Report regarding decontamination of radioisotopes by wash from polluted clothes derived from the Fukushima nuclear accident and estimation of wash on radiation safety of the general public.

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A huge amount of radioisotopes (RI), such as $^{132}\text{Te}$, $^{131}\text{I}$, $^{134}\text{Cs}$ and $^{137}\text{Cs}$ etc., was released into the atmosphere by the accident of Fukushima Daichii nuclear power plant of Tokyo electric power company. According to the news immediately after the Fukushima nuclear accident, it was reported that almost all clothes were largely contaminated with the RI, confirmed by the early screenings of the general public evacuated from the Fukushima nuclear accident. On account of a worry about the RI contamination on clothes, many inhabitants could not dry their clothes out of doors in an area indicated the high radiation dose caused by the RI contamination in both Fukushima prefecture and some prefectures next to Fukushima prefecture even after the accidental release of RI was stopped from the accidental Fukushima nuclear power plant.

In order to settle this situation effectively, the Ad Hoc Committee on Safety Measures against Radioactive Iodine and Cesium of the Japanese Society of Radiation Safety Management (JRSM) established a clothes analysis group. The Clothes Analysis Group aimed to analyze the actual RI contamination on clothes, and to develop a simple method to remove the RI by using washing machine sold on market, and so on.

The results were summarized as follows;

1. The RI contamination was recognized obviously on clothes worn around the accidental Fukushima nuclear power plant immediately after the accident. However, on the clothes worn at July 2011, the RI contamination was not detected by a survey meter, but was detected a little by a Ge semiconductor detector.

2. The RI on clothes was decontaminated easily by a wash using a usual washing machine and detergent sold on the market. The RI decontamination ratios of the March clothes and the July one in 2011 were approximately 84 % after three times wash and 88 % after a once, respectively.

3. Radioactive Cs remained slightly after the wash and attached a little on clothes dried out of doors. Whenever the public lived in Fukushima prefecture might wear continuously the clothes contaminated by a trace of Cs after the wash and drying outside, the radiation safety was sufficiently confirmed because the estimated effective dose rate would be extremely lower than the annual dose limit.

Consequently, the wash by using a commercial washing machine and detergent was useful and easy for removing the RI from clothes without a special apparatus for the RI decontamination. Furthermore, the wash was effective both for eliminating an anxiety over radiation exposure by wearing the contaminated clothes, and for bringing a feel of relief by wearing the clean washed clothes.

Key words: Contaminated clothes, Wash, Radioactivity removal, Fukushima nuclear accident, General public [doi:10.12950/rsm.12.61]
1. Introduction

A huge amount of radioisotopes (RI), such as $^{132}$Te, $^{131}$I, $^{134}$Cs and $^{137}$Cs etc., was released into the atmosphere by the accident of Fukushima Daiichi nuclear power plant of Tokyo electric power company (Abbr. Fukushima nuclear accident). According to the news immediately after the Fukushima nuclear accident, it was reported that almost all clothes were largely contaminated with the RI, confirmed by early screenings of the general public (Abbr. the Public) evacuated from the Fukushima nuclear accident. On account of a worry about the RI contamination on clothes, many inhabitants could not dry their clothes out of doors in an area indicated the high radiation dose caused by the RI contamination in both Fukushima prefecture and some prefectures next to Fukushima prefecture even after the accidental release of RI was stopped from the accidental Fukushima nuclear power plant. In order to settle this situation effectively, the Ad Hoc Committee on Safety Measures against Radioactive Iodine and Cesium of the Japanese Society of Radiation Safety Management (JRSM) established a clothes analysis group. The Clothes Analysis Group aimed at the following 4 subjects; (1) to analyze the actual RI contamination on clothes, (2) to develop a simple and effective method to remove RI from the contaminated clothes by using a washing machine and detergent sold on market, (3) to check whether or not a secondary contamination would occur by the wash and drying, and (4) to estimate a radiation safety by wearing the slightly contaminated clothes concluding the out-of-doors drying after the wash of the clothes.

The results were already published in Japanese, and this report is an English translation of the study.

2. Materials and Method

2.1 Clothes

An analyzed clothes were classified into the following 3 sorts; 1) working clothes worn by business workers stayed temporary on standby within a restricted area inside of 20 km from the accidental Fukushima nuclear power plant in March 2011 immediately after the accident, 2) clothes worn by researchers and technical staffs engaged on a screening and measurement for the RI contamination of inhabitants in an evacuation-prepared area in case of emergency from March to August 2011, and 3) towels dried out of doors in July and August 2011 at Fukushima prefecture etc. Clothes were 10 kinds as follows; trousers, jackets, shirts, socks, gloves, masks, protective covers, vests & sweaters, hats and towels. The analyzed clothes were 44 pieces in number. Additionally, 6 Bags and 7 bottoms of shoes were similarly monitored.

Consequently, clothes and so on were characterized as the following 4 groups according to the obtained area and date.

(1) Clothing 1; These were provided from two companies, of which name were simply described as A and T company. Trousers, socks, gloves, and hats were provided for the staffs of A company. They stayed temporary on standby from 11th to 12th March 2011 in Ookuma-town, which was the restricted area and approximately 5 km away from the accidental Fukushima nuclear power plant. And next day from 13th to 15th March, they removed to Hirono-town, which was the evacuation-prepared area in case of emergency. Then, they traveled through Iwaki-city, Fukushima prefecture to Mito-city, Ibaraki prefecture at 16th March. Additionally, staffs of T company provided with a protective cover coats, gloves, and protective masks, which were obtained near the area about 20 km away from the accidental Fukushima nuclear power plant, however, of which a detailed wearing history was unknown. The RI contamination of Clothing 1 was measured, and was tested to remove the RI by the usual wash at Keio University in April 2011. Then, a part of trousers were analyzed at Tottori University.

(2) Clothing 2; These were jackets, vests, sweaters, shirts, trousers, shoes, and hats to be worn by 5 researchers of Nagasaki University, involving bags to be carried during their travel. Furthermore, 5 soles of shoes were added.

The wearing history of Clothing 2 was as follows. The researchers were sent to Fukushima-city, Fukushima prefecture to support medical helps from 14th to 19th March 2011. They were almost engaged to the indoor operation, and spent on all the morning in center of Fukushima-city, and in afternoon, they worked at Fukushima medical college suburban of Fukushima-city. In afternoon of 15th, they were exposed to rain and snow containing the RI at the outside of Fukushima medical college. After 19th, without changing their wears, they traveled using Japanese Shinkansen (train) and Airplane, and arrived at Nagasaki in 20th March 2011. After arriving at Nagasaki, all of Clothing 2 was stored in the sealed vinyl bags. Then, the RI contamination of Clothing 2 was measured and tried to be decontaminated by the usual wash after 22th March 2011 at Nagasaki University.
(3) Clothing 3; These were 2 pieces of trousers, worn by one member in Tottori University of the Clothes Analysis Groups, who worked at the inside and outside for RI monitoring in Minamisohma-city and Hirono-town Fukushima prefecture, where high radiation dose was detected, and were defined as the evacuation-prepared area in case of emergency.

The wearing history of Clothing 3 was as follows. A pair of Clothing 3 was worn from 30th June to 3rd July 2011, which was defined as ‘July trousers’. The member traveled from Tottori-city to Fukushima-city by train and airplane on 30th June, and stayed at Fukushima-city from 30th June to 3rd July. From 1st to 2nd July, he visited to Minamisohma-city, and engaged to measure the RI contamination on clothes of evacuated inhabitants returned temporary to this city. Then, he returned to Tottori-city on 3rd July by using train and airplane without changing the July trousers worn during whole period.

The other trousers was worn from 29th July to 3rd August 2011, and was exposed briefly to rain5) to be defined as ‘August trousers’. The member transferred from Tottori-city to Fukushima-city at 29th July, and stayed at Fukushima-city to 2nd August. During this stay, from 30th July to 2nd, the colleague visited to Hirono-town Fukushima prefecture, and engaged to measure the RI contamination on both clothes and environment. Then, he returned to Tottori on 3rd August without changing the August trousers. The member did not wear a protective outer cover over the July and August trousers. When he sat directly on a bench, a brock, and a road etc., he did not always use a protective medium.

Regarding the concern of measurement of the RI contamination and the effect of the usual wash on removing the RI, the Clothing 3 was investigated at Tottori University. Table 1 shows the wearing history of all trousers to be examined by the Clothes Analyzed Group.

(4) Clothing 4; These were towels made of cotton. The size was 34 cm width × 86 cm length equal to be 2,924 cm². These were washed usually and dried out of doors under the help by friends of the Clothes Analyzed Group lived in Fukushima-city, Kooriyama-city, Aizuwakamatsu-city, and Kawaguti-city.

### 2.2 Apparatus

(1) Radiation measurement

Table 2 shows the radiation detection Apparatus for measuring the RI contamination of clothes. Two types of survey meter were used such as GM counting tube type and ZnS:Ag scintillator type. Furthermore, NaI:Tl well-type scintillation analyzer, Ge:Li semiconductor detector, and Both Imaging Plate and its Fluoroimaging analyzer were used. These detectors were abbreviated in Table 2 as GM survey, ZnS survey, WSC, Ge Detector, IP, and IP Fluoroanalyzer, respectively.

GM survey meter, ZnS survey meter, and IP were used for the qualitative analysis for the distribution of RI contamination. WSC and Ge Detector were used for the quantitative analysis. Furthermore, IP was used for the quantitative analysis for the distribution of the RI contamination.

A detection limit of survey meter was assumed to be twice of BG counting.

![Table 1](attachment:table1.jpg)
Report regarding decontamination of radioisotopes by wash from polluted clothes derived from the Fukushima nuclear accident and estimation of wash on radiation safety of the general public.

Before the contamination analysis, detectors were calibrated by using an adequate RI checking source, such as the $^{137}$Cs standard sealed source (740 MBq at 14th Apr. 1993, CDC26206, Amersham co., Ltd.) and so on. In case of Ge Detector, a measured energy and counting efficiency were calibrated by the special RI source for Ge Detector (MX033U8TP, 45 mm $\times$ 65 mm height, Japanese Radiation and Isotope Society). Small clothes were packaged in the U-8 plastic vessel which size was as same as MX033U8TP, and bulky clothes were packaged in a commercial plastic vessel (1-4637-06, 114 mm $\times$ 197 mm height, Azuwan Co. Ltd.). The counting efficiency of bulky clothes was determined as follows: the commercial standard sealed source of $^{137}$Cs (3.74 kBq at 13 Jan. 2004, No.72168-LU834, AEA Technology Co., Ltd.) was fastened in the commercial 1-4637-06 vessel at height of 0, 20, 50, 130, and 197 mm to be measured at each height. A counting efficiency for bulky clothes was averaged those of each height.

(2) Washing machines, detergents, and bleaches.

Table 3-1 shows washing machines sold on market used for decontaminating clothes. The used commercial washing machines were a whirlpool type or a drum type. Table 3-2 shows lists of commercial detergents used for the decontamination.

An automatical operation function was selected when washing. Then, a time of washing, rinse, and spin-dry was set approximately at 10 min, 6 min, and 4 min, respectively. In case of the washing of Clothing 4, washing time and other conditions were partly unknown because washing operations were wholly depended on the cooperators’.

In order to confirm the removal ratio of the RI from the clothes, after the automatic first washing, some clothes were additionally washed with the bleach (bleaching wash), and furthermore was pressed and rubbed against the washing board (rubbing wash).

2.3 Measurement of RI contamination on clothes.

(1) A qualitative analysis.

1) By using survey meters.

Fig. 1 shows photographs measuring the RI contamination on clothes by GM survey meter. Partitions of photograph shows (A) a working jacket, (B) a socks, (C) a glove, and (D) a trousers, respectively. As shown in Fig. 1, GM counting tube was protected by a wrap in order to prevent from the RI contamination. The distance between the GM tube and the surface of clothes were kept under approximately 1 cm. The time constant was set at 10 sec. The scanning speed of counting tube was moved at 50 cm per 10 sec. The background counting rate ranged approximately 5–100 cpm.

| University       | Detector   | Type      | Maker             |
|------------------|------------|-----------|-------------------|
| **Keio Univ.**   | GM Survey  | TGS-146   | Aloka Co., Ltd.   |
|                  | WSC        | Accu FLEX γ-7000 | Aloka Co., Ltd. |
|                  | Ge Detector| MCA7700   | SEIKO EG & G Co., Ltd. |
| **Tottori Univ.**| IP         | BAS-IP MS 3543 | Fuji Film Co., Ltd. |
|                  | Analyzer   | FLA-5000  | Fuji Film Co., Ltd. |
|                  | Fluoroimaging for IP | | |
| **Nagasaki Univ.**| GM Survey  | TGS-133   | Aloka Co., Ltd.   |
|                  | Ge Detector| Princeton | Gamma-Tech Co., Ltd. |
| **Tokyo Univ.**  | ZnS(Ag) Survey | TCS-222 | Aloka Co., Ltd. |
|                  | IP         | BAS-MS3543 | Fuji Film Co., Ltd. |
|                  | Analyzer   | FLA-9000 STARION | Fuji Film Co., Ltd. |
|                  | Fluoroimaging for IP | | |
Table 3-1  Washing Machine sold on market used for decontamination.

| University      | Type of Machine       | Name and Model   | Maker                  |
|-----------------|-----------------------|------------------|------------------------|
| Keio Univ.      | Eddy type             | AW-A60 (EG)      | MITSUBISHI Co., Ltd.   |
|                 | Rotation Drum type    | ES-V510-NL       | SHARP Co., Ltd.        |
| Tottori Univ.   | Eddy type             | ASW-T3 Model     | SANYO Co., Ltd.        |
|                 | Eddy type             | AWD-TQ900        | SANYO Co., Ltd.        |
| Nagasaki Univ.  | Rotation Drum type    | BD-V1300         | HITACHI Co., Ltd.      |
| Tokyo Univ.     | Eddy type             | Usual Marketed Washer | Unknown               |

Table 3-2  Washing Detergents sold on market used for decontamination.

| University      | Type of Detergents | Name and Model   | Maker                  |
|-----------------|--------------------|------------------|------------------------|
| Keio Univ.      | Powder             | Attack bio EX    | Kao Co., Ltd.          |
|                 | Liquid             | Shabonet F       | Saraya Co., Ltd.       |
| Tottori Univ.   | Powder             | Ariel strong type| P & G Co., Ltd.        |
|                 | Powder             | Attack neo       | Kao Co., Ltd.          |
| Nagasaki Univ.  | Powder             | Attack           | Kao Co., Ltd.          |
| Tokyo Univ.     | Liquid             | general marketed type | Unknown               |

2) By using IP.

Fig. 2 shows photograph of the trousers exposed to IP. Each partition of photograph shows (A) around the hem, (B) around the knee, and (C) around the hips, respectively. The exposing time was 3 h for the Clothing 1, 24 h for the Clothing 3 and 140 h for the Clothing 4.

(2) Counting by WSC

A contamination of gloves and socks in the Clothing 1 was measured by WSC. Before the counting, materials were cut into square of the size of each about 3–5 cm. The cut pieces were packaged into 20 ml counting vial and were measured. Fig.3 shows photographs of (A) a counting vial and (B) an automatic
conveyor of vials for the WSC counting. The used WSC did not provide with an exact analysis system for a variety of nuclides blended in the contamination. The contamination data by the WSC counting was shown in the unit of cpm.

(3) A quantitative analysis of RI contamination distributed on clothes by Ge Detector.

Fig. 4 shows the photograph of (A) an appearance of Ge Detector with the Pb shield, (B) a vessel used for measuring a bulky cloth, and (C) the set of the vessel on Ge Detector in the Pb shield.

2.4 Confirmation of safety on instruments and environments for decontamination.

It was confirmed by both the direct measurement using survey meter and the indirect way using smear papers whether or not the contamination would be detected inside of the commercial washing machines, drying apparatus, and the room used for investigating the removal of the RI. In the direct and indirect way, GM survey meter and smear papers (No.63, Toyo roshi co., Ltd.) were used respectively. After wiping by smear papers, those were counted by GM survey meter. For the estimation of an inner exposure, an air in examining room and so on was monitored with the dust sampler (L30 MK III, M&F Co., Ltd.) furnished with both the usual glass filter and the charcoal filters (GB100R, CP-20, Toyo roshi co., Ltd.). The radioactivity on filters was counted by WSC.

2.5 Effect of out-door drying on secondary contamination of clothes.

(1) Places.

Fig. 5 shows 4 out-door places for drying the Clothing 4 (towels) in order to examine the attachment of the RI on towels.

All examined places were certainly over 60 km away from the accidental Fukushima nuclear power plant. The drying tests were carried out from 23rd July to 9th August 2011. The RI contamination attached on towels was measured at Tokyo University.

(2) Washing and drying

The Clothing 4 were at first washed, and then dried outside by the same usual way, drying place, and drying time etc., which were as same as the way that the joint research partners had carried out before Fukushima nuclear accident had been occurred.

Table 4 shows the washing conditions concerning with the weather, a direction of wind, and a drying position and so on at examining places. In a total of 12 times drying, excepting twice under the eaves of 2nd floor, the other were under the eaves of 1st floor or out of doors. As for the weather5), it was fine or cloudy, except of rainy with sometimes cloud at a trial of 29th July in Kooriyama-city. A temperature were from 20.4 to 28.8°C.

After drying, the radioactivity of Clothing 4 was measured by GM survey meter, ZnS survey meter, and Ge Detector. The measuring time by Ge Detector was 13.9 h. The towels recognized to be contaminated by Ge Detector were additionally exposed to IP for 140 h, and were analyzed to image processing.

2.6 Estimation of radiation exposure dose by wearing contaminated clothes.

The radiation exposure dose was estimated by following 2 ways.
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Fig. 5. Places drying towels outside and those distances from the Fukushima accidental plant.

| Places dried                  | Number of trial | Drying Date            | Weather*¹, Temperature | Drying Position         |
|-------------------------------|-----------------|-------------------------|------------------------|-------------------------|
| Yashimada, Fukushima-city,    | 1               | 2011.07.24(8:30–15:20)  | Clear, 27.9°C          | Under Eaves at 1 Floor  |
| Fukushima Pref.              | 2               | 2011.07.25(7:10–13:00)  | Cloudy, 27.5°C         | On Garden               |
|                              | 3               | 2011.07.26(10:00–17:30) | Cloudy sometime Clear, 28.8°C | Under Eaves at 2 Floor  |
| Namiki, Kooriyama-city,      | 4               | 2011.07.29(13:00–18:00) | Rainy sometimes Cloudy, 24.7°C | Under Eaves at 1 Floor  |
| Fukushima Pref.              | 5               | 2011.08.01(14:30–18:30) | Cloudy, 20.4°C         | Under Eaves at 1 Floor  |
|                              | 6               | 2011.08.04(12:00–16:50) | Clear, 30.1°C          | Under Eaves at 1 Floor  |
| Honcho, Aizu-wakamatsu-city | 7               | 2011.07.29(9:15–15:35)  | Clear, 27.4°C          | Under Eaves at 2 Floor  |
| Fukushima Pref.              | 8               | 2011.07.23(9:20–15:36)  | Clear, 27.4°C          | On Garden               |
|                              | 9               | 2011.07.23(9:21–15:37)  | Clear, 27.4°C          | Under Eaves at 1 Floor  |
| Nagakura, Kawaguchi-city,    | 10              | 2011.08.09(6:20–10:40)  | Clear, 28.2°C*²        | Under Eaves at 1 Floor  |
| Saitama Pref.                | 11              |                         |                        |                         |
|                              | 12              |                         |                        |                         |

*¹: Weather were announced by the Japanese Meteorological Agency. Temperature was the means during drying.
*²: These information was announced at Saitama-city where was near Kawaguchi-city.
(1) Method calculating an effective dose by undergoing the skin absorbed dose rate (Abbr. ICRU_R56 Method).

By the ICRU report 56, the skin absorbed dose rate of $^{134}$Cs and $^{137}$Cs were defined as $1.000 \times 10^3$ and $1.432 \times 10^3$ (n Gy · h$^{-1}$) · (Bq · h$^{-2}$)$^{-1}$ respectively under 70 µm from skin surface. At first, the equivalent dose rate was derived from a contamination density following formula (1). Then, the effective dose was derived from the formula (2) considering with the tissue weighting factor of the skin, the ratio of space contacted to clothes against the total surface space of human body (R, the contact ratio to skin of clothes) derived from the assumption that clothes did not cover several parts of body, such as head, tips of hands and legs.

Two calculation formulas on the ICRU_R56 Method were as followed (1) and (2).

$$H = Q_R \cdot A \cdot S^{-1} \cdot t \cdot 10^{-6} \quad \text{(1)}$$

Where;

- $H$: Equivalent dose of skin (mGy)
- $Q_R$: Skin absorbed dose rate (n Gy · h$^{-1}$) · (Bq · h$^{-2}$)$^{-1}$; $^{134}$Cs: $1.000 \times 10^3$, $^{137}$Cs: $1.432 \times 10^3$
- $A$: Quantity of RI (Bq) without decay, $S$: Space(cm$^2$), $t$: Time(h)

The $Q_R$ was selected the value of $^{137}$Cs in calculation in formula (1) because it was larger than that of $^{134}$Cs in order to estimate the absorbed dose standing on the safety side.

On calculation, the other data were as follows. A density of cloth was determined to be 1.3 because those of clothes were reported to have density from 1.2 to 1.5. A thickness of cloth was decided to be 0.03 cm according with 0.01 to 0.05 cm can be measured directly. The directly measured average weight of the trousers was approximately 540 g. The size of towel was 2,924 cm$^2$. The weight of towel was led to be 114 g by multiplying 1.3 of the specific weight by both 0.03 cm of the thickness and 2,924 cm$^2$ of the size.

$$E_T = H \cdot W_T \cdot R \quad \text{(2)}$$

$E_T$: Effective dose, $H$: Equivalent dose of skin (mGy), $W_T$: Tissue weighting factor, $R$: Contact ratio to skin of clothes.

The effective dose was derived from collecting the equivalent dose of skin by 0.01 of the tissue weighting factor for skin ($W_T$), and by 0.9 of $R$ for male-adults.

(2) Method based on the Federal Guidance Report No.12 (1993) of the United States of America (Abbr. FGR12 Method).

Supposing that the skin surface of human body would be wholly and uniformly contaminated, an exposure dose was approximated to calculate the effective dose when the human body was entirely soaked into the contaminated water, such as into the swimming pool. The Federal Guidance Report No.12 (1993) of the United States of America reported the coefficient of effective dose rate in case which the human body would be soaked wholly into the aqueous solution contaminated by $^{134}$Cs and $^{137}$Cs. Those were $1.49 \times 10^{-20}$ and $1.60 \times 10^{-16}$ Sv · (Bq · s · m$^{-3}$)$^{-1}$ of $^{137}$Cs and $^{134}$Cs, respectively. Then, assuming if the water concentration would be as same as the detected one on the clothes, the effective doses caused from $^{137}$Cs and $^{134}$Cs were estimated by the following formula.

$$E_F = \Gamma \cdot [B \cdot t] \cdot 10^{3} \quad \text{(mSv)}$$

$E_F$: Effective dose

$\Gamma$: Coefficient of effective dose rate by FGR No.12, ($S \cdot (\text{Bq} \cdot \text{s} \cdot \text{m}^{-3})^{-1}$)

$^{137}$Cs: $1.49 \times 10^{-20}$, $^{134}$Cs: $1.64 \times 10^{-16}$

B: RI concentration (Bq · m$^{-3}$), t: time (s)

3. Results

3.1 Characterization of contamination on clothes.

(1) Contamination on Clothing 1.

Table 5 shows the statistics of contamination on the Clothing 1 monitored by GM survey meter. The total of surveyed items were 19 pieces of 7 items, details were as follows; 4 socks, 2 trousers, 2 jackets, 6 gloves, a protective jacket, 3 masks, and a bag. The maximum, average and minimum of contamination on each items were as follows; 4,200, 3,200 and 2300 cpm on socks, 1,400, 825, and 200 cpm on trousers, 250, 125 cpm, and ND(not detected) on jackets, 4,500, 2,600, and 200 cpm on gloves, 260, 153, and 150 cpm on masks, all 600 cpm on the protective jacket, and all ND on the bag. All quantities of contamination were lower than 100,000 cpm of the screening level regulated by the Japanese Committee of Nuclear Safety.

In addition, socks and gloves indicating a high count were examined more detailed by GM survey meter. Table 6 shows the comparison of the contamination at the top with the heel on
sockets. In all socks, the top of underside were contaminated more largely than the heel. Table 7 shows the distribution of the contamination at the fingers position on gloves. In cotton gloves, the contamination was detected remarkably in the second finger (forefinger) except for the cotton inner 1, and the maximum counting rate was 3,600 cpm. In the rubber glove, the contamination was similarly detected as well as the cotton gloves. However, the third finger showed the maximum of 4,500 cpm, that was the highest contamination of all gloves.

Besides the monitor on socks and gloves by GM survey meter mentioned above, the portions of the highly contaminated were cut down, and the RI pollution was investigated particularly by the WSC and Ge Detector. Fig. 6 shows the spectrum of the socks in the Clothing 1 by Ge Detector. From the analysis of the spectrum, 8 kinds of nuclides derived from the nuclear fission of $^{235}$U were detected, such as $^{131}$I, $^{132}$I, $^{134}$Cs, $^{136}$Cs, $^{137}$Cs, $^{129}$Te, $^{129m}$Te, and $^{132}$Te. Table 8 shows the specific counting rate and activity of gloves and socks in the Clothing 1 detected by the WSC and Ge Detector. From the WSC counting, the highest concentration was measured in the rubber glove, and was 247 cpm · g$^{-1}$. Hereinafter, the concentrations were 236 cpm · g$^{-1}$ of the inner glove No.2, and 109 cpm · g$^{-1}$ of the inner glove No.3. As for the socks, the concentrations of socks 1 and socks 2 were 99 and 168 cpm · g$^{-1}$ respectively. The quantity of $^{131}$I, $^{134}$Cs and $^{137}$Cs was determined by Ge Detector. From the analysis by Ge Detector at 13th April 2011, the maximum contamination of $^{131}$I in gloves and socks were 48 and 18 Bq · g$^{-1}$ respectively. Then, those contamination concentration were corrected by the half-life to 15th March 2013 to be multiplied by 17.3, the adjusted maximum concentration of $^{131}$I of gloves and socks were 830 and 311 Bq · g$^{-1}$ respectively. As for cesium, similarly, the maximum total of $^{134}$Cs and $^{137}$Cs were 550 Bq · g$^{-1}$ of gloves and 376 Bq · g$^{-1}$ of socks.

The measurements of the Trousers were shown later.

### Table 5: Statistics of Contamination monitored by GM survey.

| Article          | Tip of socks | Trousers | Jacket | Gloves | Protective wrapper | Mask | Bag |
|------------------|--------------|----------|--------|--------|--------------------|------|-----|
| Number of Article | 4            | 2        | 2      | 6      | 1                  | 3    | 1   |
| Max.(cpm)        | 4,200        | 1,400    | 250    | 4,500  | 600                | 260  | ND  |
| Mean(cpm)        | 3,200        | 825      | 125    | 2,600  | 600                | 153  | ND  |
| Min.(cpm)        | 2,300        | 200      | ND     | 200    | 600                | 150  | ND  |

Clothes: Clothing 1, GM survey: TGS-146, Measured by Keio Univ.

### Table 6: Comparison of Contamination at Top with Heel on Socks.

| Counting Area   | No. of sample | Kind of socks (cpm) | Maximum counting rate (cpm) |
|-----------------|---------------|----------------------|-----------------------------|
| Top of white    | 1             | 2,300                | 150                         |
| Top of black    | 2             | 3,400                | 3,600                       |
| Heel white      | 1             | 1,900                | 185                         |
| Heel black      | 2             | 2,300                | 3,600                       |

Clothes: Socks in Clothing 1, GM survey: TGS-146, Measured by Keio Univ.
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(2) Contamination on Clothing 2.

Table 9 shows the statistics of contamination on the Clothing 2 which were investigated by GM survey meter at Nagasaki University at March 2013. The total of measured items were 38 pieces of 7 items, the details were as follows; 7 trousers, 6 jackets, 4 shirts, 7 sweaters or vests, 2 hats, 5 bags, and 7 shoes. The maximum, average and minimum of contamination on each items were as follows; 5,430, 1,500 and 130 cpm on Trousers, 1,700, 550 cpm, and 110 cpm on jackets, 520, 160 cpm, and 100 cpm on sweaters and vests, 500, 290, and 130 cpm on bags, and 14,700, 4,300, and 330 cpm on underside of shoes. All quantities of contamination were lower than 100,000 cpm of the screening level regulated by the Japanese Committee of Nuclear Safety9).

(3) Trousers.

The monitored trousers were wholly 4 pairs, of which 2 were in the Clothing 1 obtained in March, and the other were in

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Table 8 Specific Counting Rate and Activity of Gloves and Socks in Clothing 1 detected by WSC and Ge Detector.

| Kinds of clothes of Clothing 1 | Measuring by Ge Detector |
|-------------------------------|--------------------------|
|                               | Counting by WSC (cps/g)  |
|                               |                          |
| Rubber Gloves                 | 4.4 g 247 27 467 254 296 550 |
| Cotton Inner Gloves 2         | 3.4 g 236 48 830 242 286 528 |
| Cotton Inner Gloves 3         | 5.5 g 109 128 297 |
| Socks Black 1                 | 5.6 g 99.1 11 190 106 125 231 |
| Socks White 2                 | 2.7 g 168 18 311 173 203 376 |

Measured at 13th March 2011 by Keio Univ.

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Fig. 6. Spectrum of socks in Closing 1 worn in March 2011 just after the Accident. Socks: Before wash, Measure: Ge Detector, Date of measure: 13th April 2011
the Clothing 3 gained in July and August. The distribution of RI pollution on the highly contaminated trousers in the Clothing 1 was investigated in detail by GM survey meter. Table 10 shows the quantity of contamination monitored by the GM survey meter and Ge Detector. As for the March, both parts of hips and hem were contaminated by the monitor using GM survey meter at April 2011, and those counting rate around the hips and hems were approximately 200–250 and 1,400 cpm respectively. On the contrary, concerning with the July and August one in the Clothing 3, nothing was counted by GM survey meter, but $^{134}$Cs and $^{137}$Cs were detected significantly by Ge Detector. The concentration of $^{134}$Cs and $^{137}$Cs was 0.034 and 0.037 Bq · g$^{-1}$ respectively in the July one, and was both 0.011 Bq · g$^{-1}$ in the August one.

Fig. 7 shows images of two-dimensional distribution of the

RI pollution on trousers by IP. The image A, B and C were each of the March, July and August respectively. In the image A, many clear spots were detected strikingly. Those were caused from RI pollutions that dotted on clothes. Secondly, a few spots were detected slightly in the image B and C.

Fig 8 shows the spectrum of the July trousers by Ge Detector. From the peak analysis, nuclides of Cs were only detected, but nuclides of Iodine, which were detected on the March trousers, were not detected.

3.2 Effect of wash on decontamination

(1) In case of the Clothing 1

After washing trousers, socks and gloves, these clothes were still contaminated slightly in monitoring by GM survey meter. Those counting rate were approximately 200 cpm of twice BG. The socks showed the highest counting rate in average after the wash. Then, the pair of socks was washed three times and was measured more carefully by Ge Detector. Fig. 9 shows the effect of the wash on the decontamination of socks. The decontamination ratio of the first, twice and third wash were approximately 74±8, 80±6 and 84±5% respectively.

(2) In case of the Clothing 2.

After washing at the Nagasaki University, all clothes were decontaminated resulting that the counting rate by GM survey meter were lower than the twice of BG.

(3) In case of Trousers

The effect of wash on the decontamination of RI was examined for 3 trousers which were worn at March, July and August.

1) One of the March trousers.

Fig. 10 shows the changes of the two dimensional RI pollution around the hem by IP before and after the wash. The image A showed the contamination before the wash, which was the
same image A of Fig. 7. The image B revealed that the number of spots reduced evidently, but a few spot still remained after the wash. Then, a pair of trousers was additionally decontaminated by the bleaching wash. The image C was the image after the bleaching wash, and showed that a few spot remained plainly. Furthermore, the pair of trousers was followed to be on the rubbing wash. The image D showed that the spot reduced considerably comparing with those before the wash, but still remained intractably even after the rubbing wash.

Table 11 shows the effect of the bleaching and the rubbing wash on the decontamination of the radioactive $^{134}$Cs and $^{137}$Cs by Ge Detector. The $^{134}$Cs and $^{137}$Cs were left with the concentration of $0.095 \pm 0.013$ and $0.11 \pm 0.013$ Bq $\cdot$ g$^{-1}$ respectively on trousers after the bleaching wash. Then, adding the rubbing wash, the concentration of $^{134}$Cs and $^{137}$Cs were still $0.097 \pm 0.013$ and $0.11 \pm 0.014$ Bq $\cdot$ g$^{-1}$ respectively. As shown in Table 11, the rubbing wash had no effect on the decontamination after the bleaching wash.
2) The July and August trousers.

Table 12 shows the effect of the automatic usual wash on the decontamination of $^{134}$Cs and $^{137}$Cs in the trousers of the Clothing 3. In the July, the concentration of $^{134}$Cs and $^{137}$Cs were 0.034 and 0.037 Bq · g$^{-1}$ before the wash, and reduced to be 0.004 and 0.004 Bq · g$^{-1}$ after the first usual wash. Therefore, the decontamination ratio of $^{134}$Cs and $^{137}$Cs were 88 and 89% respectively. Similarly, in the August, the concentration of $^{134}$Cs and $^{137}$Cs were both same of 0.011 Bq · g$^{-1}$ before the wash, and reduced to be 0.001 and 0.002 Bq · g$^{-1}$ after the first wash. The decontamination ratio of $^{134}$Cs and $^{137}$Cs were 91 and 82% respectively. The total average of decontamination ratio was approximately 88%, and was close to about 84% of socks in the Clothing 1 after the three times wash mentioned above.

3.3 Estimation of safety on places to decontaminate by wash.

The contamination was not detected in any places, such as the inside of washing machine, the drying container and the inside of tube for waste water, by monitoring with GM survey meter and Smear papers wiped at same places. The air contamination in the washing room was not detected by the air monitoring with the filters.

3.4 Attachment on clothes of environmental RI by drying out of doors.

(1) Monitoring radioactivity by survey meters.

At the monitoring of $\alpha$, $\beta$ and $\gamma$ emitters by the GM and ZnS survey meter, the significant contamination was not counted on towels dried outside at different 4 places since the counting rate of all towels was same as the BG level.
(2) Determination by Ge Detector.

Table 13 shows the amount of radioactive Cs attached on towels after drying outside. Additionally, Table 13 marked up the public information of the air speed, the air concentration of Cs and the radiation dose rate measured at the near drying places announced by the Japan Meteorological Agency and the local government. As shown in Table 13, the radioactive Cs was slightly detected on each towel at the 9 times drying in Fukushima-prefecture except for two dryings at trial No. 6 of Kooriyama-city and at trial No.7 of Aizuwakamatsu-city. The largest contamination of $^{134}$Cs and $^{137}$Cs was 1.07 and 1.22 Bq respectively, and the total was 2.29 Bq, which was at the trial No. 4 of Kooriyama-city. In whole dryings, the average of $^{134}$Cs, $^{137}$Cs and the total was 0.261, 0.296 and 0.557 Bq respectively.

The attachment of Cs on towels in the Fukushima prefecture was not related to the announced information of the wind speed, the air concentration of Cs and the space radiation dose. On the other hand, nothing of Cs was detected on the towel at Kawaguchi-city of Saitama prefecture.

(3) Distribution of contamination analyzed by IP image.

Fig. 11 shows the IP image of the radioactive pollution attached on the towel of drying trial No.1 in Table 13. The total Cs of 0.931 Bq was clung to the towel. As shown in Fig.11, the radioactive Cs would be attached to the position of black spots, and 4 spots were detected including two circled spots.

3.5 Estimation of radiation exposure dose.

Science there were no standards for the estimation of the radiation exposure dose when the clothes was contaminated by the RI, the author and members of the Cloth Analysis Group decided to use the ICRU-R56 method and the FGR12 method. We supposed that the Public would wear the clothes as follows a day; The clothes of the same contamination in the washed July trousers was put on for 16 hours in a daytime, and the clothes of the same pollution in the Clothing 4 was done for 8 hours at night. Therefore, it was assumed that the concentration of $^{134}$Cs and $^{137}$Cs were both of 0.004 Bq for 16 hours in the daytime as shown in Table 12 and were 1.07 and 1.22 Bq respectively (2.29 Bq of the total) for 8 hours at the night as shown in table 13. Then, the density of contamination for the ICRU-R56 Method were led to be $1.9 \times 10^{-4}$ Bq · cm$^{-2}$ for the day time wear and $7.8 \times 10^{-4}$ Bq · cm$^{-2}$ for the night wear. Similarly, the concentration of contamination of $^{134}$Cs and $^{137}$Cs for the FGR-12 Method was led to be both $4 \times 10^{-3}$ Bq · g$^{-1}$ for the day time wear and to be $9.4 \times 10^{-3}$ and $1.1 \times 10^{-2}$ Bq · g$^{-1}$ respectively for the night wear. The concentration of the night wear were derived from 1.07 and 1.22 Bq of the attached $^{134}$Cs and $^{137}$Cs respectively as shown in Table 13, and the towel’s weight was 114 g.

Table 14 shows the estimation of the equivalent dose for skin of adult men by the ICRU-R56 Method. Assuming that the contamination would be on spot, the equivalent dose for skin arisen from the day time wear and the night wear were 36 and 9.3 mSv · cm$^{-2} · y^{-1}$ respectively, and the total was 45.3 mSv · cm$^{-2} · y^{-1}$. Similarly, assuming that the contamination would be in uniform, the calculated dose arisen from the day time wear and the night wear were $1.6 \times 10^{-3}$ and $3.3 \times 10^{-3}$ mSv · cm$^{-2} · y^{-1}$ respectively, and the total was $4.9 \times 10^{-3}$ mSv · cm$^{-2} · y^{-1}$.

Table 15 shows the estimation of the effective dose of adult men. By the ICRU-R56 method, the effective dose of $^{134}$Cs and $^{137}$Cs were $4.9 \times 10^{-2}$ and $7.0 \times 10^{-2}$ μSv · y$^{-1}$ respectively from the daytime wear and $9.3 \times 10^{-3}$ and $1.6 \times 10^{-2}$ μSv · y$^{-1}$ from the nightwear respectively, and the total was $3.7 \times 10^{-2}$ μSv · y$^{-1}$. On the other hand, by the FGR12 method, the effective dose of...
134Cs and 137Cs were 13.8 and 1.25 × 10^{-3} mSv · y^{-1} respectively from the daytime wear and 16.2 and 1.72 × 10^{-3} mSv · y^{-1} respectively from the nightwear, and the total was 30 mSv · y^{-1}. The total of the calculated effective dose by the FGR12 method was 810 times larger than that by the ICRU-R56 method.

4. Discussion.

4.1 Characterization of contamination on clothes just after the Fukushima nuclear accident.

At the screening for the emergency radiation exposure on clothes by the monitoring at Fukushima prefecture, it was reported that over 100 persons of the Public would be contaminated with more than 100,000 cpm by survey meters at the early stage from the accident to 31th March 2011. At the monitoring by the author and members of the Clothes Analysis Group on JRSM, the analyzed clothes had not been contaminated more than 100,000 cpm by GM survey meter, the maximum contamination on clothes was 14,700 cpm of the socks in the Clothing 1.

Inquiring into the contaminated position on the socks more detailed, the sole of the foot was more polluted than the top, and the highest counting was distinguished in the sole of tiptoe.

Discussing these properties of the contamination on socks with the records of staff’s movement in Fukushima prefecture near the accidental Fukushima nuclear power plant, it was identified that the sole of the socks was contaminated on account of the staff’s walk on the floor polluted by the RI because the Japanese had

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Table 13  Amount of Cesium attached on Towels after drying outside and Other Weather Conditions.

| Drying Place       | No. of Trial | Amount of Attached Cesium (Bq)*1 | Wind Speed (m·s\(^{-1}\))\(^{*2}\) | Radiation Dose Rate in Air around drying (\(\mu\)Sv·h\(^{-1}\)) \(^{*5}\) |
|--------------------|--------------|----------------------------------|---------------------------------|---------------------------------|
|                    |              | \(^{134}\text{Cs}\) | \(^{137}\text{Cs}\) | Total | \(^{134}\text{Cs/}^{137}\text{Cs}\) | in Air (kBq·km\(^{-2}\))\(^{*3}\) |
| Yashimada,         | 1            | 0.433                           | 0.489                           | 0.931                           | 2.5(South), N.D./N.D.                |
|                    | 2            | 0.216                           | 0.207                           | 0.423                           | 1.7(South), 13/13                    |
| Fukushima-city,    | 3            | 0.268                           | 0.226                           | 0.494                           | 2.0(North), 85/100                   |
| Fukushima Pref.    | AV.          | 0.306                           | 0.31                            | 0.616                           |                                           |
| Nmiki,             | 4            | 1.07                            | 1.22                            | 2.29                            | 1.5(South), Unmeasured               |
| Kooriyama-city,    | 5            | 0.27                            | 0.371                           | 0.641                           | 2.4(North), Unmeasured               |
| Fukushima Pref.    | 6            | N.D.                            | N.D.                            | —                               | 2.9(South), Unmeasured               |
|                    | AV.          | 0.447                           | 0.53                            | 0.977                           |                                           |
| Honcho,            | 7            | N.D.                            | N.D.                            | —                               |                                           |
| AizuWaka-matsu-city | 8            | 0.072                           | 0.102                           | 0.174                           | 1.5(North), Unmeasured               |
| Fukushima Pref.    | 9            | 0.023                           | 0.06                            | 0.06                            | 0.1(North), Unmeasured               |
|                    | AV.          | 0.032                           | 0.047                           | 0.078                           |                                           |
| Nagakura,          |              |                                  |                                  |                                  | 0.1(North)*4, N.D./N.D*4             |
| Kawaguchi-city,    | 10-12        | N.D.                            | N.D.                            | —                               | 0.94(North)*4, N.D./N.D*4             |
| Saitama Pref.      |              |                                  |                                  |                                  | 0.08(North)*4, N.D./N.D*4             |

*1 Detection limit of \(^{134}\text{Cs}\) and \(^{137}\text{Cs}\) was 1.1 × 10^{-2} and 1.2 × 10^{-2} Bq respectively, and was shown as N.D. in Table.

*2 The data was announced by the Japanese Meteorological Agency. The wind speed was the mean during drying.

*3 The concentration of Cesium fallen out was announced by the Japanese Ministry of Education, Culture, Science and Technology, and was determined by the total amount from 9 am during 24 h.

*4 The general weather conditions and the amount of Cs fallen out were issued at Saitama-city near Kawaguchi-city.

*5 The dose rate of Fukushima pref. and Saitama-city were at 24th July and at 9th August 2011, respectively. The data in brackets means the height from the grand.
put the shoes off in the usual family house. This fact has suggested that the Public’s house had been broken into by the RI released into the environment after the Fukushima nuclear accident.

The RI has spread over the environment by the Fukushima nuclear power accident after the Great East Japan Earthquake, and has contaminated on the surface of outside goods. The clothes were finally contaminated by the RI due to the Public’s outside movement and contact to the surface of outside materials. The water supply had been cut off in a large area of Fukushima prefecture suffered from the great damage in March 2011. It was reported that the water supply had been retrieved after 18th March 2011 in some places. For approximately 1 week, from the earthquake to 18th March, nobody of the Public in Fukushima prefecture could wash their clothes with the water since the water supply had been stopped in the damaged area suffered from both the earthquake and the Fukushima nuclear accident. Taken the cut off of the water supply into the consideration, it was concluded that the RI had attached on the clothes and on the surface of car tires etc., and had spread to contaminate extensively inside and outside of Fukushima prefecture. After the water supply was restored, the Public became to wash their clothes and their living places and surrounding environment with the water. The wash had largely affected to reduce the RI from the living goods of the Public.

4.2 Effect of the wash on the radiation protection of the Public.

The contamination ratio by the washing machine sold on market was approximately 87% both in the highly contaminated Clothing 1 which was acquired from the restricted area inside of 10 km from the accidental Fukushima nuclear power plant just after the accident and in the slightly contaminated Clothing 3 which was obtained from the evacuation-prepared area in case of emergency from 20 km to 30 km away from accidental Fukushima nuclear power plant at June 2011. It was confirmed that washing clothes by the usual machine was easy and effective for removing the RI without using any special apparatus for

| Table 14  | Estimation of Equivalent dose for skin of Adult Men by ICRU-R56 Method. |
|-----------|--------------------------------------------------------------------------------|
| Clothes   | Time | 
|           | (h·d⁻¹) | (mSv·y⁻¹·cm⁻²) | On spot | Uniform |
| Daytime Wear*³ | 16 | 36 | 1.6 × 10⁻³ |
| Nighttime Wear*⁴ | 8 | 9.3 | 3.3 × 10⁻³ |
| Total of annual dose | 45.3 | 4.9 × 10⁻³ |

*¹: The calculated dose was estimated for the contamination of ¹³⁷Cs.
*²: The contamination was supposed to be on spot.
*³: The contamination density was assumed to be equal to the trousers’.
*⁴: The contamination density was assumed to be equal to the towel’s.

| Table 15  | Estimation for Effective Dose of Adult Men. |
|-----------|---------------------------------------------------------------------------------|
| Clothes   | Time | Nuclide | Effective Dose |
|           | (h·d⁻¹) | (μSv·y⁻¹)*¹ | ICRU-R56 | FGR12 | Method | Method |
| Daytime Wear*² | 16 | ¹³⁴Cs | 4.9 × 10⁻³ | 13.8 | |
| Nighttime Wear³ | 8 | ¹³⁷Cs | 7.0 × 10⁻³ | 1.25 × 10⁻³ | |
| Wear³ | 8 | ¹³⁴Cs | 9.3 × 10⁻³ | 16.2 | |
| Wear³ | 8 | ¹³⁷Cs | 1.6 × 10⁻² | 1.72 × 10⁻³ | |
| Total of Annual dose | 3.7 × 10⁻² | 30 |

*¹: It was assumed that the contamination was uniform.
*²: The Cs concentration was assumed to be equal to the trousers’.
*³: The Cs concentration was assumed to be equal to the towel’s.
the RI decontamination. Furthermore, the wash was effective both on eliminating a worry concerning with wearing the contaminated clothes, and on bringing a feel of the relief about wearing the washed clean clothes. The wash was, furthermore, adequate for decreasing the radiation exposure dose caused by wearing the contaminated clothes for a long period.

However, approximately 13% of contaminated RI still remained on the March, July and August trousers after the wash as mentioned in above 3.2. It was obviously reported that the large amount of the RI contaminants had been dispersed and floated in the air by the Fukushima nuclear accident. The RI residue on the clothes would be caused from the reason why a few compounds with the RI would attached to the clothes on spot, and combined much strongly to a fiber of clothes.

4.3 Effect of drying outside on radiation safety of the Public.

Based on the quantity of Cs attached on towels by drying outside, the safety of the Public should be discussed with the radiation protection on a viewpoint that the Public had worn the clothes dried outside. Taking into the consideration that the clothes had contacted to the skin, the radiation exposure would be mainly caused from that the skin was exposed by the RI both clung to the clothes and adhered to the skin surface from the clothes. The deterministic effect for the skin was appreciated by using the equivalent dose averaged on the size 1 cm$^2$ of the skin. Because the exposure was concentrated onto the point of skin in case of the spot contamination, the equivalent dose for skin was estimated to be larger than that in case of the uniform contamination under the condition that the amount of Cs put on clothes would be same. As Fig. 11 showed that the Cs contamination on clothes was obviously on spot, it would be reasonable that the deterministic effect on the skin would be estimated assuming that the radioactive Cs would be attached on a few point of clothes.

The annual dose limit of the equivalent dose for skin of the Public was 50 mSv · y$^{-1}$ for the skin size of 1 cm$^2$ at the depth of 70 μm from the surface. At first, the equivalent dose for skin was derived from multiplying the absorbed dose for skin by the radiation weighting factor (WR) $^{12}$. Since the WR for the β and γ ray was 1, and the absorbed dose rate for skin of $^{134}$Cs and $^{137}$Cs were $1.000 \times 10^{-1}$ and $1.432 \times 10^{-1}$ (nGy · h$^{-1}$) · (Bq · cm$^{-2}$)$^{-1}$ respectively at the depth of 70 μm from the surface $^{6}$, the equivalent dose for skin caused from $^{137}$Cs was larger than that caused from $^{134}$Cs $^{13}$. Therefore, assuming simply that the radioactive Cs would be all $^{137}$Cs, the annual equivalent dose for skin was estimated to be 28.7 mSv · y$^{-1}$ when the Public had worn during a year the clothes clung to 2.29 Bq of $^{137}$Cs on spot as shown in Table 13. The estimated dose rate of 28.7 mSv · y$^{-1}$ above was less than 50 mSv · y$^{-1}$ of the annual equivalent dose limit for skin of the Public.

The stochastic effect was discussed with the effective dose derived from multiplying the average equivalent dose for all surface of the skin by 0.01 of the tissue weighting factor for the skin $^{12}$. Because the effective dose would be estimated without regard to the distribution of radioactive Cs on clothes, some factors for the dose estimation were determined as follows. At first, the contamination density of the towel was calculated to $7.83 \times 10^{-4}$ Bq · cm$^{-2}$ from the results that the amount of radioactive Cs was 2.29 Bq and the size of towel was 2,924 cm$^2$. Second, the area of the skin surface contacted to clothes was finally estimated to be 15,210 cm$^2$ from some calculation bellow$^{14-17}$. The partial surface of the head and hands were calculated to be 1,521 and 169 cm$^2$ from multiplying the wholly total surface of 16,900 cm$^2$ of the average and standard Japanese adult by 0.09 and 0.01, respectively$^{14-17}$. The head and hands surface were summed to be 1,690 cm$^2$, and this was subtracted from the wholly of 16,900 cm$^2$. Therefore, assuming that a radioactive Cs would be all $^{137}$Cs similarly in calculating the equivalent dose, the annual effective dose was estimated to be $8.84 \times 10^{-2}$ μSv · y$^{-1}$ when the Public had worn for a year the clothes contaminated at the density of $7.83 \times 10^{-4}$ Bq · cm$^{-2}$ by $^{137}$Cs. The estimated effective dose rate of $8.84 \times 10^{-2}$ μSv · y$^{-1}$ was extremely less than 1 mSv · y$^{-1}$ of the annual effective dose limit of the Public. Additionally, the effective dose for Japanese children and women would be more lower than that of the adult because their wholly body surface were small$^{15, 16, 17}$.

Consequently, the RI attachment caused from drying clothes outside would not effect on the health of the Public around Fukushima-city, Kooriyama-city and Aizuwakamatsu-city in Fukushima prefecture.

4.4 Estimation of radiation exposure dose arisen from contamination on clothes on the Public.

It was proved from the Table 10 that the contamination on the July and August trousers was not measured by GM survey meter, but a trace of radioisotopes was detected by Ge Detector. In order to evaluate the safety of the Public wearing the clothes continuously contaminated by a trace of radioactive nuclides which was not measured by GM survey meter, it was enough
obviously that the radiation exposure dose should be estimated by the residual trace of $^{134}$Cs and $^{137}$Cs on clothes after the wash, of which quantity was narrowly detected by only Ge Detector. Then, the residual concentration of $^{134}$Cs and $^{137}$Cs were both 0.004 Bq · g⁻¹ for the daytime wear like as the trousers in Table 12, and for the nightwear like as the towels from the trial No.4 of Table 13, the contamination density of $^{134}$Cs and $^{137}$Cs were led to be $3.66 \times 10^{-4}$ and $4.17 \times 10^{-4}$ (Bq · cm⁻²). Therefore, it was assumed that the Public would wear alternately the daytime wear for 16 hours and the nightwear inside for 8 hours.

The equivalent dose for skin arisen from the contamination by both on spot and on uniform were 45.3 and $4.9 \times 10^{-3}$ mSv · y⁻¹ respectively as shown in Table 14, and was also lower than 50 mSv · y⁻¹ of the annual limit of the Public at any contamination²¹. According to the estimation for the equivalent dose for skin, it was confirmed that the Public was sufficiently safe from the radiation exposure on skin. Furthermore as shown in table 15, the effective dose was estimated to be $30 \mu$Sv · y⁻¹ by the FGR12 method, which led remarkably the higher effective dose than the ICRU-R56 Method. The author et al¹⁹) have already reported that the effective dose of the Public was estimated to be $50 \mu$Sv · y⁻¹ by the ICRU-R56 method under the condition that the Public had continuously worn the clothes contaminated by the radioactive Cs at concentration of 0.01 Bq · g⁻¹. In any estimation of the effective dose, the Public was concluded to be on safety because any calculated dose was lower than that of the annual dose limit even if they have continued wearing the washed clothes which the radioactive nuclide was slightly remained.

In the estimation of the effective dose concerning with the radioactive Cs, the FGR method gave us the excessive evaluation that the exposure dose was approximately 810 times larger than that by the ICRU-R56 method. Therefore, the ICRU-R56 method would be an actual estimation way.

The contamination of the soil has been reported by the reason why the RI contaminant, released into the environment by the Fukushima nuclear accident, fell down onto the earth¹⁹,²⁰. It was supposed that the RI fallen down to the soil led the clothes of the Public contaminate. Accordingly, the soil attached on the clothes would be easily removed by the wash. From this point, the wash with the usual machine sold on market will be effective on both reducing the unnecessary radiation exposure and releasing the Public’s mental stress arisen from the anxiety about the radiation exposure.

4.5 Problems for treating clothes to live in Fukushima prefecture.

Wearing the washed clean clothes would led the Public efficiently accomplish the radiation protection without any special conscious attention to the health. Next, repeating to wear the washed clothes would reduce the volume of radioactive wastes composed from clothes as the main ingredients. From these viewpoints, the wash would be efficient on decontaminating the RI on the clothes.

On the other hands, the waste water after the wash would accumulate to a sewage disposal plant through a drainage ditch and pipe, or leak from the ditch to flow out into a general river. This flow of the waste water from washing clothes would contaminate slightly the sewage disposal plant or the environment. The radiation protective problem against the environmental pollution by the RI should be studied continuously for a long time in and around the Fukushima prefecture.

5. Summary

(1) It was actually analyzed that the clothes were contaminated by the RI released into the environment from the Fukushima nuclear accident. It was also investigated that the wash by the normal washing machine, available in the market, was effective for the sufficient decontamination of the RI from the clothes. In consequence, it was obvious that just after the Fukushima nuclear accident, the Public around the accidental Fukushima nuclear power plant had worn the clothes contaminated by the RI released into the environment. However, after 3 months of the accident, the contamination on the clothes was so much reduced that the radioactive nuclides could not be measured by the survey meter, but was slightly detected by the Ge Detector.

(2) The RI on clothes was decontaminated easily by washing with the usual washing machine and detergent sold on market. The RI decontamination ratios of the March and the July clothes in 2011 were approximately 84% after three times washing and 88% after a once, respectively. Furthermore, washing with the usual washing machine sold on market will be effective on both reducing the unnecessary radiation exposure and releasing the Public’s mental stress arisen from the anxiety about the radiation exposure.

(3) Radioactive Cs remained slightly after the wash and attached a few on clothes dried out of doors. Whenever the Public lived in Fukushima prefecture might wear continuously the clothes
contaminated by a trace of Cs after the wash and drying outside, the radiation safety was sufficiently confirmed because the estimated effective dose rate would be extremely lower than the annual dose limit.

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