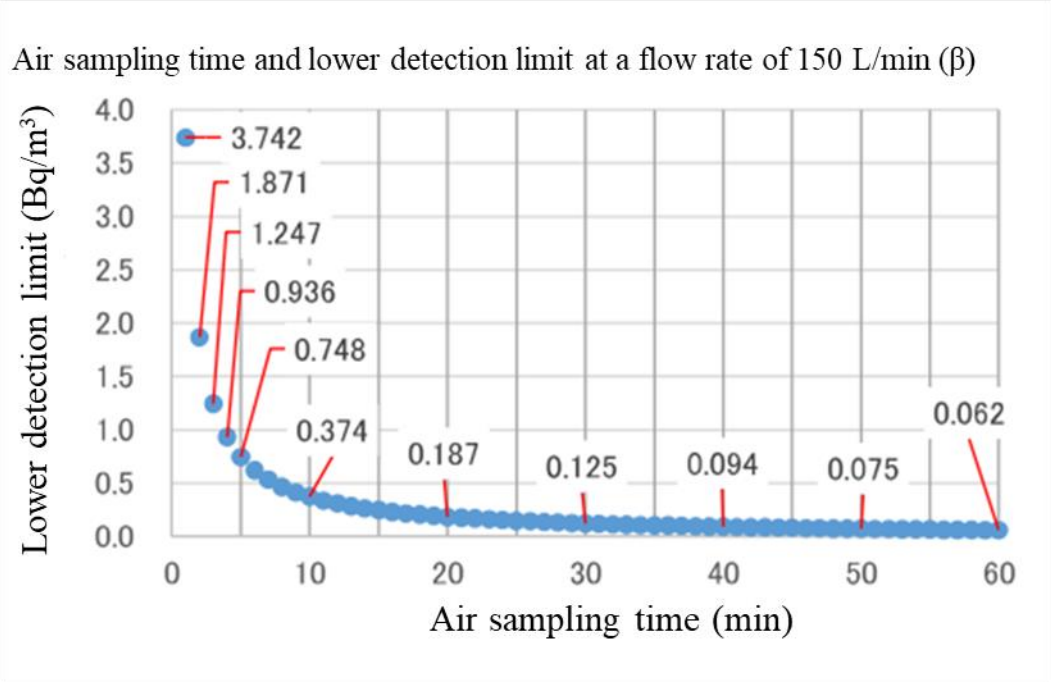
Table C-1 Example of evaluation of detection limits for α- and β-ray dust monitors

Air sampling time	Sample amount	The lower limit of detection (Bq/m^3)	
		Gross α radioactivity concentration	Gross β radioactivity concentration
10 min.	1.5 m^3	0.07	0.4
1 hour	9 m^3	0.01	0.06

- Flow rate: 150 L/min
- Equipment efficiency: α-ray approx. 49%, β-ray approx. 35%
- Detectors: α-ray ZnS(Ag) scintillator, β-ray plastic scintillator
- Detector size: 50 mmϕ
- Background count rate: α-ray 2 cpm, β-ray 15 cpm

Figure C-10. depicts the relation between air sampling times and lower detection limits at a flow rate of 150 L/min.





<Calculation conditions>

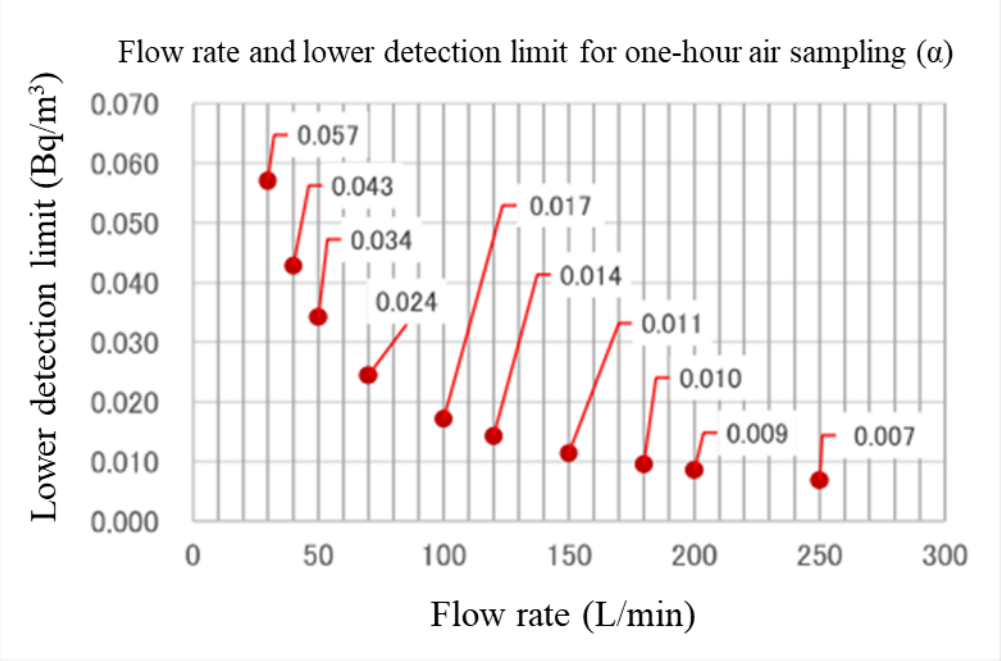
- Equipment efficiency: α-ray approx. 49%, β-ray approx. 35%
- Collection efficiency: 100%
- Detectors: α-ray ZnS(Ag) scintillator, β-ray plastic scintillator
- Detector size: 50 mmϕ
- Counting time: 2 min.

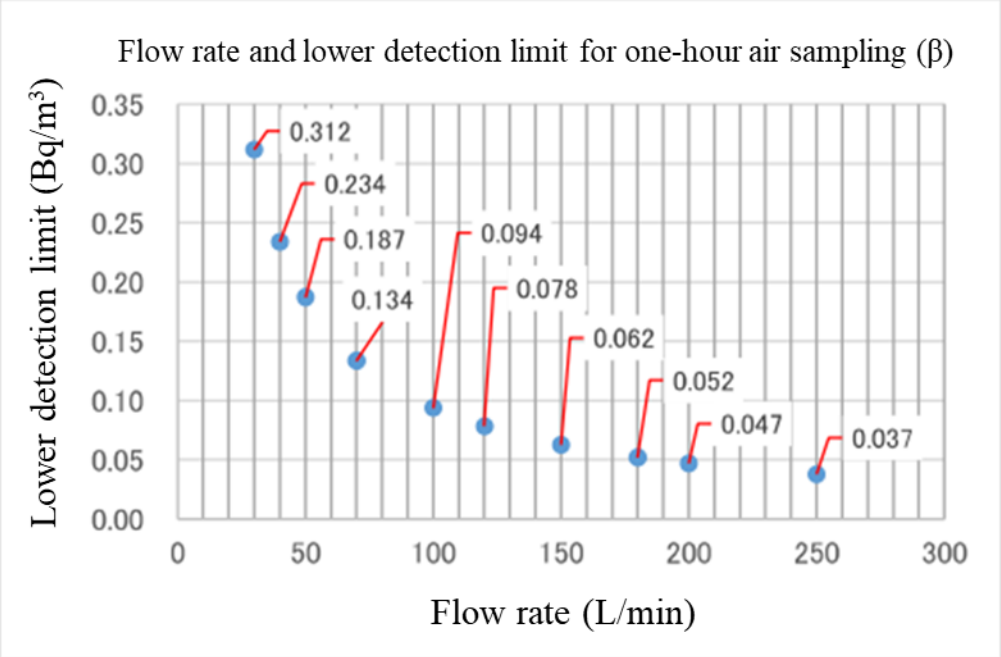
・ Background count value during 2 minutes: 2 counts for α-rays, 30 counts for β-rays

Figure C-10. Relationship between air sampling time and lower detection limit
(above Gross α radioactivity concentration, below Gross β radioactivity concentration)

(4) Relationship between flow rate and lower detection limit

Figure C-11 depicts the relation between flow rates and lower detection limits during one hour of air sampling time.





<Calculation conditions>

- Equipment efficiency: α-ray approx. 49%, β-ray approx. 35%
- Collection efficiency: 100%
- Detectors: α-ray ZnS(Ag) scintillator, β-ray plastic scintillator
- Detector size: 50 mmϕ
- Counting time: 2 min.
- Background counts during 2 minutes: 2 counts for α-rays, 30 counts for β-rays

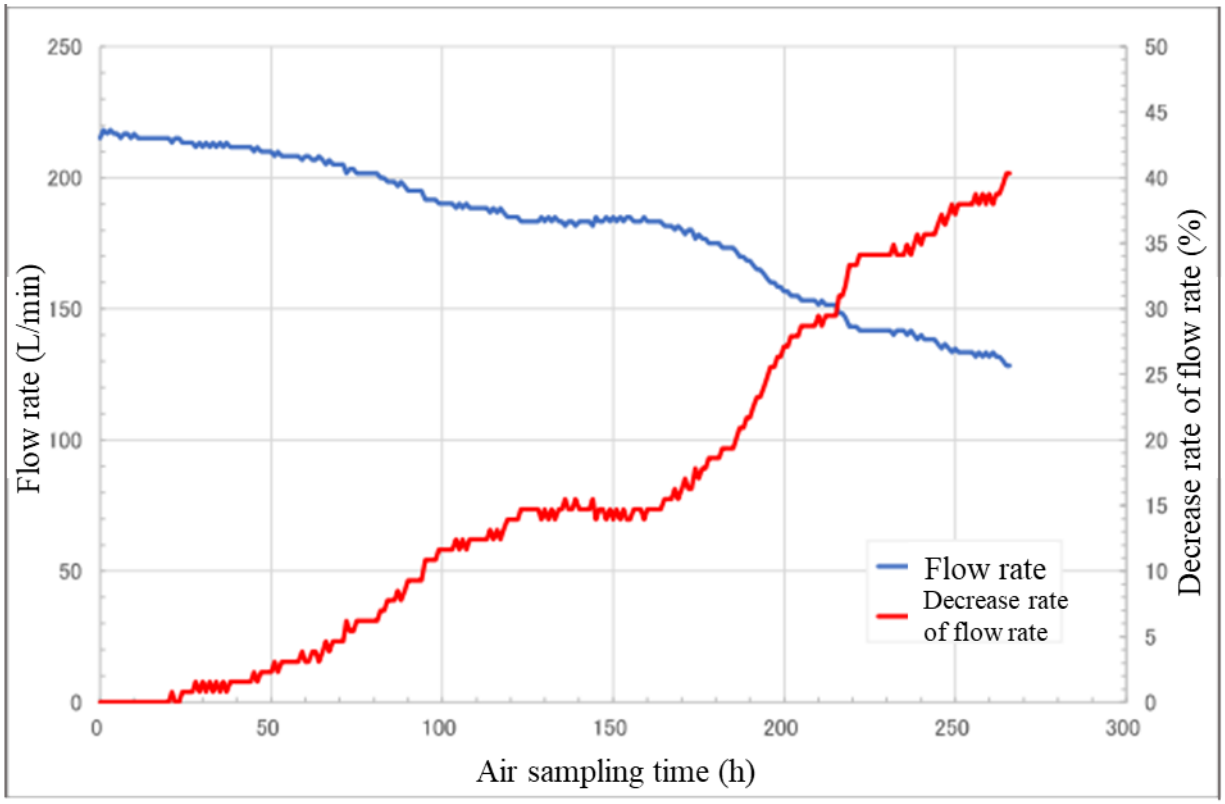
Figure C-11. Relationship between flow rate and lower detection limit
(above Gross α radioactivity concentration, below Gross β radioactivity concentration)

(5) Relationship between air sampling time and flow rate drop

The longer the air sampling time is, the larger the amount of airborne dust collected on the filter paper is, and thus the lower the flow rate is.

Figure C-12 shows an example of evaluating the rate of decrease in flow rate using cellulose and glass fiber filter paper when the flow rate at the start of air sampling was approximately 200 L/min and suction continued for approximately 10 days. The flow rate decreased by approx. 5% for 3 days and 35% for 10 days.

It should be noted that the amount of airborne dust varies depending on the installation location of the dust monitor and the season.



*If the rate of decrease in flow rate is negative, zero is displayed

Figure C-12. Example of evaluation of the rate of decrease in flow rate

Explanation D Efficiency of Dust Monitor

The concentration of radioactive materials in the air measured by dust monitors is calculated as the radioactivity concentration evaluated by a single standard radiation source used for efficiency calibration, which does not consider the energy dependence of the α and β-ray detectors.

Since changing the standard radiation source used for efficiency calibration will also change the measurement results, this method uses the standard radiation sources listed in Table 3-10 in the text as a general rule.

(1) Standard radiation source

JIS Z 4316:2013 "Radioactive dust monitors" [4] states that the radiation sources used in the tests shall be Cl-36 and Tl-204 as β radiation sources, Am-241 as α radiation source, Cs-137 as γ-radiation source, etc. Other radiation sources may be used by agreement between the delivering and receiving parties. Currently, Am-241 and Cl-36 are widely used for efficiency calibration of dust monitors for α- and β-ray measurement. For reference, Table D-1 lists examples of suitable radionuclides as β-radiation sources as described in JIS Z 4316:2013.

In addition, traceability to national standards is ensured for the surface-emission rate of the standard radiation sources for α- and β-ray dust monitors and for the radioactivity of the standard radiation sources for γ-ray dust monitors.

Table D-1. Examples of radionuclides suitable as β radiation sources [4][5]

Nuclide	Half-life	β-ray maximum energy (keV)
Ni-63	100.1 years	67
C-14	5700 years	157
Hg-203 *1	46.61 days	213
Pm-147	2.62 years	225
Ca-45	163 days	257
Co-60 *1	5.27 years	318
Cs-137 *1	30.17 years	514 (94.4%), 1176 (5.6%)
W-185	75.1 days	433
Tl-204	3.78 years	764 (97.1%)
Cl-36	3.01×10^5 years	709 (98.1%)
Au-198 *1	2.695 days	961 (99.0%)
Sr-89	50.53 days	1495
P-32	14.26 days	1711
Natural uranium*2	4.46×10^9 years	2269
Sr-90 + Y-90 *3	28.79 years	546, 2280

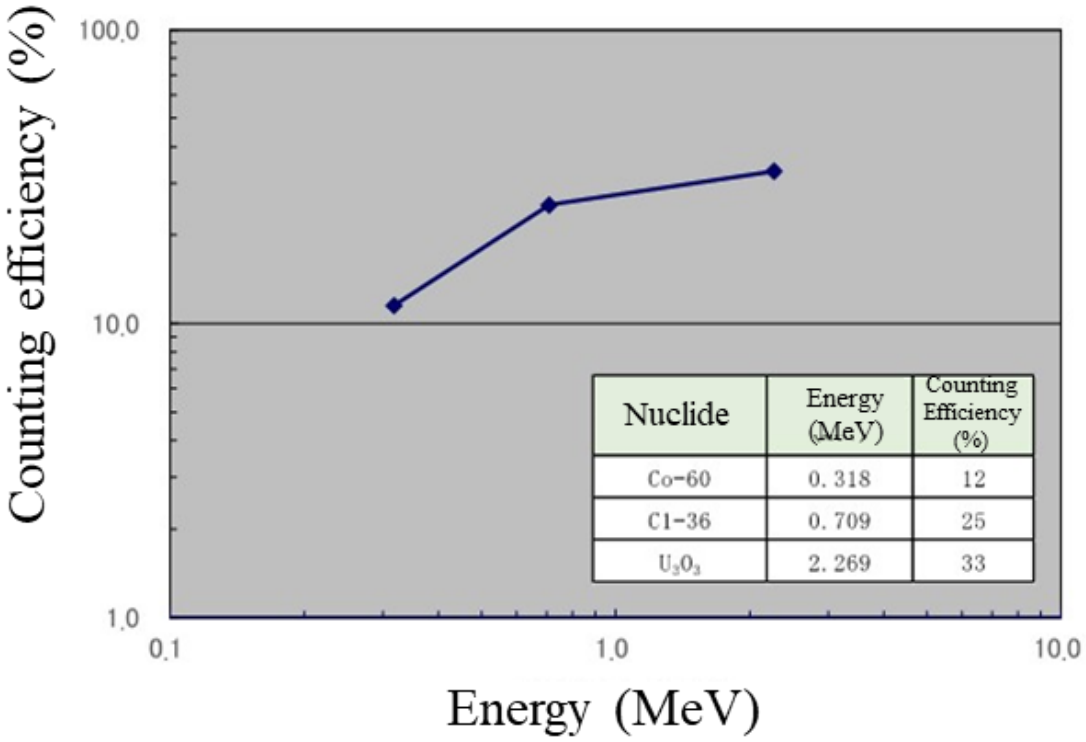
*1 These nuclides also emit γ-rays. Cs-137 and Au-198 also emit internal conversion electrons, so their effects should be considered.

*2 The half-life is the value for the main component, U-238, and the β-ray maximum energy is the value for the series nuclide, Pa-234. In addition, α- and γ-rays are emitted, so their effects should be considered when using the product.

*3 Based on JIS Z 4329:2004 "Radioactive Surface Contamination Survey Meter" [11], 2280 keV is used.

(2) Effects of changing the standard radiation source

Figure D-1 shows an example evaluation of a plastic scintillation detector for energy characteristics (dependence of efficiency on β energy)



Detector size: 50 mmϕ

Distance between the detector and standard radiation source: approx. 3.5 mm

Figure D-1. Example evaluation of energy characterization of a plastic scintillation detector [17].

Dust monitors introduced in the past underwent efficiency calibrations using U_3O_8 (α and β radiation) sources*. There may be cases where those efficiencies continue to be used. However, in principle, the standard radiation sources in Table 3-10 should be used, and their use for efficiency calibrations is not recommended.

Note that if the standard radiation source used for efficiency calibration changes, the efficiency and the measured value calculated by the efficiency will also change.

*The Japan Radioisotope Association stopped selling uranium (U_3O_8) radiation sources, which are internationally controlled materials, in 1997.

An example of the evaluation of the difference in counting efficiency between the U_3O_8 (α and β) radiation sources used in the past and the Am-241 (α) and Cl-36 (β) radiation sources listed in JIS is shown in Table D-2.

Table D-2. Evaluation example of the difference in counting efficiency of U_3O_8 (α and β) radiation sources with Am-241 and Cl-36 sources

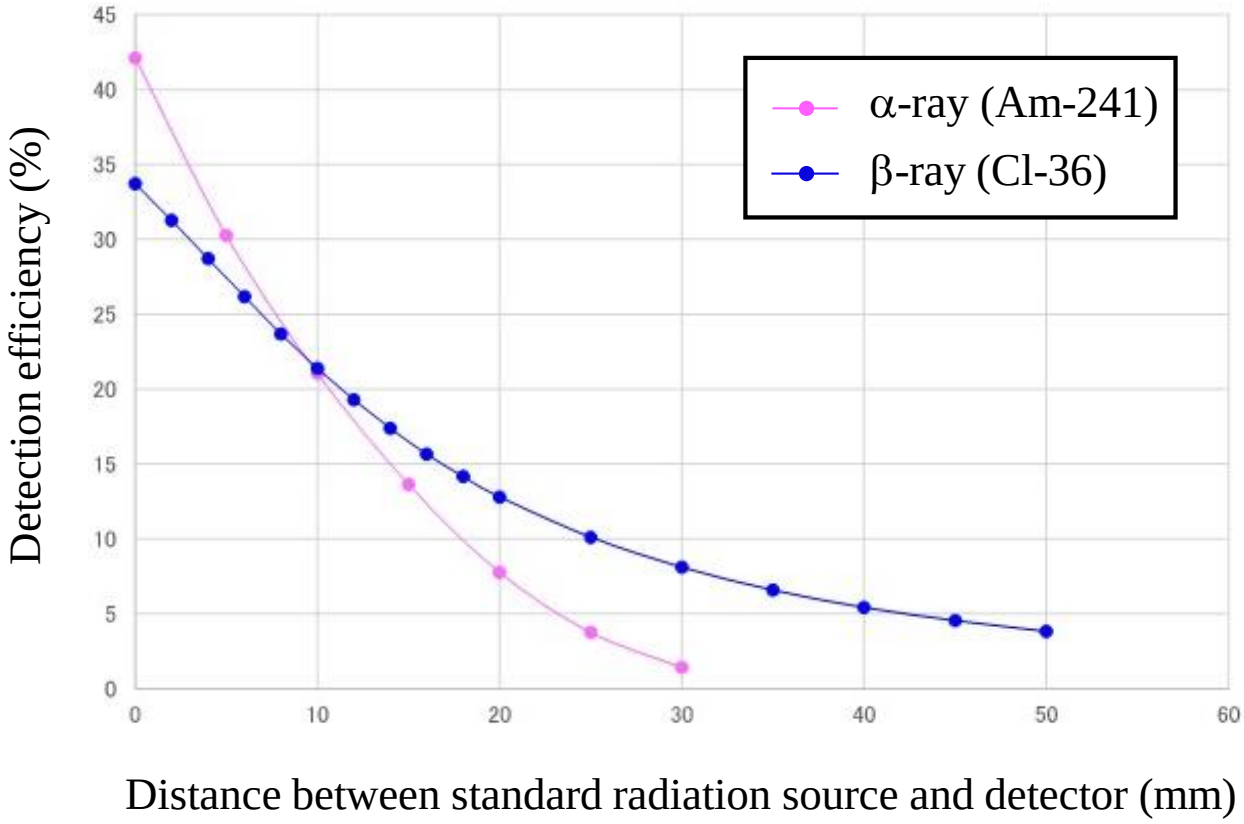
α-ray efficiency		β-ray efficiency	
U_3O_8 (4.2 MeV)	Am-241 (5.5 MeV)	U_3O_8 (2.3 MeV)	Cl-36 (0.7 MeV)
18%	24%	30%	22%

Detector: α-ray ZnS(Ag) scintillation detector
β-ray Plastic scintillation detector
Both detectors have an effective area of approximately 50 mmϕ and lead shielding of approximately 1.5 cm thick.

(3) Effect of different distances between the standard radiation source and detector in the efficiency calibration

Figure D-2 shows an example of an evaluation of the change in detection efficiency when the distance between the standard radiation source and the detector is changed. The detection efficiency decreases as the distance increases, and the amount of change is larger for α-rays with a shorter range.

For this reason, it is essential to perform efficiency calibration under precisely the same conditions as the geometrical arrangement of the filter paper and detector.



*Evaluation by Monte Carlo simulation (simulation conditions are the same as in (4))

Figure D-2. Evaluation example of changes in detection efficiency when the distance between the standard radiation source and the detector is varied

(4) Calculation of detection efficiency using Monte Carlo simulation

The Monte Carlo method can calculate the interaction between charged particles and detectors to simulate the detection efficiency for radiation sources of various energies.

Detection efficiencies were calculated from Monte Carlo simulations with Geant4 using the geometries shown in Table D-3 and Figure D-3 (Mylar membrane + ZnS(Ag) scintillator + plastic scintillator).

As shown in Figure D-4, the detection efficiency varied greatly depending on the energy of the nuclide, and both ZnS(Ag) scintillators and plastic scintillators tended to have low detection efficiency for low-energy nuclides.

Table D-3. Geometry parameters used in the simulation

Detector	Chemical formula	Density (g/cm^3)	Diameter (cm)	Thickness
Myla film	$C_6H_8O_4$	1.4	5	4.5 μm
ZnS(Ag) scintillator	ZnS	4.09	5	7.2 μm
Plastic scintillator	C_9H_{10}	1.032	5	0.5 cm

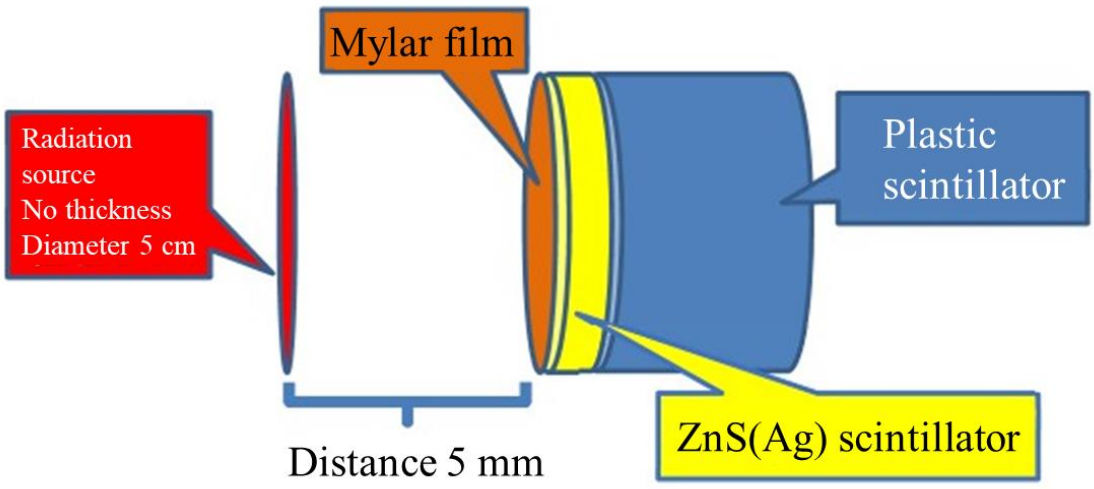
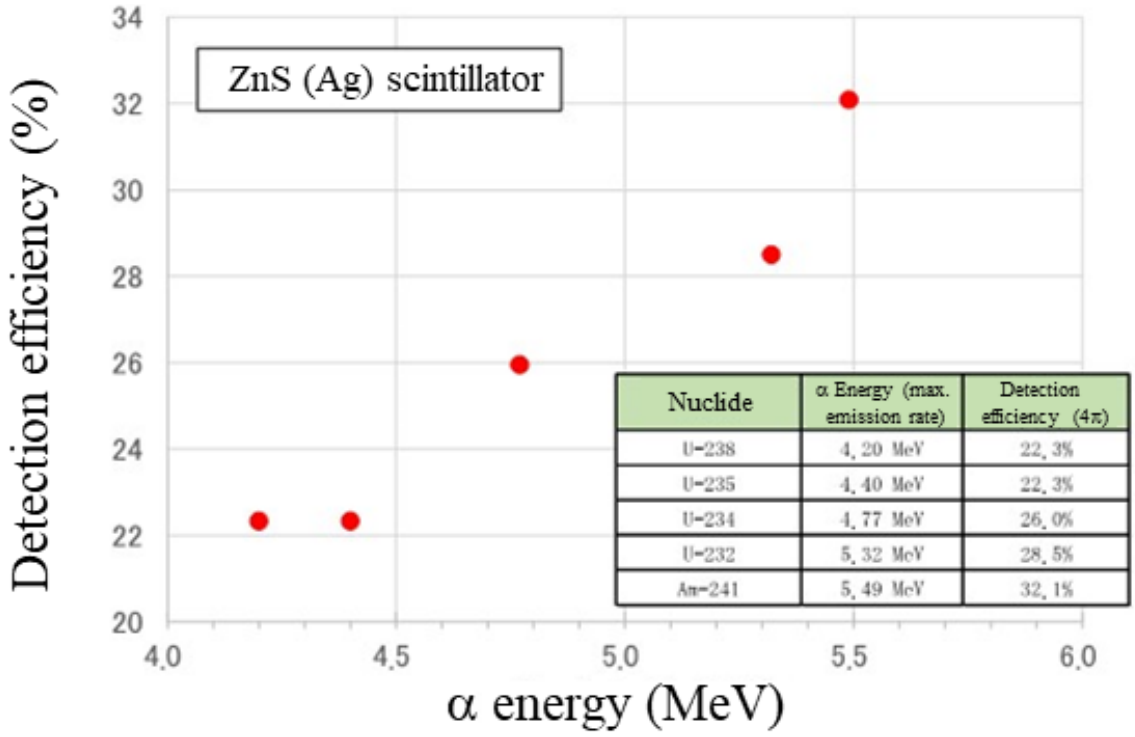
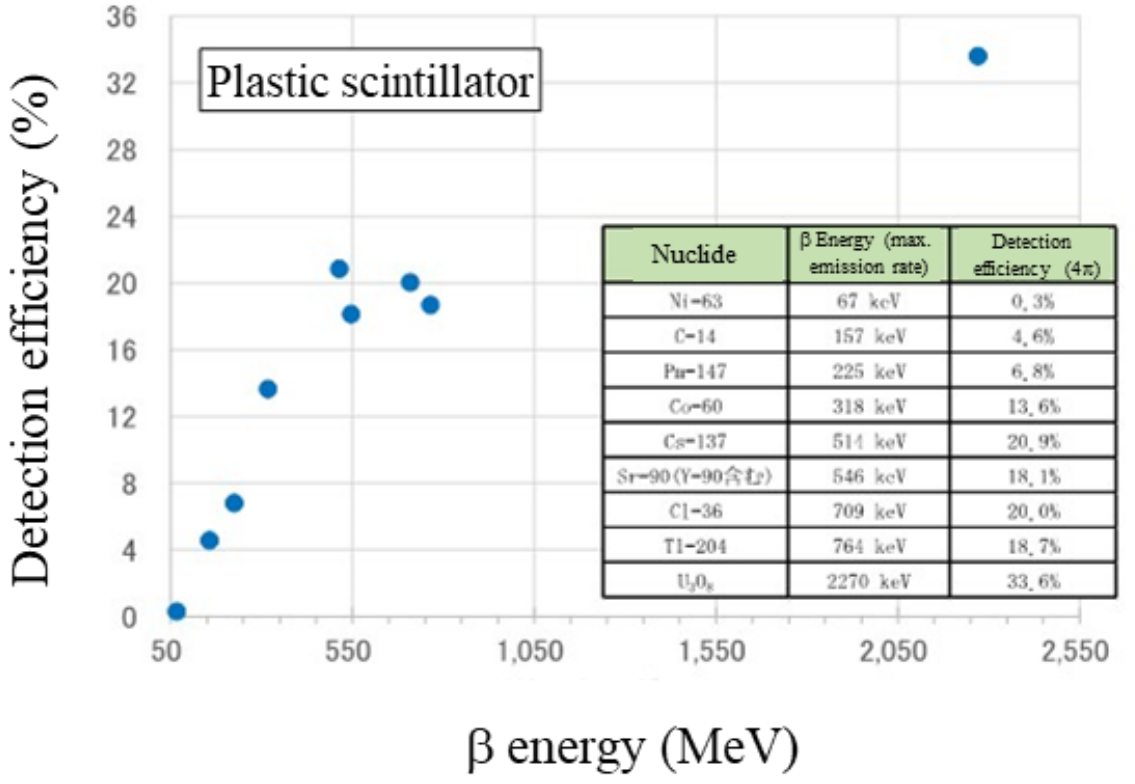


Figure D-3. Geometry used for Monte Carlo simulation



Nuclide	α Energy (max. emission rate)	Detection efficiency (4π)
U-238	4.20 MeV	22.3%
U-235	4.40 MeV	22.3%
U-234	4.77 MeV	26.0%
U-232	5.32 MeV	28.5%
Am-241	5.49 MeV	32.1%



Nuclide	β Energy (max. emission rate)	Detection efficiency (4π)
Ni-63	67 keV	0.3%
C-14	157 keV	4.6%
Pm-147	225 keV	6.8%
Co-60	318 keV	13.6%
Cs-137	511 keV	20.9%
Sr-90(Y-90含む)	546 keV	18.1%
Cl-36	709 keV	20.0%
Tl-204	764 keV	18.7%
U_3O_8	2270 keV	33.6%

Figure D-4. Example of detection efficiency evaluation using Monte Carlo simulation

<Detection efficiency calculation method>

- Simulation of the energy (energy spectrum) given to each detector (ZnS(Ag) scintillator or plastic scintillator) using Geant4.10.06.
- Number of decays of each radionuclide: 1,000,000
- The detection efficiency is calculated by dividing the total counts of energy spectra by the number of emissions.
- The detection efficiency includes the effects of radiation outside the measurement target, such as γ-rays.
- Radiation source efficiencies and radiation source surface emission rates are not considered.

Explanation E Effect of Radon-Thoron Decay Products on Dust Monitor Measured Values

The measured value of the dust monitor is calculated as the radioactivity concentration in the airborne dust collected on the filter paper. In the natural environment, the main radioactive materials in airborne dust that emit α- or β-rays are radon/thoron decay products.

Radon is Rn-222 in the uranium series, and thoron is Rn-220 in the thorium series. Even if the radioactivity concentration of radon and thoron decay products in the air is constant, the radioactivity concentration of radon and thoron decay products in airborne dust collected on filter paper varies due to the effects of increase and decay by collection and sequential decay. Figure E-1 shows the decay diagram of radon/thoron.

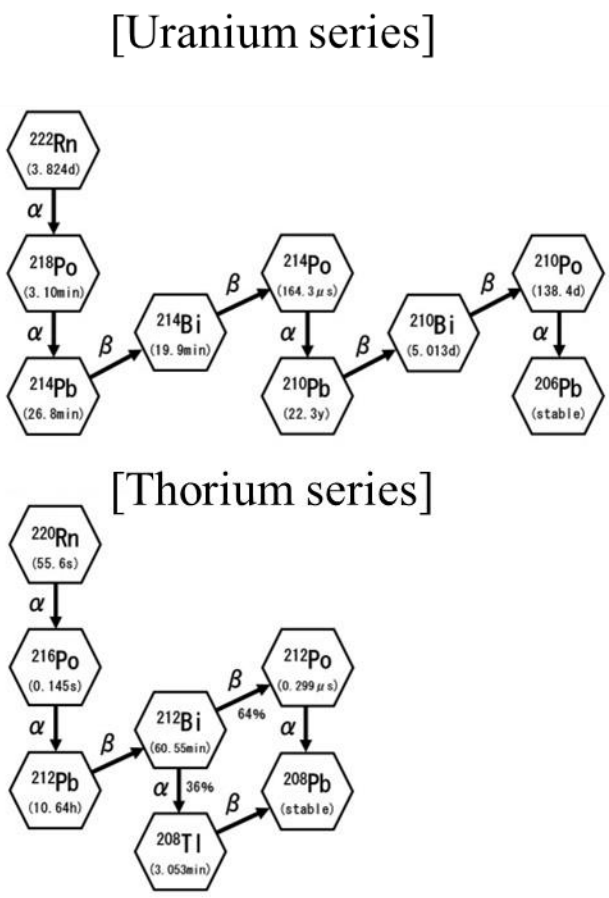


Figure E-1. Major decay diagram of radon/thoron

(1) Evaluation by actual measurement

For Company A dust monitors, which can measure the approximate radioactivity concentration of radon/thoron by spectral analysis, and Company B dust monitors, which can measure the gross α and gross β count rates, measurements were continued with the pump stopped after 6 hours of air sampling. The relationship between the standing time after air sampling and the decay of radon/thoron was evaluated (Figure E-2).

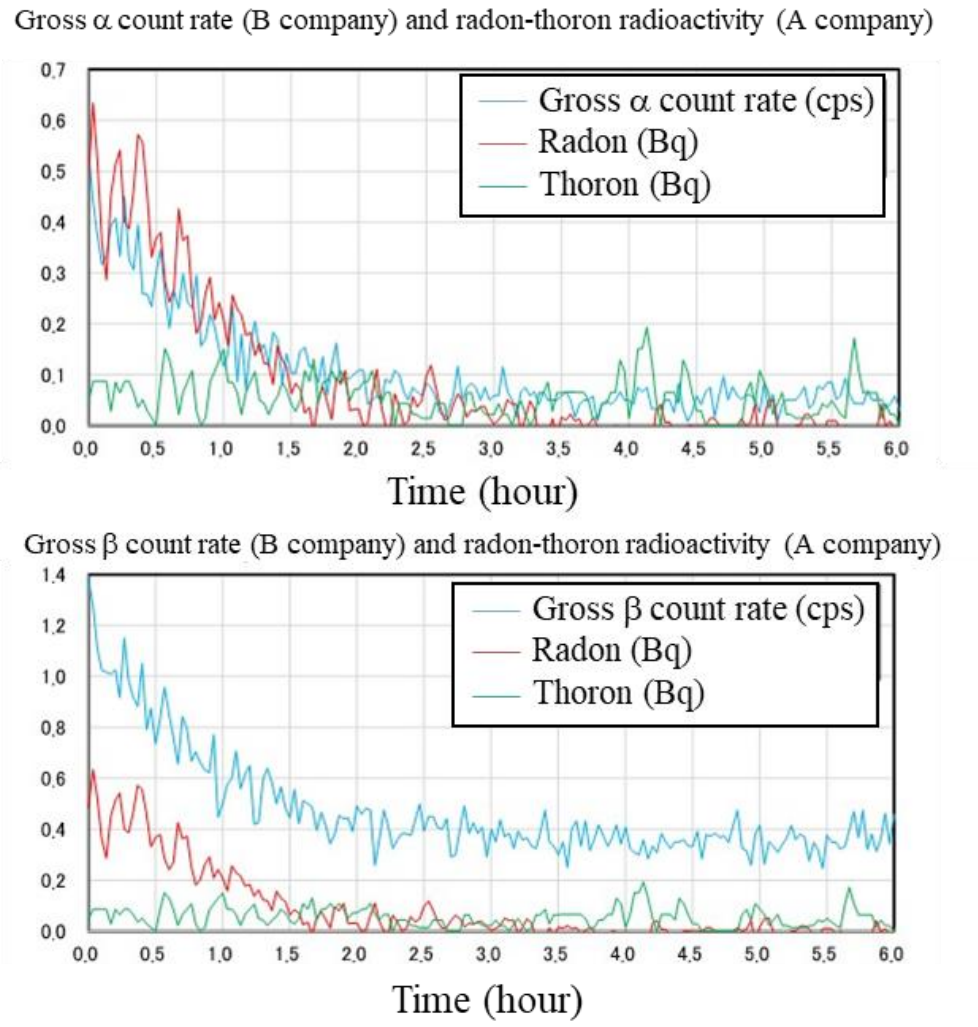


Figure E-2. Evaluation of radon-thoron impact based on actual dust monitor measurements (Top: gross α, bottom: gross β)

The decay patterns of the gross β count rate and radon were almost identical, with a half-life of about 30 minutes. The gross β count rate decreased to a BG count rate approximately 2 hours after stopping the air sampling.

*The actual measurement value of BG count rate (measured with uncollected filter paper after the pump stops) for α was 0.02 s^{-1} and for β approximately 0.3 s^{-1}.

(2) Evaluation by calculation

Assuming that each of the radon decay products Po-218, Pb-214, Bi-214, and Po-214 is present in the air at a constant concentration of 5 Bq/m^3, Figure E-3 shows the change in radioactivity on filter paper when sampling the air at a flow rate of 100 L/min and collection efficiency of 100%. The radioactivity on the filter paper is calculated on a minute-by-minute basis.

The air sampling increases radioactivity on the filter paper. On the other hand, the radioactivity decreases due to radioactive decay and becomes constant over time.

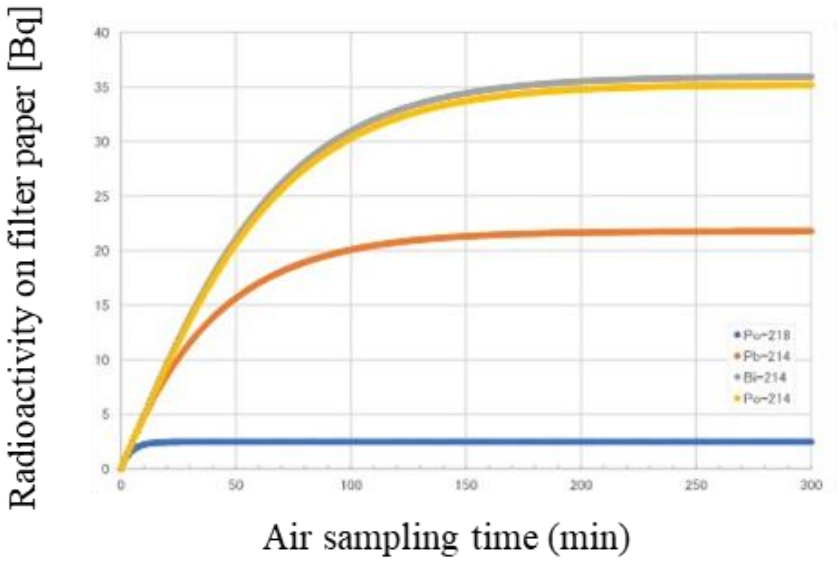


Figure E-3. Change in radioactivity (uranium series) on filter paper

Figure E-4 shows the change in radioactivity on filter paper when each of Po-216, Pb-212, and Bi-212, which are thoron decay products, are present in the air at a constant concentration of 0.1 Bq/m^3. The air is collected at a flow rate of 100 L/min and a collection efficiency of 100%. The radioactivity on the filter paper was calculated on a minute-by-minute basis.

The radioactivity on the filter paper increases almost linearly with air sampling. The radioactivity is not constant, as in the uranium series shown in Figure E-3, and that reflects the effect of Pb-212, which has a long half-life of about 11 hours.

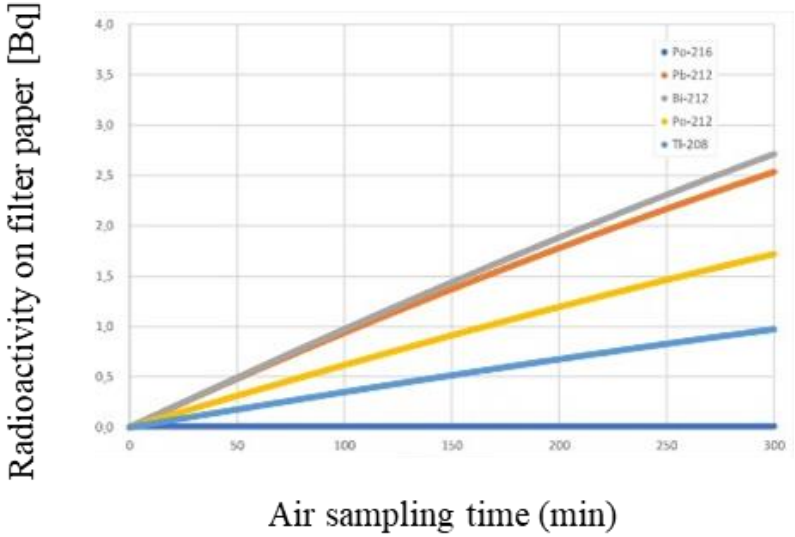


Figure E-4. Change in radioactivity (thorium series) on filter paper

Explanation F Distinction Methods for Facility-Caused Radioactive Material Contribution in Dust Monitor Measurements

Table F-1 shows the methods for distinguishing the radioactive materials caused by nuclear facilities contributing to dust monitor measurements. Since the measurement target in dust monitors differs depending on the nuclear facility, the appropriate distinction method should be selected concerning Table F-1.

Table F-1. Distinction method and distinction target for facility-caused radioactive material contribution

Distinction methods	Distinction targets	Reference
Method using β/α ratio	Gross β radioactivity concentration	Body text
Methods using α-β coincidence counting	Gross α radioactivity concentration, gross β radioactivity concentration	F.1
Methods using spectral analysis	Gross α radioactivity concentration, gross β radioactivity concentration	F.2
Methods using normalized counts	Gross α radioactivity concentration, gross β radioactivity concentration	F.3
Methods using unfolding	γ-emitting nuclide concentration	F.4

F.1 Method using α-β coincidence counting

Since β decay of Bi-214 (half-life: approximately 20 minutes), a decay product of radon, and α decay of Po-214 (half-life: approximately 160 μs), a decay product of Bi-214, occur almost simultaneously, α- and β-rays are emitted almost simultaneously (Figure F-1).

In the absence of facility-caused radioactive material effects, the regression equation can be used to evaluate the estimated natural α-ray count rate by taking advantage of the strong positive correlation between the measured α-β coincidence count rate due to natural radioactive material and the measured α-ray count rate (Figure F-2).

Obtaining the measured α radioactivity concentration from the measured α count rate and subtracting the estimated natural α radioactivity concentration from the measured α radioactivity concentration allows estimating facility-caused radioactivity concentration and distinguishing the facility-caused radioactive material contribution. However, large contributions from thorium-series nuclides could slightly reduce the distinction ability because the increased proportion of thorium-series nuclides is not counted simultaneously.

According to the evaluation by Togawa et al. [18], the level at which the effects of facility-caused radioactive materials (α-emitting nuclides) could be determined was 1.3 Bq/m^3 (Figure F-3).

There is also a strong positive correlation between the measured α-β coincidence count rate and the measured β-ray count rate that makes this method effective for estimating the facility-caused β radioactivity concentration as well as the facility-caused α radioactivity concentration (Figure F-4 and Figure F-5).

<u>Evaluation method</u>

Estimated natural α count rate (s^{-1}) = a × Measured α-β coincidence count rate (s^{-1}) + b

a, b: constants obtained by the regression equation

↓

Estimated natural α radioactivity concentration (Bq/m^3) calculated from estimated natural α count rate (s^{-1})

↓

Estimated facility-caused α radioactivity concentration (Bq/m^3)

＝ Measured α radioactivity concentration (Bq/m^3) – Estimated natural α radioactivity concentration (Bq/m^3)

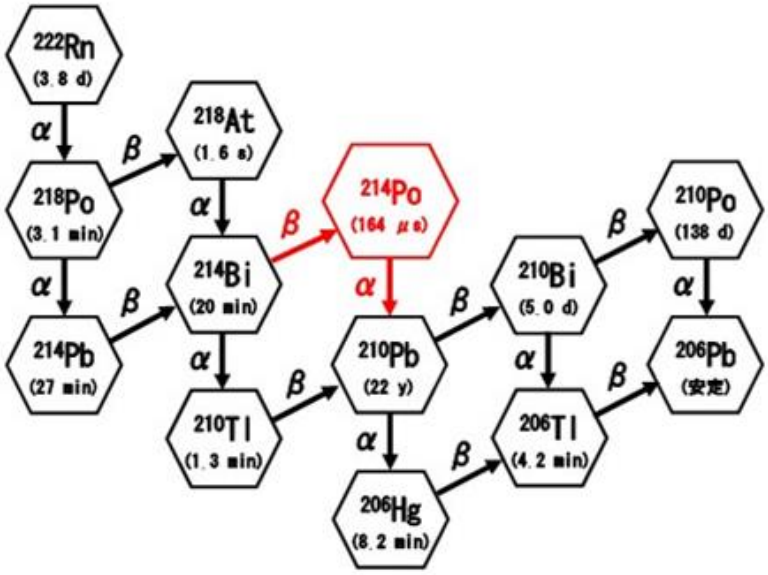


Figure F-1. Radon decay diagram

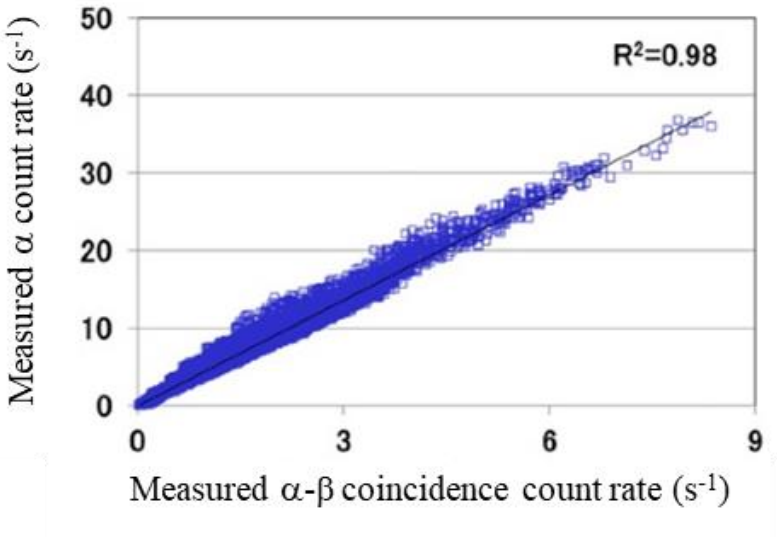


Figure F-2. Evaluation example of correlation plot between α-β coincidence count rate and gross α count rate [18].

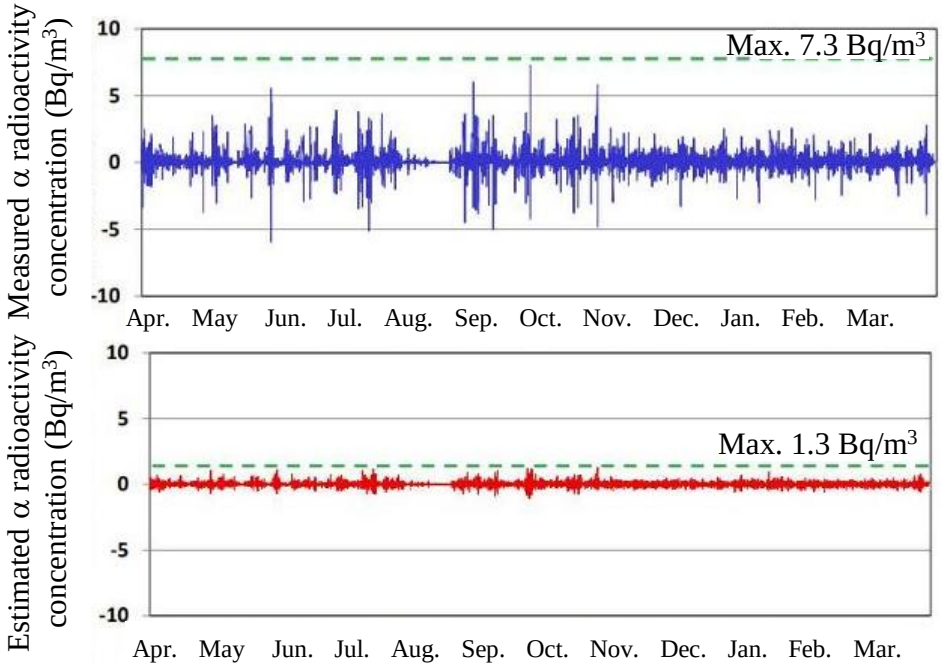


Figure F-3. Evaluation example of estimated facility-caused α radioactivity concentration [18].
(Top: Change over time of measured α radioactivity concentration (differential evaluation per unit time),
Below: Change over time of estimated facility-caused (estimated artificial in the figure) α radioactivity concentration)

<Measurement conditions (Figure F-2 and Figure F-3)>

- Measurement items: α count rate, β count rate, α-β coincidence count rate (coin gate: 100 to 400 μs)
- Detector: ZnS (Ag) + plastic scintillation detector
- Air absorbent: cellulose/glass fiber long filter paper
- Air sampling flow rate: 180 L/min
- Suction port heigh: approx. 3.1 m above ground
- Air sampling cycle: 24 hours

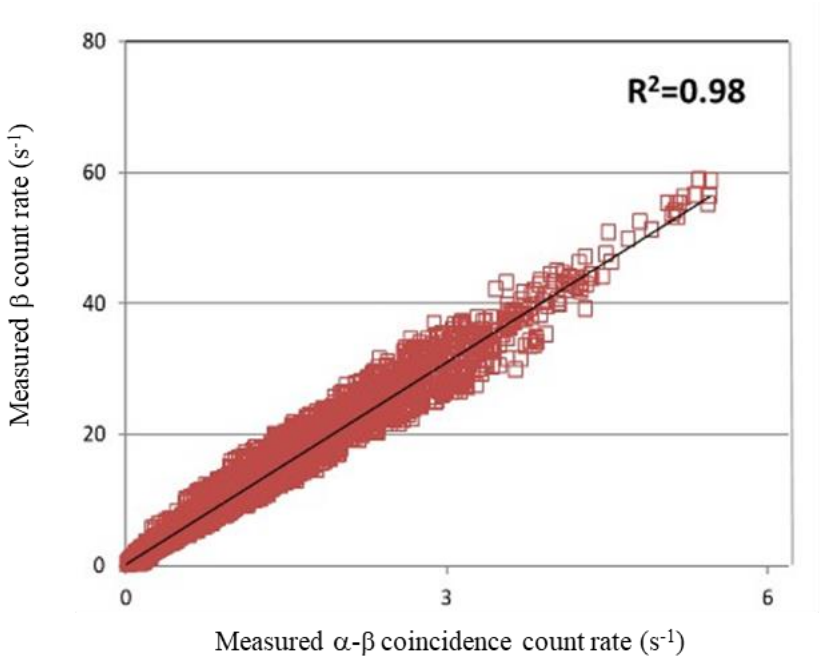


Figure F-4. Evaluation example of correlation plot between α-β coincidence count rates and gross β count rates [18].

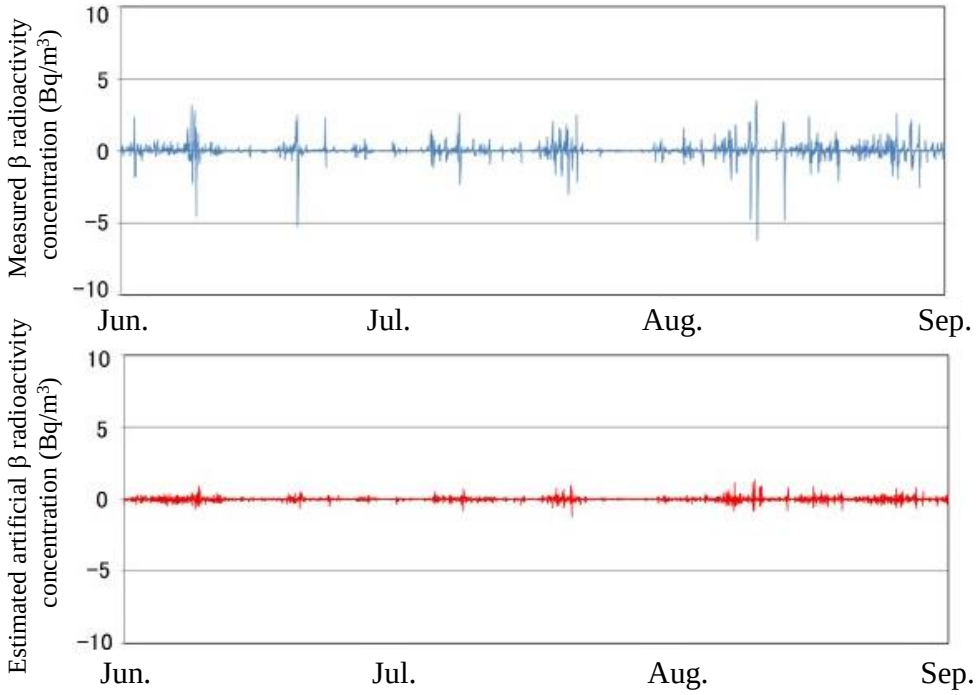


Figure F-5. Evaluation example of estimated facility-caused β radioactivity concentration [18]. (Top: Change over time of measured β radioactivity concentration (differential evaluation per unit time), Below: Change over time of estimated facility-caused (estimated artificial in the figure) β radioactivity concentration)

<Measurement conditions (Figure F-4 and Figure F-5)>

Same as Figures F-2 and F-3

F.2 Methods using spectral analysis

Analyzing the spectrum measured by the silicon semiconductor detector enables measuring the gross α and β radioactivity concentrations due to facility-caused radioactive materials by correcting for the effects of radon/thoron decay products (natural radioactive materials).

Regarding the evaluation of gross α radioactivity concentration, as shown in Figure F-6, the α energy emitted by uranium and plutonium differs from that of the radon/thoron decay products that can be distinguished as different peaks in the spectrum. Figure F-7 shows an example of the results obtained after correcting for the amount by the influence of radon/thoron decay products by spectral analysis. The facility-caused gross α radioactivity concentration is calculated from the obtained α-ray net count rate.

For the evaluation of the gross β radioactivity concentration, since β- and γ-rays are counted in the same range as shown in Figure F-6, the facility-caused gross β radioactivity concentration is calculated from the obtained β-ray net count rate by subtracting the γ-ray contribution contained therein and the α-ray contribution due to the effect of radon-thoron decay products using the following formula. Note that a separate detector to correct for the γ-ray background is required to evaluate the γ-ray contribution.

<u>The formula for evaluation of β-ray net count rate</u>

β-ray net count rate = (count rate in β + γ range) - (count rate in α range × contribution factor to the β range)
- (count rate in the γ range of the detector for γ-ray background correction × correction factor)

Table F-2 shows evaluation examples of decision thresholds. Some products can set the distinction level of gross α and β radioactivity concentrations due to facility-caused radioactive materials to 1 Bq/m^3 or less.

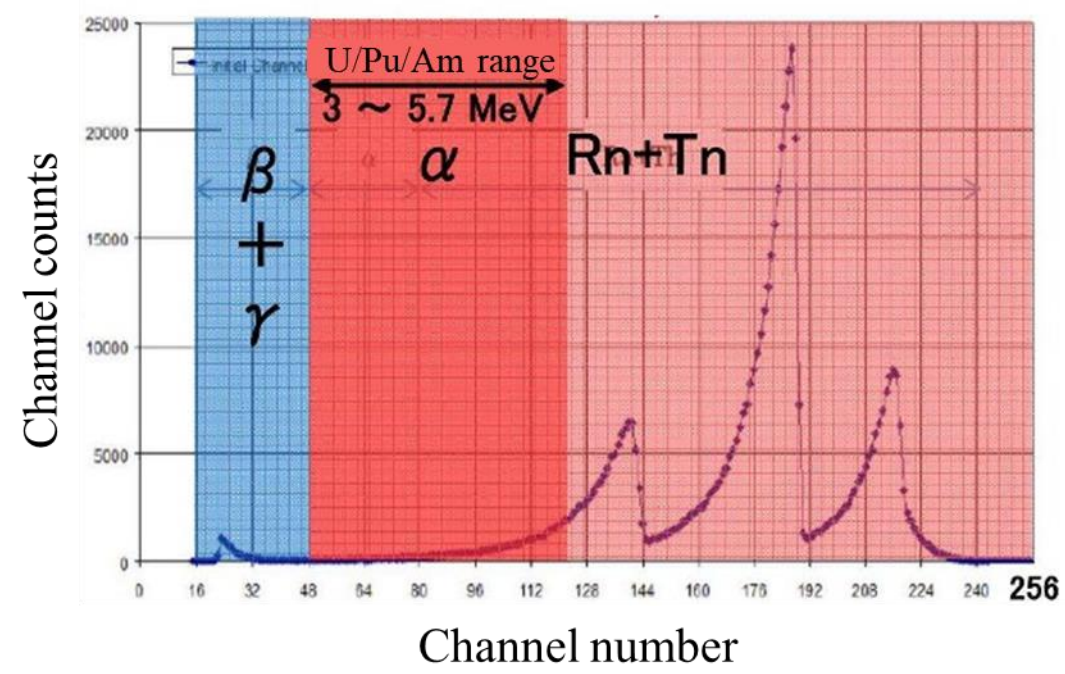
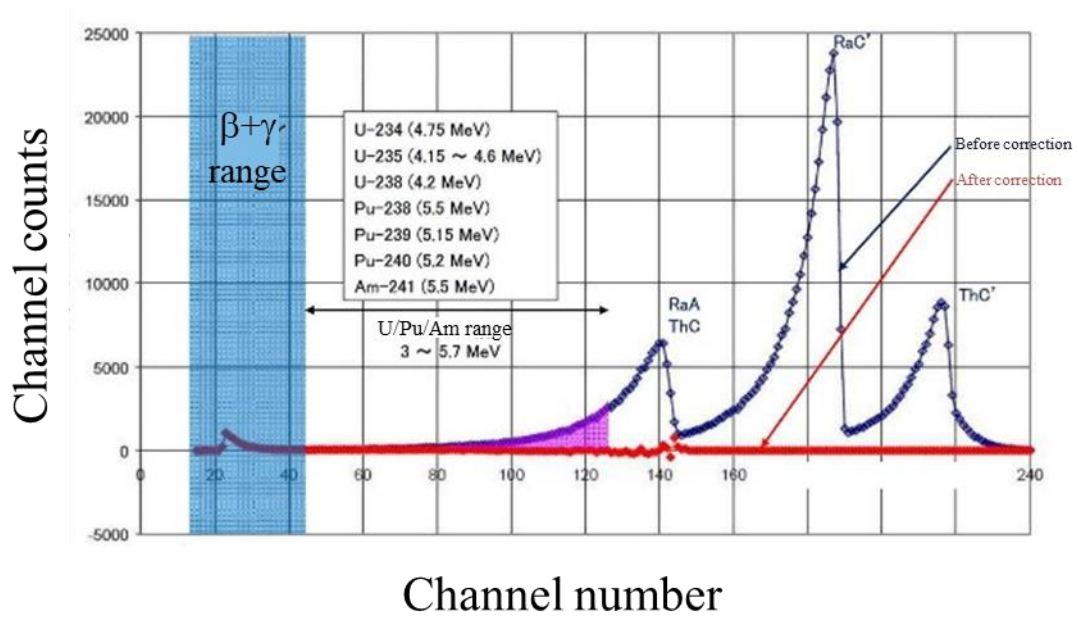


Figure F-6. Example of spectrum measured with a silicon semiconductor detector [19].



RaA: Po-218 (6.0 MeV), RaC': Po-214 (7.7 MeV),
ThC: Bi-212 (6.1 MeV), ThC': Po-212 (8.8 MeV)

Figure F-7. Evaluation of facility-caused radioactive material contribution by spectral analysis [19].

Table F-2. Evaluation examples of decision thresholds [19].

α concentration (DT: 1 hour, flow rate: 40 L/min)

^{222}Rn Radioactivity concentration (Bq/m^3)	CT (min.)	α concentration Standard deviation (Sb) (Bq/m^3)	Decision threshold (Bq/m^3)
10	5	0.127	0.295
	20	0.071	0.165
	60	0.041	0.095
20	5	0.184	0.427
	20	0.099	0.230
	60	0.057	0.132
30	5	0.226	0.524
	20	0.113	0.262
	60	0.065	0.151
40	5	0.255	0.592
	20	0.127	0.295
	60	0.073	0.169

β concentration (CT: 5 min, DT: 1 hour, flow rate: 40 L/min)

γ air dose rate (μSv/h)	β concentration Standard deviation (Sb) (Bq/m^3)	Decision threshold (Bq/m^3)
0.1	0.09	0.21
1	0.27	0.63
10	0.86	2.00
100	2.73	6.33

Detection sensitivity: α-ray: 24% min (up to 5.7 MeV), β-ray: 24% min (Cl-36 or Sr-90)
Sb: Standard deviation of background
CT: Counting time
DT: Time to find the average value of concentration
*Standard deviation is inversely proportional to $\sqrt{CT \cdot DT}$

F.3 Methods using normalized counts

The normalized count is an index value designed to monitor in real-time the contamination of artificial β radioactivity with long half life, such as I-131 and Cs-137, based on the assumption that natural radioactivity, such as radon decay products with short half life, is always present in airborne dust radioactivity [20].

The normalized counts are prepared by dividing the gross α and gross β counts obtained from dust monitors by their respective historical averages and normalizing them. In this monitoring, the possibility of contamination with artificial β radioactivity and the concentration of artificial gross β radioactivity are estimated based on the fact that if airborne dust radioactivity comes only from natural sources, the ratio will be approximately 1.

This section describes the method using normalized counts, with a case study of its introduction in Fukui Prefecture.

1. Dust monitor specifications used in Fukui Prefecture

- Measuring method: simultaneous measurement of suction and measurement (intermittent filter paper feed for 3 hours)
- Detector: ZnS (Ag) + plastic scintillator
- Collection filter paper: Cellulose glass fiber filter paper (HE-40T)
- Suction air flow rate: 100 L/min (with flow control)
- Measurement items: integrated count value from filter paper feed (gross α, gross β, α-β coincidence), integrated flow volume from filter paper feed
- Data collection interval: every 10 minutes
- Analysis processing: implemented by collection and analysis server

2. Basic flow of data analysis process

Figure F-8 shows a schematic representation of the change in radioactivity on filter paper from filter paper feeding in dust monitor measurements, where (1) is assumed to be artificial radioactivity (I-131) with a half-life of 8 days and (2) is assumed to be radon decay products with a half-life of 30 minutes.

Monitoring airborne dust radioactivity with dust monitors requires considering the difference between (1) and (2). In this monitoring method, the level of airborne dust radioactivity is first determined based on (2) as the natural part and used to calculate the excess β count. Then, the gross β count of the artificial part is estimated using a conversion formula based on (1).

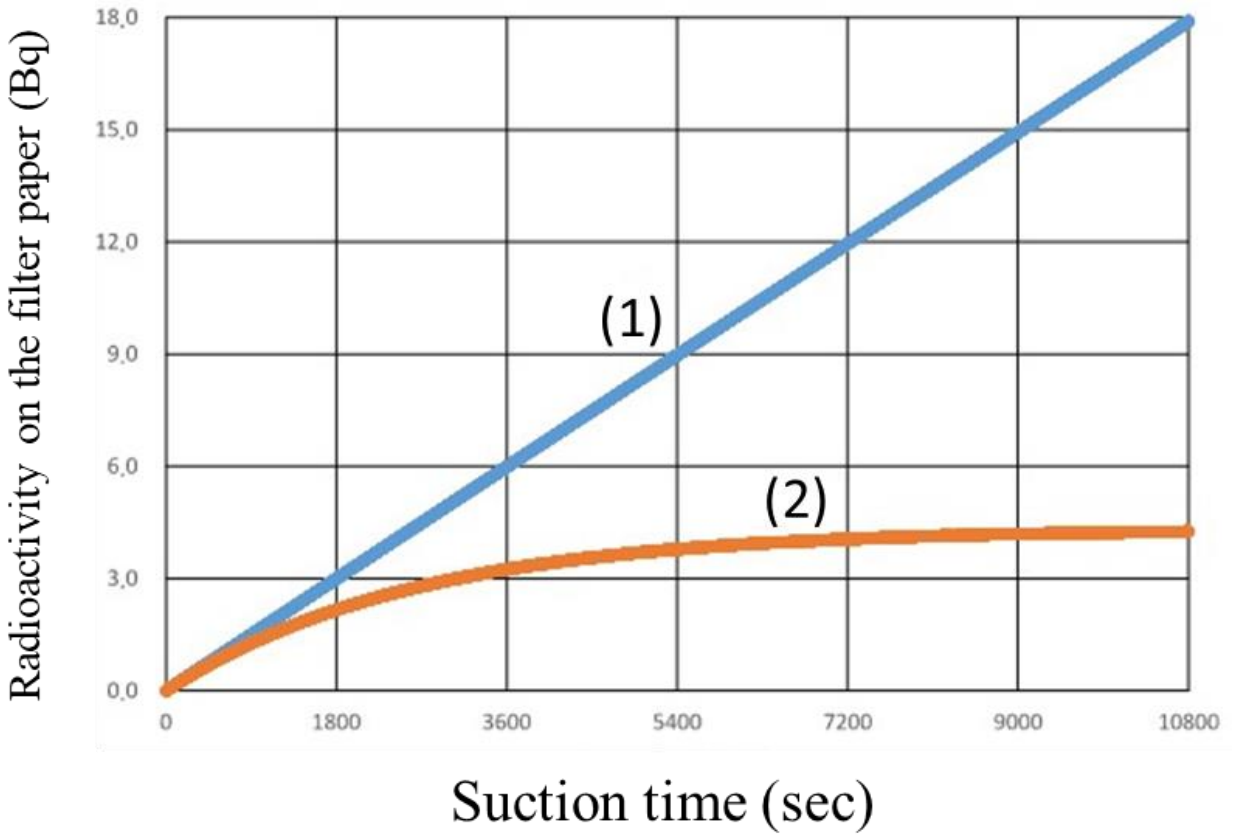


Figure F-8. Radioactivity on filter paper when suctioning 1 Bq/m^3

3. Procedures for preparing normalized counts

The airborne dust radioactivity concentration of natural origin varies depending on the topography, geology, etc., around the station where the dust monitor is installed. Accordingly, all of the following procedures should be conducted for each station.

Proce-dure	Operation details	Reference
(a)	In the past period without artificial radioactivity effects, for every elapsed time since the filter paper feeding (in this case, every 10 minutes of the data collection interval), the integrated count values of gross α and gross β are taken as a specimen for variables X and Y, and the mean value and first-order regression equation ($Y = A \times X + B$) are obtained. * The integrated count value, in this case, shall be the integrated count value, including the background count value when airborne dust is not sampled.	Table F-3.
(b)	For the specimen for every elapsed time in step (1), subtract the intercept B from the variable Y to make a variable Y' as a new specimen of gross β integrated count value and obtain the average value of Y'. * Intercept B in Table F-3 dominantly includes background counts of β counts (approximately 20 cpm for dust monitors in use) and may also include contamination effects during filter paper standby and is determined by subtracting the total of these backgrounds and effects from intercept B. This operation does not change the slope A of the first-order regression equation in Table F-3. However, the intercept B becomes "0" and presents the relationship between variables X an Y' as a regression line passing through the origin.	Table F-4.
(c)	The mean Xm and intercept B in Table F-3 and the mean Y'm in Table F-4 are used as the basic statistical values of the past data necessary for normalization and are databased in the collection and analysis server by station and by elapsed time since filter paper feeding.	Explanation a
(d)	Assuming that the specimen of past measurements belongs to the same population as the specimen of subsequent measurements, data under measurement are processed according to 1) to 3) using the basic statistical values in step (c) for every elapsed time since filter paper feeding. 1) The gross α integrated count values at the current time are divided by the past average value Xm to calculate the normalized counts (base C_α) that are used as the level of gross α radioactivity concentration in the air at the current time. 2) The normalized counts (base C_β) are calculated by subtracting the past intercept B from the gross β integrated counts at the current time and then dividing the value by the past average value Y'm and used as the level of gross β radioactivity concentration in the air at the current time. 3) The normalized count ratio at the current time (base $C_{\beta/\alpha}$ ratio) is calculated by dividing the base C_β by the base C_α to be used as the rating scale of artificial β radioactivity contamination. * From Explanation a, if the airborne dust radioactivity at present is only of natural origin, the base $C_{\beta/\alpha}$ ratio can be expected to be approximately	Explanation b Explanation c Explanation d Explanation e

	1. If there is significant contamination with artificial β radioactivity, the base $C_{\beta/\alpha}$ ratio is expected to be higher than the fluctuation range of the normal time.	
(e)	Assuming that the base C_α is only of natural origin and that the expected value of the base $C_{\beta/\alpha}$ ratio is "1" in normal times, the estimated surplus β integrated count value ZC_β estimated is obtained by the following formula with contamination of artificial β radioactivity simulated. ZC_β = (base $C_{\beta/\alpha}$ ratio -1) × base C_α ×Y'm Y'm：Y'm in Table F-4 at the relevant elapsed time from filter paper feeding.	
(f)	Based on ZC_β, the estimated artificial gross β radioactivity concentration A_β (Bq/m^3) at the current time is calculated using the following formula. $A_\beta = 2 \times ZC_\beta \div E_F \div E_{Cl} \div E_\beta \div (t \times 60) \div (D_F /1000)$ ×2: Weight constants for integrated counts in the case of simultaneous measurement of suction and measurement E_F: Collection efficiency of dust monitor (≈0.77) E_{Cl}: Counting efficiency of the detector with calibration source Cl-36 (≈ 0.21) E_β: β-ray expression efficiency of filter paper (= 1.0) t: Elapsed time from filter paper feeding (min) D_F: Integrated flow volume from filter paper feeding (L) Supplement 1: E_F = Collection efficiency of HE-40T for airborne dust (≈0.85) × Loss for monitoring airtight mechanism leakage (≈0.9) [21]. Supplement 2: Since the β energy (0.709 MeV) of the calibration radiation source Cl-36 is close to the β energy (0.606 MeV) of I-131, A_β can be regarded as the concentration considered as I-131.	

Table F-3. Example of correlation (Y = A × X + B) between gross α integrated counts (X) and gross β integrated counts (Y)

Elapsed time from the filter paper feed	10 min.	20 min.	30 min.	...	60 minutes	...	180 min.
Gross α integrated count average value (Xm)	217.6	708	1460.3	...	5024	...	28918.6
Gross β integrated count average value (Ym)	748	2313.9	4679.3	...	15459.8	...	83465.8
The slope of a first-order regression equation (A)	2.43042	2.64910	2.76874	...	2.83175	...	2.74468
The intercept of a first-order regression equation (B)	219.1	438.2	634.7	...	1233.2	...	4093.5
Correlation coefficient (r)	0.9923	0.9958	0.9968	...	0.9973	...	0.9973

*Calculated from approximately 2900 samples from the Urasoko observation station in 2019.

Table F-4. Example of correlation (Y' = A × X + B') between gross α integrated counts (X) and gross β integrated counts (Y') after subtracting the intercept

Elapsed time from the filter paper feeding	10 min.	20 min.	30 min.	...	60 minutes	...	180 min.
Gross α integrated count average value (Xm)	217.6	708. 0	1460.3	...	5024	...	28918.6
Gross β integrated count average value after intercept subtraction (Y'm)	528.9	1875.7	4044.6	...	14226.6	...	79372.3
The slope of a first-order regression equation (A)	2.43042	2.64910	2.76874	...	2.83175	...	2.74468
The intercept of the first-order regression equation (B')	0.0	0.0	0.0	...	0.0	...	0.0
Correlation coefficient (r)	0.9923	0.9958	0.9968	...	0.9973	...	0.9973

*Calculated from approximately 2900 samples of Urasoko station observations in FY 2019.

Explanation a. Sample space by normalization

For the variables X and Y's, for every elapsed time since the filter paper feeding, divide the variable X by its average value Xm to make a new variable X" and divide the variable Y' by its average value Y'm to create a new variable".

When the average values of these variable X" and Y" are obtained, the values of both are exactly "1".

∵ According to a theorem of statistics, if each variable that makes up that specimen is divided by its average value, each variable will always be a specimen with an average "1". (Definition of normalization here)

Therefore, these new specimens of variables X" and Y" are replaced by the relation Y" = 1 × X" + 0 at any elapsed time since the regression line passes through the point (1, 1). Thus, the intercept of the first-order regression equation is "0".

∵ According to a statistical theorem, the regression line between variables U and V always passes through the intersection of the averages of variables U and V.

Therefore, since the average value of normalized gross α and gross β integrated counts is "1" independent of the time elapsed since the filter paper feeding, and since they maintain a very high correlation (0.98 or higher of correlation coefficient in the example in Table F-4), it is expected that their ratio will always remain approximately "1".

Explanation b Meaning of normalized count = 1

In normal times, it is presumed that the identity of the airborne radioactivity is mainly radon decay products, but their concentration is unknown.

The long-term time-series variations in the radioactivity concentration of airborne dust in normal times are divided into short-time samples, such as 3 hours (corresponding to the filter paper feeding interval of the dust monitor). These samples are then grouped into groups every 10 minutes (corresponding to the data collection interval of the same monitor) from the starting time (corresponding to the filter paper feeding time of the same monitor). If the original time series period is sufficiently long, short-term variations in concentration, daily periodic changes due to nighttime calm weather, and seasonal differences in concentration will be canceled out, and the average value will be homogenized to the average value for the entire period.

Furthermore, when considering the correspondence with the dust monitor measurement, the variation of the integrated count average Xm and Y'm of gross α and β with the filter paper feeding time corresponds to the change of the area between the graph (2) and the suction time axis in Figure F-8, because the target measured in normal times is mainly radon decay products. The values of Xm and Y'm for which the data collection period is sufficiently long can be viewed as the integrated counts per filter paper feeding elapsed time corresponding to the average radioactivity concentration of airborne dust at the observation point in question, for the reason of homogenization mentioned above.

Therefore, the gross α and β integrated counts at a certain time divided by Xm and Y'm can be treated as a multiple (relative concentration) of the past average radioactivity concentration of airborne dust at the observation point, independent of the time elapsed since the filter paper feeding.

Therefore, "1" in the normalized count corresponds to the average value of the past airborne dust radioactivity concentration at the observation point. The normalized count can be an index value representing the airborne dust radioactivity concentration level.

Explanation c Concentration conversion of radon decay products

Procedures (1) through (3) and Explanations a and b have assumed that natural radioactivity mainly originates from radon decay products, but the conversion of radon decay products to airborne concentrations is difficult because of the following points.

- No standard radiation source matches the energy of α- and β-rays emitted by each radon decay product, and it is difficult to obtain the counting efficiency of the detector for each energy.
- Dust monitors that measure gross radioactivity do not provide information on the energy of α and β radiation, making it difficult to determine the ratio of each radon decay product.

Explanation d Correction by integrated flow volume

If the integrated flow volume variation is large, steps (1) through (4) should be corrected by the integrated flow volume.

Explanation e Monitoring of gross α radioactivity by α-β coincidence counting

Regarding the integrated counts of α-β coincidence counting for the radon decay product Po-214, the normalized counts can be obtained by operating steps (1) to (4) to be used as supplementary information for the radioactivity concentration level of natural origin.

The α-β simultaneous normalized counts agree well with the gross α and gross β normalized counts in the confirmation results in normal times (see Figure F-9), and the α-β simultaneous normalized counts can be given as an index value of the radioactivity concentration level of natural origin in the case of monitoring based on the assumption that artificial components contaminate the gross α counts.

In the dust monitor in use, the background count values of gross α counts and α-β coincidence counting are sufficiently smaller than the count values based on the collected airborne dust radioactivity so that omitting the operation of subtracting the intercept as in the case of gross β counts will not make any effect in the relationship between the two.

4. Monitoring status by normalized counting

The following is an example of the monitoring results when the basic statistical values are obtained from the 2019 measurements and applied to the normalization of the 2020 measurements.

(1) Example of time-series analysis results in normal times

Figure F-9 shows a 10-minute time series graph at a time when the normalized counts reached the highest value for the year in the Urasoko station, which has a large diurnal variation,

The normalized counts for gross α (green), gross β (red), and α-β coincidence (black) exceeded 12 near dawn on July 18 when air conditions were stable and fell below 1 in the afternoon of the same day when concentration levels dropped. However, the changes were in good agreement with each other. While the normalized counts changed largely, the β/α ratio of the normalized counts expressed as a percentage (blue) remained stable within the range of 100 ± 20 %, and the estimated artificial gross β radioactivity concentration (indicated as "dust iodine equivalent concentration") (purple) was almost within the range of 0 ± 5 Bq/m^3.

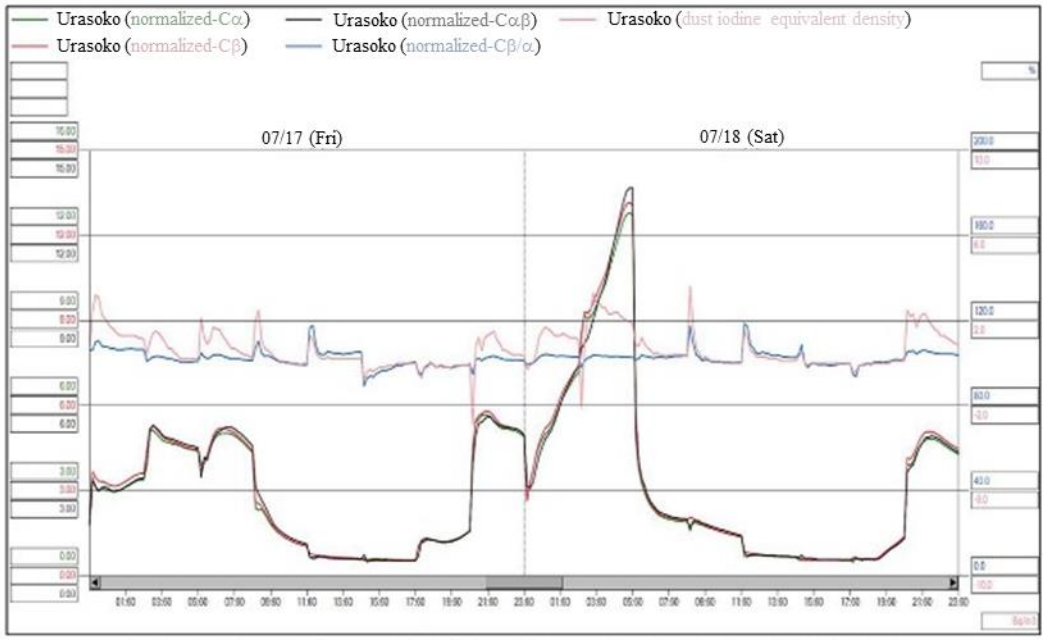


Figure F-9. Example of 10-minute time series monitoring data
(Urasoko Station, July 17 – July 18, 2020)

(2) Example of monitoring result statistical values

Table F-5 summarizes the annual statistics of one-hour values (60, 120, and 180 minutes after filter paper feeding) for the results monitored at 11 observation stations in Fukui Prefecture. The range of data in the table indicates the degree of variation among stations.

Since the integrated count values are low immediately after the filter paper feeding and the evaluation values are scattered, the statistics for only the one-hour values after filter paper feeding (values at 60 minutes after filter paper feeding) are shown in parentheses.

Based on these statistical results, if the normal fluctuation ranges in normal times of the normalized count β/α ratio and the estimated artificial gross β radioactivity concentration, which are the rating

scales of artificial β radioactivity contamination, are set to "average value ± 3 × standard deviation", the fluctuation range of the normalized count β/α ratio is about 100 ± 20% and that of the estimated artificial gross β radioactivity concentration is about 0 ± 2 Bq/m^3.

Examining the individual data showed that above 2 Bq/m3 of the estimated artificial gross β radioactivity concentration occurred when the concentrations were relatively high, with the gross α normalized count exceeding 2. However, the normalized count β/α ratio at the same time was confirmed to be within approximately 120%.

Table F-5. Example of annual monitoring result statistical values based on normalized counts (FY2020)

	Maximum value	Minimum value	Average value	Standard deviation
Gross α normalized counts	3.87 to 18.39	0.03 to 0.07	0.89 to 0.93	0.51 to 0.86
Gross β normalized counts	3.81 to 18.48	0.02 to 0.05	0.91 to 0.94	0.52 to 0.89
α-β coincidence normalized counts	3.83 to 19.88	0.03 to 0.05	0.89 to 0.93	0.51 to 0.84
Normalized counts β/α ratio (%) (1-hour value after filter paper feeding)	121.3 to 133.3	56.4 to 82.7	99.2 to 103.0 (99.2 to103.2)	5.2 to 6.7 (5.5 to 6.9)
Estimated artificial gross β concentration (Bq/m^3) (1-hour value after filter paper feeding)	2.1 to 6.4	-1.2 to -4.6	-0.0 to 0.1 (-0.0 to 0.2)	0.3 to 0.5 (0.4 to 0.6)

F.4 Methods of unfolding

Unfolding the pulse-height spectrum of γ-rays measured by a radiation detector (NaI(Tl) scintillation detector) using the response function of the detector enables evaluation of the radioactivity concentration of artificial radionuclides in the air.

Unfolding is a technique for deriving energy spectra from pulse-height spectra using the response function of a detector and can improve the accuracy of the qualitative and quantitative determinations of radionuclides.

The response function of the detector used for unfolding differs from the conventional response function for measuring the air dose rate (see The Series of Environmental Radioactivity Measuring Methods No.17, "Environmental gamma ray measurement method using continuous monitoring"). It must be derived from the Monte Carlo simulation, taking into account the geometric relationship between the detector and the dust collecting area on the filter paper that serves as the radiation source and material properties, as shown in Figure F-10.

An example of unfolding results from this method is shown in Figure F-11, and an evaluation example of decision thresholds for artificial radionuclides is shown in Table F-6.

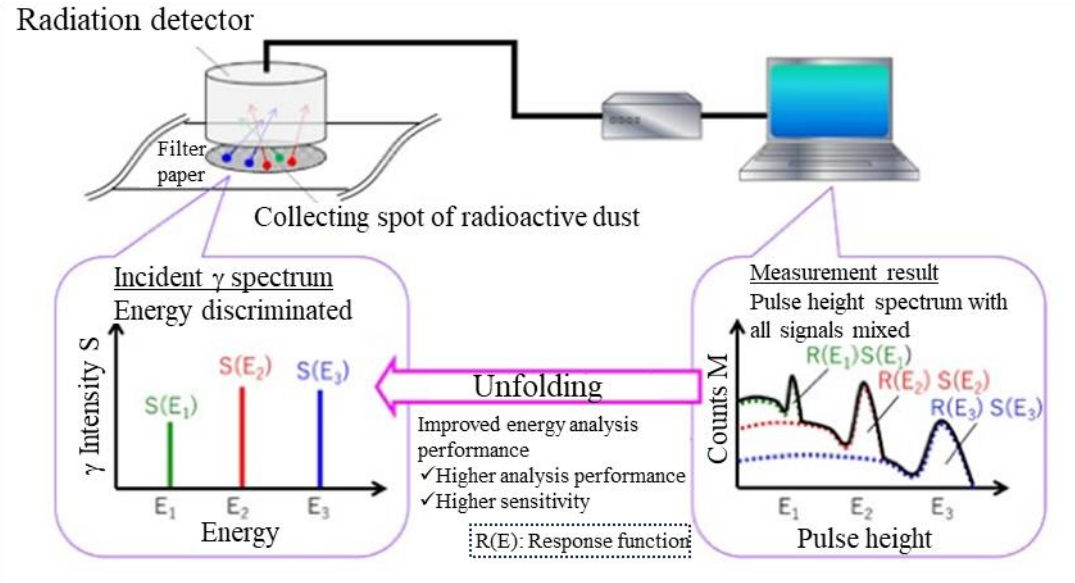


Figure F-10. Image diagram of unfolding [22].

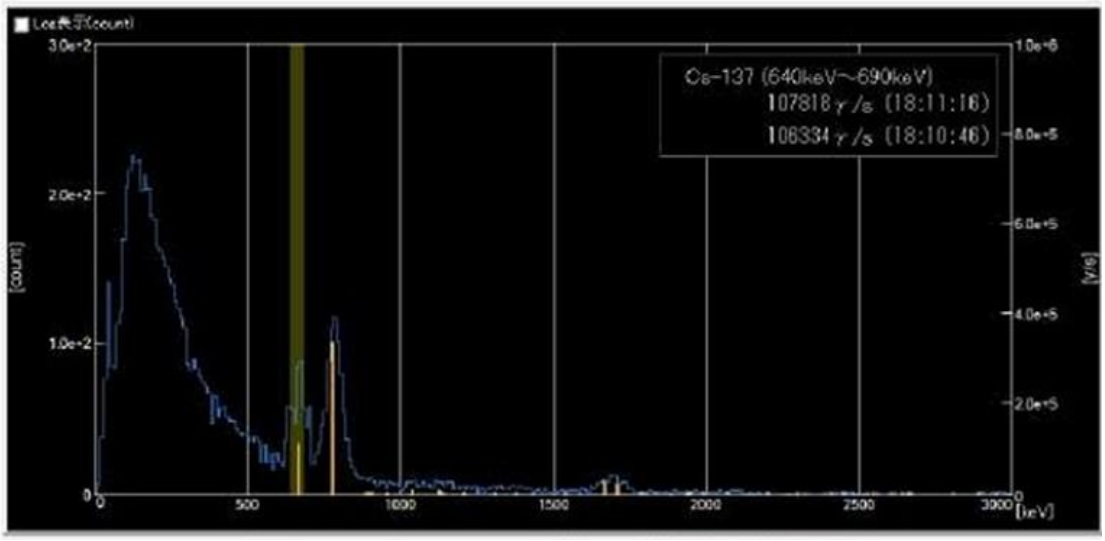


Figure F-11. Example of unfolding results [22].

Table F-6. Example of decision threshold evaluation [22].

Nuclide	Decision threshold (Bq/m^3)	Operation cycle (Minute)
Co-60	0.3	60
Cs-134	0.9	30
Cs-137	0.8	30

Measurement conditions: flow rate 100 L/min, air dose rate β approx. 0.05 μSv/h

Part 2: Measurement of Radioactive Materials in the Air in Emergency Situations

Table of Contents

Part 2: Measurement of Radioactive Materials in the Air in Emergency Situations

Chapter 1 Introduction

Emergency monitoring is described in the Nuclear Emergency Response Guidelines (Nuclear Regulation Authority, partially revised on July 21, 2021)[1] as “Environmental radiation monitoring to be conducted when there is an abnormal or threatened release of radioactive materials or radiation”.

Specific details of emergency monitoring are outlined in “Emergency Monitoring (Supplementary Reference Materials for Nuclear Emergency Response Guidelines)” (Nuclear Regulation Authority, Radiation Monitoring Division, partially revised on December 21, 2021) [3] (hereinafter referred to as “Supplementary Reference Materials for Emergency Monitoring”). The purpose of measuring the concentration of radioactive materials in the air is (1) to collect information on the status of environmental radiation due to a nuclear disaster and (2) to provide materials for evaluating the radiological impact of a nuclear disaster on residents and the environment.

Part 2 describes the measurement procedures to be conducted as emergency monitoring: continuous measurement by air monitors, collection to analysis of air samples collected by air monitors, collection to analysis of air samples by iodine samplers (only an overview is given), and collection to analysis of air samples by dust samplers.

Chapter 2 Basics and Scope of Application

2.1 Purpose of measurement

Emergency monitoring involves measuring the concentration of radioactive materials in the air for the following purposes, based on the Emergency Supplemental Reference Materials.

(a) Information collection on the environmental radiation situation due to the nuclear disaster
(b) Providing materials for evaluating the radiological impact of nuclear disasters on residents and the environment

For this purpose, we will confirm the spread of radioactive materials and utilize them for exposure assessment by establishing a measurement system that uses an air monitor that can continuously monitor changes in the concentration of radioactive materials in the air over time and an iodine sampler with an automatic sample changer that continuously samples gaseous and particulate iodine, and changes filter paper and activated carbon cartridges at regular intervals. The measuring system confirms the spread of radioactive materials and is utilized for exposure evaluation.

In addition, in order to respond to accidents at nuclear fuel facilities (excluding criticality accidents and accidents at spent fuel storage systems in reprocessing facilities), a system will be established to be able to monitor changes in the concentration of radioactive materials in the air continuously over time, mainly for α-emitting nuclides, utilizing air monitors and dust samplers.

Table 2-1 shows the emergency monitoring response according to the emergency category.

Table 2-1. Emergency monitoring response

<table>
<tr><th>Classification of emergencies</th><th>Monitoring situation</th><th>Equipment support</th></tr>
<tr><td>Information collection situation</td><td>Normal time monitoring</td><td>Confirmation of equipment abnormality, etc.</td></tr>
<tr><td rowspan="2">Alert state</td><td rowspan="2">Emergency monitoring preparation</td><td>Confirmation of equipment abnormality, etc.</td></tr>
<tr><td>Startup preparation</td></tr>
<tr><td>Facility site emergency</td><td rowspan="2">Emergency monitoring</td><td rowspan="2">Startup*</td></tr>
<tr><td>Total emergency</td></tr>
</table>

* Startup based on the emergency monitoring plan, depending on the facility's situation.

2.2 Equipment used and flow of use

This section shows the equipment used in emergency monitoring. Refer to the respective chapters for details on each piece of equipment. These devices should be inspected on a daily and periodic basis. They should be ready for prompt use in an emergency. In addition, personnel who handle this equipment must learn how to operate and check in advance through education and training.

2.2.1 Air monitor

(1) Equipment overview

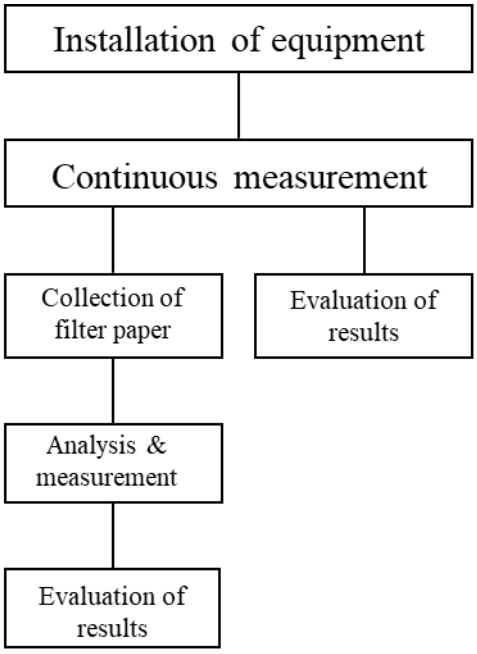
An air monitor is an equipment that continuously measures the radioactivity concentration in airborne dust as the concentration of radioactive materials in the air while collecting airborne dust on filter paper. In addition, dust monitors are continuously used as emergency equipment to strengthen the monitoring system in an emergency.

Figure 2-1. Example of air monitor

(2) Flow of use

The flowchart of the use of air monitors is shown. It also shows the major "The Series of Environmental Radioactivity Measuring Methods" to be referred to.

(a) Continuous measurement of the concentration of radioactive materials in the air and analysis of air samples



<Analysis and measurement targets>

- Gross α radioactivity, gross β radioactivity (continuous measurement)
- γ-emitting nuclides, α-emitting nuclides, β-emitting nuclides (Analysis and measurement of filter paper) (Selected according to the nuclear facility)

<The Series of Environmental Radioactivity Measuring Methods for major reference>

- No. 2, "Radioactive strontium analysis method"
- No. 7, "γ-ray spectrometry using germanium semiconductor detector"
- No. 12, "Plutonium analysis method"
- No. 14, "Uranium analysis method"
- No. 24, "Sample preparation method for gamma-ray spectrometry in emergency situations"
- No. 29, "Gamma-ray spectrum analysis method using germanium semiconductor detector in emergency situations"
- No. 35, "Environmental sampling methods in emergencies"

2.2.2 Iodine sampler

(1) Equipment overview

An iodine sampler collects radioactive iodine (particulate and gaseous) from the air on filter paper and activated carbon cartridges. An iodine sampler with an auto sample changer is used in an emergency.

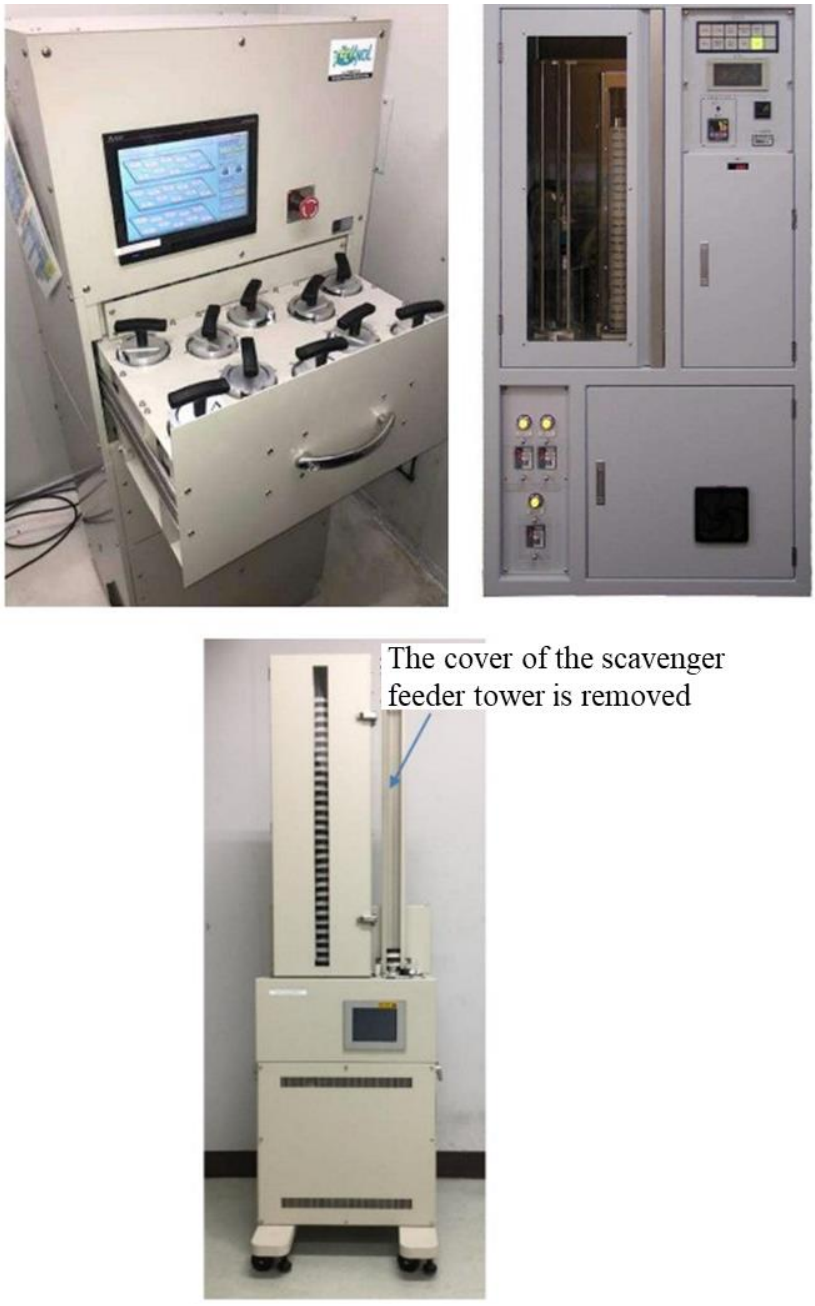
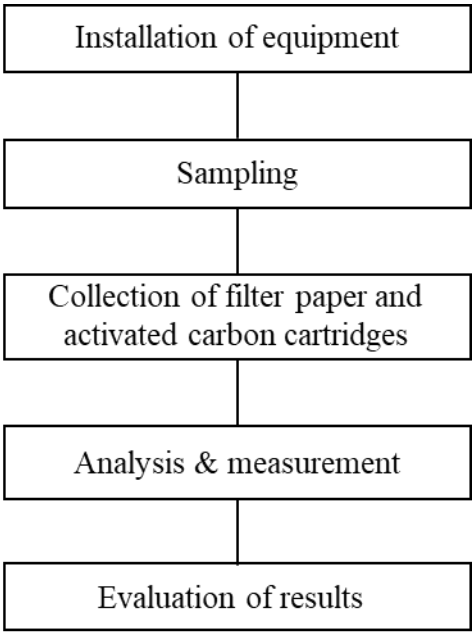


Figure 2-2. Example of iodine sampler (with auto sample changer)

(2) Flow of use

The flow chart below shows the process of using the iodine sampler. It also shows the major reference documents of “The Series of Environmental Radioactivity Measuring Methods”.

・ Radioactive iodine collection to analysis



<Analysis and measurement target>

· Radioactive iodine

<The Series of Environmental Radioactivity Measuring Methods for major reference>

· No. 7, “γ-ray spectrometry using germanium semiconductor detector”
· No. 15, “Radioactive iodine measurement method in emergencies”
· No. 24, “Sample preparation method for gamma-ray spectrometry in emergency situations”
· No. 29, “Gamma-ray spectrum analysis method using germanium semiconductor detector in emergency situations”
· No. 35, “Environmental sampling methods in emergencies”

2.2.3 Dust sampler

(1) Equipment overview

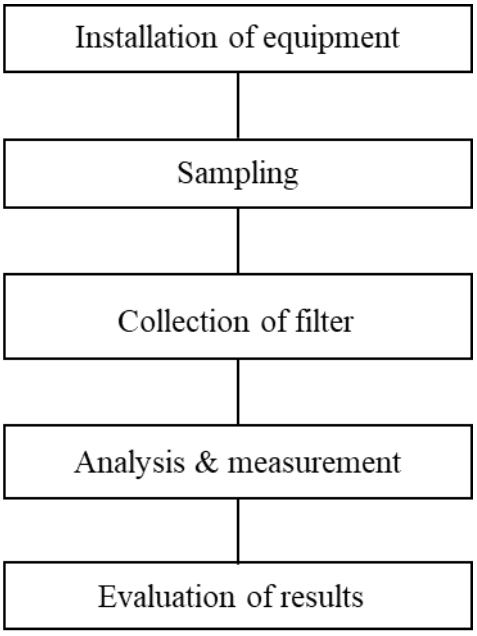
A dust sampler collects airborne dust on filter paper.

Figure 2-3. Example of dust sampler

(2) Flow of use

This section shows the flow of use of the dust sampler. The main series of radioactivity measurement methods to be referred to are also shown.

Analysis of air samples



<Analysis and measurement target>

· γ-emitting nuclides, α-emitting nuclides, and β-emitting nuclides (Selected according to the nuclear facility)

<The Series of Environmental Radioactivity Measuring Methods for major reference>

· No. 2, “Radioactive strontium analysis method”
· No. 7, “γ-ray spectrometry using germanium semiconductor detector”
· No. 12, “Plutonium analysis method”
· No. 14, “Uranium analysis method”
· No. 24, “Sample preparation method for gamma-ray spectrometry in emergency situations”
· No. 29, “Gamma-ray spectrum analysis method using germanium semiconductor detector in emergency situations”
· No. 35, “Environmental sampling methods in emergencies”

Chapter 3 Continuous Measurement by Air Monitor

This chapter describes continuous measurement by air monitors in emergencies.

The procedures, etc., in this chapter also apply when using the dust monitor in the emergency mode.

3.1 Equipment

3.1.1 Classification of equipment

Table 3-1 shows the classification of air monitors.

Table 3-1. Classification of air monitors

Classification	Definition
(1) α-ray air monitor	Air monitor to measure α radiation from airborne dust
(2) β-ray air monitor	Air monitor to measure β radiation from airborne dust

3.1.2 Measurement targets

These monitors measure either gross α radioactivity concentration or gross β radioactivity concentration. Air monitors cannot quantify individual radionuclide concentrations such as α-emitting or β-emitting nuclide concentrations.

3.1.3 Equipment selection

Table 3-2 shows the air monitors selected according to the nuclear facility and accident type listed in the Emergency Supplemental Reference Material.

Table 3-2. Air monitors are selected according to the nuclear facility and type of accident

Nuclear facility	Accident type	Air monitors to be selected
Nuclear power reactor facilities (requiring PAZ and UPZ settings)	-	β-ray air monitors
Nuclear reactor facilities for testing and research, etc. (requiring UPZ setting)	-	β-ray air monitors
Uranium processing facility (requiring UPZ setting)*	Criticality accident	β-ray air monitors
	UF_6 Release	α-ray air monitors
Processing facility to handle plutonium	Criticality accident	β-ray air monitors
	Large fire or explosion	α-ray air monitors
Reprocessing facility	Criticality accident	β-ray air monitors
	Large fire or explosion	β-ray air monitors α-ray air monitors
	Evaporation dry	β-ray air monitors

*Same for nuclear fuel facilities (not requiring UPZ setting)

3.1.4 Equipment configuration

The equipment configuration of the air monitor is the same as that of the dust monitor (Part 1, 3.1.4).

3.1.5 Detector types and measurement principles

The types of detectors are listed in Table 3-3. The measurement principle is the same as that of dust monitors (Part 1, 3.1.5), but to accommodate high-concentration measurements, detectors with smaller instrument efficiency than those used in dust monitors used in normal times are used.

Table 3-3. Detectors for air monitors

Measurement target	Detector
α-ray	ZnS(Ag) scintillation detector
	Silicon semiconductor detector
β-ray	Plastic scintillation detector
	Silicon semiconductor detector

3.1.6 Example of equipment specifications

Table 3-4 shows an example of equipment specifications for an air monitor. Compared to dust monitors used in normal times, the filter paper feed interval is short, which is used as a material for evaluating exposure doses. In addition, the flow rate is low in order to accommodate high-concentration measurements.

Note that equipment, etc., not listed in the example specifications may be used if it has the required performance.

Table 3-4. Examples of equipment specifications for air monitor

Item	Type A	Type B	Type C
Measurement target	α-ray	β-ray	α- and β-rays
Detector	ZnS(Ag) scintillator	Plastic scintillator	Silicon semiconductor
Measurement concentration range*1	10 Bq/m³ or more	100 to 100,000 Bq/m³	α radiation: 10 Bq/m^3 or higher β radiation: 100 to 100,000 Bq/m³
Air absorbent	Membrane	Cellulose/glass fiber	Membrane
Flow rate	Approx. 50 L/min		
Filter paper feeding method	Intermittent feeding		
External radiation impact elimination	Lead shielding*2		

*1 Even if the concentration exceeds the measurement range, it must be possible to confirm the presence of a radioactive plume above the concentration.

*2 The detector should be shielded with approximately 3 to 5 cm thick lead to reduce background radiation and accommodate measurement under high radiation dose conditions. For performance evaluation on the effect of external radiation, it is recommended to refer to the determination thresholds described in JIS Z 4316: 2013, “Radioactive dust monitors” [4].

3.2 Air absorbent

Dust monitors are based on using long filter paper, the membrane filter for capturing α-ray substances, and the cellulose or glass fiber filter is often used for capturing β-ray substances. (see Part 1, 3.2)

3.3 Installation, calibration, and inspection

(1) Installation

The basic installation requirements are the same as those for dust monitors in normal times (Part 1, 3.3.1). However, the following are some ideas for installation specific to air monitors.

(a)Distance and orientation from nuclear facility

The Emergency Supplementary Reference Material stipulates that an air monitor should be located at each of the 5-10 km, 10-20 km, and 20-30 km radii in each of the 16 azimuths centered on the target nuclear facility in principle (Figure 3-1).

If there is a fixed observation station in the region concerned, it shall be installed in the station building concerned.

Note that for each orientation, air monitors in the same orientation should not be installed on the same straight line.

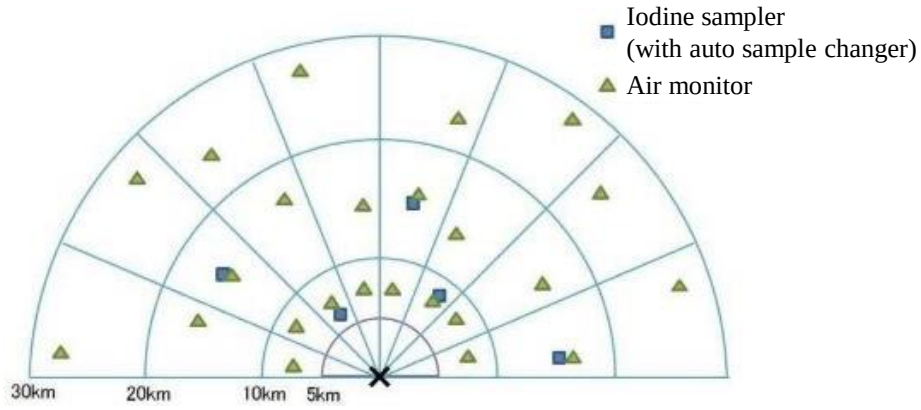


Figure 3-1. Example of an air monitor and iodine sampler arrangement with auto sample changer [3].

(b)Power supply

Assuming a commercial power failure, the system shall have a backup power source, such as an emergency generator or battery. It shall be able to operate continuously without refueling or other measures for at least 3 days after the startup of the air monitor.

(2)Calibration

The calibration method is the same as that for dust monitors in normal times (Part 1, 3.3.2).

The standard radiation source is the α or β radiation source shown in Table 3-5.

Table 3-5. Standard radiation sources for calibration

Radiation type	Standard radiation source
α-ray	Am-241
β-ray	Cl-36 or Tl-204

(3)Inspection

Although air monitors are not operating normally, daily inspections should be conducted about once a month. Periodic inspections should be implemented at least once a year to ensure they can be used promptly in an emergency. During daily inspections, it is desirable to implement an operation verification test, including the acquisition of background data.

Inspection items are the same as those for dust monitors in normal times (Section 1, 3.3.3).

3.4 Measurement

(1)Startup

All installed air monitors are activated by remote control using a telemetering system or other means. Subsequent operations are also remotely operated using a telemeter system, etc.

(2)Measurement condition setting

Set the measurement conditions of the air monitor as shown in Table 3-6. The measurement conditions should be set in advance in normal times.

Table 3-6. Measurement conditions for air monitors

Item	Measuring conditions
Flow rate*	Approx. 50 L/min
Filter paper feeding method	Intermittent feeding
Collection time* (Filter paper feeding time)	1 hour
Measurement position	Air sampling position
Measurement time	Continuous (measurements taken every 10 minutes)

*If the measurement cannot be taken properly due to counting loss or other factors, it is necessary to change the measurement conditions, including decreasing the flow rate or shortening the sampling time. It is also desirable to be able to automate the filter paper feeding when the set threshold value is exceeded.

(3)Start of measurement

Start measurement.

From the viewpoint of data evaluation, it is desirable to be able to set the start time of measurement every hour on the hour (e.g., 10:00 am, 3:00 pm, etc.).

(4)Items to be checked at the start of measurement

Check that the integrated flow volume is increasing at a constant pace, that the count rate is increasing, that the filter paper is being fed every hour, and other items to determine the normal operation.

(5) Data transmission

Transmit data to the telemetry system at least once every 10 minutes.

Data transmission items are the same as in Section 3. 4(5) of Part 1.

(6) Calculation of radioactivity concentration

The detection unit measures the α- or β-rays from airborne dust collected on filter paper to calculate the radioactivity concentration. The radioactivity concentration in the air (average concentration over the last 10 minutes) is calculated by subtracting the count rate at the previous 10s of minutes from the count rate at the current 10s of minutes or by other methods.

The following formula calculates the radioactivity concentration.

Radioactivity concentration at every 10 minutes

Radioactivity concentration（Bq/m^3）

＝ ((Count rate at the current 10s of minutes (s^{-1})-(Count rate at the previous 10s of minutes (s^{-1})))/(equipment efficiency) × Integrated flow volume for 10 minutes(m^3))

However, when evaluating the radioactivity concentration at the beginning of the measurement or the first 10s of minutes after the filter paper feeding, the count rate for the previous 10s of minutes shall be 0 (s^{-1}).

Supplementary information on how to obtain the count rate

This method is based on measurement during air sampling, and the count rate is basically measured by a count rate meter.

Note that care should be taken when calculating the count rate from the integrated counts measured by the scaler in the measurement during air sampling and refer to Explanation C in Part 1 for the concept.

In emergency monitoring, the effect of background (radon/thoron decay products) in the air monitor measurement is ignored, and no subtraction or correction is made.

3.5 Evaluation of measurement results

The measurement results of air monitors should be evaluated by the methods described in (1) and (2) to confirm the increase or decrease of radioactivity concentration in the air every 10 minutes. To evaluate the measurement results in an emergency, obtaining background data at the air monitoring location in normal times is desirable.

(1)Gross α radioactivity concentration

The concentration of gross α radioactivity in the air at the relevant time is determined by the evaluation method described in 3.4(6) to determine whether or not α emitting nuclides caused by a nuclear facility are present in the vicinity of the installation site.

(2)Gross β radioactivity concentration

The evaluation method described in 3.4(6) is used to determine the gross β radioactivity concentration in the air at the relevant time and to determine when the radioactive plume arrived in the vicinity of the point where the air monitor is installed and how long it existed and passed over the site. An example of the evaluation is shown in Figure 3-2.

Figure 3-2 uses the data during plume arrival (MS-4) in Figure B-1 in Explanation B. When the average concentration from the filter paper feeding (blue plot) increases, the increase in the average concentration (orange plot) every 10 minutes is represented as a peak, helping clearly confirm when the radioactive plume arrived and passed.

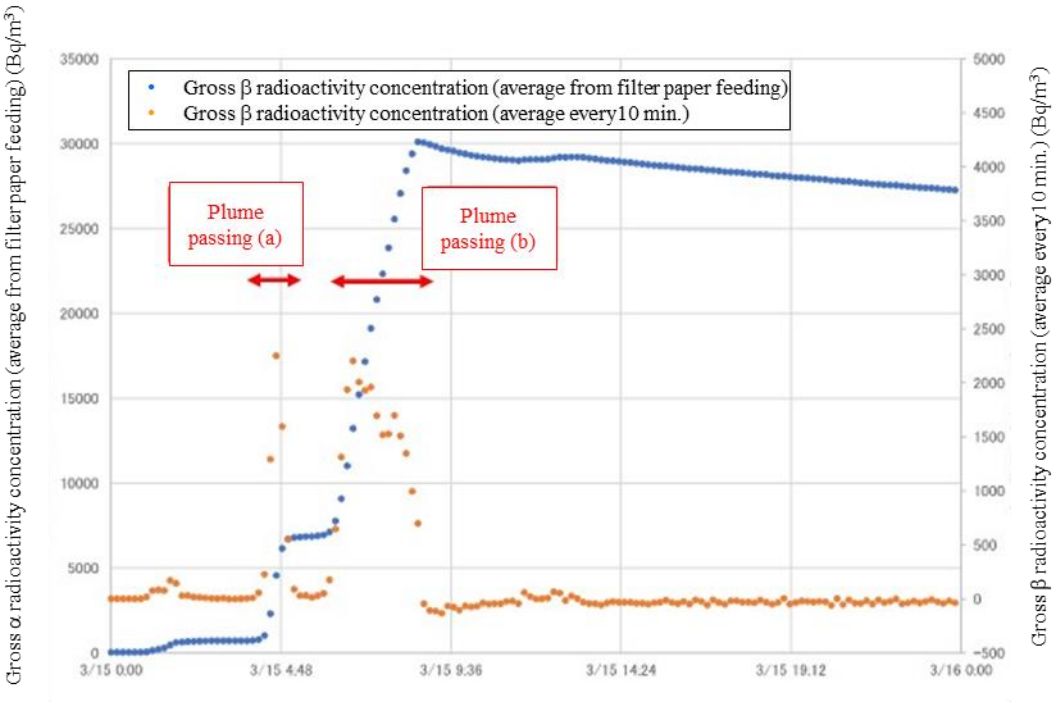


Figure 3-2. Evaluation example of the presence/absence of radioactive plume around an air monitor installation point

Chapter 4 Analysis of Air Samples Collected by Air Monitor

Analyzing filter paper of air monitors with a germanium semiconductor detector, etc., enables determining the concentration of radionuclides in the air and detailed changes in the composition of the radionuclides and using them as data for exposure dose assessment, etc.

If the dust monitor is used in an emergency mode, the procedures in this chapter also apply to analyzing its filter paper.

4.1 Collection of filter paper

Filter paper of air monitors that worked for several days is collected at a time in consideration of contamination prevention. Since radionuclides with short half life are included in the analysis, they should be collected as soon as possible while considering the reduction of exposure of monitoring personnel.

The collection procedures (excluding the description of the iodine sampler) described in The Series of Environmental Radioactivity Measuring Methods No. 35, "Environmental sampling methods in emergencies" are transcribed below. However, as a rule, air samples should be collected based on the instructions for emergency monitoring prepared by the EMC (Emergency Radiological Monitoring Center).

(1)Pre-departure preparations

	Procedure	Reference/Records*
1	Identify the point (measuring station) where the absorbent will be collected and exchanged.	
2	Prepare necessary equipment. Note 1) Replacement absorbents may be kept on hand at the measuring station where the air monitor is installed. The method of keeping the absorbent on hand should be in accordance with the user manual for the absorbent to be used. Note 2) In order to prevent contamination of the measuring station, the absorbent should be replaced quickly. The method of replacing the absorbent should be confirmed in advance in the device's instruction manual.	
3	Check the operation of equipment (especially communication equipment).	
4	Cure the equipment, if necessary.	3.1 Prevention of equipment contamination
5	Check the operation of electronic personal dosimeters.	
6	Wear appropriate protective equipment (protective clothing, protective masks, etc.) in accordance with the instructions for use. Also, if indicated, take stable iodine tablets. Note: A dedicated air sampling team should perform the replacement of absorbents, or, if it is difficult to	3.2 Protection of monitoring personnel

	organize a dedicated team, it should be done first before collecting other environmental samples.	

*Reference and record of The Series of Environmental Radioactivity Measuring Methods No. 35 "Environmental sampling methods in emergencies"

(2) Collection procedure (collection of absorbents)

	Procedure	Reference/Records*
1	Move to the point (measuring station) to collect and install absorbents.	
2	Collect the absorbents and record the collection date and time, the lot number of the absorbents, and other information. If the absorbent is long filter paper, there are two methods: collecting the entire roll of filter paper and cutting off and collecting the used portion. After issuing the instructions, collect within the period indicated in the instructions. Note: The collection and exchang methods of absorbents should be in accordance with the instruction manual of the equipment used.	Collection record sheet B1-d
3	Place the collected absorbent in a polyethylene bag.	
4	Fold the mouth of the bag, seal it with plastic tape, and affix (or clearly write) a label with the identification code.	Collection record sheet B1
5	Pack the used absorbent by adding another bagging (i.e., outer bag).	
6	Set a new absorbent and verify that the equipment is operating properly.	
7	Verify packaging, records, and photographs.	Collection record sheet B1-e

* Reference and record of The Series of Environmental Radioactivity Measuring Methods No. 35 "Environmental sampling methods in emergencies"

Note: If monitoring posts are not installed at the collection point, it is necessary to measure the air dose rate around the collection point using a survey meter, etc., before Step 2.

Sampling record form	
B1	Air

Date: / / Start time: hour min

Weather (day of): Weather (day before):

Team leader: Member:

Sampling point information

a	Sampling location (Location name, address, etc.)			
b	GPS	N (latitude)	E (longitude)	
b	Snow accumulation	☐ Yes ☐ No	Snow depth	Approx. cm

Air dose rate at the sampling point

c	Type of equipment	☐ NaI (Tl) scintillation survey meter ☐ Ionization chamber survey meter ☐ Neutron radiation survey meter ☐ Other:
c	Device name (device number)	
c	Time constant	*Elapsed time to measurement:
c	Detector direction	

C	Air dose rate (☐ μSv / h ☐ μGy / h)
	1 m above ground surface (at waist position)
1	
2	
3	
4	
5	
Ave-rage	

Hot (sampling) person in charge: _____

Cold (no sampling) person in charge: _____

d	Sampling equipment	☐ High-volume air sampler ☐ Low-volume air sampler ☐ Other: _____
d	Type of absorbent	☐ Filter paper: ☐ Activated carbon cartridge: ☐ Other: _____
d	Sampling start time	
d	Flow rate at the start	[L/min]
d	Sampling end time	
d	Flow rate at the end	[L/min]
d	Suction time	[min]
d	Average flow rate	[L/min] *For equipment that does not indicate the total flow rate, the average flow rates at the start and the end are used as the average flow rate.
d	Integrated flow volume	[m^3] *For equipment that does not display an integrated flow volume, the integrated flow volume is obtained by "Integrated flow volume = Average flow rate [L/min] x Suction time [min]/1000".
d	Remarks	

Confirmation of collected samples and records _____

e	Sample packaging	☐ Inner bag OK ☐ Outer bag OK ☐ Sealing OK
e	Omission of record	☐ None
e	Pictures	☐ Landscape ☐ Sampling point ☐ Situation of sampling, close-range view

Recorder: _____ End time: hour min.

Sample identification code	
Sample classification	☐ Treat as a high-concentration sample
Receipt	Date and time: / / Recipient signature: _____

4.2 Pretreatment

Collected filter paper is pretreated according to the nuclides to be analyzed and measured.

(1) When performing γ-ray spectrometry

In order to measure γ-emitting nuclides with a germanium semiconductor detector, etc., filter paper must be filled into the measurement container. During the measurement of air monitors, cross-contamination from the air sampling surface occurs due to the winding of the long filter paper. Since the effect on the analysis results cannot be corrected by calculation or other means, this shall not be considered. However, it is desirable to be able to take measures to prevent cross-contamination, such as automatically covering the air sampling surface with polyethylene film, etc., after air sampling.

This section describes the case where filter paper used for 6 hours*¹ is collected together and filled into a measurement container (select a small container or Marinelli container according to the capacity of the filter paper). In this case, from the viewpoint of preventing contamination of instruments used for pretreatment, cutting along the shape of the air sampling surface is not performed in principle. The boundary between the air sampling surfaces is cut, as shown in Figure 4-1*². Since the cut filter paper may be cut into pieces for detailed measurement for each hour at a later date, it should be wrapped in polyethylene film or the like, as shown in Figure 4-3, filling into the measurement container to prevent cross-contamination among the six air sampling surfaces.

When filling, the air sampling surface should be as close to the bottom of the measuring container as possible, and the filter paper should be folded or cut into pieces and filled for each hour. Figure 4-4 shows an example of folding and filling the filter paper. For the pretreatment procedure, an appropriate method should be selected by also referring to section 6.4 and "Sample preparation method for gamma-ray spectrometry in emergency situations" in The Series of Environmental Radioactivity Measuring Methods No. 24.

*1 The setting of 6 hours is determined in accordance with the sampling cycle of the iodine sampler assumed in the Emergency Supplementary Reference Materials. This setting does not exclude the possibility of further subdividing the period into one hour or other periods in order to grasp detailed temporal changes in the concentration of radioactive materials in the air.

*2 Depending on the amount of airborne dust, the air sampling surface may not be visible, as shown in Figure 4-2. If, for this reason, it is not possible to separate the air sampling surfaces into 6-hour portions, collect the air sampling surfaces for several days from the startup of the air monitor to the collection of filter paper and use them as a measurement sample. To prevent cross-contamination between the air sampling surfaces, they should be covered with polyethylene film or the like and filled into the measurement container. It is desirable to be able to record the air sampling start position and the date and time of air sampling on a long filter paper by time stamping or other means so that the filter paper can be subdivided at arbitrary time intervals.

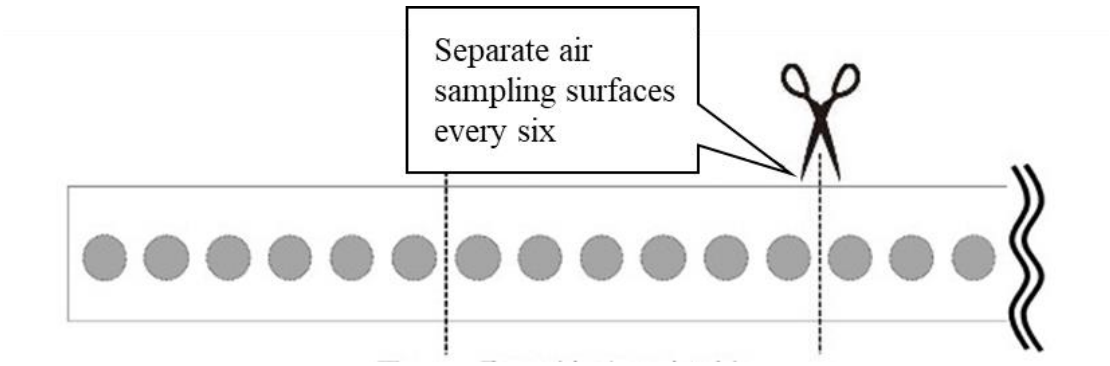


Figure 4-1. Example of cutting long filter paper

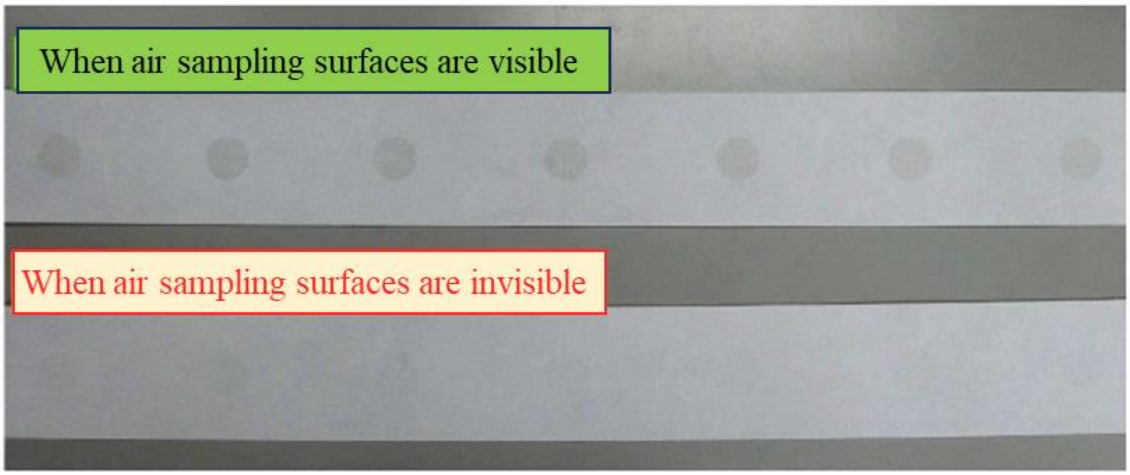


Figure 4-2. Air sampling surface of long filter paper for air monitor (example of air sampling at approx. 50 L/min for 1 hour)

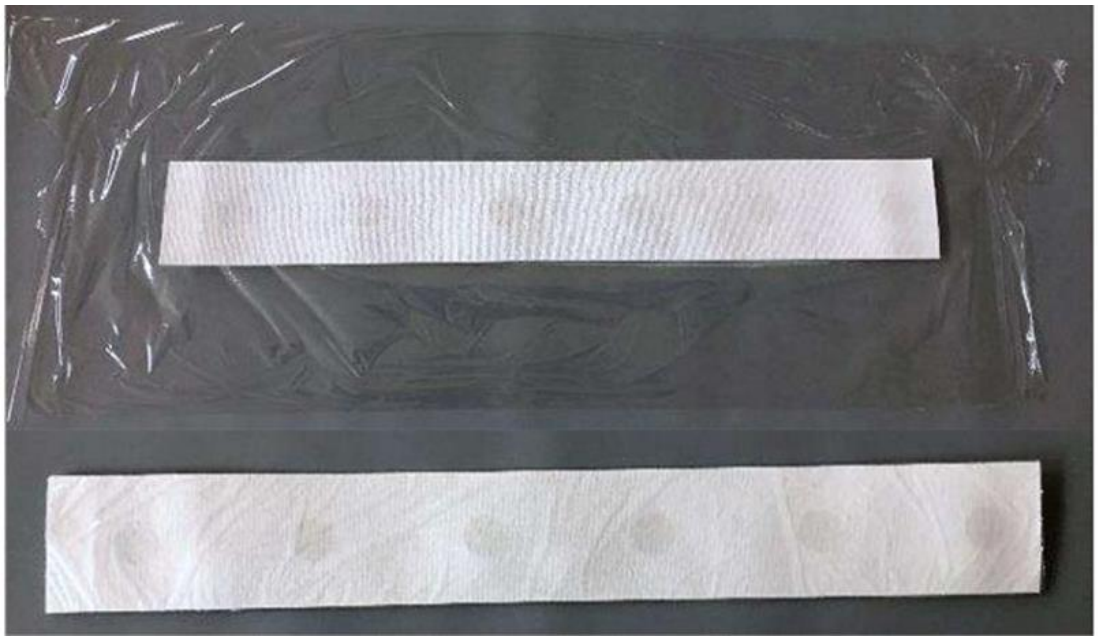


Figure 4-3. Example of long filter paper wrapped with polyethylene film, etc.
(Top - before wrapping, bottom - after wrapping)

Figure 4-4. Example of filling long filter paper (78 mm x 700 mm) used for 6 hours
(Top: An example of filling a U-8 container with filter paper folded long and narrow so that the air sampling surface is close to the bottom.
Bottom: Example of filling a V-9 container by overlapping and folding it for each hour so that the air sampling surface is centered)

(2) When performing radiochemical analysis

If the measurement of γ-emitting nuclides is necessary, the radiochemical analysis should be performed for α-emitting nuclides and β-emitting nuclides after the measurement is completed.

If necessary, such as when multiple nuclides must be measured, dividing the sample or conducting a systematic analysis is needed. Therefore, the analysis method should be carefully considered and determined before conducting the analysis.

Although clipping the air-sampling surface is not precluded when conducting radiochemical analysis, clipping should be avoided after γ-ray spectrometry since cross-contamination also occurs in the measurement container of the germanium semiconductor detector.

4.3 Analysis

γ-ray spectrometry with a germanium semiconductor detector is performed for γ-emitting nuclides, and radiochemical analysis is performed for α-ray and β-emitting nuclides.

Table 4-1 shows the nuclides to be measured according to the nuclear facilities and accident types listed in the Emergency Supplementary Reference Material.

Table 4-1. Examples of nuclides to be analyzed in filter paper collected by air monitors [3].

Facility	Accident type	Nuclides for analysis
Nuclear reactor facility for power generation*1	-	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.) β-emitting nuclides (Sr-89, Sr-90, etc.) γ-emitting nuclides (Co-58, Fe-59, Co-60, Zr-95, Nb-95, Mo-99, Tc-99m, Ru-103, Te-129, Te-129m, I-131, Te-132, I-132, I-133, Cs-134, Cs-137, etc.)
Nuclear reactor facility for test research, etc.*2	-	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.) β-emitting nuclides (Sr-89, Sr-90, etc.) γ-emitting nuclides (Co-58, Fe-59, Co-60, Zr-95, Nb-95, Mo-99, Tc-99m, Ru-103, Te-129, Te-129m, I-131, Te-132, I-132, I-133, Cs-134, Cs-137, etc.)
Uranium processing facility*2*3	Criticality accident	α-emitting nuclides (U-235, U-238, etc.) β-emitting nuclides (Sr-89, Sr-90, etc.) γ-emitting nuclides (I-131, I-133, Cs-134, Cs-137, etc.)
	UF_6 release (Dispersal)	α-emitting nuclides (U-235, U-238, etc.)
Plutonium (Pu) processing facility	Criticality accident	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.) β-emitting nuclides (Sr-89, Sr-90, etc.) γ-emitting nuclides (I-131, I-133, Cs-134, Cs-137, etc.)
	Large-scale fire or explosion	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.)
Re-processing facility	Criticality accident	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.) β-emitting nuclides (Sr-89, Sr-90, etc.) γ-emitting nuclides (Co-58, Fe-59, Co-60, Nb-95, Tc-99m, Te-129, Te-129m, I-131, I-133, Cs-134, Cs-137, etc.)
	Large-scale fire or explosion	α-emitting nuclides (U-235, U-238, Pu-238, Pu-239+240, Am-241, etc.) β-emitting nuclides (Sr-90, Y-90, Tc-99, Pm-147, etc.) γ-emitting nuclides (Rh-106(Ru-106), Cs-134, Cs-137, Ce-144, etc.)
	Evaporation dry	α-emitting nuclides (Pu-238, Pu-239+240, Am-241, Cm-244, etc.) β-emitting nuclides (Sr-90, Y-90, Tc-99, Pm-147, etc.) γ-emitting nuclides (Rh-106(Ru-106), Cs-134, Cs-137, Ce-144, etc.)

*1 PAZ and UPZ settings are required.

*2 UPZ setting is required.

*3 The same applies to nuclear fuel facilities (not requiring UPZ).

(1) γ-ray spectrometry

Table 4-2 shows the approximate measurement time for the germanium semiconductor detector.

The sample amount from sampling per 6 hours of air monitoring is about 18 m^3 (50 L/min x 360 min).

Table 4-2. Relationship between measurement time and quantifiable level when measuring samples at the time of the early stage of the accident (when multinuclear species were detected) using a small container (50 mmϕ × 50 mm) [3]

Sample amount	I-131 quantifiable level				Cs-137 quantifiable level				unit
	Measurement time				Measurement time				
	10 min.	30 min.	1 hour	10 hours (Reference)	10 min.	30 min.	1 hour	10 hours (Reference)	
1 m³	6	4	3	0.8	6	3	2	0.7	Bq/m³

*If the sample amount is not 1 m^3, the value obtained by dividing the quantifiable level by the sample amount is used.

For details, see The Series of Environmental Radioactivity Measuring Methods No. 29, "Gamma-ray spectrum analysis method using germanium semiconductor detector in emergency situations", and The Series of Environmental Radioactivity Measuring Methods No. 15, "Radioactive iodine measurement method in emergencies".

Uneven distribution of radionuclide concentrations in airborne dust occurs in the measurement container. For an example of the evaluation of the effect of uneven distribution, refer to "Document 2: Effect of inhomogeneous distribution of samples in measurement container (example of U-8 container)" in The Series of Environmental Radioactivity Measuring Methods No. 7 "γ-ray spectrometry using germanium semiconductor detector".

(2) Radiochemical analysis

After measuring γ-emitting nuclides, radiochemical analysis of α-emitting nuclides and β-emitting nuclides is conducted.

Since the radionuclides released differ depending on the nuclear facility, the nuclides to be analyzed should be selected with reference to Table 4-1.

The Series of Environmental Radioactivity Measuring Methods referred to for the nuclides to be analyzed are listed in Table 4-3. In the radiochemical analysis of α-emitting nuclides, if it is difficult to analyze the membrane filter paper used in the α-ray air monitor, a filter paper that can appropriately accommodate radiochemical analysis, such as cellulose/glass fiber filter paper, should be used. Analyzing the cellulose/glass fiber filter paper of dust samplers or iodine samplers collected separately is also acceptable.

For Tc-99 and Pm-147, which do not have a reference in The Series of Environmental Radioactivity Measuring Methods, β-ray measurement with a liquid scintillation counter or ICP mass spectrometry can be applied.

Table 4-3. The Series of Environmental Radioactivity Measuring Methods referred to concerning the nuclides to be analyzed and measured

Nuclides for analysis		The Series of Environmental Radioactivity Measuring Methods for reference
α-emitting nuclides	U-235, U-238	No. 14 "Uranium analysis method"
	Pu-238, Pu-239+240	No. 12 "Plutonium analysis method" No. 28 "Rapid analysis method for plutonium in environmental samples"
	Am-241, Cm-244	No. 21 "Americium analysis method" No. 22 "Plutonium and americium sequential analysis method" No. 30 "Americium-241 in environmental samples, curium rapid analysis method "
	-	No. 31 "Rapid analysis method for total alpha radioactivity in environmental samples"
β-emitting nuclides	Sr-89, Sr-90, Y-90	No. 2 "Radioactive strontium analysis method" No. 23 "Radionuclide analysis method using liquid scintillation counter"
	Tc-99, Pm-147, etc.	N/A

4.4 Evaluation of analysis results

The analysis results will be used for the following evaluations for emergency monitoring: (1) collecting information on the environmental radiation situation caused by a nuclear disaster and (2) providing materials for evaluating the radiological impact of a nuclear disaster on residents, etc., and the environment.

(1) Determination of the concentration of radioactive materials in the air and their nuclide composition in detail

Obtaining detailed information on changes over time in the concentration of radioactive materials in the air and their nuclide composition contributes to evaluating the effects of accidents at nuclear facilities.

Explanation B describes an example of an impact evaluation of the TEPCO's Fukushima Daiichi NPP accident.

(2) Provision of materials for evaluating exposure doses

The concentration of radioactive materials in the air evaluated in (1) is used as material for evaluating internal exposure doses due to inhalation and ingestion of airborne dust.

Refer to the Normal Time Supplementary Reference Material for the evaluation method of exposure doses.

When calculating the concentration of gross radioactive iodine (particulate and gaseous) from the analytical evaluation of the filter paper of the air monitor, the following procedure is used with the measurement results of air samples collected from the iodine sampler.

(a) Calculate the ratio of particulate radioactive iodine to gaseous radioactive iodine from the results of measurements with a germanium semiconductor detector of air samples collected with an iodine sampler.

(b) Calculate the gross radioactive iodine concentration at the location where the air monitor is installed from the concentration of particulate radioactive iodine evaluated from the analysis results of the filter paper of the air monitor and the ratio calculated in (1) above.

4.5 Sample storage

When storing filter paper before analysis, samples for γ-ray spectrometry measurement, and filter paper after analysis that has not been used for radiochemical analysis, store them in a desiccator, etc., to prevent moisture absorption.

Chapter 5 Sampling to Analysis of Air Sample via Iodine Sampler

Radioactive iodine sampling and analysis using an iodine sampler with an auto sample exchanger that continuously samples gaseous and particulate iodine and changes filter paper and activated carbon cartridges at regular intervals confirm the spread of radioactive materials and evaluate exposure. The Emergency Supplementary Reference Materials stipulates that monitoring shall be conducted for actual nuclear power reactor facilities and nuclear reactor facilities for test research.

For details, refer to The Series of Environmental Radioactivity Measuring Methods No. 15, "Radioactive iodine measurement method in emergencies".

5.1 From sampling to analysis

(1) Equipment specifications

The following are the requirements for an iodine sampler.

- Filter paper samples particulate radioiodine and activated carbon cartridges collect gaseous radioiodine, so a combination of both is used.
- The collection time per set of absorbents (a set of filter paper and activated carbon cartridges) can be approximately 6 hours.
- The auto sample changer shall be capable of automatically changing 20 or more absorbents (a set of filter paper and activated carbon cartridges) and continuously operating for at least 5 days.
- With an assumption of a power outage from the commercial power supply, the iodine sampler shall have a backup power supply, such as an emergency generator or battery. It shall be able to operate continuously without refueling, etc., for at least 3 days after startup.

(2) Installation

When installing an iodine sampler, the location of an iodine sampler should be considered in light of the actual situation of the region, including population distribution, past wind condition records, and other social and natural environment.

Iodine samplers shall be basically located at one site in a radius of 5 to 30 km in every one or two of the 16 azimuths centered on the target nuclear facility (see Figure 3-1). As with air monitors, if there is a fixed observation station site in the area, it is desirable to install the air sampler in that station building.

(3) Sampling

Sampling is conducted by sampling air for a certain period (approx. 6 hours) and adsorbing radioactive iodine on filter paper and an activated carbon cartridge. Continuous sampling is carried out by automatically replacing the filter paper and an activated carbon cartridge after a certain period.

After sampling, filter paper and an activated carbon cartridge shall be collected carefully to prevent contamination. In order to analyze radionuclides, including those with short half life, filter paper and an activated carbon cartridge shall be collected as soon as possible while considering the radiation exposure reduction to monitoring personnel.

(4) Analysis

A germanium semiconductor detector measures each filter paper and activated carbon cartridge. The sample amount from the iodine sampler sampling per 6 hours is approximately 18 m^3 (50 L/min x 360 min).

Table 5-1. Relationship between measurement time and quantifiable level [3] in the case of measurement using a small container (50 mm ϕ × 50 m)

Sample amount	I-131 Quantifiable level				Unit
	Measurement time				
	10 min.	30 min.	1 hour	10 hours (Reference)	
1 m^3	6	4	3	0.8	Bq/m^3

* If the sample amount is not 1 m^3, the value obtained by dividing the quantifiable level by the sample amount is used.

(5) Evaluation of result

Evaluating both particulate radioiodine concentration from the measurement result of filter paper and gaseous radioiodine concentration from the measurement result of activated carbon cartridges, gross radioiodine concentration is calculated by adding up these concentrations to be used for exposure evaluation.

Chapter 6 Sampling to Analysis of Air Sample via Dust Sampler

The purpose of collecting air samples is to obtain information on the environmental radiation situation caused by nuclear disasters and to obtain information for evaluating the effect of radiation due to nuclear disasters.

The analysis result of radioactive material concentration in air is not only used to estimate internal exposure caused by inhalation of radioactive materials but is also useful for estimating the amount of fallout on the ground surface.

In this section, as the sampling procedure using a transportable type dust sampler, The Series of Environmental Radioactivity Measuring Methods No. 35, "Environmental sampling methods in emergencies" (excluding the description on the iodine sampler), is transcribed. No. 35 names the dust sampler as a "transportable sampler" to distinguish it from a installed type sampler. It describes sampling procedures using a low-volume air sampler and a high-volume air sampler.

In principle, air sampling shall be implemented in accordance with the emergency monitoring instructions prepared by the EMC.

6.1 Equipment and air absorbent

A transportable type dust sampler and an air absorbent used in emergencies are the same as those used in normal times (Part 1, Chapter 4).

6.2 Installation and inspection

Installation concepts and inspection methods for a transportable type dust sampler are the same as those for normal time (Part 1, Chapter 4). If equipment for emergencies is maintained, operational checks should be conducted periodically at normal times to keep the equipment in good condition.

6.3 Sampling

6.3.1 Preparation

	Procedure
1	Receive a written instruction.
2	Prepare necessary materials and equipment according to the checklist, etc.
3	Check the operation of equipment (especially communication equipment and GPS).
4	Check sampling points on the map.
5	Cure materials and equipment to prevent contamination.
6	Check the operation of an electronic personal dosimeter.
7	Wear appropriate protective equipment (protective clothing, protective masks, etc.) in accordance with the instructions for use. Also, if so instructed, take a stable iodine drug.

6.3.2 Identifying the sampling point

	Procedure
1	Move to the sampling point indicated in the instructions.
2	Record the information about the sampling point, address, etc., including photography.
3	If GPS is available, record the latitude and longitude of the sampling point. If GPS is unavailable, identify the location, mark it on the map, and record it.

6.3.3 Sampling procedure using a low-volume air sampler

	Procedure
1	The air dose rate around the sampling points is measured and recorded using a NaI (Tl) scintillation survey meter or an ionization chamber survey meter.
2	Install the sampler so that it does not interfere with the airflow. Note 1) To evaluate internal exposure doses, the suction port of the sampler should be installed approximately 1 m above the ground. Note 2) As sucking in raindrops degrades the collection performance of the filter paper, an air sampler is installed at a roofed place, etc., during rain to prevent raindrops from entering the sampler. If there is no coverage, such as a roof around the measuring point, use an umbrella or other means to avoid the suction of raindrops. Note 3) If a generator is used as a power source, avoid suction of its exhaust. Note 4) Avoid getting a power supply from a vehicle used for transportation, if possible, because the exhaust gas may affect an air sampler (except for the case of a vehicle-mounted air sampler). Note 5) When multiple samplers are used together, their exhaust air should not affect each other.
3	Set the filter paper in the suction holder. The surface of the filter paper without the lattice structure is on the front side, collecting dust. Note) Use tweezers to handle the filter paper.
4	Start sampling and record the time and the volume (flow rate) collected. Note) The flow rate of the air sampler should be set at approximately 50 L/min (set to the flow rate indicated in the instruction).
5	Sample air until the integrated flow volume indicated in the instruction is reached. Note 1) If the flow rate is 50 L/min, the integrated flow volume is 1000 L (= 1 m^3) after 20 minutes of sampling. Note 2) If it starts raining while sampling air, stop the suction and use the integrated flow volume obtained from a sample collected before the rain starts. Alternatively, the sampling may be continued while holding an umbrella or other object to avoid the suction of raindrops.
6	Read and record the sampled volume (flow rate) just before the end of sampling.
7	Stop the air sampler and record the time.
8	Remove the filter paper from the sampler. Note: Handle with care as the adhered radioactive materials may make the radiation dose high.
9	Place the filter paper in a polyethylene bag (i.e., inner bag).

10	Fold the mouth of the bag, seal it with plastic tape, and affix (or clearly write) a label with an identification code.
11	Pack the sample in a second layer of bag (i.e., outer bag).
12	Check packaging, records, and photographs.
13	Remove the air sampler and load it into the car. Note 1) Decontaminate the used equipment by wiping, etc. Note 2) Decontaminate power cords and extension cords by wiping them while coiling them.

6.3.4 Sampling procedure with a high-volume air sampler

	Procedure
1	Measure and record the air dose rate around the sampling points using a NaI (Tl) scintillation survey meter or an ionization chamber survey meter.
2	Install air samplers without interfering with airflow. Note 1) The sampler's suction port is installed approximately 1 m above the ground to evaluate internal exposure doses. Note 2) Since the suction of raindrops reduces the collection performance of the filter paper, the air sampler is installed in a roofed place, etc., when it is raining to prevent raindrops from entering the sampler. If there is no roof around measuring points, an umbrella or other means are used to avoid the suction of raindrops. Note 3) If a generator is used as a power source, avoid suction of its exhaust. Note 4) Avoid power supply from a vehicle used for transportation, if possible (except in the case of vehicle-mounted air samplers), to prevent the effects of exhaust gas. Note 5) When multiple samplers are used together, their exhaust air should not affect each other.
3	Set the filter paper in the suction holder.
4	Start sampling and record the time and the sampled volume (flow rate). Note) The time required to collect an air sample depends on the radioactivity concentration in the air.
5	Sample air until the integrated flow volume indicated in the instructions is reached. Note) If the flow rate is 1000 L/min, the integrated flow volume is 1000 L (= 1 m^3) when collected for 1 minute.
6	Read and record the sampled volume (flow rate) just before the end of sampling.
7	Stop the sampler and record the time.
8	While keeping the sampler placed vertically, remove the holder fixing the filter paper. Note) For holders secured with screws, remove all screws.
9	Remove the filter paper from the sampler. Note 1) Since adhered radioactive materials may make the radiation levels high, handle them with care. Note 2) After removal, promptly set a new filter paper to prevent foreign matters from entering the air sampling unit. After the filter paper is removed, the suction surface often appears to be mesh-like. Work quickly since small dust and other particles may pass through the net and enter the air sampling unit.
10	Place the filter paper measured with the α-ray spectrometer in a Tupperware or box, etc., without folding it, with the suction side up, and with care not to touch the wall or lid of the container.

	Fold the filter paper used for other measurements in two with the suction side facing inward and place it in an inner polyethylene bag.
11	Attach a label (or clearly write) with an identification code to the container or inner bag with the mouth folded over and sealed with plastic tape. Seal the lid of the container with plastic tape, etc., and place it in a polyethylene bag (i.e., inner bag).
12	Pack the sample in a second layer of bagging (i.e., outer bag).
13	Check the packaging, records, and photographs.
14	Remove the air sampler and load it into the vehicle. Note 1) Decontaminate the used equipment by wiping, etc. Note 2) Decontaminate power cords and extension cords by wiping them while coiling them.

6.3.5 Notes

Consider and understand the following when collecting samples.

- The types of radioactive materials released into the air during an emergency include (a) particulate matter, (b) noble gases, and (c) volatile halogens (especially radioactive iodine).
- This section describes the collection of air samples using two types of transportable type samplers (low-volume air sampler: flow rate of 10 to 100 L/min, high-volume air sampler: flow rate of 500 L/min or more). Select the sampler to ensure the necessary detection level.
- A sampler may be installed in a monitoring vehicle.
- If an air sample is collected to determine the radioactivity concentration in the air relative to the radioactivity concentration in the soil, the soil sample should be collected at the same time and in the same location as the air sample.
- The filter paper is usually cellulose-glass fiber filter paper.
- The electrical outlets to be used as the power supply for the sampler during emergency monitoring should be determined in advance and clearly indicated in a drawing and a photograph. Also, investigate measurements involved in power supply during power outage in advance, and plan to make prompt response possible on site.

6.4 Pretreatment

This section presents the pretreatment and storage methods for preparing cellulose-glass fiber filter paper as a measurement sample for radioactive materials in the air. This section also shows the method of using a Marinelli container or small container as the measuring container.

The pretreatment procedures are transcribed from "Sample preparation method for gamma-ray spectrometry in emergency situations" The Series of Environmental Radioactivity Measuring Methods No. 24.

6.4.1 Considerations for sample pretreatment

	Procedure
1	Determine the order of pretreated samples in advance to prevent cross-contamination, referring to the results of measurements by the survey meter at the time of sample delivery.
2	When handling a sample with a high radiation level, confirm the work procedure or other plan among workers in advance to shorten the sample handling time as much as possible.
3	Cure the room (floor, workbench, etc.) before the work. Note) For curing methods, refer to Chapter 2 of "Sample preparation method for gamma-ray spectrometry in emergency situations".
4	Spread a plastic sheet over a cured worktable, place a large filter paper on it, and work on each sample. Note) Replacing the covers of the workbench and floor requires much work. Applying a simple, disposable curing to each sample can reduce the frequency of replacement.
5	In order to avoid spreading contamination from the sample, it is advisable to distinguish between a hot operation of directly touching the sample and a cold operation of not directly touching the sample and to separate workers and workbenches for them whenever possible.

6.4.2 Filling the measuring container

(1) When using small containers

	Procedure
1	After writing or attaching a number or other data identifying the sample to the small container, weigh and record the tare weight of the small container.
2	While paying attention to homogeneity, pack the filter paper that has been pre-folded or otherwise processed into the small container prepared in procedure 1, leaving as small gaps as possible. (Photo 6.1) Pack small filter paper and punch filter paper with the surface with airborne dust facing the bottom. (Photo 6.2) Note) If there are multiple sheets of filter paper, stack them.
3	Cover the small container and measure and record the height of the sample.
4	Wipe the outside of the container well with a paper towel moistened with deionized water, ethanol, etc.
5	Weigh the small container and subtract the earlier tare weight to obtain and record the weight of the measurement sample.
6	To prevent contamination of the analyzer, cover a small container with a polyethylene bag and remove air. Seal the bag by tying the mouth so as to avoid wrinkles at the bottom of the container, and use it as the measurement sample. (Photo 6.3)

Photo 6.1. Example of filling a sample into a small container (glass fiber filter paper)

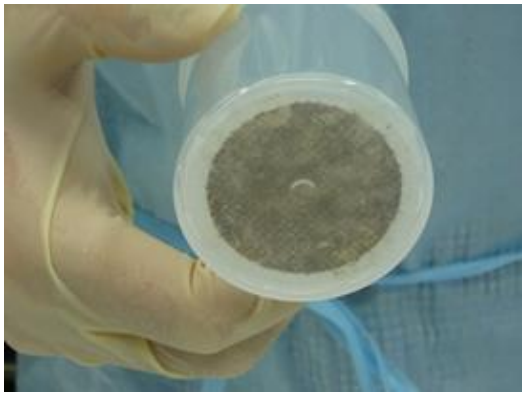


Photo 6.2. Example of filling with the adhering surface facing the bottom (glass fiber filter paper)

Photo 6.3. Example of a small container (glass fiber filter paper) covered with a polyethylene bag

[The Series of Environmental Radioactivity Measuring Methods No.24]

(2) When using Marinelli containers

This method is intended to measure a large amount of filter paper quickly. As a method to measure only the air sampling portion, fill a small container, as shown in (1).

	Procedure
1	Attach the inner bag for the Marinelli container inside the Marinelli container without a gap (use a disposable inner bag to avoid contamination of the measuring container wall as much as possible).
2	After writing or attaching a number or other data identifying the sample to the Marinelli container, weigh and record the tare weight of the Marinelli container, a lid, and an inner bag.
3	Pack the filter paper that has been pre-folded, clipped, or otherwise processed into the Marinelli container up to the marked line with as little gap as possible, ensuring homogeneity. (Photo 6.4) After filling the container with the sample, weigh the Marinelli container and lid together with the sample and subtract the tare weight to obtain and record the weight of the measurement sample.
4	Seal the mouth of the Marinelli container inner bag with plastic tape. (Photo 6.5) Note) Rubber bands, cable ties, etc., may be used in place of plastic tape.
5	Cover the Marinelli container and seal it by wrapping plastic tape around the lid joint. (Photo 6.6 and Photo 6.7)
6	Wipe the outside of the Marinelli container well with a paper towel moistened with deionized water, ethanol, etc. To prevent contaminating the measuring instrument, place the Marinelli container in a polyethylene bag, seal it by tying the mouth while sufficiently removing air, and use it as the measurement sample. (Photo 6.8)

Photo 6.4. Filling a sample into a Marinelli container (long filter paper)

Photo 6.5. Closing the inner bag with plastic tape (long filter paper)

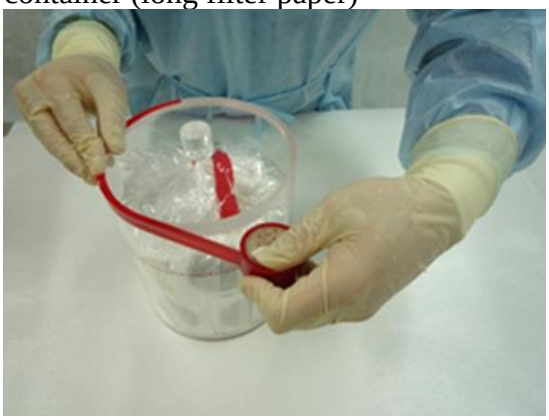


Photo 6.6. Fixing the lid with plastic tape (long filter paper)

Photo 6.7. Fixing the lid with plastic tape (long filter paper)

Photo 6.8. Marinelli container (long filter paper) covered with a polyethylene bag

[The Series of Environmental Radioactivity Measuring Methods No.24]

6.4.3 Sample storage method

(1) Relatively short-term storage

	Procedure
1	Place the measurement sample contained in the small container into another polyethylene bag or container while leaving it in the measurement container and storing it.
2	Place the measurement sample in the Marinelli container into a separate polyethylene bag or container while leaving it in the inner bag and storing it.

(2) Long-term storage

	Procedure
1	Place the measurement sample contained in the small container into a separate polyethylene bag or container while leaving it in the measurement container and storing it.
2	Place the measurement sample contained in the Marinelli container into a separate polyethylene bag or container while leaving it in the inner bag and storing it.
3	The sample may be incinerated according to the methods described in The Series of Environmental Radioactivity Measuring Methods No. 13, "Sample pretreatment method for instrumental analysis using germanium semiconductor detectors, etc." and The Series of Environmental Radioactivity Measuring Methods No. 16, "Environmental sampling method", but take due care to avoid contaminating other samples by washing and cleaning the apparatus and equipment after use. Store an incinerated sample in a low-humidity environment, such as in a desiccator, or in such a way that it is not exposed to air as much as possible.

6.5 Analysis

Conduct γ-ray spectrometry with a germanium semiconductor detector for γ-emitting nuclides and radiochemical analysis for α- and β-emitting nuclides.

The content is the same as the procedure (4.3) for an air monitor.

6.6 Evaluation of analysis result

The content is the same as procedure (4.4) for an air monitor.

6.7 Sample storage

The content is the same as the procedure (4.5) for air monitor.

Explanation

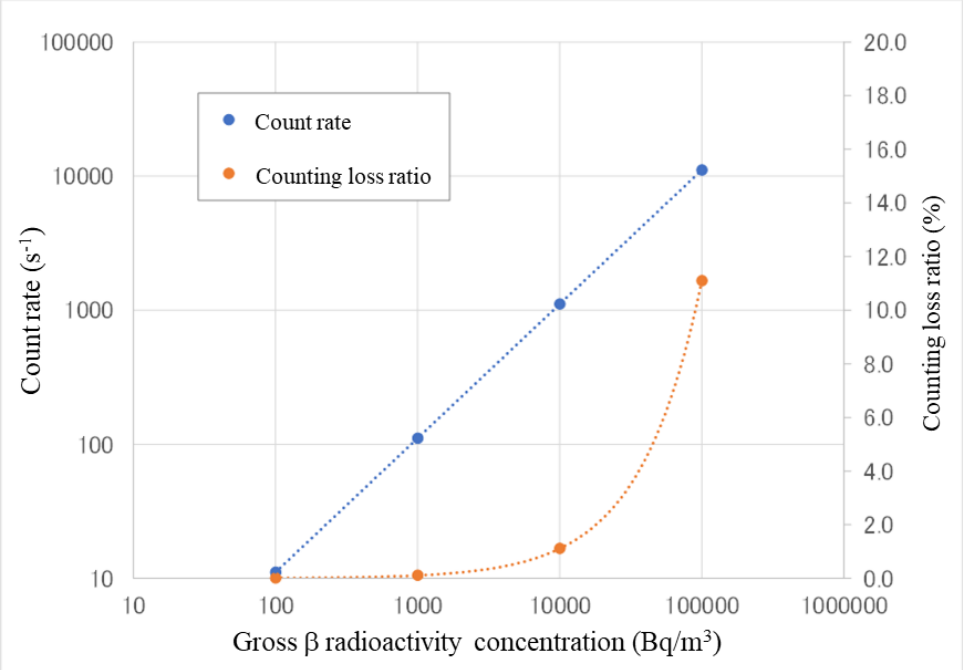
Explanation A Measurement Range of Air Monitor

The Emergency Supplementary Reference Material requires that the measurement range of the air monitor shall be 10 Bq/m^3 or higher for gross alpha radioactivity concentration and 100 to 100,000 Bq/m^3 for gross beta radioactivity concentration. Even if the concentration exceeds 100,000 Bq/m^3, it must be possible to confirm the presence of a radioactive plume above that concentration.

There is concern that when a highly concentrated radioactive plume flows during an emergency, the number of radiative particles from collected airborne dust entering the detector of the air monitor increases, and the increase causes the detector to get saturated and counting loss.

Figure A-1 shows an example of evaluating the ratio of counting loss assuming an air monitor using a 1-inch ϕ plastic scintillation detector and a decomposition time of the detector of 10 μsec. The ratio of counting loss in the gross β radioactivity concentration at the upper limit of 100,000 Bq/m^3 is approximately 11%. It should be noted, however, that Figure A-1 is an evaluation example assuming air sampling for 10 minutes and that the ratio of counting loss would be larger for air sampling for 1 hour.

Figure A-1. Example of evaluation of the ratio of counting loss in an air monitor



(1 inch ϕ plastic scintillation detector)

<Measurement conditions>

Counting efficiency: 0.23, collection efficiency: 0.99, average flow rate: 50 L/min,

Air sampling time: 10 min, measurement time: 10 min

Explanation B Example of Impact Assessment of the Accident at TEPCO's Fukushima Daiichi NPP

The release of radioactive materials due to the accident at the TEPCO's Fukushima Daiichi NPP following the Great East Japan Earthquake on 11 March 2011 caused an increase in the concentration of radioactive materials in the air. Here are some examples of observations and impact assessments. It also includes some measurement methods that differ from those described in the text.

(1) Example of continuous measurement with a dust monitor

Although the dust monitors continuously taking measurements in Fukushima Prefecture were unable to obtain measurement data for March 2011 due to the power outage caused by the earthquake, the dust monitors continuously taking measurements in Tokai-mura, Ibaraki Prefecture, approximately 120 km away from the Fukushima Daiichi NPP, observed increase in the concentration of radioactive materials in the air caused by the accident (Figure B-1).

Early on 15 March, the radioactive plume largely increased the gross β radioactivity concentration. Although measurements were not taken immediately after the earthquake on 11 March due to a power outage, measurements at MS-3 and MS-4 were restored before the radioactive plume arrived on 15 March. That at MS-2 was restored on 22 March.

Subsequently, the gross β radioactivity concentration gradually declined to a level where fluctuations due to natural radioactive materials could be observed around the end of April. Generally, it was confirmed to return to the original level around September by referring to annual fluctuations.

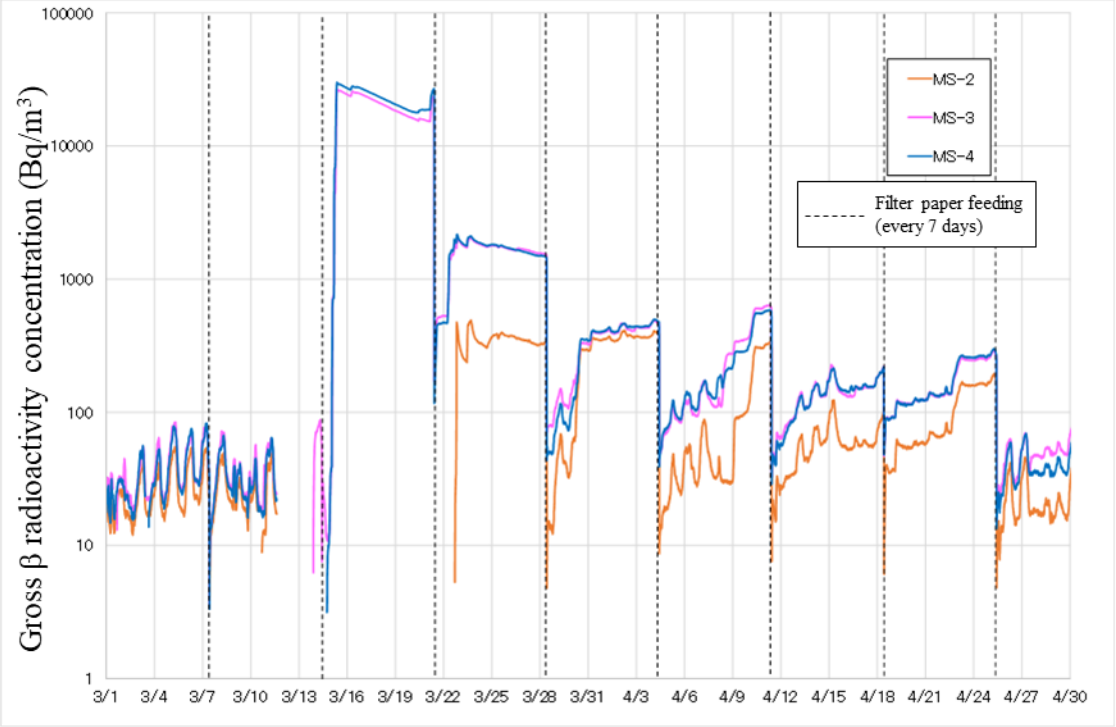
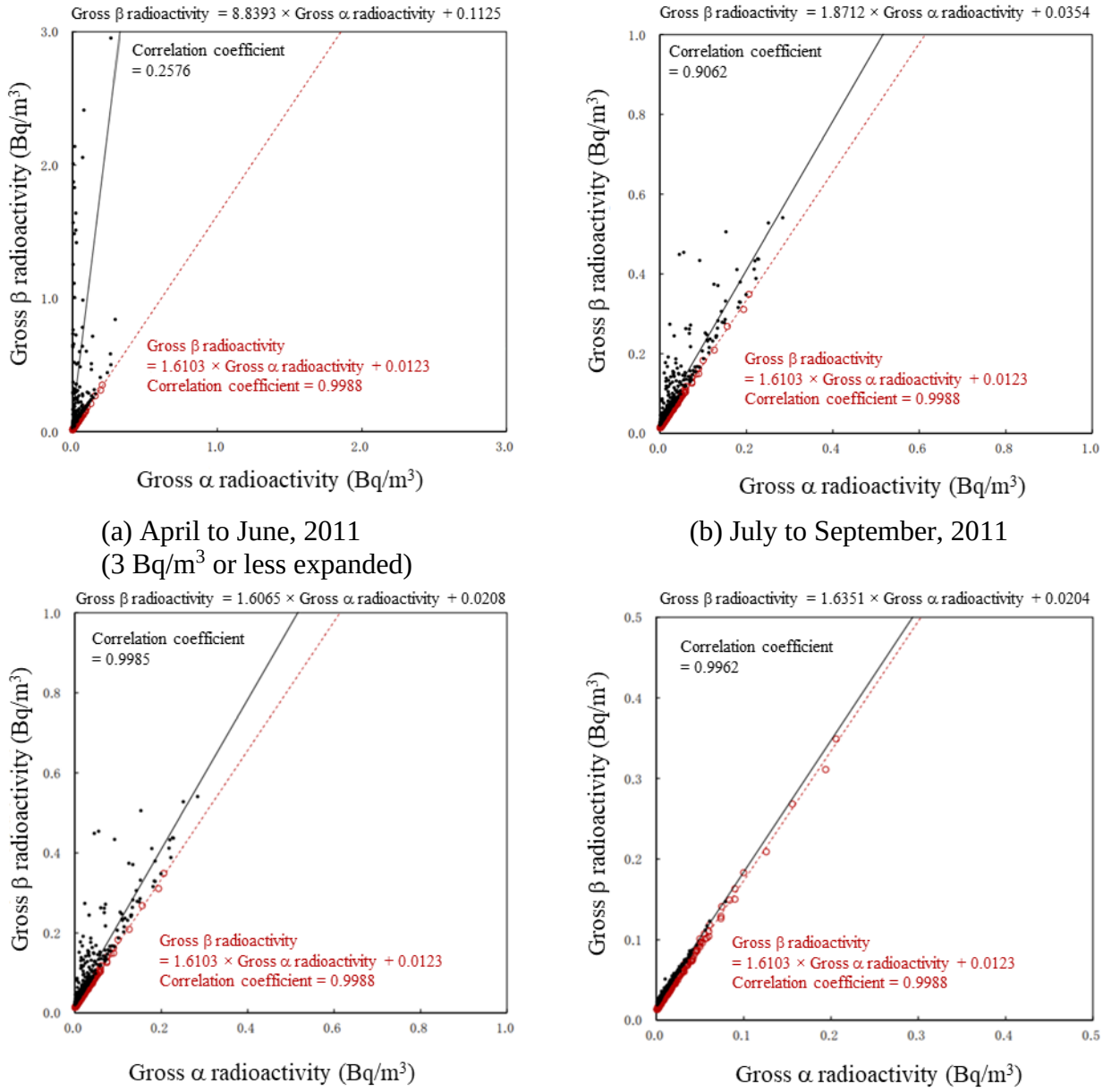


Figure B-1. Change over time in gross β radioactivity concentration in Ibaraki Prefecture during the accident at the TEPCO Fukushima Daiichi NPP (March-April, 2011) [23].

(MS-2, MS-3, and MS-4 are the names of the station buildings, and the distance between them is approximately 2 to 3 km. Airborne dust was collected continuously on cellulose filter paper for one week and measured with a plastic scintillation detector.)

Dust monitor measurement in Fukushima prefecture resumed around April 2011. Figure B-2 shows the correlation between the gross α and β radioactivity concentrations in dust monitors at Naraha-town, Fukushima Prefecture, from April 2011 to March 2012.

Over time, it was observed that the slope was getting closer to the pre-accident slope, and the correlation was getting better. In October 2011, the observations were almost the same as before the accident.



(a) April to June, 2011
(3 Bq/m^3 or less expanded)

(b) July to September, 2011

(c) October-December, 2011

(d) January-March, 2012

Black (plots and approximate straight lines): data for each period (a) 14 Apr. -30 Jun., 2011

(b) 1 Jul. - 30 Sep., 2011

(c) 1 Oct.– - 31 Dec., 2011

(d) 1 Jan. - 31 Mar., 2012

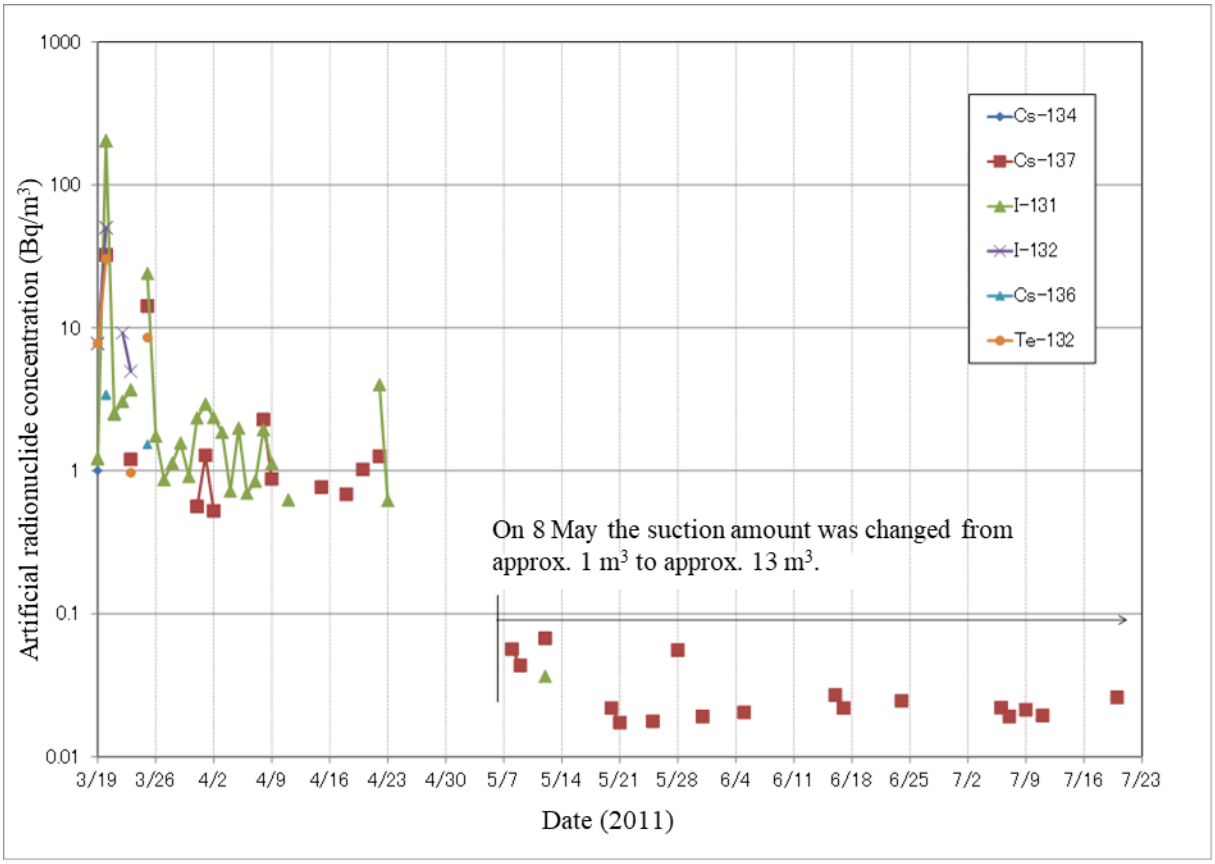
Red (plots and approximate straight lines): Data from January to 10 March, 2011

Figure B-2. Trends in the correlation between gross α and gross β radioactivity concentrations in Fukushima Prefecture after the accident at the TEPCO Fukushima Daiichi NPP [24].

(2) Example of measurement of airborne dust sampled by a dust sampler

Figure B-3 shows a time-course change in the concentration of artificial radionuclides in airborne dust collected in Fukushima City, Fukushima Prefecture.

In March 2011, Cs-134, Cs-137, I-131, I-132, Cs-136, and Te-132 were detected. In late May, only Cs-137 was detected, and its radionuclide concentration decreased to 0.1 Bq/m^3 or less.



* Measurements were taken daily, and only the detected data were plotted. All were ND(Not detected) from 24 April to 7 May.

Collection method: Dust samplers were placed at a height of approximately 1 meter above the ground and sampled once a day.

Air absorbent: cellulose-glass fiber filter paper (HE-40T) + activated carbon cartridge (CHC-50-A10)

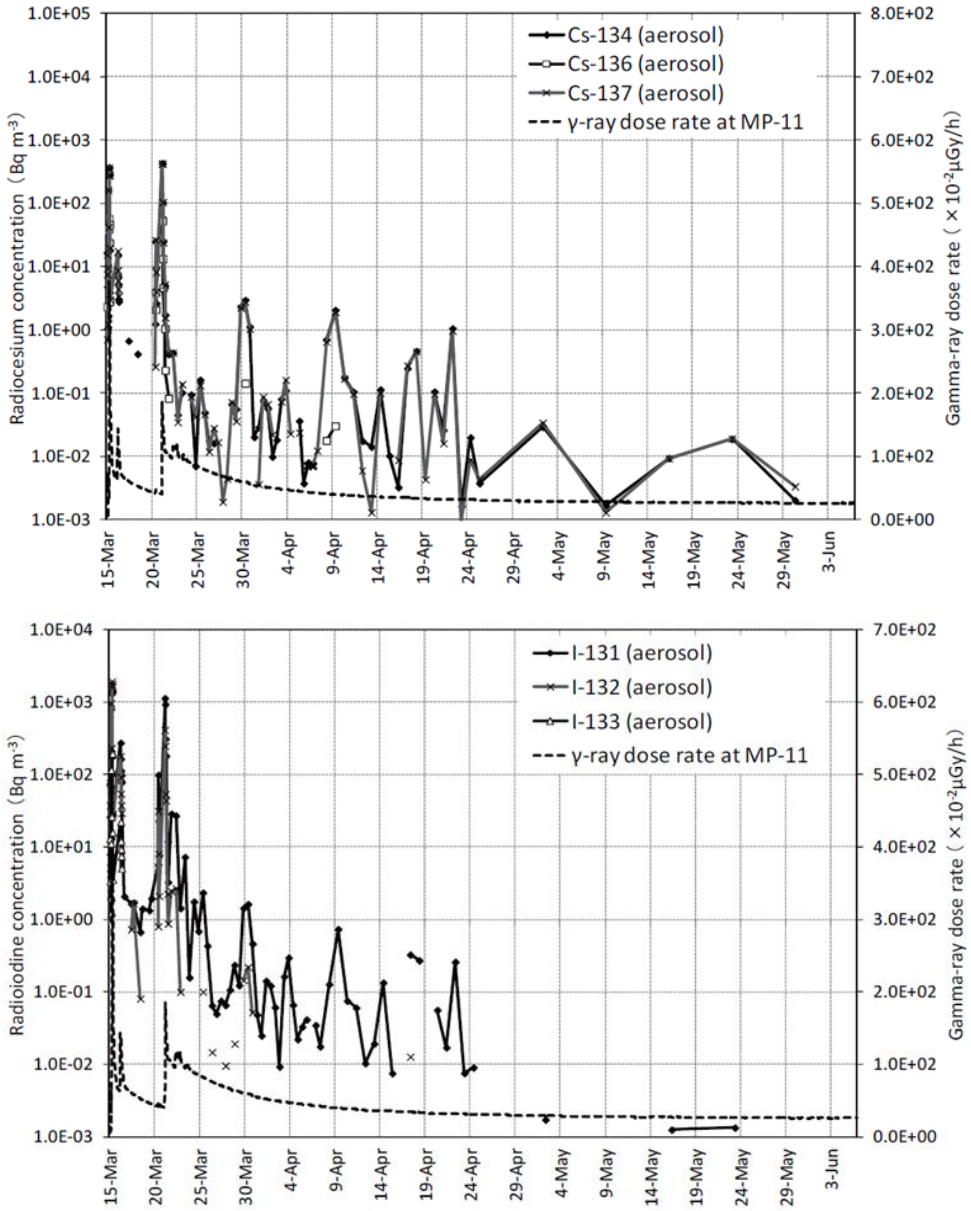
Suction amount: 1 m^3 (19 March to 8 May), approx. 13 m^3 (from 8 May)

Figure B-3. Change over time in the concentration of artificial radionuclides in airborne dust collected in Fukushima Prefecture [25].

Figure B-4 shows the change over time in concentrations of radioactive cesium and radioactive iodine (particulate form) among the concentrations of artificial radionuclides in airborne dust collected in Tokai-mura, Ibaraki Prefecture.

In March 2011, Cs-134, Cs-136, Cs-137, I-131, I-132, I-133, Te-132, Te-129m, Te-129, Tc-99m, and Xe-133 were detected.

Radionuclide concentrations of Cs-134 and Cs-137 were observed at a maximum of 426 Bq/m^3 for both nuclides but decreased to 0.1 Bq/m^3 or less in late April. The radionuclide concentration of I-131 was observed at a maximum value of 1430 Bq/m^3, but by late April, it was almost ND (Not Detect).



* Only the detected data are plotted.

* The air dose rate at the monitoring post (MP-11) is plotted at the same time.

Collection method: Dust sampler (approximately 1 meter above the ground) maintained in the monitoring car and monitoring post

Air absorbent: cellulose-glass fiber filter paper (HE-40TA)

Suction amount: 1 m^3 (15 to 21 March), approx. 35 m^3 (21 March to 7 April), approx. 70 m^3 (7 to 25 April), approx. 500 m^3 (25 April to 6 June)

Figure B-4. Change over time in concentrations of artificial radionuclides in airborne dust sampled in Ibaraki Prefecture.
(Upper figure: radioactive cesium, lower figure: radioactive iodine(particulate form)) [26].

Figure B-5 shows an example of the evaluation of Cs-137 radioactivity concentration in the air inside and outside the area under evacuation order in Fukushima Prefecture. The data for 12% detected are shown since 88% of the data was ND (Not Detect) up to 2 years after the accident in the area under evacuation order (due to short measurement time and small sample volume).

The radioactivity concentration of Cs-137 in the air was in the range of 10^{-1} to 10^{0} Bq/m^3 up to two years after the accident in the area under evacuation order and in the range of 10^{-4} to 10^{-1} Bq/m^3 after two years.

Outside the area under evacuation order, a decrease in Cs-137 radioactivity concentration in the air was observed five years after the accident, probably due to decontamination work in the surrounding areas.

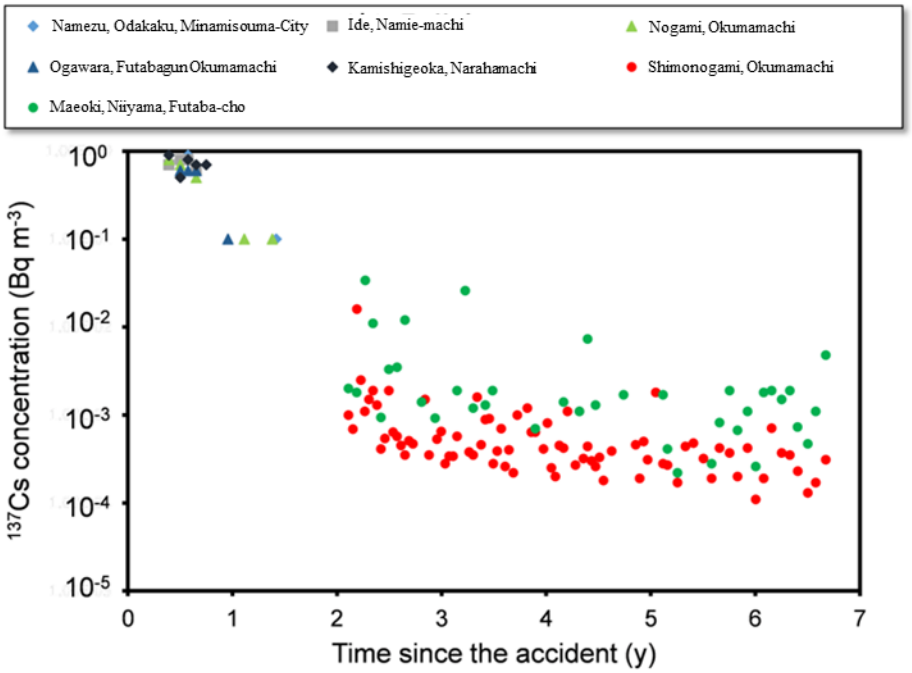
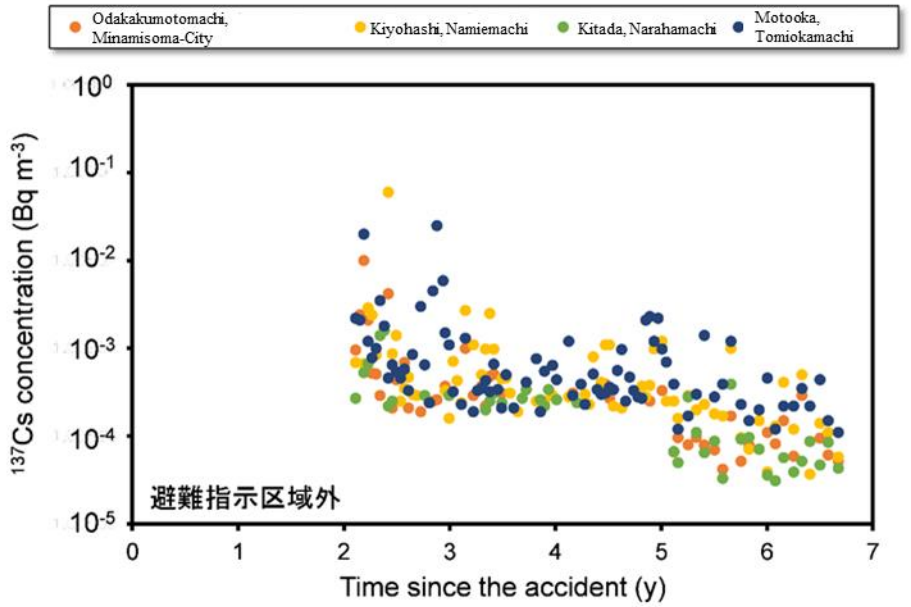


Figure B-5. Change over time of Cs-137 radioactivity concentration in



airborne dust (partially edited figure [27])

Top: within the hazard area for evacuation, Bottom: outside the hazard area for evacuation

(0: urban area, △: forest, □: grassland, ◇: paddy field)

Common to Part 1 and Part 2

Table of Contents

Common to Part 1 and Part 2

Information

Information A Characteristics of Air Absorbent

For the collection of an air sample, an appropriate method must be selected to measure the concentration of radioactive materials in the air, taking into consideration the type of radioactive materials, their physical and chemical properties, the measurement method, and other factors.

The relationship between the properties of radioactive materials and sampling methods, etc., is shown in Table Information A-1, which classifies radioactive materials into particulate and gaseous (volatile) forms.

Table Information A-1. Relationship between properties of radioactive materials and sampling methods, etc.

Property of radioactive material	Sampling method	Absorbent	Main nuclide	Measurement method
Particulate	Filtering and collection	· Cellulose, glass fiber filter paper · Membrane filter paper	Cs-137, U, Pu	· Gross α, β, and γ measurements · α-, β-, and γ-ray spectrum analyses
Gaseous (volatile matter)	Solid collection	· Activated carbon-impregnated filter paper · Activated carbon cartridge · Activated carbon fiber filter paper	I-131, I-132, I-133	· Gross β and γ measurements · γ-ray spectrum analysis

In collecting an air sample, it is necessary to select appropriate air absorbent in consideration of the properties of radioactive materials in Table Information A-1.

Airborne dust is a particulate matter and is generally collected by a filtration collection method, with cellulose-glass fiber filter papers being widely used. They can be round, square, and rolled.

(1) Filter paper for airborne dust collection

Types of filter paper for airborne dust collection include cellulose-glass fiber filter paper and membrane filter paper. Factors in selecting filter paper include collection efficiency, pressure drop, physical strength, etc. In particular, collection efficiency is greatly affected by the particle size of the sample and ventilation speed.

Cellulose-glass fiber filter paper is widely used as filter paper for collecting airborne dust. For the catalog values of the most commonly used cellulose-glass fiber filter paper, collection efficiency is 99.5% or higher at a ventilation speed of 57 to 141 cm/s, and pressure drop is 0.27 kPa at a ventilation speed of 5 cm/s. It is commercially available in round and roll shapes and in many sizes.

However, it has been reported [28] that some types of cellulose-glass fiber filter paper do not necessarily have sufficient collection efficiency for particles 0.1 μm or smaller in diameter. Caution should be exercised when collecting them in environments where particles with 0.1 μm or smaller in diameter dominate. Cellulose-glass fiber filter paper with improved collection efficiency in the submicron range has also been developed, although the pressure drop is larger.

Table Information A-2 shows an example of the properties of cellulose-glass fiber filter paper.

Table Information A-2. Example of cellulose-glass fiber filter paper properties

Item		Product (a)	Product (b)
Weight (g/m^2)		145	120
Paper thickness (m/m)		0.41	0.40
Air permeability (sec/cm ϕ)		12	19
Tensile strength (kg/15 mm width)		4.5	3.0
Fiber composition (%)	Cellulose: glass	80 : 20	70 : 30
Fiber diameter (μm)	Cellulose-glass	20 to 25/0.8	20 to 25/0.6
Minimum collection efficiency (%)	DOP* 0.07 μm Surface velocity 20 to 130 cm/s	43 to 57	87 to 92
	NaCl 0.075 μm Surface velocity 40 to 60 cm/s	70	93
Relative pressure drop	Surface velocity 30 to 130 cm/s	1.0	1.2

* Dioctyl phthalate

Cellulose-glass fiber filter paper is considered to have sufficient performance for practical use when measuring the concentration of radioactive materials in the air and monitoring to contribute to evaluating internal exposure.

However, when collecting and measuring α-emitting nuclides as targets, there is a possibility that particles may enter the filter materials and cannot be counted, etc., and thus, correction should be considered as needed. It should be noted that moisture adhering to or contained in the filter paper reduces the α-ray count as well.

(2) Filter paper for α particle collection

The surface collection rate* of filter paper is an important factor in the direct measurement of α-emitting radionuclides.

Comparisons of surface collection performance and pressure drop have been reported for many types of filter paper available in Japan [29]. An example of the report is shown in Table Information A-3.

Among membrane filter paper types, the PTFE (polytetrafluoroethylene resin) type, with a reinforced back side of the filter paper, includes products with a high surface collection rate and low-pressure drop that are suitable for use in α-ray dust monitors.

* Percentage occupied by particles captured near the surface of the filter paper, of the particles collected on the filter paper.

Table Information A-3. Example of characteristics of filter paper for α-particle collection

Types of filter paper	Surface collection efficiency (%)[*1]	Relative pressure drop[*2]
Cellulose-glass fiber		
Product (a) (glass 20%, cellulose 80%)	45±0.9	0.17
Product (b) (glass 30%, cellulose 70%)	56	0.20
Glass fiber		
Product (a)	65±1.5	0.26
Product (b)	56±0.3	0.11
Product (c)	94	1.4
Silica fiber		
Product (a)	76±1.6	0.48
Membrane (cellulose mixed ester)		
Product (a) (0.8 μm pore size)	94±0.7	1
Product (b) (0.8 μm pore size)	95	1.2
Product (c) (1.0 μm pore size)	90	0.76
Product (d) (5.0 μm pore size)	79	0.42
Membrane (PTFE type)		
Product (a) (0.8 μm pore size)	97±1.9	2.1
Product (b) (1.0 μm pore size)	98	1.5
Product (c) (3.0 μm pore size)	87	0.5
Membrane (PTFE type with back side reinforced)		
Product (a) (1.0 μm pore size)	99	0.63
Product (b) (3.0 μm pore size)	99	0.31
Product (c) (3.0 μm pore size)	95	0.28
Pre-filter		
Product (a)	98	1.8
Product (b)	82	0.83
Product (c)	69	0.27
Product (d)	91	0.54

*1 Value evaluated from the spread of α-ray spectra of thoron decay products.

*2 Value obtained based on membrane (cellulose mixed ester) product (a).

（Surface velocity 50 cm/sec)

Information B Comparative Measurement of Dust Monitors

(1) Comparative measurement methods

Comparative measurements were made at the same location and time using two or more dust monitors with different specifications. The specifications of the two dust monitors are shown in Table Information B-1.

Table Information B-1. Specifications of dust monitor used for comparative measurement

Item	Dust Monitor (a)	Dust Monitor (b)
Air absorbent	Membrane filter paper	Cellulose-glass fiber filter paper
Flow rate	Approx. 35 L/min (2 m^3/h)	Approx. 200 L/min (12 m^3/h)
Detector	Double silicon semiconductor detector (PIPS)	ZnS (Ag) + plastic scintillation detector
Removal of the effect of external radiation	Shielding by α/β absorber (Cu plate), correction by γ -ray background compensation detector(γ-ray from outside and filter paper)	Lead shielding (approx. 3 cm)
Nuclide discrimination	Analyzing the spectrum attributed to radon and thoron and correcting the effect level.	None
Data interval	2 minutes	2 minutes
Recorded Information	Flow rate (m^3/h), integrated flow volume (m^3), Gross α and β radioactivity concentrations (Bq/m^3) and count rates (s^{-1}) (Radon-thoron correcting data), Radon radioactivity concentration (Bq/m^3), Thoron radioactivity concentration (Bq/m^3), etc.	Flow rate (m^3/h), integrated flow volume (m^3), Integration time (s), Gross α radioactivity concentration (Bq/m^3), Gross β radioactivity concentration (Bq/m^3), Count rate (s^{-1}), etc.

Figure Information B-1. Dust monitor used for comparative measurement

(Left: dust monitor (a), Right: dust monitor (b))

(2) Comparison measurement result

Since dust monitor (a) can only output the gross α and β radioactivity concentrations after subtracting the contribution from natural radioactive materials (radon/thoron), the measured radon and thoron radioactivity concentrations were used for comparison. For dust monitor (b), gross α and gross β radioactivity concentrations were used for comparison.

The results of comparative measurement are shown in Figure Information B-2. The change trends of radon radioactivity concentration in dust monitor (a) and gross α and β radioactivity concentrations in dust monitor (b) showed good agreement. The maximum thoron radioactivity concentration in dust monitor (a) was approximately one-tenth of the maximum radon radioactivity concentration. It was considered that thoron contributed little to the gross α and β radioactivity concentrations in dust monitor (b).

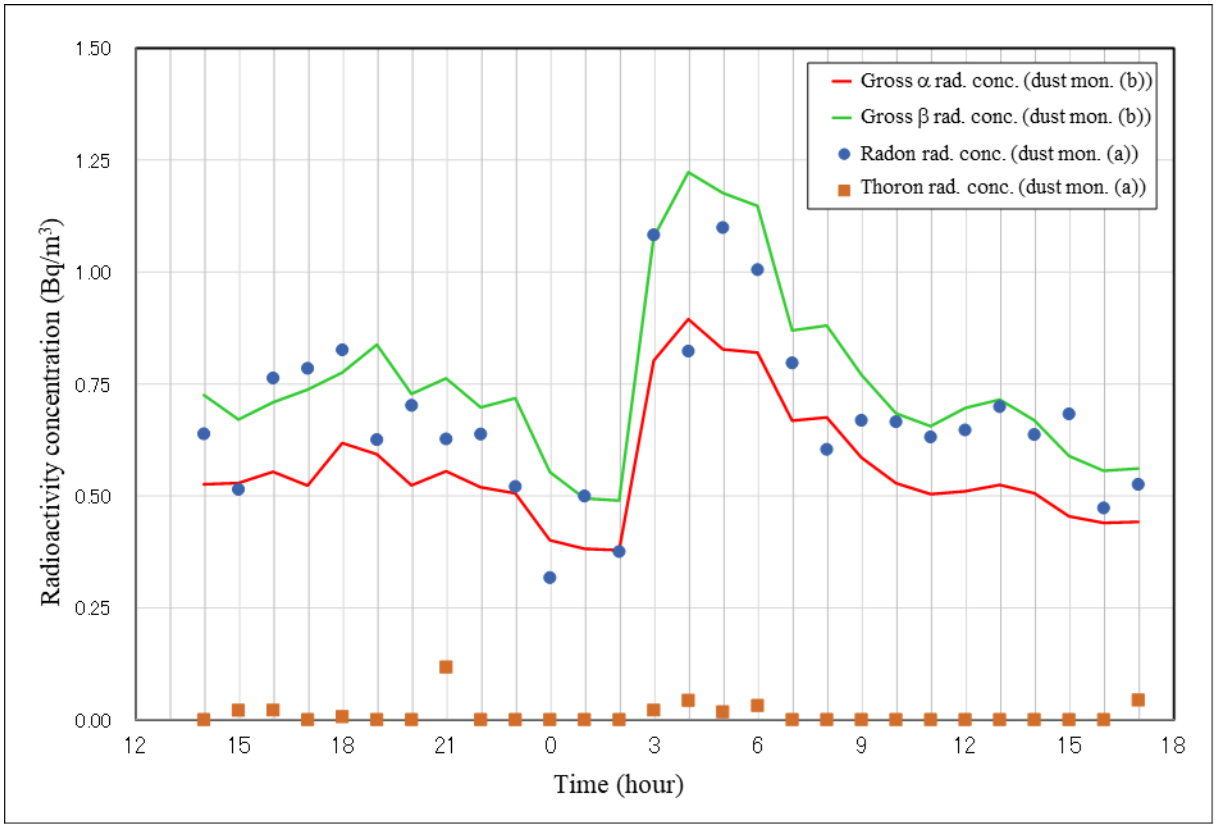


Figure Information B-2. Comparative measurement result of dust monitor

Information C Evaluation Methods for Radioactive Material Concentration in the Air by γ-ray Pulse Height Spectra

This section describes methods and examples of evaluating the concentration of radioactive materials in the air using γ-ray pulse height spectra obtained from monitoring posts that measure air dose rate, transportable type germanium semiconductor detectors, dust monitors, etc.

The method described here also allows for the estimation of the radioactivity concentration in the air of short half-life nuclides such as radioactive iodine and noble gases, which are difficult to measure in practice.

In addition, measurements for radiation sources in the air are characterized by the ability to evaluate the average concentrations of radionuclides around the measurement points to measure γ-ray from radiation sources distributed over a wide space.

(1) Evaluation using pulse height spectra of monitoring post

Terasaka et al. and Moriizumi et al. used pulse height spectra observed at monitoring post using NaI (Tl) scintillation detectors in Ibaraki Prefecture during the Fukushima Daiichi NPP accident (Figure Information C-1) to establish peak regions for analysis for each radionuclide (Table Information C-1). The radioactivity concentration of each radionuclide in the air was estimated using a Monte Carlo simulation. Examples of evaluation are shown in Figures Information C-2 through C-4.

The radioactivity concentrations of several radionuclides in the air have been evaluated. They agree well with the actually measured values of radioactive iodine and other radionuclides, as shown in Figure Information C-2.

However, the application of this method assumes that the pulse height spectrum of the NaI (Tl) scintillation detector can be properly acquired. Counting loss, etc., may prevent evaluation in case of high radiation dose rates in the air during an emergency.

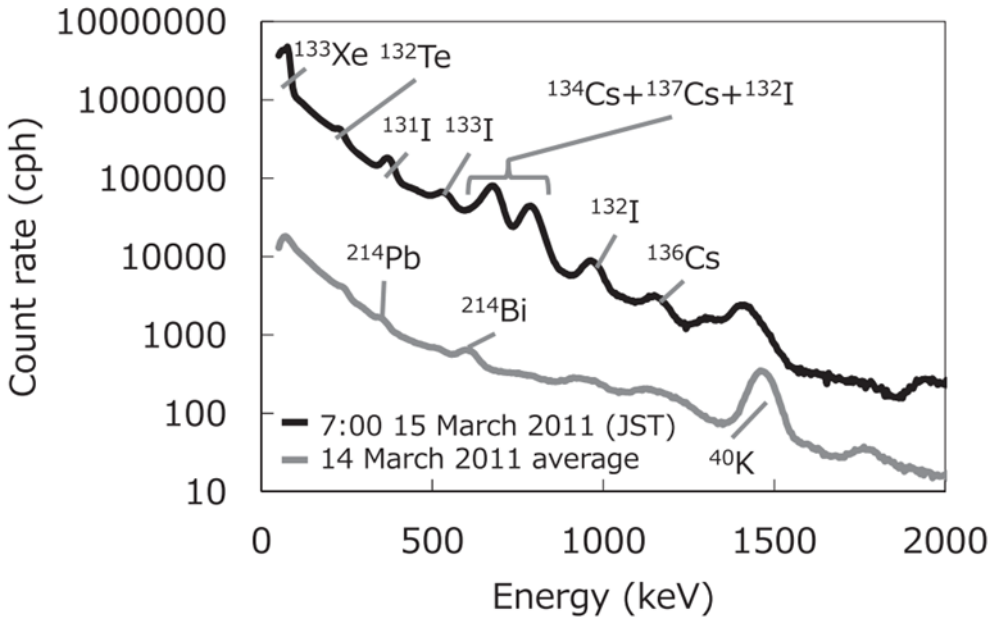


Figure Information C-1. Pulse height spectra were observed at a monitoring post in Ibaraki Prefecture [30].

Table Information C-1. Radionuclides and energy ranges were used in the analysis [30].

Energy range (keV)	Radionuclides
70–90	**^{133}Xe**
210–250	**^{132}Te**
340–390	**^{131}I**, ^{136}Cs
500–560	**^{133}I**, ^{132}I
630–700	**^{137}Cs**, ^{131}I, ^{132}I
760–840	**^{134}Cs**, ^{132}I, ^{136}Cs
900–1000	**^{132}I**
1020–1080	**^{136}Cs**

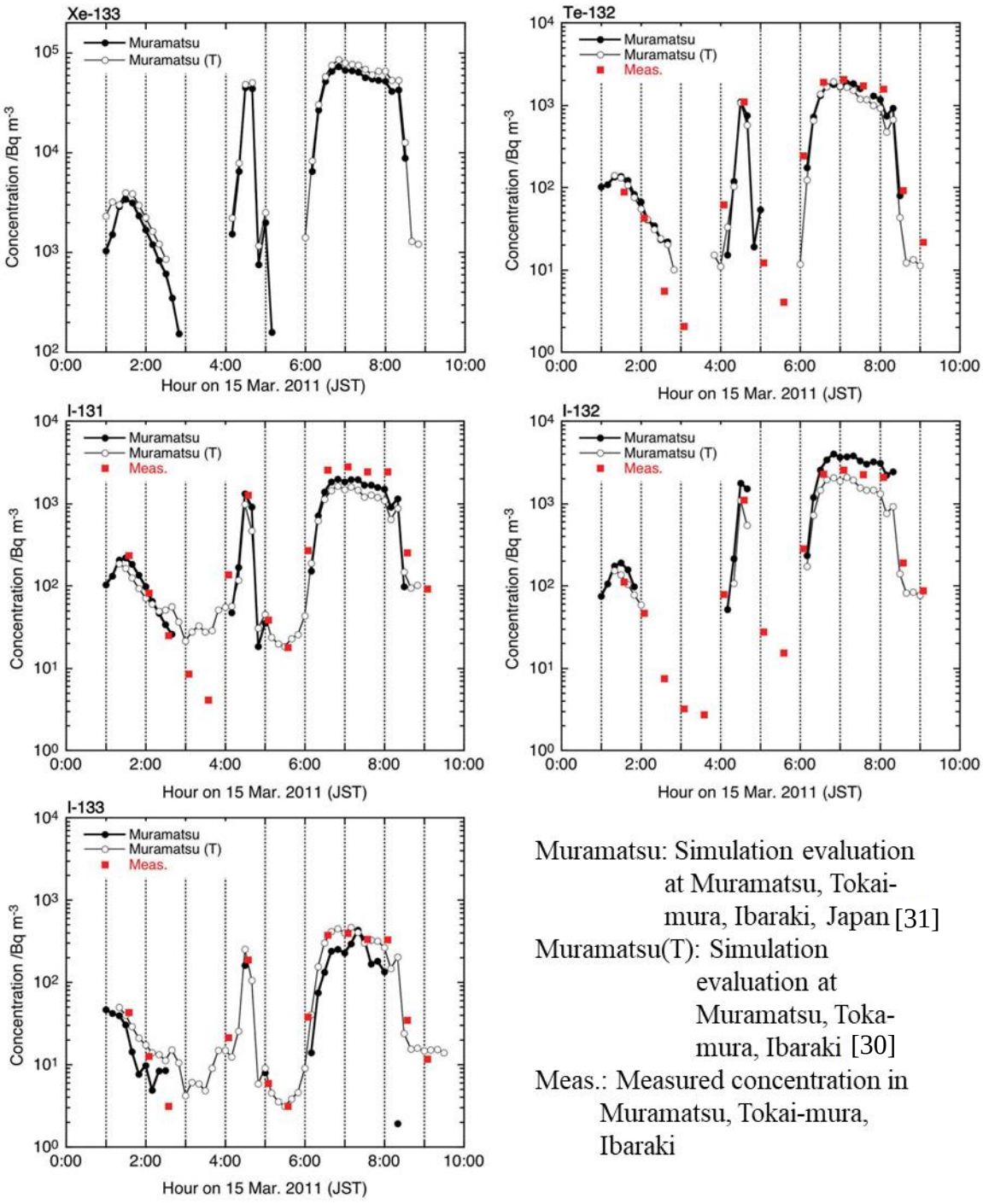


Figure Information C-2. Time-series chart of radionuclide concentrations in the air evaluated by simulation [31].

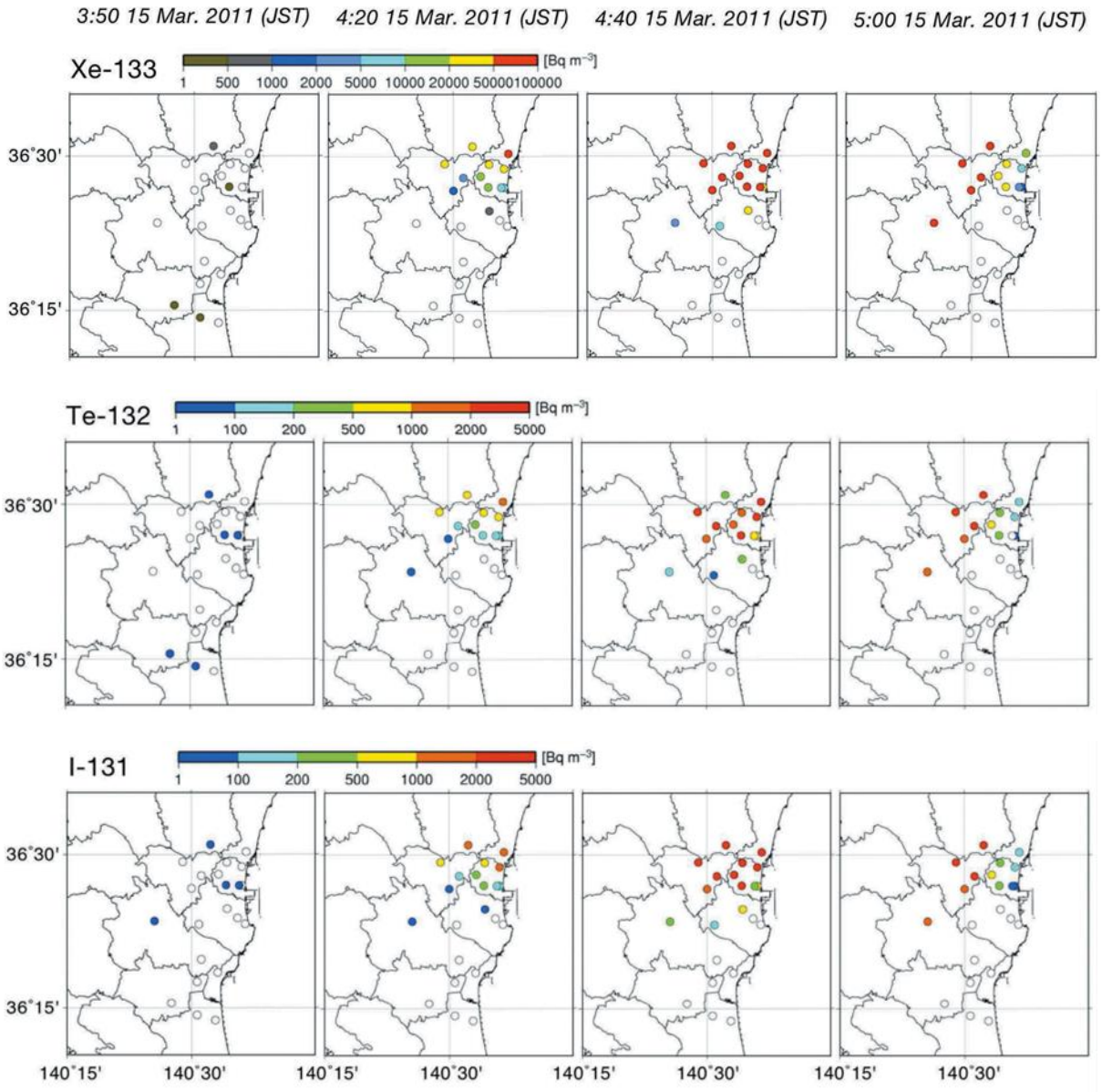


Figure Information C-3. The Distribution of radionuclide concentrations in the air was evaluated by simulation [31].

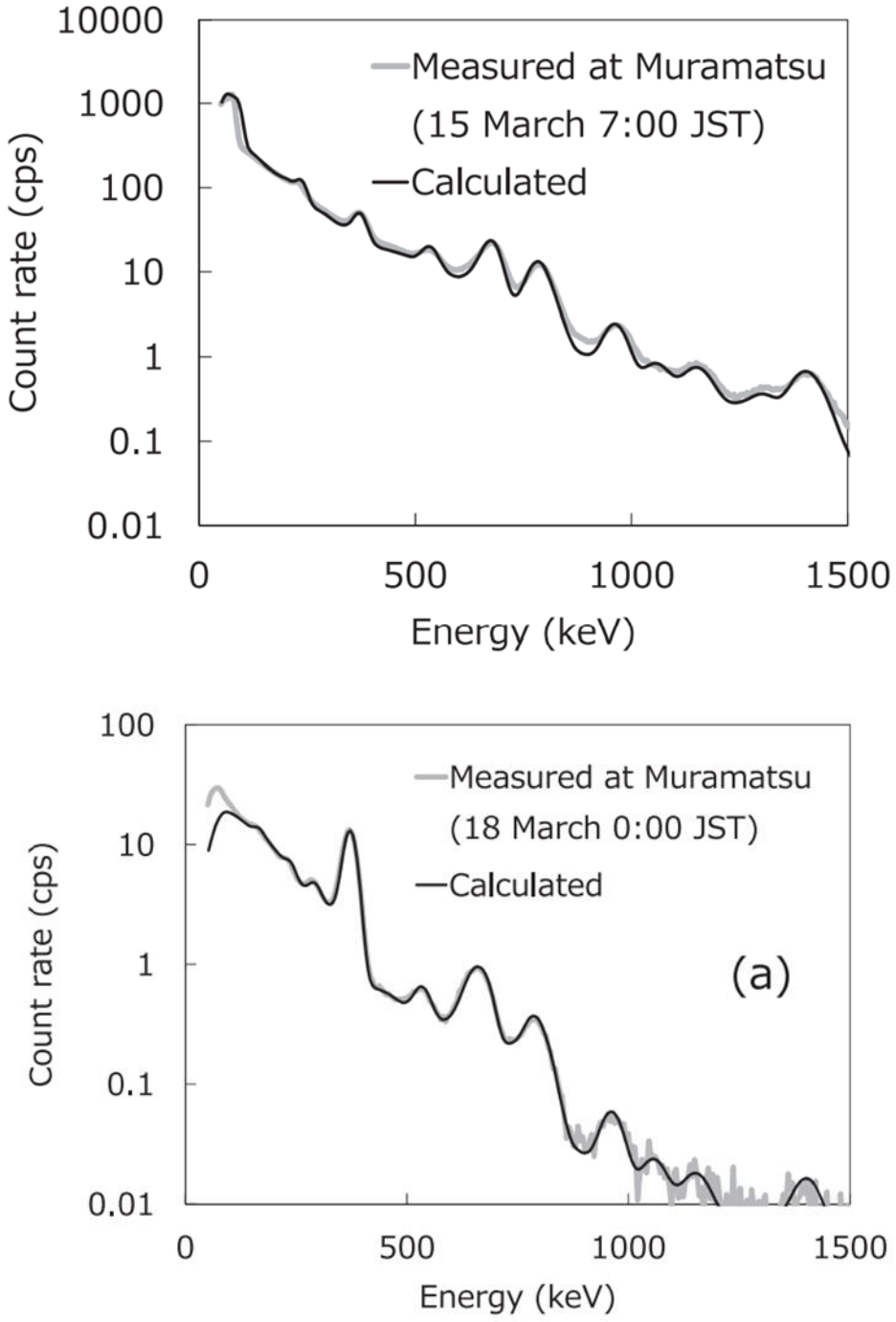


Figure Information C-4. Pulse height spectra reconstructed by simulation [30].

(Top: with passing plume, Bottom: without the effect of plume)

(2) Evaluation of a transportable type germanium semiconductor detector using pulse height spectra

The radioactivity concentration in the air for each radionuclide can be evaluated from the γ -ray pulse height spectrum measured in situ using a transportable type germanium semiconductor detector.

For the measurement method using a transportable type germanium semiconductor detector and the description of each parameter, refer to The Series of Environmental Radioactivity Measuring Methods No. 33, "In-situ measurement method using germanium semiconductor detector".

Assuming that radionuclides are uniformly present in the air, the radioactivity concentration A (Bq/m^3) of the radionuclide in the air is calculated by the following formula.

$$A = N_f / \frac{N_f}{A}$$

A: Radioactivity concentration in the air (Bq/cm^3)
N_f: Peak count rate at a certain energy E in in-situ measurement (s^{-1})
Nf /A: Efficiency in in-situ measurements

$$\frac{N_f}{A} = \frac{N_0}{\phi} \cdot \frac{N_f}{N_0} \cdot \frac{\phi}{A}$$

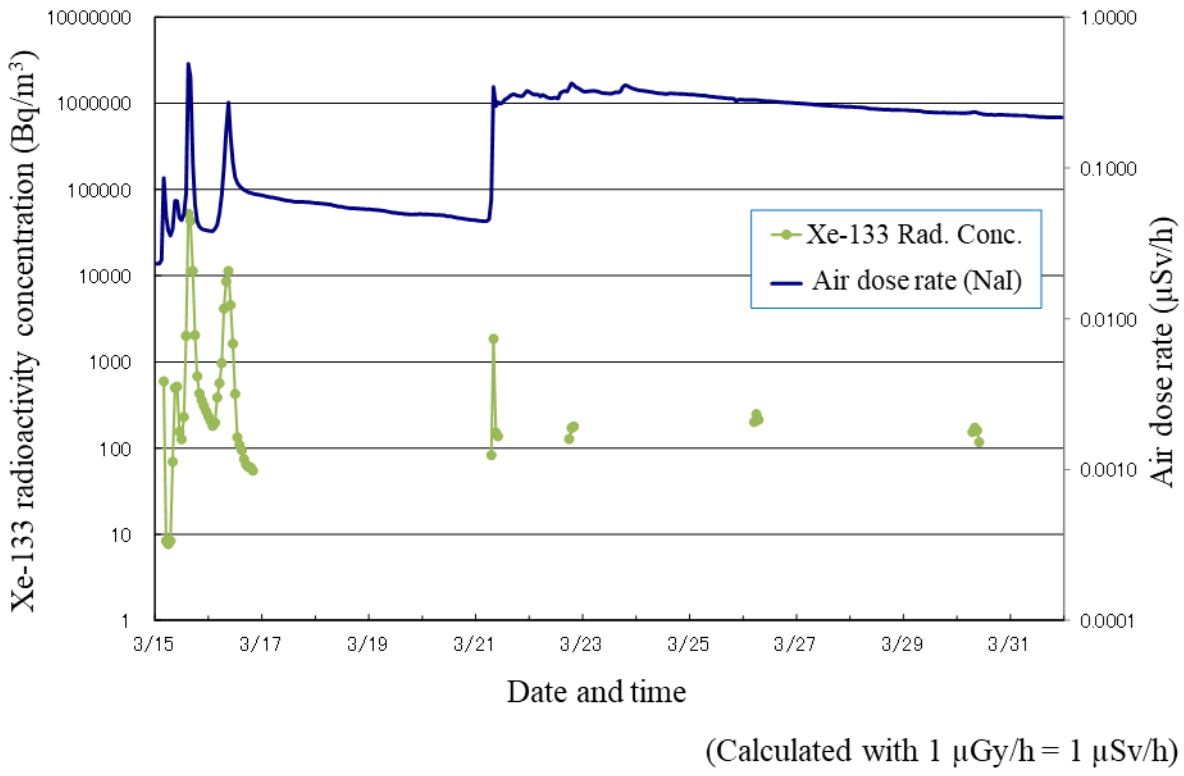
N_0: Peak count rate due to γ rays with energy E incident from the detector axis direction (0°) (s^{-1})
ϕ: fluence rate ($cm^{-2}s^{-1}$)
N_0/ϕ and N_f/N_0 are detector-specific values. ϕ/A uses the parameters in the Table Information C-2 corresponds to the radionuclide and photon energy.

Figure Information C-5 shows an example of evaluating changes over time in Xe-133 radioactivity concentration in the air using this method from the pulse height spectrum of a transportable type germanium semiconductor detector that was continuously measuring outdoors in Chiba City, Chiba Prefecture, during the TEPCO Fukushima Daiichi NPP accident in March 2011.

The air dose rate measured at the monitoring post on 15 March showed the same trend of change as the Xe-133 radioactivity concentration, and it was confirmed that the Xe-133 contained in the radioactive plume contributed largely to the increase in the air dose rate.

The increase in the air dose rate on 21 March was attributed to the deposition of radioactive materials from the air on the ground surface due to rainfall. The Xe-133 radioactivity concentration at that time was not as high as on 15 March.

When evaluating the air radioactivity concentration of radionuclides present in particulate form, it is necessary to subtract the effect of radionuclides deposited on the ground surface. The air dose rate in Figure Information C-5 includes the contribution of radioactive cesium, radioactive iodine, and other radionuclides released during the accident. However, the radioactivity concentration in the air is not shown because it was difficult to evaluate it properly.



* Xe-133 is shown by a 1-hour value. The period with no plot is non-detectable.
* Germanium semiconductor detector: installed approximately 1 m above the ground with a relative efficiency of approximately 25%.

Figure Information C-5. Example of evaluation of Xe-133 radioactivity concentration in the air in Chiba City, Chiba Prefecture (March 2011)

Table Information C-2 Concentration of radionuclides in the air vs. γ-ray fluence rate at 1 m above the ground [32].

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
14.8	Cm-248	0.058	0.2
27.8	Te-129	0.156	2.1
28.6	Xe-125	0.539	7.7
30.6	Xe-133	0.083	1.3
31.0	Xe-133	0.155	2.5
32.0	Ba-137m	0.059	1.0
74.8	Pb-212	0.104	3.0
77.1	Pb-212	0.176	5.0
81.0	Xe-133	0.371	10.6
99.6	Np-239	0.157	4.7
103.8	Np-239	0.251	7.7
106.1	Np-239	0.272	8.3
122.1	Co-57	0.855	27.1
133.0	Hf-181	0.419	13.6
136.5	Co-57	0.106	3.5
140.5	Tc-99m	0.890	29.2
143.8	U-235	0.110	3.6
145.4	Ce-141	0.484	16.1
148.9	Xe-123	0.490	16.4
149.7	Te-131	0.689	23.1
151.2	Kr-85m	0.755	25.3
172.1	Xe-127	0.255	8.9
185.7	U-235	0.572	20.3
188.4	Xe-125	0.549	19.7
202.5	Y-90m	0.958	35.1
202.9	Xe-127	0.683	25.0
205.3	U-235	0.050	1.8
210.5	Te-134	0.223	8.2
228.2	Np-239	0.113	4.3
228.2	Te-132	0.882	33.4
234.7	Nb-95m	0.261	10.0
238.6	Pb-212	0.434	16.7
241.9	Pb-214	0.075	2.9
243.4	Xe-125	0.288	11.2
249.8	Xe-135	0.901	35.2

Cont. (a)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
258.3	Xe-138	0.315	12.4
277.6	Np-239	0.144	5.8
278.0	Te-134	0.209	8.5
295.2	Pb-214	0.192	7.9
304.9	Kr-85m	0.140	5.8
312.1	Te-133	0.624	26.2
340.5	Cs-136	0.422	18.4
344.3	Eu-152	0.266	11.6
345.9	Hf-181	0.120	5.2
351.9	Pb-214	0.369	16.2
364.5	I-131	0.812	36.1
375.0	Xe-127	0.172	7.7
402.6	Kr-87	0.496	22.9
407.6	Te-133	0.271	12.6
414.5	Sb-126m	0.857	40.0
414.8	Sb-126	0.833	38.9
418.0	I-130	0.341	16.0
427.9	Sb-125	0.294	13.9
434.5	Xe-138	0.203	9.7
435.1	Te-134	0.186	8.9
452.3	Te-131	0.182	8.8
459.6	Te-129	0.074	3.6
461.0	Te-134	0.099	4.8
462.8	Cs-138	0.307	15.0
463.4	Sb-125	0.105	5.1
469.4	Ru-105	0.175	8.6
473.0	Sb-127	0.247	12.2
477.6	Be-7	0.103	5.1
479.5	W-187	0.253	12.5
479.5	Y-90m	0.900	44.5
482.0	Hf-181	0.830	41.1
487.0	La-140	0.459	22.8
497.1	Ru-103	0.889	44.6
507.7	Zr-97	0.053	2.7
511.0	Co-58	the 0.301	15.3

Table Information C-2 Cont. (b)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
511.0	Na-22	the 1.810	91.8
511.0	Xe-123	0.450	22.8
511.9	Rh-106	0.207	10.5
514.0	Kr-85	0.004	0.2
526.6	Xe-135m	0.812	41.7
529.9	I-133	0.863	44.4
536.1	I-130	0.990	51.2
537.3	Ba-140	0.244	12.6
544.7	Sb-129	0.179	9.3
550.3	Pm-148	0.220	11.5
550.3	Pm-148m	0.944	49.4
551.5	W-187	0.059	3.1
555.6	Y-91m	0.949	49.8
569.3	Cs-134	0.150	8.0
583.2	Tl-208	0.851	45.6
590.3	Sr-93	0.328	17.6
590.9	Mo-101	0.164	8.8
600.6	Sb-125	0.178	9.6
602.7	Sb-124	0.979	53.2
604.6	Cs-134	0.975	53.0
606.6	Sb-125	0.050	2.7
609.3	Bi-214	0.469	25.6
610.3	Ru-103	0.056	3.1
618.4	W-187	0.073	4.0
621.8	Rh-106	0.098	5.4
630.0	Pm-148m	0.866	49.0
635.9	Sb-125	0.113	6.3
637.0	I-131	0.073	4.1
641.3	La-142	0.474	26.4
642.3	Sb-131	0.220	12.3
647.5	Te-133m	0.194	10.9
652.9	Sr-91	0.080	4.5
657.7	Ag-110m	0.947	53.4
657.9	Nb-97	0.983	55.4
661.6	Ba-137m	0.899	50.8
664.5	Ce-143	0.053	3.0
666.1	Sb-126m	0.857	48.5

Cont. (c)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
666.3	Sb-126	0.997	56.5
667.7	T-132	0.987	56.0
668.5	I-130	0.961	54.5
676.4	Ru-105	0.157	8.9
685.7	Sb-127	0.353	20.2
685.8	W-187	0.316	18.1
694.8	Sb-126m	0.823	47.4
695.0	Sb-126	0.997	57.5
697.0	Sb-126	0.289	16.7
710.4	Sr-93	0.213	12.4
719.7	Te-133	0.089	5.2
720.5	Sb-126	0.538	31.5
723.3	Eu-154	0.197	11.6
724.2	Zr-95	0.444	26.1
724.3	Ru-105	0.473	27.8
725.7	Pm-148m	0.327	19.2
727.2	Bi-212	0.068	4.0
739.5	Mo-99	0.112	7.2
739.5	I-130	0.823	48.7
742.6	Te-134	0.151	9.0
749.8	Sr-91	0.236	14.1
756.7	Zr-95	0.549	32.9
763.9	Ag-110m	0.224	13.5
765.8	Nb-95	1.000	60.2
767.2	Te-134	0.290	17.5
772.6	I-132	0.762	46.0
773.7	Te-131m	0.382	23.1
778.9	Eu-152	0.130	7.9
783.7	Sb-127	0.145	8.8
793.8	Te-131m	0.139	8.5
795.8	Cs-134	0.851	52.1
810.8	Co-58	0.994	61.4
811.8	Eu-156	0.103	6.4
812.8	Sb-129	0.430	26.6
815.8	La-140	0.236	14.6
818.5	Cs-136	0.997	61.8
834.8	Mn-54	1.000	62.6

Table Information C-2 Cont. (d)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
834.8	Kr-88	0.130	8.1
845.4	Kr-87	0.073	4.6
846.8	Mn-56	0.989	62.3
846.8	Co-56	0.999	62.9
847.0	I-134	0.954	60.1
852.2	Te-131m	0.206	13.0
856.7	Sb-126	0.176	11.1
864.0	Te-133m	0.156	9.9
873.2	Eu-154	0.115	7.3
875.7	Sr-93	0.239	15.3
881.6	Br-84	0.420	26.9
884.1	I-134	0.649	41.7
884.7	Ag-110m	0.729	46.8
888.1	Sr-93	0.216	13.9
889.3	Sc-46	1.000	64.4
898.0	Rb-88	0.140	9.1
911.3	Ac-228	0.290	19.0
912.7	Te-133m	0.550	35.8
914.6	Sb-129	0.200	13.1
914.8	Te-133m	0.109	7.1
914.8	Pm-148	0.115	7.5
915.3	Pm-148m	0.171	11.2
933.1	Sb-131	0.246	16.2
937.5	Ag-110m	0.343	22.7
943.4	Sb-131	0.440	29.1
954.5	I-132	0.181	12.1
964.1	Eu-152	0.145	9.7
964.8	Ac-228	0.055	3.7
966.4	Sb-129	0.077	5.2
969.2	Ac-228	0.175	11.7
984.5	Np-238	0.278	18.8
996.3	Eu-154	0.103	7.0
1004.8	Eu-154	0.174	11.9
1009.8	Cs-138	0.298	20.4
1012.5	Mo-101	0.128	8.8
1013.8	Pm-148m	0.202	13.8
1024.3	Sr-91	0.334	23.0

Cont. (e)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
1025.9	Np-238	0.096	6.6
1028.5	Np-238	0.203	14.0
1030.1	Sb-129	0.126	8.7
1031.9	Rb-89	0.580	40.0
1038.8	I-135	0.080	5.5
1048.1	Cs-136	0.798	55.5
1072.6	I-134	0.150	10.5
1085.9	Eu-152	0.099	7.0
1099.2	Fe-59	0.565	40.2
1112.1	Eu-152	0.136	9.7
1115.5	Ni-65	0.148	10.6
1115.5	Zn-56	0.507	36.3
1120.3	Bi-214	0.155	11.1
1120.5	Sc-46	1.000	71.8
1121.3	Ta-182	0.349	25.1
1123.6	Sb-131	0.083	6.0
1125.5	Te-131m	0.114	8.2
1131.5	I-135	0.228	16.4
1153.5	Eu-156	0.071	5.2
1157.5	I-130	0.113	8.2
1173.2	Co-60	0.999	73.4
1189.0	Ta-182	0.164	12.1
1206.6	Te-131m	0.098	7.3
1221.4	Ta-182	0.273	20.5
1230.7	Eu-156	0.089	6.7
1231.0	Ta-182	0.116	8.7
1235.4	Cs-136	0.200	15.1
1238.3	Co-56	0.670	50.5
1242.4	Eu-156	0.067	5.1
1248.1	Rb-89	0.423	32.0
1260.4	I-135	0.289	22.0
1274.4	Eu-154	0.355	27.1
1274.5	Na-22	0.999	76.4
1291.6	Fe-59	0.432	33.3
1332.5	Co-60	1.000	78.2
1333.2	Te-133	0.107	8.4
1368.6	Na-24	1.000	79.3

Table Information C-2 Cont. (f)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
1383.9	Sr-92	0.900	71.8
1384.3	Ag-110m	0.243	19.4
1408.0	Eu-152	0.209	16.8
1435.9	Cs-138	0.763	62.0
1457.6	I-135	0.087	7.1
1460.8	K-40	0.107	8.8
1465.1	Pm-148	0.222	18.2
1481.8	Ni-65	0.235	19.4
1505.0	Ag-110m	0.131	10.9
1529.8	Kr-88	0.109	9.1
1532.5	Mo-101	0.060	5.0
1596.2	La-140	0.954	81.7
1678.0	I-135	0.096	8.4
1691.0	Sb-124	0.488	43.1
1736.5	Sb-129	0.060	5.4
1764.5	Bi-214	0.162	14.6
1768.3	Xe-138	0.167	15.1
1771.4	Co-56	0.155	14.0
1791.2	I-135	0.078	7.1
1810.7	Mn-56	0.272	24.8
1836.0	Rb-88	0.214	19.7
1897.6	Br-84	0.147	13.8
1901.3	La-142	0.072	6.7
2004.8	Xe-138	0.054	5.2
2015.8	Xe-138	0.123	11.9
2032.1	Mo-101	0.069	6.7
2091.0	Sb-124	0.056	5.5
2113.0	Mn-56	0.143	14.2
2195.8	Kr-88	0.132	13.4
2195.9	Rb-89	0.133	13.5
2204.1	Bi-214	0.052	5.3
2218.0	Cs-138	0.152	15.5
2392.1	Kr-88	0.346	36.6
2397.8	La-142	0.133	14.1
2484.1	Br-84	0.067	7.2
2542.7	La-142	0.100	10.9
2554.8	Kr-87	0.092	10.1

Cont. (g)

Energy [keV]	Nuclide	Release ratio [s^{-1} Bq^{-1}]	ϕ/A_v [m s^{-1} Bq^{-1}]
2570.2	Rb-89	0.099	10.9
2598.6	Co-56	0.167	18.5
2614.5	Tl-208	0.999	110.7
2639.6	Cs-138	0.076	8.5
2754.0	Na-24	0.999	113.5
3253.5	Co-56	0.074	9.2
3927.5	Br-84	0.068	9.3

(3) Evaluation using pulse height spectra of a dust monitor

Using a germanium semiconductor detector as the detector for the dust monitor enables quantifying radionuclides and evaluating the concentration of radionuclides in the air due to the excellent energy resolution of the germanium semiconductor detector.

Dust monitors are used for early detection of radioactive releases from nuclear facilities, and the NaI (Tl) scintillation detector is superior in terms of sensitivity for this purpose.

It should also be noted that a germanium semiconductor detector is expensive and requires cooling, which places a heavy administrative burden on the detector when it is used as a continuous monitor.

For the quantitative measurement method of radionuclides using a germanium semiconductor detector, refer to The Series of Environmental Radioactivity Measuring Methods No. 7 " γ-ray spectrometry using germanium semiconductor detector".

Figure Information C-6. Example of dust monitor using a germanium semiconductor detector

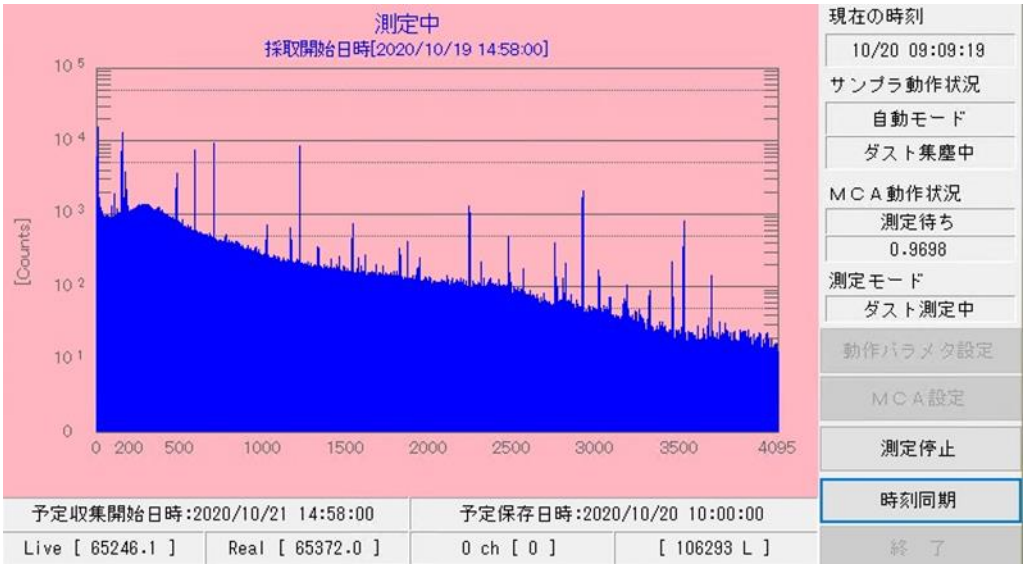


Figure Information C-7 Example of a pulse height spectrum of a germanium semiconductor detector [33].

Appendix

Appendix A Definition of Terms

Definitions of terms used in this measurement method are given below.

Term	Description
Dust monitor	An instrument for continuous measurement of radioactivity concentration in airborne dust and for use at normal times. Although “dust monitor” is a generic instrument name, this measurement method defines a dust monitor as an instrument used at normal times in principle. In case of emergency, a dust monitor is operated additionally in emergency mode to strengthen the monitoring system. In this measurement method, the use of a dust monitor as a dust sampler is included in the scope.
Air monitor	An instrument for continuous measurement of radioactivity concentration in airborne dust and use in an emergency. The measurement principle is the same as that of a dust monitor. However, an air monitor is an additional instrument for emergency use. It is designed to quickly measure the concentration of radioactive materials in the air at short time intervals.
Dust sampler	An instrument for collecting airborne dust on filter paper.
Iodine sampler	An instrument for collecting radioactive iodine (particulate and gaseous) in the air on filter paper and an activated carbon cartridge.
Gas monitor	Instrument for continuous measurement of gaseous radioactive material concentration in the air.
Air absorbent	Material for collecting air samples. This measurement method means filter paper and an activated carbon cartridge.
PAZ	**Precautionary Action Zone** The area where preventive, protective measures are prepared. · The area where preventive, protective measures are prepared from the stage before the release of radioactive materials, such as immediate evacuation according to the EAL, in order to avoid or minimize a serious deterministic effect due to radiation exposure. · The specific routine range of a PAZ for a nuclear power reactor facility is "within approximately 5 km radius from the nuclear facility".
UPZ	**Urgent Protective action planning Zone** Area where an emergency protective measure is prepared. · Area where an emergency protective measure is prepared in accordance with EAL and OIL to reduce the risk of stochastic effect. · The specific routine range of the UPZ for a nuclear power reactor facility is "within approximately 30 km radius from the nuclear facility".
Normal time monitoring	Environmental radiation monitoring that should be conducted after the start of the operation of the nuclear facility (excluding emergencies).
Term	Description
Emergency monitoring preparation	Environmental radiation monitoring that should be conducted in an alert state based on the Nuclear Emergency Response Guidelines.
Emergency monitoring	Environmental radiation monitoring should be conducted during facility site emergency and total emergency based on the Nuclear Emergency Response Guidelines.

Information collection situation	Stage to confirm whether or not radioactive materials have been released, etc.
Classification of emergencies	Classified into "alert state", "facility site emergency", and "total emergency" based on the Nuclear Emergency Response Guidelines.
Alert state	The stage where the occurrence or threat of an abnormal event at a nuclear facility requires the start of information collection, preparation for emergency monitoring, or preparation for protective measures such as the evacuation of those who need to be evacuated in a facility site emergency.
Facility site emergency	The stage in which an event potentially causing radiological consequences to the public has occurred at a nuclear facility, and it is necessary to start preparing for major protective measures, such as evacuation, in the vicinity of the nuclear facility in case of emergency.
Total emergency	The stage in which an event has occurred at a nuclear facility with a high probability of causing radiological consequences to the public and prompt protective actions need to be taken to avoid (minimize) severe deterministic effects and to reduce the risk of stochastic effects.
Airborne dust	Airborne particulate matter.
Air	Gase covering the earth's surface. In this measurement method, in some cases, the air is treated as gaseous matter and is distinguished from particulate matter (airborne dust).
Air moisture	Moisture existing in the air.
Radioactive plume	A group of air containing radioactive gaseous or particulate matter.
External exposure	Receiving radiation from a radiation source outside the body.
Internal exposure	Ingesting radioactive materials into the body by inhalation, oral intake, etc., and receiving radiation from radiation sources in the body.
Lower limit of detection	The minimum value at which the measurement target can be detected when the measurement sample and the measurement conditions (measuring instrument, measurement time, etc.) are determined.
Maximum detection sensitivity	Detection sensitivity is required for a dust monitor to measure radioactivity concentration as specified in JIS Z 4316:2006
Decision threshold	The threshold value of dust monitor measurement where the difference from the background is significant, as specified in JIS Z 4316:2013
Confirmation start setpoint	The value that triggers the initiation of the causal investigation to determine if there is a contribution from a nuclear facility. Confirmation start setpoint is set considering the variation of an individual equipment and past maximum values, with the maximum dust monitor measurement value after facility contribution discrimination set at approximately 5 Bq/m^3 (gross β radioactivity concentration or γ-ray emitting nuclide concentration) or 1 Bq/m^3 (gross α radioactivity concentration).
Term	Description
Normal fluctuation range	The range of fluctuation of measured values that is generally considered to fall within a certain range at the time of normal operation of a nuclear facility and when measurement conditions, etc., are properly controlled.
Counting	One response (count) of the counting instrument.
Count rate	Count value per unit time. Usually indicated in cpm (m^{-1}) or cps (s^{-1}).

Count rate meter	An instrument that continuously indicates the average count rate. Also called the rate meter.
Scaler	A part of a counting instrument that integrates and displays the number of input pulses.
Gross α radioactivity concentration	Radioactivity concentration (Bq/m^3) of α-ray from α-emitting nuclides contained in airborne dust that is measured without energy discrimination (except when spectrum analysis is performed) and evaluated by one type of α standard source used in the efficiency calibration of the dust monitor.
Gross β radioactivity concentration	Radioactivity concentration (Bq/m^3) of β-ray from β-emitting nuclides contained in airborne dust that is measured without energy discrimination (except when spectrum analysis is performed) and evaluated by one type of β-ray standard source used in the efficiency calibration of the dust monitor.
γ-ray count rate	Count rate of γ-ray emitted from airborne dust (s^{-1})
β/α ratio	The ratio of gross β radioactivity concentration measured by a dust monitor divided by gross α radioactivity concentration
Counting loss	When counting radioactive particles or pulses, decrease in the measured count value due to detector dead time, decomposition time, pile-up, etc., or the amount of decrease.
Facility contribution	Effects of radioactive materials released from a nuclear facility
Station building	A facility that concentrates radiation measuring equipment to measure outdoor air dose rate, concentration of radioactive materials in the air, etc., around a nuclear facility or radiation facility.

Reference

1. Nuclear Regulatory Authority (Partially amended on July 21, 2021), Nuclear Emergency Response Guidelines
2. Radiation Monitoring Division, Radiation Protection Department, Nuclear Regulation Authority (Revised December 21, 2021), Monitoring in Normal Times (Supplementary Reference Materials for the Nuclear Emergency Response Guidelines)
3. Radiation Monitoring Division, Radiation Protection Department, Nuclear Regulation Authority (Partially revised on December 21, 2021), Emergency Monitoring (Supplementary Reference Materials for the Nuclear Emergency Response Guidelines)
4. JIS Z 4316, (2013) Radioactive dust monitors
5. JIS Z 4316, (2006) Radioactive dust monitors
6. JIS Z 8814, (2012) Low-volume air sampler
7. JIS Z 4601, (2009) Radioactive dust sampler
8. JIS K 0901, (1991) Shape, size, and performance test methods for filter materials for collecting dust samples in gas
9. JIS Z 4336, (2010) Radioactive iodine sampler
10. JIS Z 4317, (2008) Radioactive noble gas monitor
11. JIS Z 4329, (2004) Radioactive surface contamination survey meter
12. 木谷進 他, , (1968) JAERI-memo 3221.
13. D. A. COLLINS, L. R. TAYLOR and R. TAYLOR, (1967) The developments of impregnated charcoals for trapping methyl iodide at high humidity, TRG Report, 1300 (W)
14. K. Nagaoka et al., (2012) Changes of radionuclides in the environment in Chiba, Japan after the Fukushima nuclear power plant accident, Health Physics Volume 102, Issue 4, P437-442
15. 新潟県, （2011）平成 23 年度柏崎刈羽原子力発電所周辺環境放射線監視調査結果速報　第 1 四半期（4 月～6 月）
16. IAEA-TECDOC-1162, (2000) Generic procedures for assessment and response during a radiological emergency
17. Ohyo Koken Kogyo Co., Ltd., technical data, not disclosed
18. Y. Togawa et al., (2019) Calculation method of estimated artificial radioactivity concentration using α β coincidence counting function in dust monitors, 52nd Annual Meeting of the Health Physics Society of Japan
19. Chiyoda Technol Corporation/Mirion Technologies, Inc. (Canberra) technical data, not disclosed
20. 島田秀志, （2009）基準化計数による大気浮遊じん放射能のリアルタイム監視について, 福井県原子力環境監視センター所報：16, P43～58
21. 島田秀志 他, （2004）ダストモニタの捕集効率に関する調査, 福井県原子力環境監視センター所報：11, P51～61
22. Mitsubishi Electric Corp. technical data, not disclosed
23. T. Okura et al., (2021) Investigation of monitoring method of radioactivity concentration in the air using continuous dust monitor (gross β) during nuclear emergency with air release, The 54th Research Presentation Meeting of the Health Physics Society of Japan
24. Fukushima Prefecture, TEPCO Company Holdings, Incorporated, (2011) Report on the results of environmental radioactivity measurements around the nuclear power plant
25. Nuclear Regulation Authority, Measurements of airborne dust by the Nuclear Regulation Authority and Fukushima Prefecture (Houkida, Fukushima City), https://radioactivity.nsr.go.jp/ja/list/222/list-1.html

26. T. Ohkura et al., (2012) Emergency Monitoring of Environmental Radiation and Atmospheric Radionuclides at Nuclear Science Research Institute, JAEA Following the Accident of Fukushima Daiichi NPP, JAEA-Data/Code 2012-010
27. T. Abe et al., (2021) Temporal Change in Atmospheric Radiocesium during the First Seven Years after the Fukushima Dai-ich Nuclear Power Plant Accident, Aerosol and Air Quality Research
28. 小泉彰　他, （1989）集じん用フィルタの粒子捕集効率の面風速依存性, 保健物理　2 巻, P123
29. N. Kinouchi et al., (2001) Selection of Filter Media Used for Monitoring Airborne Alpha-Emitting Particles in a Radiological Emergency, RADIOISOTOPES, 50, 403
30. Y. Terasaka et al., (2016) Air concentration estimation of radionuclides discharged from Fukushima Daiichi NPP using NaI(Tl) detector pulse height distribution measured in Ibaraki Prefecture, Journal of Nuclear Science and Technology, Vol.53, No.12, 1919-1932
31. J. Moriizumi et al., (2020) Spatial distributions of atmospheric concentrations of radionuclides on 15 March 2011 discharged by the Fukushima Dai-Ichi Nuclear Power Plant Accident estimated from NaI(Tl) pulse height distributions measured in Ibaraki Prefecture, Journal of Nuclear Science and Technology, Vol. 57, No. 5, 495-513
32. ICRU Report 53 (1994) Gamma-Ray Spectrometry in the Environment
33. Shimane Prefecture, Dust monitor (germanium semiconductor detector) measurement data, not disclosed