Management Course," which educates community health care workers in the acquisition of public health information. Workers can upload current data by using a system entitled the "Health Crisis Management Library System (H-CRISIS)," which allows local public health authorities to promptly gather and evaluate information regarding health risks.[11] Human resources are critical to adequate pandemic control, and both the NIID and the NIPH are key organizations with the capacity to improve public health emergency management skills.

Development of Safer Vaccines and Vaccination Policies

During the WHO smallpox eradication campaign, Japanese scientists developed a highly attenuated, third-generation vaccine called LC16m8. The new vaccine was derived from the Lister strain commonly used in the WHO program and was selected for temperature sensitivity and pock size through plaque cloning and cell culture of rabbit kidney cells. Clinical trials in the 1970s, which enrolled approximately 100,000 infants, revealed that the induced immunity level was similar to that of the Lister strain without any of the serious adverse events.[12] LC16m8 is known to induce fewer neurotoxicity and dermal reactions, because it lacks the B5R gene that encodes the envelope protein. Although LC16m8 has never been used to prevent smallpox in the field, an animal model of *Orthopoxvirus* infection showed adequate immunogenic reaction to LC16m8 as well as a full protective effect.[12] A recent study by Japan Self-Defense Forces (JSDF) personnel found immunogenicity in vaccine-naïve adults as well as an excellent booster effect in previously vaccinated individuals (no serious adverse events were observed).[13] These findings indicate that LC16m8 is a good candidate for national use, given its high safety and immunogenicity. Although vaccination is the only effective tool for controlling smallpox, the global eradication program has made it possible to discontinue routine global vaccination. In the past, smallpox was targeted to military personnel, although there has been a recent shift to potentially targeting civilians, which would result in enormous individual, social, and economic harm. Concerning emergency preparedness, the potentially susceptible population must be estimated, and a national vaccination policy developed. In Japan, the current supply of smallpox vaccine is exclusively LC16m8. Although it has never been tested in the field, and further investigation into its use in immunocompromised or atopic cases is important, LC16m8 is a suitable candidate for a national stockpile.

Initiation of Military Response to a Biological Attack

In the event of CBRN weapons that do not correspond to an armed attack, but against which the general police force alone cannot maintain public security, the JSDF will assist in the response. The JSDF will coordinate with public security personnel to suppress a biological attack and assist victims in cooperation with related agencies. In preparation, the JSDF has improved their capability for responding to a CBRN attack by forming the Central CBRN Weapon Defense Unit under the Central Readiness Force and ensuring that each division has a counter-CBRN unit. Upgrades to specialized CBRN equipment are ongoing, including armored reconnaissance vehicles, field detection devices, decontamination vehicles, personal protective gear, portable automatic biological sensors, and new decontamination kits. In addition, the JSDF has designated personnel to take immediate action in CBRN events, which will facilitate a response in approximately 1 hour. The JSDF has also engaged in efforts to establish and improve partnerships with relevant external institutions, including local authorities and police and fire departments. These efforts include launching the first-ever joint training exercise for civil protection in preparation for possible terrorism.

DISCUSSION

Extensive efforts have been made to ensure that national and international relationships are available to support the response system if the emergency requirements exceed normal medical resources. In this section, we examine integration of expertise and the provision of a sustainable response in the case of a smallpox pandemic.

Strengthening Public Health Capacity Against Bioterrorism

One specialist stated the opinion that although the risk of a large-scale biological incident is not high, unless the international community takes decisive action, there is still a concern that biological attacks could be used by terrorist groups.[14] In such a case, first responders would include rescue workers, security personnel, health care providers, and clinicians, all working together to contain the public health emergency. Therefore, every responder is expected to play a pivotal role and can prepare by fostering strong and responsible partnerships. To this end, each responder must understand how to organize and utilize all available resources in order to support optimal outcomes.

During the initial phase, the most important consideration is establishing an effective command structure. The Incident Command System (ICS) provides a relevant command structure that can produce solutions in the face of difficult situations. The ability of the ICS to integrate multiple local and national organizations into a coordinated response makes it particularly suitable for use during biological attacks.[15] To strengthen Japan's surge capacity against a biological attack, the ICS plays an important role in the current incident response training. To manage the large number of patients, most key hospitals employ medical staff who have been trained in implementing the ICS during emergencies to efficiently manage resources and personnel.

Promoting Cooperation With International Society

Although emerging infectious diseases may be of great concern to national security, they may also directly affect human health throughout the world. The Global Health Security Initiative (GHSI) is an international partnership intended to strengthen global responses to CBRN threats and pandemic diseases. This partnership was launched in 2001 by ministers of health from Canada, the European Union, France, Germany, Italy, Japan, Mexico, the United Kingdom, and the United States (the WHO serves as an expert advisor). The GHSI was envisaged as an informal group to allow like-minded countries to address health issues of the day, including global health security. According to the recent ministerial meeting in 2013 in Italy, the GHSI has recognized the significance of shared medical information in facilitating public health preparedness for pandemic events.[16] Lessons learned from past outbreaks (eg, avian flu, SARS) indicate that a global network that shares laboratory, sample, and patient information is essential to expediting research and epidemiological surveillance. Japan, as a member of the international community, has recognized the need to take action to meet the health and security needs of the global population.

The new International Health Regulations (IHR) adopted at the WHO assembly of 2005 address an international concern that national borders cannot prevent the spread of infectious diseases, especially those that are airborne. The IHR improves global surveillance, alerts, and response, and all countries, especially industrialized countries, are required to strengthen their existing public health capacity and to contribute to international collaboration.[17] Preventing pandemics requires early detection and containment of any suspicious outbreak, and the international surveillance laid out in the IHR depends upon flexible public health systems and multilateral cooperation.

CONCLUSION

Although bioterrorism may seem like a distant threat, it is important to note that biological agents have been used throughout history and effective responses should be prepared. Many hospitals must improve their response plan through annual training exercises with local health officials, which will further strengthen the national capability to respond appropriately to a biological attack. The most effective response to biological attacks requires close coordination between clinical facilities and public health agencies. Medical and emergency professionals should become familiar with relevant biological agents, which will allow them to manage pandemic situations. Through these steps, individuals contribute to both domestic and international health security.

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Public health activities for mitigation of radiation exposures and risk communication challenges after the Fukushima nuclear accident

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ABSTRACT

Herein we summarize the public health actions taken to mitigate exposure of the public to radiation after the Fukushima accident that occurred on 11 March 2011 in order to record valuable lessons learned for disaster preparedness. Evacuations from the radiation-affected areas and control of the distribution of various food products contributed to the reduction of external and internal radiation exposure resulting from the Fukushima incident. However, risk communication is also an important issue during the emergency response effort and subsequent phases of dealiing with a nuclear disaster. To assist with their healing process, sound, reliable scientific information should continue to be disseminated to the radiation-affected communities via two-way communication. We will describe the essential public health actions following a nuclear disaster for the early, intermediate and late phases that will be useful for radiological preparedness planning in response to other nuclear or radiological disasters.

KEYWORDS: disaster preparation, Fukushima, nuclear disaster, public health, radiation exposure, risk communication

INTRODUCTION

During radiological emergencies, many public health actions need to be coordinated in order to best protect the health of the affected populations. As has been recently pointed out, such public health protections may need to be enforced for years to come [1]. The following presents the case of the public health actions taken after the Fukushima earthquake, tsunami, and subsequent radiological disaster of 2011.

The Great East Japan Earthquake and Tsunami of 2011, a magnitude 9.0 earthquake with a 14-m or more tsunami following, occurred on 11 March 2011. This disaster left approximately 18 000 people dead or missing. The Great East Japan Earthquake and Tsunami severely damaged the Fukushima Daiichi Nuclear Power Plant 1 (henceforth referred to as the 'damaged reactors'), owned and operated by the Tokyo Electric Power Company (TEPCO), resulting in a large release of radioactivity into the environment. Radionuclides were released into the atmosphere by hydrogen gas explosions from the damaged reactor [2]. This serious event has been temporarily classified as Level 7 on the International Nuclear and Radiological Event Scale ('Severe Accident'), which was also applied in the case of the 1986 Chernobyl power plant accident. The Nuclear and Industrial Safety Agency of Japan (NISA) reported that 1.6×10^{17} Bq of ^{131}Iodine (^{131}I) and 1.5×10^{16} Bq of ^{137}Cesium (^{137}Cs) were released into the environment during the Fukushima event [3]. In comparison, 1.8×10^{18} Bq of ^{131}I and 8.5×10^{16} Bq of ^{137}Cs were released into the environment in the Chernobyl accident [4, 5]. Japan declared a nuclear emergency after the failure of the cooling system at the damaged reactors. International Commission on Radiological Protection (ICRP) Publication 109 indicated that a reference levels should be set in the band of 20–100 mSv effective dose (acute or per year), so the Japanese government tried to limit additional public exposure to radiation to under 20 mSv/year [6]. There are early, intermediate and late disaster response and recovery phases, which have distinctive public health characteristics and parameters. The early phase is dealing with the atmospheric transport of the initial radioactive plumes, which involved the radionuclides of ^{131}I and ^{134}Cs/^{137}Cs in the Fukushima prefecture event for at least 2 weeks after the accident. There are two main ways that radiation exposure occurs with humans: external exposure from radionuclides deposited on the ground and in the radioactive cloud, and internal exposure from inhalation and ingestion of radionuclides in the radioactive cloud and in contaminated food and water, respectively. It is important to avoid the acute doses from inhalation (^{131}I for exposure to the thyroid), and from external exposure (^{134}Cs/^{137}Cs, whole body) by evacuating the affected populations and administering stable iodine (KI) (blocking the radioactive ^{131}I intake). In the intermediate phase, the primary concerns are regarding sheltering, relocation, control of the radioactively contaminated environment, and foods or drinking water intake controls. In the late response and early recovery phases, long-term management and monitoring are necessary to lay the foundation for the long recovery process. Thus, the long-term health of exposed populations requires continued public health tracking.

EVACUATIONS

Approximately 150 000 people in the Fukushima prefecture were evacuated in response to the 2011 Fukushima radiological incident. Evacuation from the 3-km zone was ordered at 21:23 on the evening of 11 March. The evacuation zone was extended to 10 km away from the damaged reactor at 5:44 on 12 March. Finally, the evacuation zone was extended to 20 km within 24 h of the initial release from the damaged reactor. Although some people in the prefectures neighboring Fukushima were voluntary evacuated, mandatory evacuation due to radiological exposure risk was ordered by the Japanese government only in regions of the Fukushima prefecture. Evacuation of hospitalized patients within 20–30 km of the damaged reactor was commenced on 15 March 2011 and completed on 18 March 2011. Some elderly hospital patients died during their transportation. This concern has been well documented by other groups [7, 8].

For predicting the atmospheric transport of radioactive materials, a System for Prediction of Environmental Emergency Dose Information (SPEEDI) was utilized [9]. Unfortunately, the data from SPEEDI had not been used when setting evacuation areas during the early phase of the Fukushima incident. Although residents had been told repeatedly that the radiation level was tolerable, on 11 April 2011 evacuation zones were suddenly extended to incorporate those areas where residents would potentially be exposed to a cumulative effective dose >20 mSv in the first year if they were not evacuated. Residents and some evacuees from the initial evacuation zone were still in this area at that early stage after the Fukushima event. Therefore, untill 16 June 2011, people had been evacuated from these locations. This secondary evacuation caused confusion and mistrust among residents of the area because many were being evacuated for the second time.

IODINE PROPHYLAXIS

In Japan, people usually eat large amounts of seafood, which contains a high concentration of stable iodine [10]. Iodine deficiency is rare in Japanese people, unlike in the people around the Chernobyl Nuclear Power Plant. As mentioned by the World Health Organization (WHO) [11], the high iodine content of the Japanese diet may reduce the uptake of radioactive iodine by the thyroid. At the time of the earthquake, stable iodine had not been pre-distributed to households in Japan. On 13 March, the Central Nuclear Emergency Response Headquarters (NERHQ) instructed evacuees less than 40 years of age to receive stable iodine for the protection of their thyroid from radioiodine as a precaution due to their potential radiation exposure of >10 000 cpm. Administration of stable iodine was not advised for people over 40 years of age because the risk of radiation-induced thyroid cancer is considered to be low in this age group. On 15 March 15 2011, the Nuclear Safety Commission (NSC) advised that the daily potassium iodide (KI) dose was 100 mg for children >13 years of age, 50 mg for children 3–13 years of age, 32.5 mg for infants 1 month – 3 years of age, and 16.3 mg for new-born infants under 1 month of age. Medical personnel were required to assist with the administration of stable iodine to patients with an iodine allergy or thyroid disease. However, this order for administration of stable iodine was not properly communicated to evacuees due to the confusion under the complex disaster circumstances, and KI was not administered to the general population except in a few local areas. In contrast, first responders, such as emergency workers at the Fukushima Nuclear Power Plant, were given KI. After the accident, the Nuclear Regulation Authority mandated the pre-distribution of KI by the local government in case of future accidents [12].

MORGUE MANAGEMENT

Management of dead bodies during disasters is a major public health concern. However, the many deaths in this event were all caused by the tsunamis, not by the radiation exposure. We translated the text of *'Management of Dead Bodies after Disasters: a Field Manual for First Responders'* published by the Pan American Health Organization into Japanese and made it electronically available to emergency managers [13]. Initially, radionuclide-contaminated dead bodies from inside the evacuation zone (within 20 km of the damaged reactor) were washed with water and then transported to outside the evacuation zone. The Ministry of Health, Labour and Welfare (MHLW) rapidly provided a manual for screening dead bodies that was followed in the evacuation zone (within 20 km of the damaged reactor) [14] because such guidelines were not available there. Decontamination was then to be carried out by clothing removal, then the body re-surveyed for radioactivity. Then the dead bodies whose dose rates were less than 10 μSv/h were treated, as with uncontaminated dead bodies. Decontaminated dead bodies with count values >10 μSv/h were washed with a wet towel and then covered with cloth and retained for identification. Initially dead bodies were buried temporarily due to a lack of crematories; however, within a few months almost all dead bodies were cremated.

FOOD AND DRINKING WATER SUPPLY PROTECTON

Before the Fukushima accident, the Japanese government prepared a safety manual for measuring the radioactivity of foods and indices for Food and Beverage intake restriction [15]. These Indices were derived from research following the earlier nuclear accident at the Chernobyl Nuclear Power Plant [15]. The MHLW adopted these Indices as provisional regulation values on 17 March 2011.

Provisional regulation values (PRVs) were based on protective action guides (PAGs) of a 50 mSv/year of thyroid equivalent dose for radioactive iodine and tellurium (^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I, ^{132}Te) and a 5 mSv/year for the effective dose for radioactive cesium and strontium (^{134}Cs, ^{137}Cs, ^{89}Sr, ^{90}Sr) during radiological emergency situations. The basic concept of PAGs and derived intervention levels (DILs) for food control in the Fukushima radiological emergency were described by Yamaguchi in a previous paper [16]. Briefly, after considering the radionuclide transfer characteristics, foods were grouped into five categories: drinking water, milk and dairy products, vegetables, grains, and others (meat, eggs, fish, nuts, etc.). We assumed that people continued to consume foods from the affected area. Derived regulatory values for the intake of each food category were calculated so that the permissible dose would not exceed 5 mSv/year. Non-contaminated food on the market diluted the concentration of contaminated radionuclides in the food supply. Thus, the average concentration of contaminated food was assumed to be half of the peak concentration for the long-lived radionuclides of cesium (physical half-life: 2 years for ^{134}Cs and 30 years for ^{137}Cs) for the induction of DILs. However, that assumption was not applied for short-lived radionuclides of ^{131}I (half-life: 8 days), where we used a dilution factor of 1. The new standard limits for radioactive cesium were established with the goal that the effective dose of radionuclides (including ^{137}Cs, ^{90}Sr, ^{106}ruthenium (^{106}Ru-106), plutonium (Pu) would not exceed 1 mSv/year in affected populations [16]. Standard limits were not established for radioactive iodine (which has a short half-life and is no longer detected at this time) or uranium (the uranium levels are almost the same level in the nuclear power plant site as in the natural environment). We determined that the intervention level to assign to general foods was 100 Bq/kg (500 Bq/kg in general foods for previous PRV) by taking into consideration the food intake and dose coefficient according to specific age categories. According to the MHWL estimation of effective dose from radioactive cesium based on the monitoring data of the radionuclides in foods, the median total committed effective dose was 0.043 mSv; the 90th percentile was 0.074 mSv when non-detected samples were set to be the detection limits for each measurement or 10 Bq/kg for ^{134}Cs and ^{137}Cs, respectively [17]. Natural background radiation has been estimated at 2.4 mSv/year in the world and 2.09 mSv/year in Japan [18, 19]. Compared with natural background radiation, the internal radiation exposure due to contaminated food affected by the Fukushima accident was at a low level. However, some residents outside the evacuation zone might have consumed highly contaminated local food or water before regulation values were in effect. At that time, many residents suffered from a shortage of fresh food and water because of the earthquake, and local farmers had no means of knowing whether their fields were contaminated or not. Some further consideration of the magnitude of any high-dose exposure arising via the ingestion pathway for people outside the evacuation zone might be worthwhile.

EXPOSURE ESTIMATION

Many steps were taken to monitor the radioactivity within the air after the Fukushima event. Various monitoring data from the damaged reactor area suggested that the radiological air emissions occurred from hydrogen explosions, venting and leakage throughout the month of March 2011 [20]. For the rapid assessment of dose rates, a car-borne radiological survey was performed along a motor vehicle expressway northwest of the damaged reactor [21]. The maximum dose rate observed was 11 μGy/h between Fukushima City and Osaki City on 16 March 2011 [21]. In addition to monitoring the ambient radiation dose rate, additional testing was done to measure the radioactive contamination of surfaces, like skin and clothing, of 219 743 evacuees and emergency responders [22, 23].

A basic survey (part of the Fukushima Health Management Survey) began at the end of June 2011 to estimate levels of external radiation exposure, based on behavioral records. Individual external exposure was estimated, based on a respondent's trail, using the system for external exposure dose assessment developed by the National Institute of Radiological Sciences in Japan. Almost all people (99.9%) measured <10 mSv of committed effective dose [24]. Internal contamination can be estimated for evacuees and emergency responders by a nasal smear. However, this test was not carried out because of the many logistical challenges under the complex disaster circumstances. Therefore, such data were not available in the Fukushima incident. The local nuclear emergency response headquarters performed a simplified survey using a Sodium Iodide (NaI) scintillation survey meter for thyroid internal exposure to radioiodine, particularly ^{131}I [25]. From 28–30 March 2011 they surveyed 1149 children aged 0–15 years who were living in areas with relatively high radiation dose rates (Iwaki City, Kawamata Town and Iitate Village). Sixty-six people were unable to be measured appropriately due to a higher radiation background from radio-contaminated soil at the survey site. The thyroid radiation dose was estimated for other groups [26, 27]. The survey results for all people tested were below a thyroid equivalent dose of 100 mSv. For Fukushima residents in areas where the possibility of internal exposure might be relatively high, internal radiation levels were measured using a whole-body counter (WBC) within two years of the disaster [28, 29]. Almost all people (99.9%) measured <1 mSv of committed effective dose. Only 26 of the 90 024 total people tested measure >1 mSv. The maximum internal exposure level was 3 mSv. Fortunately, no case of acute health problems resulting exclusively from radiation exposure has yet been reported in the Fukushima event. Thus, Fukushima area residents and emergency responders were apparently not exposed to radiation doses higher than the threshold for induction of deterministic effects.

The WHO conservatively estimated that the effective doses during the first year following the Fukushima event in the most affected region of Namie town and Iitate village would have been 10–50 mSv [11] if they had not been evacuated. These values have been revised to 12–25 mSv [30]. In the rest of Fukushima prefecture, the effective dose was estimated to be within a dose band of 1–10 mSv. Effective doses for most of Japan were estimated to be within a dose band of 0.1–1 mSv, and in the rest of world, all the doses were estimated to be <0.01 mSv [11]. As described in the WHO reports, a comparison was made between the doses estimated by WHO and those estimated from direct measurements of radionuclides in Japanese residents. This gave the government health officials confidence that the estimated doses did not underestimate the actual dose in Japan [11]. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimated that the evacuation of settlements within the 20-km zone averted effective doses to adults of up to ~50 mSv and absorbed doses to the thyroid of 1-year-old infants of up to about 750 mGy [31]. Although UNSCEAR estimated radiation doses to the public by assuming more realistic scenarios than those that WHO adapted, there are still uncertainties associated with the results as a result of incomplete knowledge and information.

For example, to estimate the maximum ingestion dose among general residents in Fukushima precisely, more detailed analysis should be considered.

DECONTAMINATION AND DECOMMISSIONING

In order to mitigate public radiation exposure from contaminated soil, the Japanese government decided to carry out decontamination work. Establishing the Act on Special Measures concerning the Handling of Pollution by Radioactive Materials that was fully put into force on 1 January 2012, the Ministry of Environment committed itself to measuring and monitoring the radioactive contamination of the environment, and to processing the disposal of contaminated soil and wastes removed by decontamination activities. The Japanease goverment conducted the decontamination work in a special decontamination area within the former restricted zone or planned evacuation zone, whereas it was conducted by each municipality in other areas where the air dose rate was >0.23 μSv/h (equivalent to 1 mSv/year). The aim of decontanination is to reduce the additional exposure dose to <1 mSv/year for areas where the radiation exposure dose is <20 mSv/year. In the case of a radiation exposure dose range from 20 to 50 mSv/year, the long-term aim of decontamination is to reduce the additional radiation dose to <20 mSv/year in residential and farmland areas. Decontamination should be implemented taking into consideration in future decontamination policy for extremely high-dose areas of >50 mSv/year. Radiation protection should be planned for workers, including decontamination workers. This topic has been well documented in another paper [32]. We also summarized health management and radiation protection for radiation workers involved in the Fukushima accident in a previous paper [33]. In addition, the radiation safety of radiation workers engaged in decommissioning the nuclear power plant should be secured. During the fiscal year ending November 2014, radiation doses of 17 317 workers at the Fukushima Daiichi Nuclear Power Plant were monitored. Among these, although radiation doses to 468 workers were >20 mSv, all workers were <50 mSv [34].

RISK COMMUNICATION

Risk communication is considered an important issue during the early emergency situation [35]. Appropriate and targeted risk communication can help to reduce the health impact of radiation emergencies and help promote food safety and food security [36]. The risk communication scientific literature has significantly contributed to our current understanding of the existing exposure situation in the Fukushima region today. WHO is trying to develop a risk communication tool that can guide policy makers, national and local governments and the medical community to establish risk consensus in public communication.

Communication difficulties between local governments, scientific experts and the local citizens were a major concern during the early radiation safety response in the Fukushima incident, and they have been recognized to be one of the difficult issues in affected areas during three years. Confusing messages in the inital phase (such as the reference level for schools), confusion about setting of deliberate evacuation areas, and difficulties in human relationships exacerbated by compensation issues associated with specific spots recommended for evacuations and the surrounding areas caused severe difficulties in risk communication. Public health nurses have been assisting in the recovery of local communities by empowering them [37]. Public health nurses have strong communication skills. Improving nurse's health literacy skills helps in the process of effective communication. WHO reported that mental, psychological and central nervous system effects following the Chernobyl accident were due to the mental stress from fear of radiation exposure [38]. The same thing has been occurring again after the Fukushima incident [39]. There are serious concerns about mental health in relation to the Fukushima incident, including stress-related symptoms, and a potentially elevated suicide rate in Fukushima clean-up workers. The reference dose was changed from 1 mSv/year to 20 mSv/year under the existing exposure situation after the Fukushima incident, consistent with ICRP publication 60 [40]. This change was not acceptable to the public due to the lack of proper risk communication. Risk communication should be organized according to a sound strategy based on public health ethics and scientific evidence [36]. Messages to the public about the radiation risks due to the Fukushima nuclear disaster have been misunderstood because of the inappropriate manner of risk communication that has been used, without deep consideration of the situation of each person within the audience. We learned that to deal with the difficulty of risk communication we should strengthen the relationship with social scientists to find good approach. Stakeholder involvement in post-nuclear or post-radiological emergency management is a key to resolving this problem. Indeed, stakeholder involvement in preparedness planning in the UK seems to be partially adaptable to the situation in Fukushima [41–43]. For example, one of the main topics for the UK Agriculture and Food Countermeasures Working Group in this workshop was the issue of the disposal of contaminated dairy milk, which was a very real issue in Fukushima [44]. Also, in the workshop organized by the Organisation for Economic Co-operation and Development – Nuclear Energy Agency to discuss issues concerning recovery from a nuclear accident, involving relevant stakeholders in Fukushima, it was suggested that the stakeholder involvement provided a good opportunity for networking together to resolve the outstanding communication challenges.

PUBLIC HEALTH PREPAREDNESS FOR FUTURE NUCLEAR DISASTERS

Development of planning guidance is proposed for preparation in advance of a nuclear detonation [45]. The International Atomic Energy Agency (IAEA) previously published information on the importance of preparedness and emergency management plans in response to a nuclear disaster on public health [46, 47]. We have summarized public health actions after the Fukushima incident in order to provide valuable lessons for disaster preparedness (Table 1). Because this disaster was a combined severe disaster involving environmental contamination, evacuation of hospital patients and elderly persons who were not ambulatory created many challenges. Some of evacuees from Fukushima were rejected in hospitals and nursery homes basically due to confusion over radiation risk. Although the Radiation Emergency Medicine Information network (REMNET) (an informative website for radiation emergency medical information in Japan) has been established and provides many training courses, secondary or lower-level network hospitals did not sufficiently receive

Table 1. Public health actions after the Fukushima incident

	What has been done at the Fukushima incident	Problem to be solved	Proposed guideline for nuclear disaster preparedness
1. Evacuations	• Evacuation zone was set within 24 h after the initial release from the damaged reactor. • Evacuation of hospitalized patients within 20–30 km from the damaged reactor was delayed.	• Setting of planned evacuation areas and transition from the emergency exposure situation to the existing exposure situation. • Some hospital patients with advanced disease died during transportation.	• Radioprotection action of evacuation should be done 1 day after a nuclear incident according to the contamination level (Refer to Operational Intervention Level) and step-by-step radiation protection considering the local situation. • Pay attention to evacuation of hospital patients immediately after the nuclear incident.
2. Exposure estimation	Radiological assessments were utilized for dose estimation including internal dose of thyroid exposure.	• Due to the high background radiation, the detection limit was elevated so that radiological judgement became difficult for relatively lower exposures. • Individual dose calculation is challenging to estimate at present because of insufficient datasets.	• Monitoring systems should be prepared on the assumption of insufficient materials due to the complex disaster. • Biospecimens shoud be collected during the emergency exposure situation for later dose accuracy etimation.
3. Iodine prophylaxis	NSC advised nuclear emergency response headquarters on administration of stable iodine in case surface contamination was above 10 000 cpm by using ordinary GM survey meters. However, headquarters failed to instruct local governments.	Administration of stable iodine was not conducted for the general population.	• Stable iodine should be administrated to people who are potentially exposed to a thyroid equivalent dose of >50 mSv. • Local governments should provide stable iodine to the general public.
4. Risk communication	Lack of proper risk communication during the emergency exposure situation.	• Misunderstanding of messages to the public about the radiation risks. • Difficulty of risk communication without a planned strategy and scientific evidence in social sciences.	• Building capacity in risk communication and paradigm shift in communication approaches are challenging issues.

such training. Because it is very common for each hospital to treat radioactive patients outside a nuclear medicine department, the general principle should be preparedness for radiation protection in the entire hospital. Furthermore, although REMNET has provided educational courses that have dealt with internal radiation exposure, training for external measurement using a WBC was insufficient for almost all hospitals equipped with WBCs, and the use of bioassay samples, such as nasal swabs, were very limited. In addition, the public health rationale for exposure screening using a survey meter was not well communicated in Fukushima. The main role of such screening should be for iodine prophylaxis decision-making. Excessive attention to decontamination and the lack of sufficient decontamination resources due to the massive contamination in Fukushima caused the change in the screening level to rise from 13 000 cpm to 100 000 cpm. This level corresponds to a dose rate of 1 μSv/h at a distance of 10 cm as the screening level of first responders, according

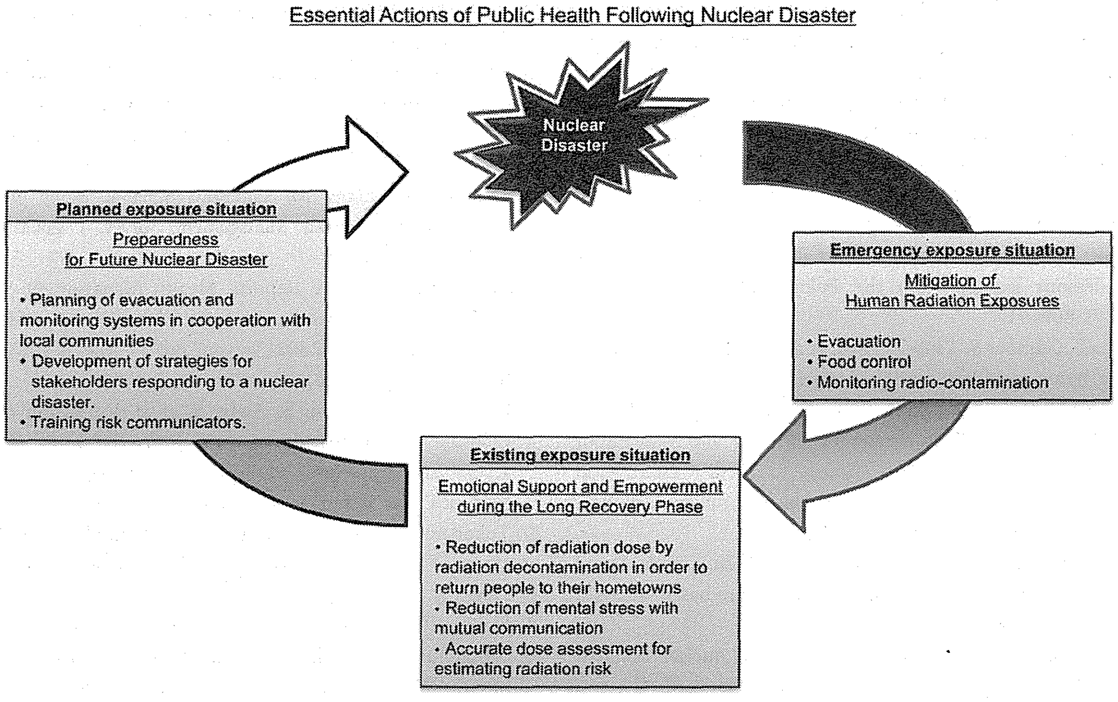

Fig. 1. Public Health Actions in response to nuclear disaster. Essential public health actions under emergency exposure situation, the existing exposure situation and a planned exposure situation are represented.

to the *'Manual for First Responders to a Radiological Emergency'* published by the IAEA [48].

Essential public health actions are depicted in Fig. 1 for 'emergency exposure situations', 'existing exposure situations' and 'planned exposure situations', as defined by ICRP [49]. In an emergency situation, evacuation and food control during the early phase of the emergency response contributes to mitigating human exposures to radioisotopes after the nuclear disaster. Monitoring radio-contamination data during the emergency exposure situation, such as monitoring of radioactivity concentrations in air, radioactive contamination of surfaces, internal contamination of a nasal smear and thyroid internal exposure, are essential for accurate estimation of the effective doses. Under the existing exposure situation, there have been major concerns about public health and the future of the Fukushima children due to internal exposure caused by food consumption and external exposure during daily life. In order to return to their hometown, decontamination was carried out in radiation-affected areas to reduce the existing radiation exposure dose. For the people who live in these affected areas, we should provide accurate radiological evaluations of sustainable living conditions, including assessments based on their respective lifestyles and livelihoods. In the preparation phase, evacuation and monitoring systems should be planned in cooperation with local communities. Strategies for responding to a nuclear disaster should be developed by the stakeholders in preparation for a future nuclear disaster.

All aspects of daily life in Fukushima have been affected by the nuclear disaster. The rich agricultural environment of Fukushima has been ruined. Although members of the public were exposed to low levels of radiation from Fukushima incident, we should continue to support risk communication activities in Fukushima about the public health ethics perspective under the existing exposure situations so that public health is protected. We need to tackle radiological preparedness planning for public health in case of future nuclear disasters under preparation phase.

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Paper

ASSESSING THE EFFECTIVENESS OF RISK COMMUNICATION FOR MAINTENANCE WORKERS WHO DEAL WITH INDUCED RADIOACTIVITY MANAGEMENT OF MEDICAL LINEAR ACCELERATORS

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Abstract—**In Japan, an amended law that mandates levels of unintended induced radioactivity has been in effect since 1 April 2012. According to the new regulation, if the concentration of induced radioactivity in affected parts is above the clearance level, the parts must be regarded as radioactive even if they weigh less than 1 kg. This regulation reform raises several new issues concerning medical linear accelerators, including how to determine the decay period for induced radioactivity before maintenance can be performed and how to identify what parts should be considered radioactive waste. The authors performed several risk communication (RC) activities aimed at improving the understanding of maintenance workers at medical accelerator manufacturers and establishing good guidelines by involving stakeholders. For this purpose, a working group was established and conducted RC activities, such as holding opinion exchange meetings between medical staff and maintenance workers and creating a booklet to answer questions from maintenance workers. To evaluate these activities, three questionnaire surveys were conducted between 2011 and 2014. According to the results of this study, the ratio of maintenance workers who accepted "The decay period is within one week" was approximately 60% at the third survey and significantly increased ($P < 0.0001$) during the survey period. Approximately 25% of the maintenance workers felt that not enough information was provided about the decay period, and approximately 63% thought that the information provided on the health effects of radiation was sufficient. These results suggest that the present RC was successful.**

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Key words: accelerators; occupational safety; radiation protection; radiation therapy; risk communication

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The authors declare no conflicts of interest.

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INTRODUCTION

THE TARGET and peripheral parts of a linear accelerator are activated by photonuclear reactions and subsequent secondary neutron capture. Exposure of medical and maintenance workers to radiation from induced radioactivity in medical linear accelerators has been reported (Almen et al. 1991; Beckham 1990; Rawlinson et al. 2002; Perrin et al. 2003; Fischer et al. 2008; Fukuma et al. 2010; Suzuki et al. 2010). The authors detected several induced radionuclides, such as ^{24}Na, ^{28}Al, ^{54}Mn, ^{56}Mn, ^{57}Ni, ^{58}Co, ^{60}Co, ^{64}Cu, ^{65}Zn, ^{122}Sb, ^{124}Sb, ^{181}W, ^{187}W, ^{196}Au, and ^{198}Au, using a high-purity germanium detector-based gamma spectrometer (Fujibuchi et al. 2011). The ambient dose equivalent rate at 20 cm from the target was approximately 20 μSv h^{-1}. However, the law for management of induced radioactivity in medical linear accelerators has not been clearly outlined in Japan. Therefore, an amended law that covers comprehensive unintended induced radioactivity using clearance levels for radioactive waste was drafted on 10 May 2010 and came into force on 1 April 2012; transitional measures ended in April 2014 in Japan.

The International Electrotechnical Commission regulations have provisions for induced radioactivity in medical linear accelerators (IEC 2009), but the established regulation based on the clearance levels is the first in the world. Therefore, a joint working group (WG) on induced radioactivity and clearance, comprising medical societies and organizations, was formed to collaborate on drafting reasonable legislation. Activities of the WG included gathering scientific evidence of actual use (Yamaguchi et al. 2010), determining the range of radioactivity concentration associated with induced radionuclides, and measuring the radiation exposure rate around the radioactive parts of medical linear accelerators. Activities of the WG over the last 10 y include 23 meetings, measurement of induced radioactivity, and creating the society's standards. The WG comprised members dispatched from societies and organizations related to radiation therapy as well as representatives from the maintenance departments of each of the five manufacturers of radiation therapy equipment.

The main issues to incorporate into the new laws are: 1) to determine the decay period for induced radioactivity in medical linear accelerators for manual dismantling before replacement or removal, 2) to secure a safe environment for maintenance workers who work near the accelerator, and 3) to disseminate radiation management standards for induced radioactivity and provide an overview of the amended law.

The first risk communication (RC) for the maintenance workers of medical linear accelerators with the aim of improving staff understanding on these issues (Watanabe et al. 2013) took place in 2012.

The authors found that although the maintenance workers understood that the radiation dose that they receive during their work is small, they felt that information on induced radioactivity provided by hospitals was insufficient and additional explanation about its effects on the human body was needed.

Furthermore, it was found that there was a lack of information for deepening their understanding of an adequate decay period. Therefore, a second RC based on the results of the first, short-term RC was performed with the aim of deepening the understanding of the maintenance workers.

MATERIALS AND METHODS

Distribution, collection, and contents of the questionnaire

The questionnaire was sent to each member of the maintenance staff, and the answers were collected at each manufacturer anonymously. According to the previous survey, the first intervention did not help workers formulate their own opinions on the decay period, nor did it give sufficient information on the effects of radiation. The survey questions were developed to assess factors related to the main issues to incorporate into the new laws. The questionnaire was vetted in a small preliminary study but not validated, since it was the first attempt to survey workers' attitudes toward induced radioactivity in medical accelerators.

The following manufacturers participated in the study: Toshiba Medical Systems Corporation, Varian Medical Systems, Elekta Corporation, Hitachi Medical Corporation, and Siemens Japan KK. The questionnaire included questions about the reasonableness of the amended law on induced radioactivity regulation, concerns about radiation in controlled areas, the effects of radiation on the human body, and the decay period for induced radioactivity in medical linear accelerators for the purpose of dismantling, among others. The first investigation (before the first RC) was conducted in October 2011, the second (after the first RC) in March 2012, and the third (after the second RC) in March 2013.

RC activities as interventional studies

The following activities were performed during the RC for the maintenance staff.

First edition booklets (A5-size, 26 pages) were distributed on 1 February 2012 (Radioactive Waste Research Group of The Japanese Society of Radiological Technologists 2012). The contents included: effects of radiation on the human body (four pages); actual occupational exposure of the maintenance staff (one page); mechanisms of activation, induced radioactivity level in accelerator parts (six pages); method and work flow to process induced radioactivity (two pages); purpose and overview of the new regulation (two pages); clearance system (three pages); basic information about radiation (four pages); the purpose of the booklet, and other information (four pages).

A 2.5-h seminar on the standards established by related scientific societies for the disposal and management of induced radioactivity associated with using medical linear accelerators was held on 7 February 2012. The contents of the seminar included an overview of new regulation enforcement due to the newly introduced clearance system, a review of the society standards draft, and an exchange of opinions.

The draft of the society standards was published on the website of the Japanese Society of Radiological Technologists on 10 July 2012. The contents of the draft included the handling of induced radioactivity (seven pages); radiation measurement (10 pages); purpose, scope, and energy classification (one page); preparation of medical institutions (six pages); education, training, and medical examination (three pages); application based on the relevant laws and regulations (three pages); questions and answers (four pages); and other information (12 pages).

A 90-min radiation management forum was held on 13 April 2013. Forum attendees, including representatives of the maintenance departments of two radiation therapy equipment manufacturers, radiologic technologists who

Table 1. Relationship between occupation and timing of risk communication.[a]

Occupation	Ratio at each timing of inquiry comparing the risk communication (RC) program (%)		
	Before 1st RC	After 1st RC	After 2nd RC
Operating and checking the accelerator	70	67	83
Installing and dismantling the accelerator	67	46	46
Constructing a building	4	4	0
Assembling equipment and accessories	14	9	2
Managing waste disposal	7	9	11
Measuring radiation	3	5	2
Others	5	6	3

[a]Occupations did not change during the RC.

have experience with induced radioactivity management based on the new regulation in medical institutions, and attendees from the first RC, exchanged opinions on "How the management and disposal of parts containing induced radioactivity should be performed."

A meeting on the management of induced radioactivity in medical linear accelerators was held on 17 December 2013. During the meeting, a draft of guidelines developed by scientific societies and organizations was circulated, and the actual work involved in dismantling medical linear accelerators, the exposure of maintenance staff, and effects of radiation on the human body were discussed. Information on the type and amount of induced radioactivity and a methodology for determining the decay period were provided, including how to convert the dose rate around an assembly to the amount of induced radioactivity based on the decay period.

Afterward, opinions were exchanged between the maintenance staff of medical linear accelerators and the radiologic technologists of the medical institutions. A paper on the results of the first RC was published in December 2013. The second edition of the booklet (A5-size, 26 pages) was distributed on 1 February 2014 and included revisions of the induced radioactivity management flow, a concept of the effects of low-dose radiation exposure on the human body, and the latest exposure data for the maintenance staff (four pages).

Ethics and statistical analysis

This study was approved by the Yokohama Rosai Hospital Ethics Committee (approval number: 25-21). Statistical analysis was performed with Ekuseru-Toukei 2012 (Social Survey Research Information Co., Ltd.) and R version 2.14.1 (R Development Core Team 2011). For identical questions in the three questionnaires, an independence test using the chi-squared distribution was performed for categorical data aggregated in a contingency table. In addition, in the case of more than three groups, Kruskal-Wallis tests with the Steel-Dwass method for non-parametric data, or sequential Bonferroni adjustments for pair-wise comparisons in categorical data, were used for comparison. Differences with $P < 0.05$ were considered significant. The results for company E were excluded because their response ratios were low.

RESULTS

Response ratios

Questionnaires were distributed to 135 workers before the first RC, 137 workers after the first RC, and 174 workers after the second RC, and responses were received from 81, 72, and 130 workers, respectively, for each (response ratios were 60, 53, and 75% with valid response ratios of 60, 53, and 75%, respectively). The results below are presented in a similar order (i.e., before the first RC, after the first RC, and after the second RC).

The number of questionnaires distributed and the response ratios for the second RC increased by approximately 30% compared to before the first RC and after the first RC. The response ratios increased significantly (before first RC

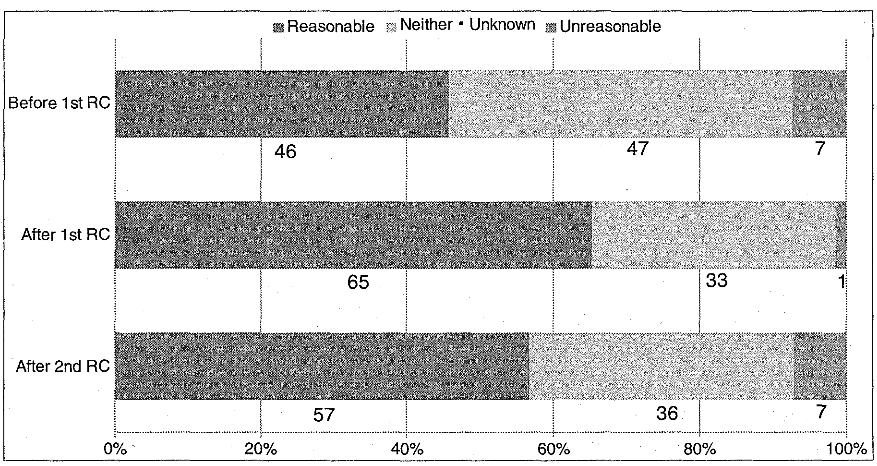

Fig. 1. Do you think that a decay period should be decided by the maximum x-ray energy?

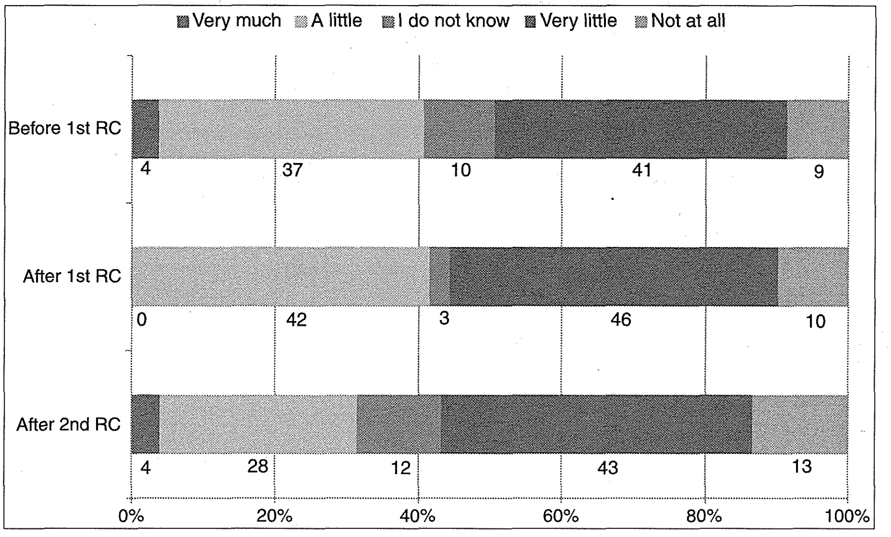

Fig. 2. Do you have concerns about radiation in controlled areas?

vs. after second RC: $P < 0.01$, after first RC vs. after second RC: $P < 0.001$).

Occupations

Table 1 shows the occupations of the responders. The proportions of workers in charge of operating and checking accelerators were 70, 67, and 83%, respectively. The proportions of maintenance workers involved with installing and dismantling accelerators were 67, 46, and 46%, respectively.

Classification based on the maximum x-ray energy

Fig. 1 shows the results of examining the reasonableness of determining the range of induced radioactivity based on the maximum x-ray energy. The response ratios for "Reasonable" responses were 46, 65, and 57%, respectively, and those for "Unreasonable" were 7, 1, and 7%, respectively.

Concerns about radiation in controlled areas

Fig. 2 shows the results of concerns about radiation in controlled areas. The response ratios for "Very much" and "A little" were 41% before the first RC, 42% after the first RC, and 32% after the second RC. These did not decrease significantly from before the first RC to after the second RC (Before RC vs. after 2nd RC : $P = 0.38$, after 1st RC vs. after 2nd RC : $P = 0.77$).

Effects of radiation on the human body

Fig. 3 shows the results for "Do you think radiation affects your health during work?" The response ratios for "Very little" and "Not at all" were 70% before the first RC, 78% after the first RC, and 59% after the second RC. The extreme answers were reduced after the second RC

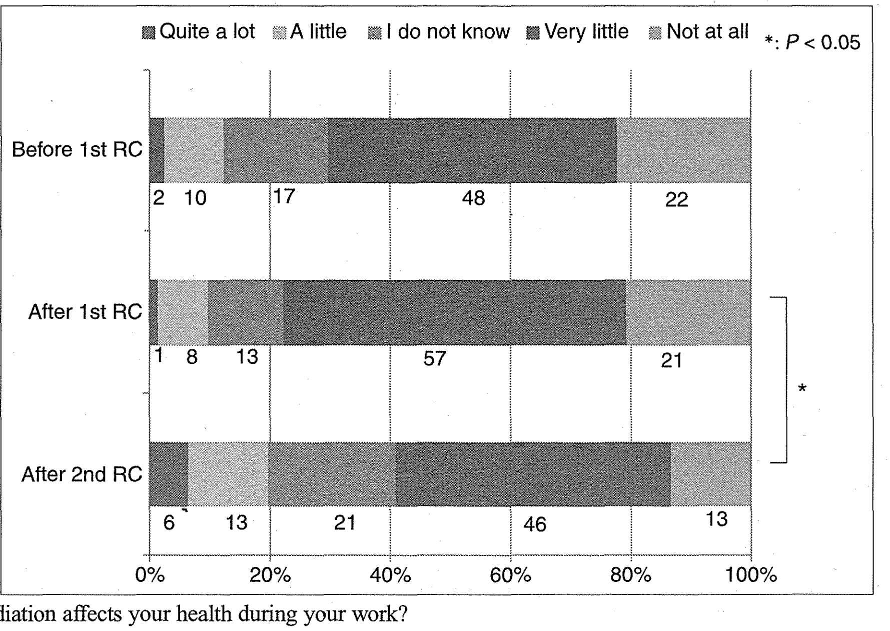

Fig. 3. Do you think radiation affects your health during your work?

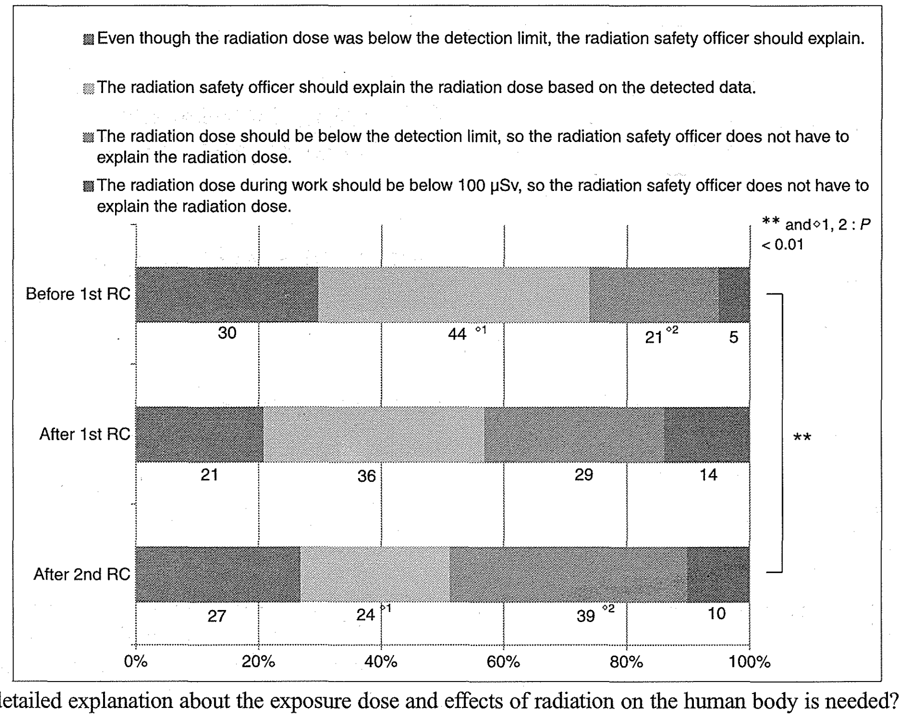

Fig. 4. Do you feel a detailed explanation about the exposure dose and effects of radiation on the human body is needed?

compared to before the first RC ($P = 0.094$), and reduced after the second RC compared to after the first RC ($P = 0.019$).

Detailed explanation about the exposure dose and effects of radiation on the human body

Fig. 4 shows the results for "Do you feel a detailed explanation about the exposure dose and effects of radiation on the human body is needed?"

The response ratios for "Even though the radiation dose was below the detection limit, the radiation safety officer should still explain" were 30% before the first RC, 21% after the first RC, and 27% after the second RC, and those for "The radiation safety officer should explain the radiation dose based on the detected data" were 44, 36, and 24% (before first RC vs. after second RC: $P = 0.0025$), respectively. The response ratios for "The radiation dose should be below the detection limit, so the radiation safety officer does not have to explain the radiation dose" were 21, 29, and 39%, respectively (before first RC vs. after second RC: $P = 0.0078$), and those for "The radiation dose during work should be below 100 μSv, so the radiation safety officer does not have to explain the radiation dose" were 5, 14, and 10%, respectively.

The response ratios for "Explanation is required" were 74% before the first RC, 57% after the first RC and 51% after the second RC, and those for "Explanation is not required" were 26, 43 and 49%, respectively. Comparing the response ratios from before the first RC to after the second RC, the requirement for an explanation decreased ($P = 0.00011$).

Providing information on human body effects

The results for responses about information being provided for the understanding of the effects of radiation on the human body were: "Very much" at 29%, "Minimum necessary" at 34%, "No opinion" at 28%, "A little" at 8%, and "Not at all" at 2%. Two-thirds (63%) of the maintenance workers think radiation has some effect on the human body.

Decay period

Table 2 shows the results for questions regarding the decay period for induced radioactivity in a 6–10 MeV

Table 2. How long should the decay period be?[a]

	Ratio at each timing of inquiry comparing the risk communication (RC) program (%)					
Decay period or other options	Before 1st RC		After 1st RC		After 2nd RC	
Less than 3 d	14	14◇1	8	8◇2	42	59◇1,2
Less than 1 wk	0		0		17	
At least 1 wk	15	15	13	13	20	20
I do not know, or, response other than a specific period	72	72◇3	79	79◇4	21	21◇3,4

[a]Note: In before 1st RC and after 1st RC, responses that depend on the physical mechanism, the results of each measurement and the maximum x-ray energy, etc. are included in "response other than a specific period". ◇1, 2, 3, 4 : $P < 0.0001$.

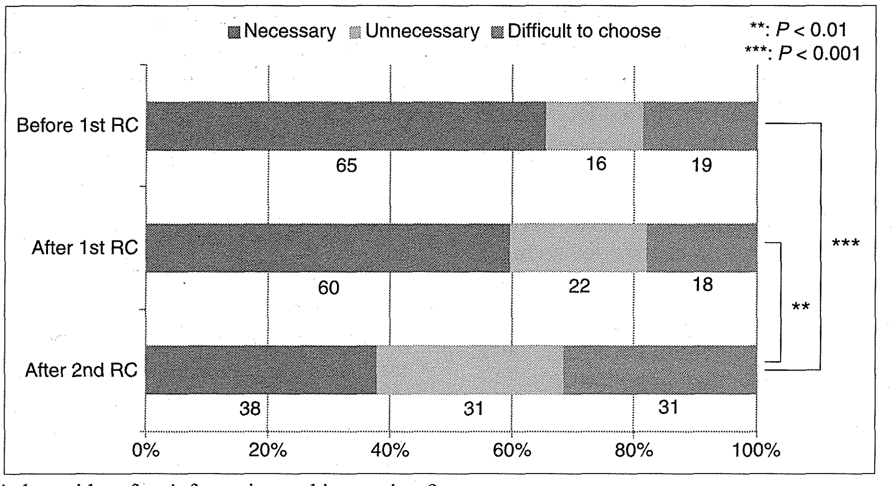

Fig. 5. Should the hospital provide safety information and instructions?

medical linear accelerator. Response ratios for "Within three days (The shortest of the society standards)" were 14% before the first RC, 8% after the first RC, and 42% after the second RC; those for "Less than 7 days but more than 4 days" were 0, 0, and 17%, respectively; those for "More than 7 days" were 15, 13, and 20%, respectively; and those for "I do not know" or a response other than a specific period were 72, 79, and 21%, respectively.

The proportions of those answering that before the amendment of the law, the decay period was, on average, less than 7 d were 13, 8, and 59%, respectively (before first RC vs. after first RC and after second RC: both, $P < 0.0001$).

Are there problems with how the current decay period is determined?

Results on whether there are problems with how the current decay period is determined were "Very much" at 2%, "A little" at 13%, "I do not know" at 60%, "Very little" at 17%, and "Not at all" at 7%.

Specific reasons for problems with how the current decay period is determined

The specific reasons workers answered "Very much" and "A little" regarding problems with how the current decay period is determined (multiple answers possible) were analyzed. Approximately 80% answered, "The decay period should be determined based on the situation regarding induced radioactivity, but it is not possible;" 50% answered, "It has not been sufficiently discussed between manufacturers and medical institutions yet;" and 15% answered, "It has not been sufficiently discussed by individual manufacturers yet."

Should the hospital provide safety information and instructions?

Fig. 5 shows the results for "Should the hospital provide safety information and instructions?" The proportions

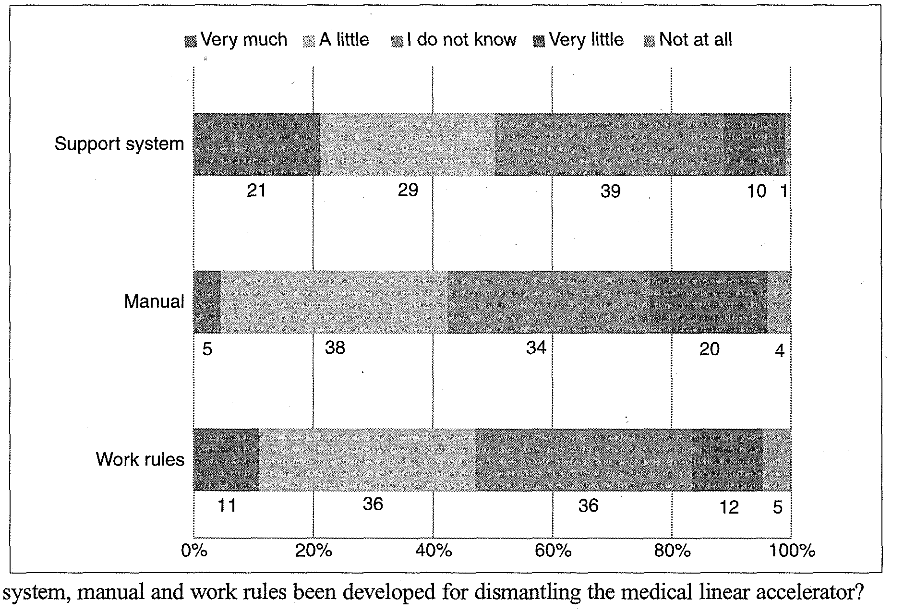

Fig. 6. Have a support system, manual and work rules been developed for dismantling the medical linear accelerator?

of those stating safety information and instructions are "Necessary" were 65% before the first RC, 60% after the first RC, and 38% after the second RC, and had significantly decreased by the second RC (before first RC vs. after second RC: $P = 0.0011$ after first RC vs. after second RC $P = 0.009$).

Was information provided to determine the decay period?

Regarding whether information was provided about induced radioactivity and estimated exposure dose for maintenance staff in order to determine the decay period; 8% responded "Very much," 25% "Minimum necessary," 40% "Neither," 24% "A little," and 2% "Not at all."

Equipment dismantling system

Fig. 6 shows the results for the support system, development of a manual, and work rules to accurately dismantle the equipment, including how to deal with induced radioactivity.

Response ratios for the development of a support system were: "Very much" at 21%, "A little" at 29%, "No opinion" at 39%, "Very little" at 10%, and "Not at all" at 1%.

Results for the demand for development of a manual for the management of induced radioactivity and dismantling were: "Very much" at 5%, "A little" at 38%, "No opinion" at 34%, "Very little" at 20%, and "Not at all" at 4%.

Results for whether the dismantling rules became clearer were: "Very much" at 11%, "A little" at 36%, "No opinion" at 36%, "Very little" at 12%, and "Not at all" at 5%.

Concerns about dismantling medical linear accelerators

To dismantle a 6–10 MeV medical linear accelerator, many parts need to be managed and fractionation needs to be performed in order to contain induced radioactivity. Therefore, workers' concerns were investigated. Fig. 7 shows the results for concern regarding dismantling medical linear accelerators. Response ratios for "Very much" and "A little" were 56% before the first RC, 43% after the first RC, and 34% after the second RC, but the decrease was not significant (before first RC vs. after second RC: $P = 0.27$, after first RC vs. after second RC: $P = 0.99$).

DISCUSSION

Decay period

The new regulations require users to determine the decay period for radioactive components. Until the new regulations were implemented, the decay period was determined on a case-by-case basis without clear criteria. The new regulations provide the clearance level as one of the criteria for induced radioactivity. This makes it possible to show model cases. According to the results of this study, as a suitable decay period for the replacement or removal of an activated linear accelerator, selections of "less than a week" were significantly increased (before first RC vs. after first RC and after second RC: $P < 0.0001$). In addition, approximately 60% of workers supported the typical decay period before the amendment, because the decay period before the amendment was approximately 1 wk. The result for "three days" was 42%, which also indicates that shortening the period is possible by applying the new criteria. Only 15% responded that there is a problem with the current method for determining the decay period. Furthermore, about a quarter of the respondents stated that not enough information to determine the decay period is provided. Of the respondents, 38% stated that an explanation is required from the medical institution on radiation safety, which was significantly decreased after each RC (before first RC vs. after second RC $P < 0.01$, after first RC vs. after second RC: $P < 0.001$). These results indicate that the RC helped many maintenance workers deepen their understanding of the decay period and that they are satisfied with the information provided to determine the decay period.

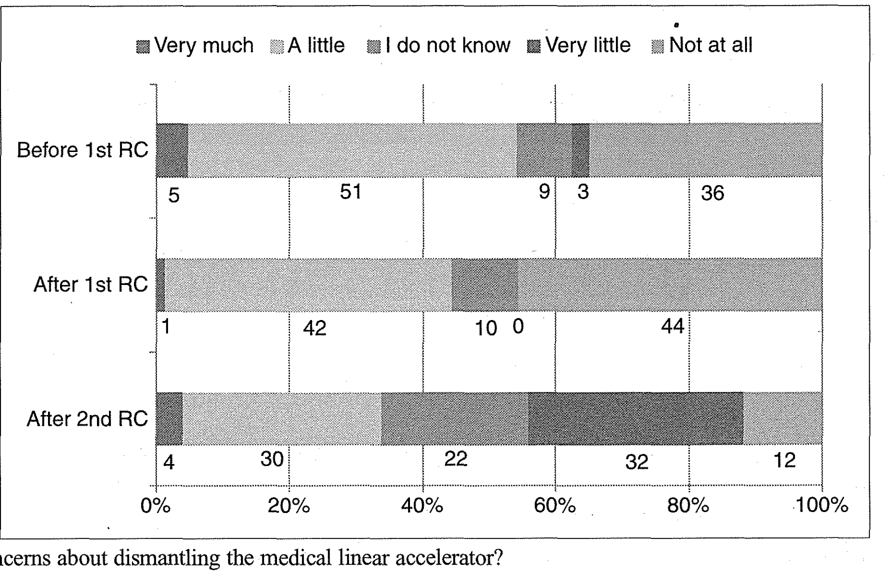

Fig. 7. Do you have concerns about dismantling the medical linear accelerator?

Although the intention of the RC is not to form a consensus (NRC 1989), this RC facilitated establishment of a sound consensus on the adequate decay period among stakeholders, including medical institutions and radiation therapy equipment manufacturers. If medical institutions were satisfied with the typical decay period implemented before the amendment, this result indicates that a consensus could be reached. However, a large number of workers (40%) did not have an opinion about the training on this subject. This indicates the lack of specific information from a hospital for adequate decision making to set the decay period. The lower number of "I don't know" responses on the third survey revealed an effect from continuous intervention.

Human body effects

Many maintenance workers (approximately 60%) thought that the effects of radiation on the human body during work were small compared with other occupational risks. In addition, the feeling that an explanation is required about the effects of the received dose on the human body was significantly decreased (after first RC vs. after second RC: $P < 0.05$). The number of respondents stating, "The radiation safety officer should explain the radiation dose based on the detected data" was significantly decreased (before first RC vs. after second RC: $P < 0.01$). Moreover, the number stating, "The radiation dose should be below the detection limit, so the radiation safety officer does not have to explain the radiation dose" was significantly increased (before first RC vs. after second RC: $P < 0.01$).

Many maintenance workers thought that information for understanding the effects of radiation on the human body was adequately provided, and only one-third of the maintenance staff had concerns about radiation exposure in radiation controlled areas.

These results indicated that many maintenance workers deepened their understanding of the effects of radiation on the human body and were satisfied with the information.

Development of a support system for dismantling medical linear accelerators

The results for the development of a support system, in particular a manual and work rules for dismantling medical linear accelerators, were 11% before the first RC, 24% after the first RC, and 17% after the second RC for "Not at all" and "A little." These results show that some of the maintenance staff were satisfied with the status of the development of the support system. However, if responses of "I do not know" are included, the response ratios become 50, 57, and 53%, respectively. It appears that although many maintenance workers were satisfied, certain issues remain.

According to normal business practice in Japan, an accelerator to be replaced is dismantled by the manufacturer installing a replacement medical linear accelerator in many cases. Therefore, it would possibly not be dismantled by the original manufacturer. To ensure good communication, one should recognize perception gaps. This study revealed that there were differences of opinion between experts and workers in the manufacturing company concerning communication issues between the original manufacturer and the manufacturer that is in charge of dismantling the accelerator. The authors believe that this study confirmed the importance of information sharing and that effective RC activities should be based on this kind of analysis. At the opinion exchange meeting attended by all equipment manufacturers, it was confirmed by the representatives of the manufacturer that, "When a

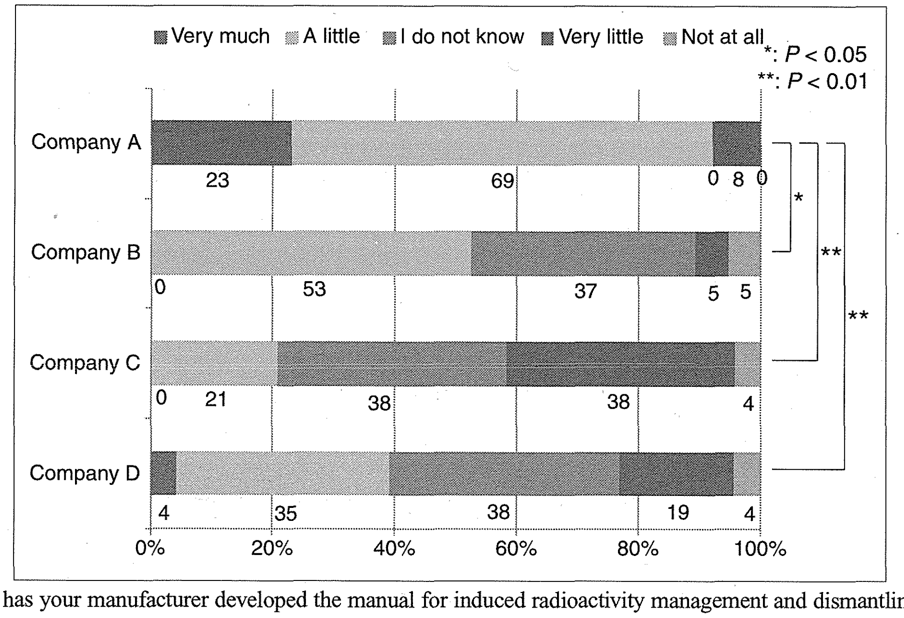

Fig. 8. To what extent has your manufacturer developed the manual for induced radioactivity management and dismantling work?

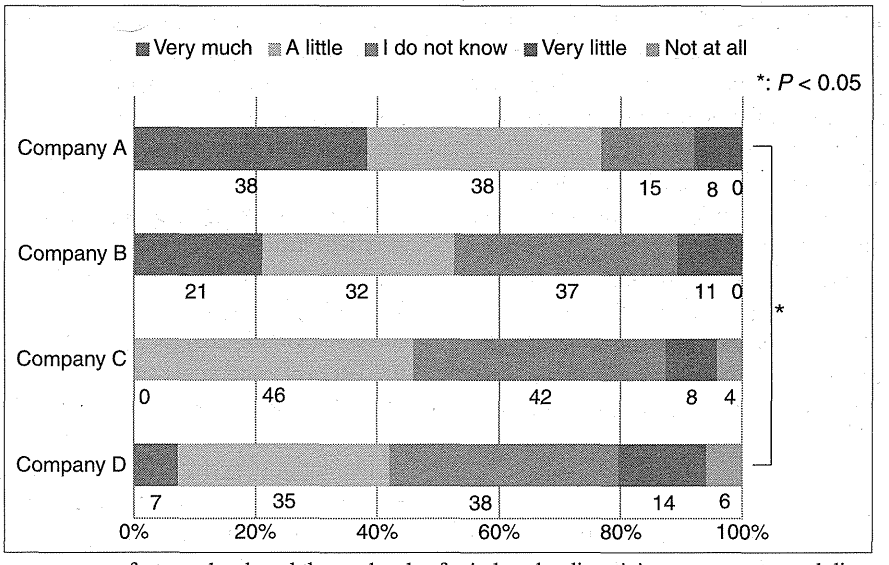

Fig. 9. To what extent has your manufacturer developed the work rules for induced radioactivity management and dismantling work?

medical linear accelerator is dismantled not by its original manufacturer but by a manufacturer installing a replacement medical linear accelerator, information gaps would be minimized by exchanging information such as a manual to clarify the work showing a picture of each part," and "They are trying to clarify the work procedure and prevent mistakes regarding the management of parts by developing a manual which includes many pictures of parts, etc." It appears that there is a slight gap between the results of this survey and the presentation at the opinion exchange meeting attended by representatives of the manufacturers maintenance workers. Therefore, it seems that there are problems with information sharing among manufacturers due to a conflict between disclosing confidential business information and safety information.

Future issues

The response ratio for "The classification of induced radioactivity based on the maximum x-ray energy is reasonable" was 57% after the second RC. This is a significant increase when compared to before the first RC and after the first RC ($P = 0.025$). However, the increase is not significant between before the first RC and after the second RC ($P = 0.33$).

In addition, 15% or less of the maintenance workers thought, "There is a problem with the current setting of the decay period." However, 80% of these respondents stated that the "decay period has not been determined based on the activation situations." Concerning the level of understanding that the maintenance workers had concerning the new regulation and induced radioactivity, they understood that the maximum x-ray energy is not enough to accurately

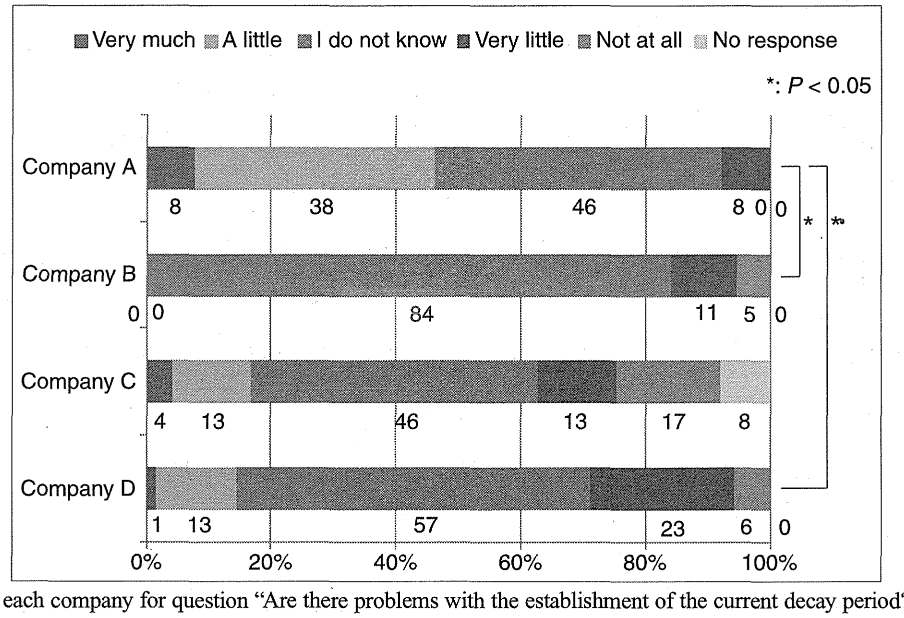

Fig. 10. The results of each company for question "Are there problems with the establishment of the current decay period?"

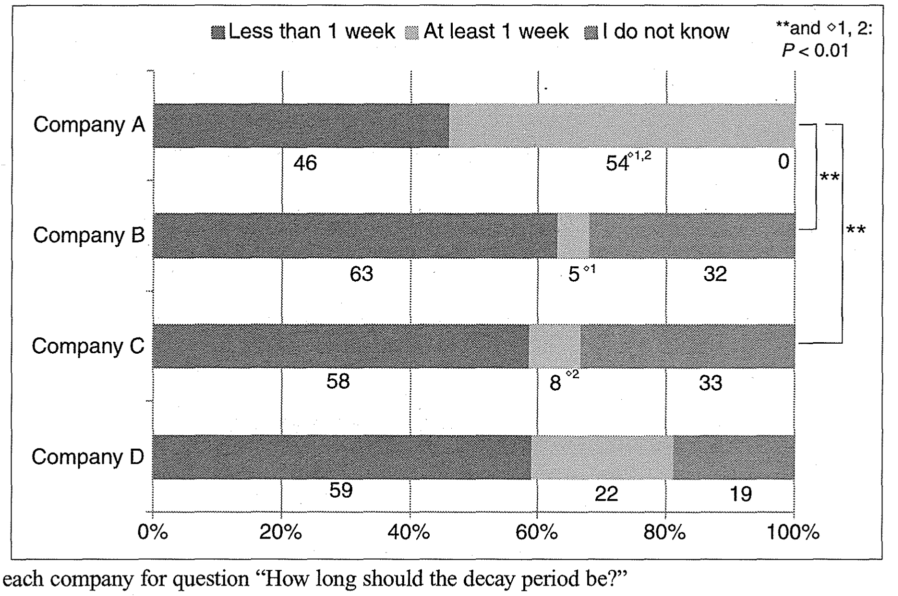

Fig. 11. The results of each company for question "How long should the decay period be?"

estimate the amount of activation. Thus, it appears that they believe the system should reflect activation situations more accurately, as indicated by their enhanced understanding and their desire to obtain higher-level information. Depending on their degree of understanding, a change in the amount and quality of information that should be provided has been confirmed.

It was confirmed that there is a significant difference of opinion between the manufacturers in some survey items. The maintenance workers of company A thought that the manual for dismantling is more developed compared to the workers of companies C and D ($P < 0.01$) and company B ($P < 0.05$ (Fig. 8) and that the work rules for dismantling are more developed compared to those of company D ($P < 0.05$) (Fig. 9). However, significantly more staff members at company A thought that there were problems with the setting of the decay period compared to staff at companies B and D (both, $P < 0.05$) (Fig. 10). The decay period desired by workers differed among companies. Whereas in company A about half of the workers desired at least 1 wk, only 5% in company B ($P = 0.0025$) and 8% in company C ($P = 0.0030$) desired this decay period (Fig. 11). In this analysis, a P-value cutoff was set to be 0.0083 using sequential Bonferroni adjustments for pairwise comparisons.

These results show that maintenance workers at company A more often disregard the set decay period than workers at the other companies. Moreover, fewer maintenance workers

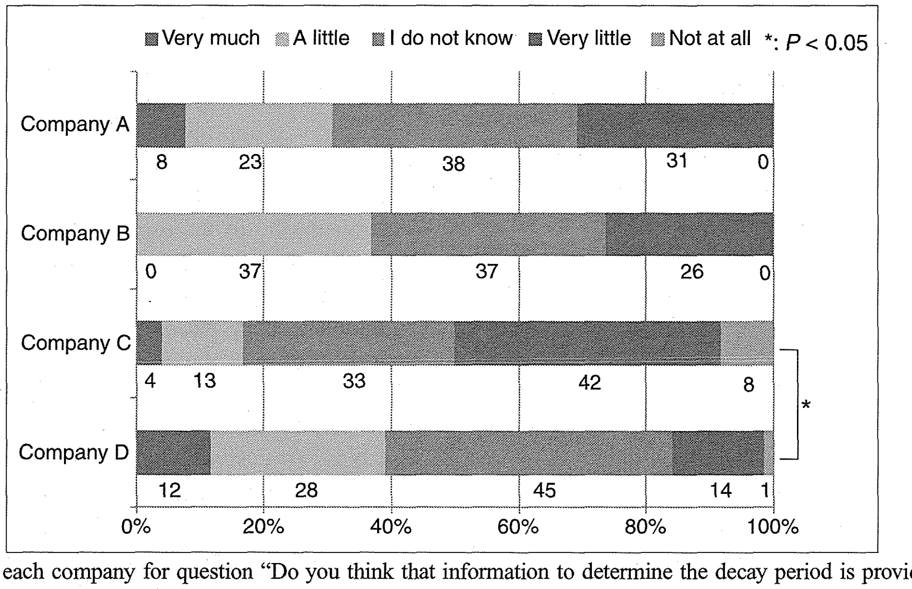

Fig. 12. The results of each company for question "Do you think that information to determine the decay period is provided after second risk communication?"