RADIOLOGICAL CONSIDERATION REGARDING LOGISTICAL MANAGEMNET OF RADIOACTIVE SURFACE CONTAMINATION AFTER FUKUSHIMA NUCLEAR ACCIDENT

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Abstract:

Several key issues have been argued nationwide pertaining to the Fukushima nuclear accident such as the amendment of laws concerning specific countermeasures against nuclear disaster, the development of frameworks for countermeasure planning at the national and regional levels. The improved nuclear disaster prevention system should be enhanced in order to prepare for emergency response. In this paper, we focus on screening examination for decontamination as one of the significant issues related to the protection of the general public exposed in emergency situations following the Fukushima nuclear accident with a large-scale radioactive release. The background for setting numerical values, the outlines of the actual conditions of application, and the ongoing discussion on the revision of guidance values on screening levels are described. Social concerns on screening levels are briefly summarized from the experience of risk communication activities through a website established by Japan Health Physics Society immediately after the Fukushima nuclear accident. On the basis of the dose assessment model developed for deriving surficial clearance levels in previous studies, the annual effective dose and skin-absorbed dose that may arise from handling objects and direct deposition on skin contaminated at the level of the screening criteria are calculated. Radiological consideration regarding screening levels for decontamination is described from the viewpoint of both process-based protection approach using intervention and situation-based protection approach using reference levels in the system of radiation protection recommended by the International Commission on Radiological Protection.

Key Words:

Fukushima nuclear accident, Decontamination, Screening survey, Dose assessment, Intervention exemption

1. Introduction

Since the Fukushima nuclear accident in 2011, changes in the nuclear safety regulation have been widely argued in Japan, calling for widespread changes such as the amendment of the Atomic

Energy Basic Act and the Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors to enhance the nuclear disaster prevention systems of Japan. In the argument, nuclear regulations should be improved reflecting the experience at operational facilities and the latest findings about safety, on the basis of a strong concern to "protect the people and the environment from the harmful effects of radiation", and the utilities should have some responsibility to tackle safety improvements constantly. An executive summary of the interim report has been published by the investigation committee on the accident at the Fukushima nuclear power stations of Tokyo Electric Power Company on 26 December 2011 [1]. From April 2012, the Nuclear Regulatory Agency will be set up within the Ministry of the Environment from the viewpoints of the separation of nuclear regulation and the use and centralization of the regulatory framework. The agency will conduct a review process of regulatory and institutional basis of nuclear safety to recover public trust in nuclear safety and to improve the functions in regulations, on the basis of the experiences in the Fukushima nuclear accident. Since July 2011, the Nuclear Safety Commission of Japan (NSC) has already started some preliminary review from the viewpoint of the revision of guidance values for the emergency preparedness and response [2]. The strengthening of nuclear emergency preparedness is a significant issue under the reflection of the accident, which includes the revision of the law concerning specific countermeasures against nuclear disasters, the development of frameworks for countermeasure planning at the national and regional levels, and the improvement of off-site centers.

Concerning the protection of the general public from exposure to the radioactive plumes in emergency exposure situations following a nuclear accident with a large-scale radioactive release, the screening examination of surficial contamination on the human body after passing through such plumes and on handling objects [3] plays an important role in assessing the possible incidence of deterministic effects, the dose from internal exposure, and the need for medical treatment, as well as preventing and controlling the dispersion of radioactive materials, in addition to the management of contaminated foodstuff [4]. Before the Fukushima nuclear accident, the screening criteria were given in relevant guidelines of the NSC, assuming hypothetical nuclear accidents. However, the Fukushima nuclear accident was triggered by natural disasters (i.e., earthquake and tsunami), which led to conditions beyond the assumption where lifelines and essential materials for decontamination became unavailable for a long time owing to the extensive damage in wide disaster areas. Following the above extreme conditions, the screening levels were changed to a value approximately ten times higher than the numerical value given in previous guidelines.

In this paper, we focus on the background for setting numerical values and the outlines of actual conditions of application. Social concerns on screening levels for decontamination are also summarized from the experience of risk communication website established by Japan Health Physics Society during 1 year after the Fukushima nuclear accident. The doses that may arise from handling objects contaminated at the level of the screening levels are calculated, and radiological consideration regarding the screening levels for decontamination is described from the viewpoint of intervention exemption and reference levels in emergency and existing exposure situations in the system of radiation protection recommended by the ICRP.

2. Screening Implemented after the Fukushima Nuclear Accident

The first concern in the event of a radiological emergency is to keep the exposure of individuals from all pathways below the thresholds for serious deterministic health effects. In addition to preventing serious deterministic effects, the unacceptability of a high risk of stochastic health effects on individuals becomes a significant factor in the decision making process.

Before the Fukushima nuclear accident, screening level was the indicator of the adoption of stable iodine, and it was determined on the basis of the equivalent dose of 100 mSv for pediatric thyroid. A document given by the commission of the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) gave four derived levels that correspond to an equivalent dose of 100 mSv for pediatric thyroid: (1) surface contamination density of 40 Bq cm^{-2} on the human body, (2) effective dose of 100 mSv, (3) nasal contamination of 1,000 Bq, and (4) radioactivity in thyroid of 3,000 Bq. In these, the surface contamination density on the human body can be used in a first-step screening, and the other levels can be used in the second-step screening if the human body is contaminated at higher levels of over 40 Bq cm^{-2}. The other three derived numerical values also correspond to the equivalent dose of 100 mSv of pediatric thyroid. The 13,000 counts per minute (cpm) is given as the count rate of a typical GM survey meter that correspond to the surface contamination density level of 40 Bq cm^{-2}.

After the Fukushima nuclear accident, the Nuclear emergency response headquarters and Fukushima prefecture set the screening level to 13,000 cpm assuming the use of a typical GM survey meter, but increased it to 100,000 cpm, which is the maximum range of the survey meter, considering the difficulty in dealing with increasing background radiation. The revised screening level corresponds to a dose rate of 1 μSv h^{-1} at a distance of 0.1 m given in the IAEA document entitled "Manual for First Responders to a Radiological Emergency" [5], according to the suggestion of the NSC, although the purpose of the IAEA manual was to prevent the incidence of the deterministic effect of the human skin. The flow of screening procedures in first-aid stations is predetermined in the framework of emergency preparedness in Japan. However, in the situation after the Fukushima nuclear accident, so many people rushed into these stations under conditions of water and electricity outage, and thus it was difficult to strictly follow the predetermined procedures (e.g., nose smear and records). Furthermore, when the people left the warning area set within a 20 km radius around the Fukushima Daiichi nuclear power plant, the screening levels of 100,000 cpm was similarly applied for the inspection and decontamination criteria. Most of the 245,464 people measured as of 29 February 2012 were under the 100,000 cpm, and decontamination was performed for 102 people exceeding 100,000 cpm, but their contamination levels fell to below the criterion after such decontamination [6].

The dominant radionuclides change according to the phase of the emergency owing to the half-life effect. The NSC recommended to reduce the screening levels on 29 August 2011 for the screening examination of human and objects on the basis of As Low As Reasonably Achievable (ALARA), considering the conditions that radioiodines with a short half-life were the dominant radionuclide soon after the nuclear power plant accident but the radiocesiums with relatively long half-life eventually became dominant. The attempt to minimize the large-scale radioactive release during the control of the damaged power plant was also taken into account [7]. The Nuclear Emergency Response Headquarters and Fukushima Prefecture have lowered screening levels to 13,000 cpm, following the suggestion by the NSC. From the viewpoint of the prevention of spread of contamination, it was requested by the NSC to decontaminate the surface even below the screening level.

In the early phase after the Fukushima nuclear accident, the volunteers in Japan Health Physics Society (JHPS) established the Question and Answer (Q&A) website linked from the JHPS homepage [8] on 25 March 2011 to provide the precise information on exposure to radiation, especially in daily life. In August 2011, Steering Committee of the Q&A website was officially established in JHPS and took over the risk communication activities by the volunteers. As of 11 March 2012, approximately 1,500 Q&A are available on the website in Japanese. In the analysis of the Q&A, it can found that there have been high social concerns about the health effect of the children. Concerning the screening levels discussed in this paper, there are similar questions with high concern about the health effect of low dose exposure to surface-contaminated objects, health survey of pediatric thyroid, the decontamination method, and the logic behind the numerical values of screening levels. In answering these questions, the Committee introduced the latest information as easy as possible in an appropriate description, and in some cases, calculated the dose that may arise in each exposure situation of the questioner by assuming a hypothetical condition, and compared to the associated incremental radiation risk. Based on the experience of risk communication activities, authors recognized the importance of clarifying each objective of the countermeasure, deeper understanding in the scientific background of applied numerical values for radiation protection, and further pursuit to efficient explanation that can be easily understandable for the general public.

According to the technical consideration of NSC [2], the purposes of the screening examination implemented after the Fukushima nuclear accident are classified into four types: Type I, decontamination of the human body; Type II, administration of stable iodine; Type III, logistical management; and Type IV, acceptance of medical treatment. The type I is for swift action against the possible acute radiation damage due to the contamination of the surface of the human body including the limbs. A dose rate of 1 μSv h^{-1} at a distance of 0.1 m from the skin given in the IAEA Manual [5] has been a level equivalent to 1/100 of the incidence of acute radiation injury level, which can be easily detected at the time of the accident. However, in the response during the Fukushima nuclear accident, the measurement of 1 μSv h^{-1} became practically difficult under emergency conditions with high background radiation levels. The skin-absorbed dose that may arise from direct disposition of radionuclides on the human body is discussed in the next section. Concerning the type II, it has been internationally argued that the equivalent dose criteria for pediatric thyroid should be changed from 100 mSv to 50 mSv in 7 days, and thus there shall be follow-up discussions to derive numerical values corresponding to the new dose criteria in Japan for international consistency. The type III particularly plays an important role in the control of radioactive surface contamination on humans, handling objects, and vehicles in emergency and existing exposure situations (referred hereinafter as logistical management), and thus the radiological consideration is described in the next section. The type IV can be primarily used to give advance measures to prevent the spread of secondary contamination when a hospital accepts the contaminated patient. However, in some cases in Fukushima, there was a situation in which attitude of rejecting the bringing in of radioactive materials helped hospitals ensure that there are enough employees to conduct medical practice.

Although the objectives of these four types of screening levels differed, the same numerical value of 100,000 cpm obtained using a typical GM survey meter was applied in all cases, in a state of confusion, after Fukushima nuclear accident. In the next section, we focus on the dosimetric aspects of Type I and III by assessing the annual effective dose that may arise from handling objects and skin-absorbed dose on the human body both contaminated at the levels of decontamination (100,000 cpm).

3. Dose Assessment of Screening Level for Type I and III

The authors verified the screening levels for decontamination implemented after the Fukushima nuclear accident [3], from the viewpoint of logistical management based on available information gathered as of August 2011, applying a dose assessment model of surface contamination to the derivation of isotope-specific surficial clearance levels [9,10]. In this section, we summarized the key result of previous studies [3,9,10].

To assess the dose that may arise from surface contamination, the densities of representative radionuclides that correspond to the screening levels given by the count rate obtained using a typical GM survey meter should be specified. Figure 1 shows the trend of the concentrations of radioactive ^{131}I, ^{134}Cs, and ^{137}Cs in air measured at the site of the Fukushima Daiichi nuclear power plant. On the basis of observations such as those shown in Figure 1, in this paper, the surfaces of handling objects and human bodies are assumed to be contaminated with ^{131}I, ^{134}Cs, and ^{137}Cs. The contamination density ratio of ^{134}Cs to ^{137}Cs was set to one and the same ratio of ^{131}I to these radiocaesiums was set to 100, 10, 1, 0.1 and 0.01. The surface density of radioactive contamination is given by equation (1), where A_i [Bq cm^{-2}] is the surface density of radioactive contamination for radionuclide i, N [count sec^{-1}] is the measured count rate, N_b [count sec^{-1}] is the background count rate, $\varepsilon_{e,i}$ [% 2□$^{-1}$] is the instrument efficiency for radionuclide i, W [cm^2] is the area of the detector window, $\varepsilon_{s,i}$ is the source efficiency for radionuclide i, and f_i [%] is the emission rate of □eta-ray for radionuclide i.

$$A_i = (N - N_b) / (\varepsilon_{e,i} \times W \times \varepsilon_{s,i} \times f_i) \qquad (1)$$

A count rate of 100,000 cpm corresponds to 1,670 counts per second (cps). The background count rate should be higher after the Fukushima nuclear accident, however, it was conservatively set to zero. The beta-ray emission rates of ^{131}I were set to 89.4 % at an energy of 606 keV, 7.4 % at an energy of 334 keV, 2.1 % at an energy of 248 keV, 0.6 % at an energy of 304 keV and 0.4 % at an energy of 807 keV. Those of ^{134}Cs were set as 70.2 % at an energy of 658 keV and 2.5 % at 415 keV. Those of ^{137}Cs were set as 94.4 % at an energy of 514 keV and 5.6 % at an energy of 1.176 MeV. The instrumental efficiency for □eta-rays was uniformly set as 0.4, conservatively considering the maximum □-ray energies of ^{131}I, ^{134}Cs and ^{137}Cs. The source efficiency was set as 0.5 in accordance with the ISO 7503-1, considering that the maximum □eta-ray energies of ^{131}I, ^{134}Cs and ^{137}Cs are higher than 0.4 MeV, although an experimental study has shown a higher source efficiency of radiocesiums for various materials [11]. The area of the detector window was set as 20 cm^2, which is the same as that for an Aloka Type TGS-136 GM survey meter with a 5 cm bore, which has typically been applied to the screening after the Fukushima nuclear accident.

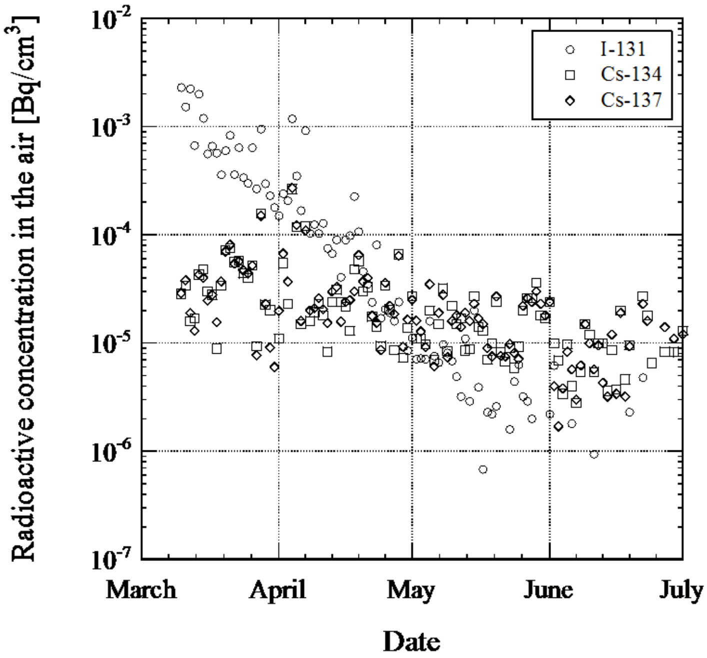

Figure 1 Radioactive concentration in the air observed at the site of Fukushima

With regard to the methodology of dose assessment from surface-contaminated objects, the original dose assessment model for the derivation of isotope-specific surface clearance levels [Bq cm^{-2}] was developed by integrating the existing stylized approach of IAEA for protecting people in the waste and transport safety fields. In dose assessment, the exposure scenario was classified into three categories: manually handled objects, closely handled objects, and remotely handled objects. The assessed exposure pathways were external irradiation and the inhalation of resuspended radionuclides from closely and remotely handled objects, and ingestion via contaminated hands, and skin contamination from manually handled objects. In the model developed, external irradiation was assessed using the QAD-CGGP2 code assuming independent surface-contaminated areas for closely and remotely handled objects. Inhalation was assessed using resuspension rate [h^{-1}], the volume of the room [m^3], exchange rate [h^{-1}], breathing rate [m^3 h^{-1}] and the dose conversion coefficient of inhalation for each radionuclide [Sv Bq^{-1}] as parameters. Ingestion was assessed using the area for ingestion of radionuclides from contaminated areas [cm^2], the transfer factor from contaminated objects to the hands, the transfer factor from the hands to the mouth, the ingestion frequency [h^{-1}] and the dose conversion coefficient for each radionuclide [Sv Bq^{-1}] as parameters. The dose conversion coefficients for inhalation and ingestion for workers and the public were given by the ICRP.

In the assessment of skin contamination, there should be a direct pathway after the Fukushima nuclear accident, such as radiocesiums existing in the atmosphere being deposited on the human body, in addition to the above assessment via the handling of a surface-contaminated object. Here the assessment of the skin-absorbed dose and the effective dose through dermal absorption becomes important. The skin-absorbed dose that arises from such direct deposition was calculated by using the conversion factors of the skin-absorbed dose rate to the basal layer of the epidermis for beta and gamma irradiation given in Radiation Protection 65 of Commission of the European Communities.

The annual doses that arise from handling objects contaminated at the screening level for decontamination are shown in Table 1. The dominant pathway in Cases I and II was found to be ingestion of radionuclides from manually handled objects, and the annual effective doses in these cases were calculated to be 0.68 mSv y^{-1} and 0.45 mSv y^{-1}, respectively. The annual effective doses for other pathways such as external irradiation and inhalation from closely handled objects and remotely handled objects were calculated to be lower than that for the ingestion of radionuclides from manually handled objects. On the other hand, the dominant pathway in Case III, IV, and V was found to be external irradiation from closely handled objects, and the annual effective doses in these cases were calculated to be 0.35 mSv y^{-1}, 0.51 mSv y^{-1}, and 0.53 mSv y^{-1}, respectively. The doses from other pathways such as ingestion of radionuclides from manually handled objects and inhalation of radionuclides from closely and remotely handled objects were calculated to be lower than that for external irradiation.

Since 16 September 2011, the screening level for decontamination has decreased to 13,000 cpm; the final dose that may arise can be assumed to 13 % (13,000 cpm/100,000 cpm) than the numerical values given in Table 1, namely around 0.1 mSv y^{-1}. From the viewpoint of optimization of radiation protection using the basic concept of ALARA, in the long-term objectives, the screening levels for logistical management should be gradually lowered to the surface contamination criteria used under normal conditions and in planned exposure situations, which correspond to 4 Bq cm^{-2} for non alpha emitters, considering the status and social circumstances surrounding the residual contamination.

The ICRP mentions in Publication 111 on the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency that the reference level for optimizing the protection of people living in contaminated areas should be selected from the lower part of the 1-20 mSv y^{-1} band recommended in Publication 103 for the management of this category of exposure situation, and that past experience has demonstrated that a typical value used for constraining the optimization process in long-term post accident situations is 1 mSv y^{-1}.

The ICRP recommendations evolved from the process-based protection approach using practices and interventions by moving to an approach based on the exposure situation. The ICRP mentions in Publication 82 on the protection of the public in situations of prolonged radiation exposure that an intervention in the supply of commodities is exempted if the additional annual dose is approximately 1 mSv y^{-1}. Furthermore, the ICRP also mentions in Publication 104 that exemption or exclusion for naturally occurring radioactive material (NORM) -based industries could be handled with an individual dose criterion of approximately 1 mSv y^{-1} excluding the dose from radon. In this context, the additional annual dose of approximately 1 mSv y^{-1} can be considered as the intervention exemption level in existing exposure situations.

Considering the result of dose assessment for handled objects contaminated at the same level as the screening level for decontamination after the Fukushima nuclear accident, it was found that the calculated annual effective doses in all cases are lower than the intervention exemption level. Although the calculated absorbed doses of the skin were found unlikely to reach the threshold of the deterministic effect on the skin in a practical exposure situation, countermeasures for preventing the contamination of the human body should be applied in advance for parts of the body that may be contaminated, and even parts of the body possibly contaminated below the screening level should be decontaminated to a level as low as reasonably achievable to ensure optimal radiation protection.

With regard to the vehicles, the effective external exposure dose of car mechanics during the maintenance of the cars from the risk cautionary area was assessed by the Japan Nuclear Energy Safety Organization (JNES) [12] at the request of the Local Nuclear Emergency Response Headquarters, on the basis of the fact findings about actual screening and contamination levels in the affected areas.

The results show that the effective external exposure dose of car mechanics treating the cars screened with the emergency situation screening level is estimated to be less than 1 mSv y^{-1} under the conservative conditions, and particular health concern isn't necessary for them, which can be considered as consistent with the key result of this paper.

Appropriate logistical management can also prevent reputational damage and discrimination rooted in the fear of the spread of contamination. There has been high social concern about the surface contamination on the human body, especially evacuees from Fukushima prefecture. However, screening to prevent the spread of contamination can also disturb the movement of people and goods in affected areas, which can lead to interference in evacuation, accident response, and recovery work. Thus, the screening should be applied with proper consideration of the overall status of the implementation of other protective countermeasures.

Table 1. Dose assessment at screening levels for decontamination (100,000 cpm)

Ratio of radionuclides (I-131 : Cs-134 : Cs-137)			Case I 100:1:1	Case II 10:1:1	Case III 1:1:1	Case IV 0.1:1:1	Case V 0.01:1:1
Surface contamination density [Bq cm^{-2}]		I-131	560	360	150	23	2.4
		Cs-134	5.6	3.6	150	230	240
		Cs-137	5.6	3.6	150	230	240
Objects	Manual [0.1 m^2]	Ingestion [mSv y^{-1}]	0.68	0.45	0.24	0.11	0.085
		Skin[mGy y^{-1}]	2.3	13	56	83	87
	Close [1 m^2]	External [mSv y^{-1}]	0.056	0.11	0.35	0.51	0.53
		Inhalation [mSv y^{-1}]	0.001	0.001	0.0019	0.0024	0.00025
	Remote [10 m^2]	External [mSv y^{-1}]	0.039	0.039	0.17	0.24	0.25
		Inhalation [mSv y^{-1}]	0.00015	0.00015	0.00028	0.00036	0.00038
Direct deposition to skin		Skin [mGy h^{-1}]	1.4	1.0	1.1	1.1	1.1

4. Conclusion

Here we have described the background of screening examination implemented after Fukushima nuclear accident, actual conditions of implementation, social concern obtained through risk communication website, and ongoing discussion of enhancing emergency preparedness and response in Japan. On the basis of the dose assessment for the surface-contaminated human body and handling objects, the annual effective dose was found to be less than 1 mSv y^{-1}, which can be considered as lower than the intervention exemption level and the risk band of reference levels given in the system of radiation protection recommended by the ICRP. Further it was clarified as a result of the skin-absorbed dose calculation that the screening level of decontamination can also prevent the skin from the incidence of a deterministic effect. These verifications correspond to the screening levels of Types I and III preliminary clarified by the NSC. Overall verification of screening examination implemented after Fukushima nuclear accident and lessons learned should lead to an improved nuclear emergency preparedness and response all over the world.

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