Radioactive Contamination Monitors

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1. Introduction

In order to prevent the spread of radioactive contamination to areas outside a controlled area at a nuclear power plant, surface contamination inspection monitors are installed at the perimeter of the control area, and all articles moved from inside the control area to outside are monitored for surface contamination. The main types of surface contamination monitors include body surface contamination monitors that measure the surface contamination on a worker's body, article surface contamination monitors that measure the surface contamination of articles ranging in size from large objects such as a scaffolding boards to small objects such as portable tools carried by workers, and laundry monitors that measure the surface contamination of clothes worn by workers inside the controlled area.

Other types of radioactive contamination monitors include a whole body counter that measures the internal exposure (internal contamination) levels of workers who work inside controlled areas, and a hand-foot-clothes monitor which is used mainly in hospitals and measures the surface contamination on hands, feet and clothes.

Fuji Electric uses large-area radiation detectors, signal processing units capable of high-speed arithmetic processing, mechanical units that establish the optimal conditions for measurement, and human-machine interfaces that use audible guidance and/or a large-screen color liquid crystal displays (LCDs) to make the high-sensitivity high-speed measurement of radioactive matter commercially practical, and has supplied these monitors to nuclear power plants throughout Japan. Additionally, these monitors are provided with a self-diagnosis function, which when connected to a data processing device apparatus, enables the central control of contamination inspection and measurement data.

This paper presents brief overviews and descriptions of the features of these monitors.

2. Body Surface Contamination Monitor

2.1 Overview

The body surface contamination monitor is installed at the exit of a controlled area and tests for the presence of contamination on the body surface of people exiting that controlled area. This apparatus is provided with detectors positioned to sense the entire surface of a person's body, and it capable of highly efficient contamination measurement within a short time. The height of the overhead detector adjusts automatically so that the head region can be measured with good sensitivity. This adjustable height function enables inspections for people of all heights, from short elementary school age children to tall adults, or more specifically from heights of 1,300 to 2,000 mm.

If the inspection finds no contamination, the worker is urged to go to the exit (non-controlled area), however if contamination is detected, the worker is prevented from exiting the controlled area. Figure 1 shows the appearance of this apparatus.

2.2 Characteristics

(1) Detection sensitivity

Beta-rays can be measured at a sensitivity of 0.4 Bq/cm^2. Conditions are listed in Table 1.

(2) Detector unit

A large-area plastic scintillation beta-ray detector is used.

(3) Optimum measurement time operating function

Measurement is usually performed within a fixed period of time (settable according to the type of operation), however, in order to minimize processing time according to the type of monitor, this function computes the optimal measurement time that satisfies the detection sensitivity, based upon the background (BG) count rate, and sets these parameters automatically to enable measurement within the shortest amount of time possible.

(4) Visitor function

The number of visitors has been increasing recently and this function allows the operation to be explained during measurement while the door is open.

(5) Miniaturization of the apparatus

Fig.1 Body surface contamination monitor

Table 1 Specifications of the body surface contamination monitor

Item	Specification
Detector	Plastic scintillation detector
Number of detectors	15 to 18 detectors
Detector sensitivity Conditions : BG Measurement time Radiation source Distance	0.4 Bq/cm^2 0.1 μSv/h 10 s U_3O_8 100×100 (mm) Hands & feet : close contact Head : 50 mm Other : 100 mm
Processing capacity	Approx. 20 s
External dimensions	860 (W)×1,000 (D)×2,250 (H) (mm)
Inner dimensions of measurement room	500 (W)×700 (D)×2,000 (H) (mm)
Mass	780 kg

Two models are available, one with dimensions of 860 (W) × 1,200 (D) mm, and another model, developed for the purpose of increasing the number of machines within a limited space, and having dimensions of 800 (W) × 1,200 (D) mm. The inner dimensional width of the measurement room ranges from 400 to 500 mm for the former, and 400 to 440 mm for the latter.

(6) Easier maintainability

Maintenance can be performed in an open space in a non-controlled area.

(7) Guidance function

Operational guidance for measuring is provided to workers via an LCD and audible instructions. A model having a function to switch the screen display and spoken instructions to the English language is available to support use by non-Japanese speaking users.

(8) Connection to the data processing apparatus

The interface to the data processing apparatus is selectable as a LAN or as serial transmission. The data processing apparatus enables real-time monitoring of the operation status, display of measurement results, creation of forms and trend graphs, and the

Fig.2 Large article transfer monitor

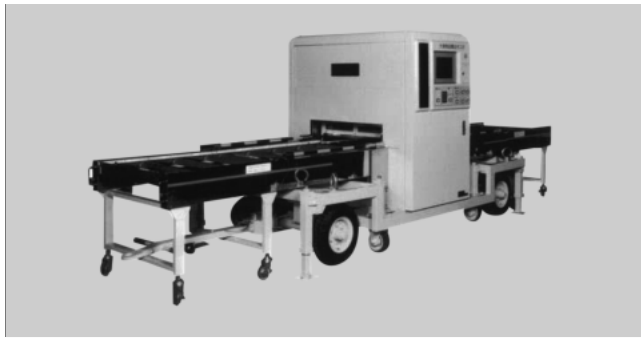

Fig.3 Small article transfer monitor

Fig.4 Transportable small article monitor (type 1)

Fig.5 Transportable small article monitor (type 2)

long-term storage of measurement data.

(9) Improved design

Because the structure was designed to feel spacious and open, the subject being measured will not endure a sense of oppression.

3. Article Surface Contamination Monitor

3.1 Overview

The article surface contamination monitor tests whether there is any contamination on the outer or inner surface of an article carried out from the controlled area. Variations of this monitor include a large object transfer monitor, a small article transfer monitor, and a personal handyphone system (PHS) transfer monitor. The appearance of each of these models is shown in Figs. 2 to 6.

3.2 Common features

(1) Detector sensitivity

Beta-rays can be measured at a sensitivity of 0.4 Bq/cm^2 and gamma-rays can be measured at a sensitivity of 1.1 Bq/cm^2. Conditions are listed in Table 2.

(2) Use of a beta + gamma-ray detector

The monitor is fitted with a detector that integrates both a beta-ray and gamma-ray scintillator, and is able to measure the inner surface contamination (gamma-ray) of a pipe or the like.

(3) Moveable overhead detector

The overhead detector is lowered according to the profile of the article, and then measurement is performed. This enables the article to be measured at a close range and achieves highly efficient measurement regardless of the profile of the article.

(4) Safety measures

The moving parts of the apparatus, the conveyor and door, are provided with a bar switch or photoelectric sensor that halts their operation when touched in order to prevent accidental entangling of the operator's fingers or arms.

3.3 Large article transfer monitor

The large article transfer monitor is installed at the exit for carrying out large objects, and is used to measure efficiently the contamination of large and flat objects such as scaffolding boards and pipes that are removed in large quantities from the controlled area

Table 2 Monitor specifications

Item \ Monitor name	Large article transfer monitor	Small article transfer monitor	Transportable small article monitor (type 1)	Transportable small article monitor (type 2)	PHS transfer monitor
Detector	Plastic scintillation detector	Plastic scintillation detector	Plastic scintillation detector	Plastic scintillation detector	Plastic scintillation detector
Detector positioning	Top & bottom of object to be measured	Top & bottom, left & right,front & back of object to be measured	Top & bottom of object to be measured	Top & bottom of object to be measured	Top & bottom of object to be measured
Detector sensitivity (beta-ray) Conditions : BG Moving speed or measurement time Radiation source Distance	0.4 Bq/cm^2 0.1 μSv/h 20 mm/s U_3O_8 100×100 (mm) 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s U_3O_8 100×100 (mm) 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s U_3O_8 100×100 (mm) 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s U_3O_8 100×100 (mm) 30 mm	0.4 Bq/cm^2 0.1 μSv/h 10 s U_3O_8 100×100 (mm) 30 mm
Detector sensitivity (gamma-ray) Conditions : BG Moving speed or measurement time Radiation source Distance	1.1 Bq/cm^2 0.1 μSv/h 20 mm/s ^{60}Co 100×100 (mm) 30 mm	1.1 Bq/cm^2 0.1 μSv/h 10 s ^{60}Co 100×100 (mm) 30 mm	———	———	———
Size of object to be measured	W1,500 mm D 4,000 mm H 300 mm	W 500 mm D 500 mm H 300 mm	W 420 mm D 300 mm H 270 mm	W 310 mm D 220 mm H 120 mm	W 160 mm D 60 mm H 30 mm
Mass of object to be measured	200 kg	20 kg	5 kg	5 kg	Lightweight object such as a PHS phone
Examples of objects to be measured	○ Steel scaffolding ○ Scaffolding material ○ Scaffolding board ○ Pipe	○ Documents ○ Tools ○ Writing instruments ○ Small measuring instruments	○ Helmets ○ Tools ○ Writing instruments ○ Documents	○ Documents ○ Tools ○ Writing instruments	○ PHS
Size	W4,550 mm D 2,110 mm H 1,950 mm	W1,000 mm D 1,900 mm H 1,600 mm	W 560 mm D 550 mm H 750 mm	W 400 mm D 315 mm H 470 mm	W 260 mm D 350 mm H 270 mm
Mass	4,000 kg	1,800 kg	60 kg	18 kg	15 kg

Fig.6 PHS transfer monitor

during regularly scheduled inspections.

(1) Processing capacity

The detector unit has a width of 1,500 mm, enabling scaffolding boards, pipes and the like to be measured in bulk. For example, it is possible to measure more than 150 pipes (having a length of 4 m) within one hour.

(2) Measurement method

Long articles such as scaffolding boards and pipes can be placed directly on the conveyor and measured. However, small articles such as clamps and bolts are placed in a measuring dish and then measured.

(3) Creation of transfer forms

By registering the article and its quantity prior to measurement, the monitor's internal printer is able to printout a transfer form.

(4) Conveyor speed

Conveyor speed can automatically be set in the range of 10 to 100 mm/s, in increments of 10 mm/s. The automatic setting function calculates the optimal conveyor speed according to the BG level at the installation site and then sets the speed automatically.

(5) Moving the apparatus

The apparatus is fitted with a moveable dolly (with tires), and in the case of a battery-powered self-propelled dolly, the apparatus can be moved with just one person.

(6) Lateral movement

For locations having insufficient space for turning the apparatus, sideways-oriented wheels are provided in order to allow lateral movement so that the apparatus may be moved to any arbitrary position.

3.4 Small article transfer monitor

The small article transfer monitor is installed near the access control room, and is used to measure efficiently the contamination of small articles such as writing instruments and tools that were hand-carried by workers into the controlled area.

(1) Detector positioning

Two monitor models are manufactured to correspond to the shape of the article to be measured for contamination. One model is provided with detectors located at the top and bottom, front and back, and left and right positions, entirely surrounding the article to measured. The other model is provided with detectors positioned at the top and bottom (2 surfaces) of the article to be measured.

(2) Storage of measured articles

After being measured, the articles are transferred to a conveyor on the non-controlled area side, where a stocker that stores the measured articles may be attached. The number of articles storable by the stocker is selectable according to the operation as 8 tiers of 100-mm-tall articles, 4 tiers of 300-mm-tall articles, and so on.

3.5 Transportable small article monitor (type 1)

The transportable small article monitor developed for and delivered to customers in China is limited to the measurement of helmets, documents and tools, and weighs only approximately 60 kg since it is provided without a drive mechanism. With its small footprint, this monitor is also suitable for temporary use when large quantities of articles are being transported out of the controlled area.

The upper detector can be manually positioned at any of the 4 stages of 40, 120, 200 and 280 mm above the article loading surface.

3.6 Transportable small article monitor (type 2)

This monitor weighs only approximately 18 kg, which is even lighter in weight than the abovementioned transportable small article monitor, and can be moved easily by one worker wearing the shoulder belt accessory. Also, an optional battery unit can be used to power the monitor at locations where power could not otherwise be supplied.

3.7 PHS transfer monitor

This monitor is specialized for the measurement of small articles such as PHS phones. With compact external dimensions of 260 × 350 × 270 (mm), this monitor can be installed in the vacant space above a counter.

4. Laundry Monitor

4.1 Overview

The laundry monitor is used to detect efficiently the surface contamination of clothing worn inside the controlled area, before or after washing. The objects to be measured are clothing such as overalls and undergarments, small articles such as hats, gloves and socks, and molded articles such as helmets and shoes.

A front monitor inspects unwashed clothes and the like, and screens out highly contaminated articles not suitable for washing. The small article front monitor is an example of this type of monitor. A rear monitor inspects washed clothes and the like for residual contamination, and the clothes monitor is one example of this type of monitor. A folding machine and a

sorting machine automatically separate contaminated articles from normal articles. While separating the articles, the folding machine automatically folds the normal uncontaminated clothing. By connecting these machines to contamination monitors, labor savings and higher throughput can be realized. This paper will introduce the front monitor, small article front monitor and clothes monitor.

4.2 Features

(1) Monitors for clothing, small articles and molded articles, and the front monitor, are completely compatible with the inspection goal and with the article to be measured.
(2) The clothes monitor and small article front monitor have detection sensitivities capable of detecting 1/10 the legally prescribed reference value for articles removed from controlled areas.
(3) The high-capacity clothes monitor is capable of processing about 250 pairs of overalls within one hour.
(4) The conveyor unit of the clothes monitor recently has been using a resinous round belt having low cost, low noise and long life, instead of the conventional wire net conveyor.
(5) A static eliminator is provided to protect workers from static electric shocks.
(6) The measurement system has an extensive self-diagnosis function that enables easy confirmation of the well-being of the system.

4.3 Function

(1) Clothes monitor

This monitor measures clothes and small articles after they have been washed. When used in combination with the folding machine, this monitor handles clothes exclusively. The article to be measured is placed into the monitor, picked up by a vertical conveyor and moved between upper and lower detectors, to inspect it for contamination. The large-area beta-ray detector that is provided has no dead zones over the entire width of the conveyor, and this monitor achieves smaller size and lighter weight than previous models. If a folding machine is connected, normal articles and contaminated articles are separated automatically and the normal articles are folded. The external appearance of the clothes monitor is shown in Fig. 7 and its specifications listed in Table 3.

(2) Small article front monitor

This monitor measures small articles exclusively, before they have been washed. The measurement method is the same as that of the clothes monitor. A sorting machine provided at the rear of this unit separates normal articles from contaminated articles. However, due to a different method of operation, this monitor also supports the return of contaminated articles to the insertion site. Moreover, the belt used is highly durable and compatible with wet articles. The external appearance of the small article front monitor is shown in Fig. 8 and its specifications listed in Table 4.

(3) Front monitor

This monitor inspects the contamination of unwashed clothes and the like that have been placed in a stainless steel wire-mesh bucket (well area). When placed into the bucket, measurement starts automatically and the result is displayed after a fixed-time measurement has been performed. An alarm is issued if the articles are judged to be contaminated. To simplify decontamination, the bucket has been designed to be easily detachable. The entire monitor is smaller and requires less installation space than prior models. The external appearance of the front monitor is shown in Fig. 9 and its specifications listed in Table 5.

Fig.7 Clothing monitor, folding machine

Table 3 Specifications of the clothing monitor

Item	Description
Radiation detected	Beta-rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (radiation source : ^{60}Co) 0.37 Bq/cm^2 or less (radiation source : U_3O_8)
Processing capability	Approx. 250 (or more) articles of clothes per hour
Size	Approx. 1,350 (H)×1,000 (W)×2,500 (D) (mm), not including projections
Mass	Approx. 3,000 kg

5. Whole Body Counter

5.1 Overview

In order to determine whether radiation workers who work inside a controlled area have internal radioactive contamination and to ascertain the internal radioactive mass necessary for qualitative and quantitative analyses and for computation of the committed effective dose equivalent (internal exposure

Fig.8 Small article front monitor

Table 4 Specifications of the small article front monitor

Item	Description
Radiation detected	Gamma-rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (moving speed : 100 mm/s, radiation source: ^{60}Co)
Processing capability	Approx. 250 (or more) undergarments per hour
Size	Approx. 1,420 (H)×950 (W)×2,500 (D) (mm)
Mass	Approx. 1,600 kg

Fig.9 Front monitor

Table 5 Specifications of the front monitor

Item	Description
Radiation detected	Gamma-rays
Detector	NaI (Tl) scintillation detector
Detection sensitivity	37 Bq/cm^2 or less (radiation source: ^{60}Co)
Processing capability	300 or more kg/h (evaluated at 5 kg per collection bag, and process time of 60 s/cycle)
Size	Approx. 1,000 (H)×800 (W)×950 (D) (mm), not including projections
Mass	Approx. 2,500 kg

Table 6 Basic specifications of the whole body counter for screening measurement

Detector	Plastic scintillation detector or NaI scintillation detector
Shielding method	Shadow shield method (bed type)
Measurement time	30 s to 20 min
Energy range	0.1 to 2.0 MeV
BG value	Approx. 2,500 to 4,000 m^{-1} (30-minute measurement)
Detector sensitivity	Approx. 150 to 250 Bq (^{137}Cs) Approx. 50 to 100 Bq (^{60}Co)

Table 7 Basic specifications of the whole body counter for precise measurement

Detector	High-purity germanium detector or NaI scintillation detector
Shielding method	Shadow shield method (bed type)
Measurement time	Approx. 10 min
BG value	Approx. 2,500 to 4,000 m^{-1} (0.1 to 2.0 MeV: 30-minute measurement)
Detector sensitivity	Approx. 150 to 250 Bq (^{137}Cs) Approx. 60 to 90 Bq (^{60}Co)

dose equivalent), a whole body counter (WBC) externally measures gamma-rays emitted from radioactive matter within the human body.

5.2 Features

(1) Measurement system that suits the objective

The measurement to determine the presence of contamination in the body is known as screening, and the measurement implemented after internal contamination has been detected is known as precise measurement. Accordingly, Fuji Electric manufacturers both a WBC for screening use and a WBC for precise measurement use.

Specifications of bed-types of the WBC for screening use and the WBC for precise measurement are listed in Tables 6 and 7, respectively.

(2) Types

WBCs are categorized as either bed-type or chair-type, according to the position of the subject being measured. With the bed-type WBC, the subject lies on a bed and measurement is implemented by moving the bed inside a shield. With the chair-type WBC, the subject sits on a chair inside an open-type shield and is measured. Additionally, in some cases a sealed-type shield that encloses the entire room with 200-mm-thick steel plates is used. At the entrance/exit, either a door or a maze configuration is employed. WBCs are characterized by low BG and the capability for precise measurement.

The external appearance of these WBCs are shown in Figs. 10 and 11.

(3) Concern for the subject being measured

The subject must be tested while inside a shielded

Fig.10 Bed-type whole body counter

Fig.11 Chair-type whole body counter

body, but guidance for the measurement is provided via audible and displayed instructions so that the subject does not become confused. Additionally, the shield is designed to be soft and to have smooth contours so that it appears less intimidating.

Also, in some cases the showing of a movie during measurement lessens the stress endured by the subject. Fuji Electric is continuing to improve comfort during testing.

(4) Easing the burden on the operator

Processing, from the provision of measurement guidance until implementation of the measurement, can be automated and when measurement is complete, the measurement data can be transmitted to an upper level computer. This data is used in the WBC inspection performed when entering a controlled area.

The measurement results can also be stored in a data processing apparatus and verified on the display screen of that apparatus. The data processing apparatus runs on a Windows*[1] operating system to improve visibility and simplify the process of verifying the measurement results.

If the operator has an ID card, measurement can be performed even during the nighttime hours or on holidays. This is a large factor in easing the burden on the operator.

(5) Support of diversifying data control methods

The data processing apparatus is provided with an end user computing (EUC) function, and in accordance with the control, necessary data can be extracted and displayed on a screen.

(6) Support of unmanned operation

In response to requests for laborsavings and to support unmanned operation, a network is utilized to share input data effectively with an upper level computer, and WBC inspection scheduling, the transmission of relevant measurement data among related departments and companies and the like is systematized. A system capable of unmanned measurement for regular users is also pursued.

6. Hand-foot-clothes Monitor

6.1 Overview

The hand-foot-clothes monitor is installed in contamination inspection rooms at facilities that handle radioactive matter such as research laboratories, hospitals, and nuclear power plants, and detects the surface contamination of radioactive matter that has adhered to workers' hands, feet, clothes and the like. The monitor detects beta-rays emitted from radioactive matter, and if the detected value exceeds a preset alarm level, the monitor sounds an alarm and displays the location of contamination on hands, feet or clothes.

The external appearance of the hand-foot-clothes monitor is shown in Fig. 12 and its specifications listed in Table 8.

6.2 Features

(1) Simply placing a hand or foot at the measurement position will cause measurement to begin, the contamination evaluated and the results displayed automatically.

(2) The BG value is automatically measured at regular intervals, and a subtraction calculation is performed according to the latest BG value. By reducing the effect of BG fluctuation, contamination can be measured with greater accuracy.

(3) According the latest BG value, the detectable limit is computed and the measurement time is automatically adjusted so that contamination can be measured within a short amount of time.

(4) When contamination is detected, a color display graphically shows the location of the contamination so that measurement results can be easily verified.

(5) A plastic scintillation detector is used and, unlike a finite-life GM tube, does not require replace-

*1 Windows: A registered trademark of US-based Microsoft Corp.

Fig.12 Hand-foot-clothes monitor

Table 8 Specifications of the hand-foot-clothes monitor

Item	Description
Radiation detected	Beta-rays
Detector	Plastic scintillation detector
Detection sensitivity	1.0 Bq/cm^2 or less (radiation source: ^{36}Cl) 0.2 Bq/cm^2 or less (radiation source: U_3O_8)
Measurement time	15 s (can be set within range of 1 to 999 s)
Size	Approx. 1,350 (H)×630 (W)×730 (D) (mm), or less
Mass	Approx. 80 kg

ment.

(6) The detector for measuring clothes contamination is made of hard plastic and light in weight.

(7) The low footboard is easy to step onto at the time of measurement.

(8) By using the rear wheels, one person can move the monitor by himself or herself.

(9) The monitor can be separated into three sections, simplifying delivery and installation.

(10) The contamination-preventing film at the foot measurement unit can easily be rolled up and replaced.

(11) A printer is optionally available.

6.3 Functions

The two functions of BG measurement and contamination measurement are performed repeatedly. In the case where the BG value has not yet been measured, BG measurement is prioritized and performed for the preset number of times before contamination can be measured. Normally, BG measurement is performed and the value is updated to the latest BG value.

Contamination measurement falls into two categories, hand-foot contamination measurement and clothing contamination measurement, each of which is performed independently. The hand-foot contamination measurement begins when all hand-foot sensors have been detected. After the measurement is completed, the judgment results are displayed on a screen. The probe-shaped detector that is provided is used to measure clothing contamination while surveying the surface of the clothes. Results are displayed on the screen in real-time. In cases where results of the completed contamination measurement are abnormal, the BG verification setting function can be used to check whether the cause is due to the measurer's contamination level or a monitor malfunction.

7. Conclusion

In the future, Fuji Electric intends to expand this market by: (1) developing equipment that supports the recent JIS standards established for surface contamination inspection equipment, and (2) developing low cost equipment that is compliant with IEC standards in order to expand sales overseas.

Finally, the authors wish to express their deep gratitude to the electric power companies and all individuals who have provided guidance and cooperation.