Lessons Learned in Protection of the Public for the Accident at the Fukushima Daiichi Nuclear Power Plant

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Abstract

What insights can the accident at the Fukushima Daiichi nuclear power plant provide in the reality of decision making on actions to protect the public during a severe reactor and spent fuel pool emergency? In order to answer this question, and with the goal of limiting the consequences of any future emergencies at a nuclear power plant due to severe conditions, this article presents the main actions taken in response to the emergency in the form of a timeline. The focus of this paper are those insights concerning the progression of an accident due to severe conditions at a light water reactor nuclear power plant that must be understood in order to protect the public.

Key words: Emergency preparedness; nuclear emergencies; public protection; public information

Introduction

Before analysing the response, it is important to recall the tragic circumstances surrounding this nuclear emergency. The combined earthquake and tsunami, which culminated in the loss of more than 15, 000 people‡. The magnitude of this event overwhelmed the government's 'crisis management system' that was established for responding to emergencies of all types (NERHQ 2011).

The nuclear emergency at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant (NPP) began on 11 March 2011 following the impact of a tsunami that was triggered by the 9.0 magnitude 'Great East Japan Earthquake'. The tsunami height was estimated to be approximately 14 m, which exceeded the defences of the NPP that were designed to withstand 5.7 m (IAEA 2011a).

The number of evacuees exceeded 146, 000 people§ (NAIIC 2012). There have been no health effects attributable to radiation exposure observed among the public (UNSCEAR 2013). However, the unsafe evacuation of patients from hospitals and nursing homes located within the vicinity of the NPP caused 51 deaths (as of April 2011) that may have been preventable (NAIIC 2012; Tanigawa et al. 2012).

The main events of the accident have been compiled into chronological order and presented in a timeline (Table 1) and were identified from the following official reports: (IAEA 2015, Investigation Committee 2012a, 2012b; NAIIC 2012; NERHQ 2011; TEPCO 2012a). The events were categorized and analyzed according to the functional requirements that most directly apply to protecting the public in the event of a nuclear or radiological emergency – as described in the international guidance publication (IAEA et al. 2002), which was in place at the time of the emergency**. These functional requirements are: (1) *Identifying, Notifying and Activating,* (2) *Taking Urgent Protective Action,* (3) *Assessing the Initial Phase,* (4) *Managing the Medical Response,* (5) *Keeping the Public Informed,* (6) *Taking Agricultural Countermeasures, Countermeasures Against Ingestion and Longer Term Protective Actions,* (7) *Mitigating the Non-Radiological Consequences of the Emergency and the Response.* Insights are provided in the analysis and lessons identified are listed at the end of each functional requirement section. The paper finishes with conclusions.

Table 1 Timeline of the main events of the accident at the Fukushima Daiichi nuclear power plant relevant to protection of the public.

Time and date[a]		Event
11 March	14:46	Earthquake: loss of off-site power, all reactors in operation automatically shut down.
	15:36	Impact of tsunami flooding NPP site.
	15:42	First notification sent by operator to off-site officials: station blackout at all units.
	16:45	Second notification sent to off-site officials: inability to inject water using the emergency core cooling systems for units 1 & 2.
	18:10	Unit 1 core uncovered (estimated by TEPCO computer code analysis after the accident).
	20:50	Local government issued evacuation order for 2 km radius of NPP.
	21:00	Operator sent notification to off-site officials stating: “we are preparing to request the local governments to evacuate residents”.
	21:23	National government issued evacuation order for 3 km radius and sheltering within 3 to 10 km radius of NPP.
12 March	05:44	National government issued evacuation order for 10 km radius of NPP.
	18:25	National government issued evacuation order for 20 km radius of NPP.
	-	Monitoring of evacuees began using criterion 13, 000 cpm.
14 March	10:30	Evacuation began of critically ill and bedridden patients from a hospital located 5 km from NPP.
	-	Criterion for monitoring evacuees (full decontamination warranted) increased from 13, 000 cpm to 100, 000 cpm.
	-	Rescue team assisting with evacuation aborted their mission to comply with occupational dose limit of 5 mSv for females.
15 March	09:00	Maximum dose rate measured at main gate of NPP site (about 12 mSv h^{-1}).
	11:00	Sheltering advised within 20 to 30 km radius.
	20:40	Dose rates of about 200 to 300 μSv h^{-1} measured in some locations beyond area evacuated (more than 20 km from NPP).
16 March	-	National government provided advice on implementing ITB (evacuation of areas already completed).
17 March	-	Adoption of activity concentration levels to restrict food and drinking water as regulatory limits.
	-	170 μSv h^{-1} measured 30 km north west of NPP at location Monitoring Point 32.
	-	U.S. embassy in Tokyo issues instructions for American citizens within 80 km to evacuate.
17 to 19 March	-	U.S. performed aerial monitoring of the dose rate at 1 m above ground (Japan received data on 20 March 2011).
18 March	-	Request made to check the existence of houses around Monitoring Point 32 where 170 μSv h^{-1} was measured.
19 March	-	Information on preventing livestock being affected by contaminated animal feed provided to cattle farmers.
	-	Activity concentrations measured in leafy vegetables and milk (at locations more than 100 km from NPP) exceeded criteria to restrict food.
21 March	-	Restrictions on certain foods being distributed started to be issued.
23 March	-	Diagram of dose projection model results released to the public.
25 March	-	Voluntary evacuation within 20 to 30 km radius recommended.
27 March	-	European Union restricted food and animal feed from Japan and required confirmation of monitoring/ analysis or certificate of origin.
30 March	-	IAEA provided information to Japanese counterpart that IAEA criterion for evacuation exceeded more than 30 km from NPP.
Start of April	-	Dose rate monitoring results for schools submitted and advice requested on re-opening of schools.
11 April	-	20 mSv dose criterion established to determine areas beyond 20 km evacuation area that will relocate.
19 April	-	20 mSv dose y^{-1} criterion established to determine which schools will re-open (subsequently lowered to 1 mSv y^{-1}).
22 April	-	Area for relocation established (beyond 20 km evacuation area).
25 April	-	Press conferences held in conjunction with all response organizations.
15 May	-	Public started to be relocated from the area established for relocation.

[a] All from the year 2011.

Identifying, notifying and activating

The fuel of a reactor must always be kept covered with water for cooling otherwise it will overheat and fail, releasing radioactive material (IAEA 1997). The inability to inject water into the reactor at the Fukushima Daiichi NPP meant that damage to the fuel would take place shortly and radioactive material will be released into the atmosphere if the containment fails. The containment could have failed at any time, and it was impossible to predict when this would happen. Thus, following damage to the fuel in the core, there is always the possibility of an unpredictable release of radioactive material to the atmosphere. In the most severe emergencies, the plume of radioactive material that is released can possibly result in injuries and deaths within hours for those located within about 2 to 5 km of the NPP, if protective actions are not taken. Certain protective actions need to be taken off site before, or shortly after, a release of radioactive material in order to prevent radiation-induced health effects. These protective actions include evacuation, sheltering, iodine thyroid blocking (ITB) and restrictions of potentially contaminated food†† (IAEA 2013).

Insight: Notification of the public of the protective actions to be taken was delayed several hours after conditions at the NPP meant that those located near the plant were at risk.

The operator correctly recognized that the loss of power at the NPP and the inability to inject water into the reactor warranted notification of the off-site decision makers. As shown on Table 1, the first fax was sent at 15:42‡‡ (station blackout) and the second fax was sent at 16:45 (failure to inject water using the emergency core cooling systems of units 1 & 2) (Investigation Committee 2012a). At about 21:00, the operator included in a fax sent to off-site officials that "we are preparing to request the local governments to evacuate residents" (IAEA 2015). Current understandings of the accident indicate that the reactor core of unit 1 was uncovered at approximately 18:10 on 11 March (TEPCO 2012a). At this point a severe release of radioactive material with the potential to cause health effects among the public located off-site was possible (McKenna 2000).

While delayed, the off-site decision makers took actions to protect the public (e.g. evacuation out to 2 km at 20:50), before there was an uncontrolled major release of radioactive material to the environment§§. The evacuation was advised approximately four hours after conditions were identified that immediate actions were warranted to protect the public, as specified in international guidance (IAEA et al. 2011). A delay in the notification of the public could have been avoided since it was caused by: (a) a notification system that required several approval processes; and (b) time spent deciding on which protective actions the public should take.

The lesson identified for identifying, notifying and activating is:

- If conditions are detected at an NPP that could result in a release off site that could cause radiation-induced health effects among the public***, there is a need to predetermine the protective actions the public will take in order to ensure the instructions can be provided promptly and effectively.

Taking urgent protective action

This functional requirement addresses taking urgent protective actions, which are those actions that must be taken promptly (within hours) to be effective, with effectiveness significantly reduced if delayed (IAEA et al. 2002). These are actions that usually have to be taken before monitoring can be used to make decisions on protective actions. This is because waiting for monitoring results would mean the public would already start being exposed. Urgent protective actions are evacuation, sheltering, ITB, restrictions on consumption of food and water that could be consumed immediately e.g. vegetables grown in the garden (IAEA 2013).

Insight: Initial decisions on urgent protective actions were taken *ad-hoc*, based on conditions at the NPP and not from dose projection models or monitoring results, as originally intended.

Computer-based prediction models that predict the accident progression and source term of radioactive releases and off-site doses was the basis for protective action decision making established prior to the accident (NAIIC 2012). Data provided by the NPP would be used in the calculations of the accident progression and source term and then the results assessed against the projected dose criteria for protective actions. However, the data from the NPP could not be used because of the loss of all on-site power (NAIIC 2012). The projections of doses were performed from 11 March onwards using the pre-determined source term of typical severe accident scenarios and also unit releases (NAIIC 2012). This information was not used to determine urgent protective actions, such as evacuation or sheltering. Instead, the actual severe plant conditions were used (NERHQ 2011). The diagrams of the dose projections were published, which resulted in confusion and mistrust of the public. This is discussed further in section 'Keeping the public informed'.

It should be emphasized that, for many severe accidents, the use of projections of off-site doses based on estimated releases from the NPP would not be effective in deciding on initial urgent protective actions (Homma et al. 2015; McKenna 2000). This is because the timing, size and composition of any release would not be predictable, and in order to be effective, the off-site protective actions, in most cases, must be taken before, or shortly after, the release occurs (AESJ 2015; IAEA et al. 2011; NRC 2012). As expected, (McKenna 2000, McKenna et al. 2007), the timing, magnitude, composition, effective height and duration of the severe releases could not be predicted, with estimates of the source term continuing to be revised as more data became available (TEPCO 2012b). Consequently, dose projection models cannot be used effectively for making decisions concerning protective actions that need to be taken following severe damage to the fuel in the reactor core.

The arrangements in place in Japan were revised after the accident so that indicators of conditions in the plant will be used as a basis for taking urgent protective actions. All recommendations to use dose projection models for deciding on urgent protective actions were removed (IAEA 2015).

Insight: A specific emergency zone to ensure the prompt and prioritized evacuation of those located in the area of greatest risk (3 to 5 km from the NPP) had not been established prior to the accident. There were multiple evacuations beyond the 10 km emergency planning zone that had been established.

Evacuation was undertaken in an *ad-hoc* basis as the areas that were instructed to evacuate had not been predetermined, apart from the 10 km emergency planning zone. There was an overlap in responsibilities between the local and national levels of government for instructing the public to evacuate (Government of Japan 1997, 1999). An absence of coordination caused an expansion of the evacuation zone from 2 km to 3 km in approximately 30 minutes (NAIIC 2012), as shown in Table 1, and resulted in confusion and mistrust of the public. Evacuation was expanded over several days, from 11 to 25 March, from 2, km, 3 km, 10 km, then 20 km and finally out to 30 km (NERHQ 2011). This is because severe accidents were not taken into account in the emergency plans established prior to the accident.

Insight: Uncoordinated and *ad-hoc* evacuation of hospitals resulted in fatalities that may have been avoidable. Public screening (monitoring of the public) delayed or interfered with the implementation of protective actions.

There were several hospitals located within the areas that had been evacuated (Investigation Committee 2012a; NAIIC 2012). Patients were evacuated from a hospital located within 5 km of the NPP that included critically ill and bedridden patients (NAIIC 2012). They were evacuated during a period of about 10 hours taking a route that was more than 200 km and some of the patients were not accompanied by medical staff (Investigation Committee 2012a; NAIIC 2012). The local authorities that were managing the evacuation shelters would only accept patients if they had been monitored for contamination and decontaminated (NAIIC 2012). Radioactive material that would be deposited on the skin or clothing during such an emergency, would not be a significant danger to the health of anyone that is located off-site.

While it is important to bear in mind the difficult conditions under which the response to the nuclear emergency was being undertaken, i.e. in addition to the response to the tsunami and earthquake; issues have been identified related to the evacuation of hospitals that can provide lessons to be learned from. These issues include:

- No arrangements had been made prior to the accident for the full evacuation of all patients from hospitals located within evacuation zones (NAIIC 2012);
- Inappropriate transport and evacuation shelters was provided to critically ill and bedridden patients (Tanigawa et al. 2012); and
- Decontamination and screening of critically ill and bedridden patients was a prerequisite of evacuation shelters accepting these individuals, when priority should have been given to ensuring necessary medical care is provided (NAIIC 2012). Universal precautions against infection (gloves, mask etc.) provide sufficient protection from handling possibly contaminated patients (IAEA 2013).

Insight:. The criterion used for screening and decontamination of the public was revised from 13, 000 cpm to 100, 000 cpm. This caused variations in which criterion was used by the health care centres that were responsible for implementing screenings and decontamination.

As already explained, contamination on the skin or clothing would not be a danger to health for those located off the site. From 12 March onwards, 13, 000 cpm was selected by the response organization responsible for implementing screening based on the criterion of surface contamination of 40 Bq cm^{-2} (Investigation Committee 2012a). However, during screening and decontamination 13, 000 cpm was found to be unsuitable due to the increase from background levels of radiation during the emergency and the conditions for decontamination measures (no showering facilities, no spare clothes and low tempertaures making removal of outer clothing unsuitable). Implementation of 100, 000 cpm began on 14 March – two days after screening had begun with 13, 000 cpm (Investigation Committee 2012a). Consideration needs to be given to the operational criteria used for screening, enusring that it is appropriate for emergency conditions. This is because screenings will be undertaken in areas that are above background levels of radiation.

Insight: Sheltering was implemented for too long. This protective action resulted in significant difficulties for people and impacted necessary services (e.g. closing of supermarkets). During the 10 days the protective action was advised, many residents had already spontaneously evacuated from the area, or local governments issued an evacuation order. The subsequent recommendation from the national government for the public to voluntarily evacuate was problematic.

Implementing only sheltering as a protective action is insufficient to protect from radioactive material that is released from a severely damaged reactor core. As feasible, it should be implemented along with ITB (IAEA 2013). Furthermore, sheltering should only be considered as a short term protective action, implemented just for a few days (IAEA et al. 2002). Sheltering in a standard house or a large building may not provide adequate protection within 30 km from a release that warranted protective actions off the site (IAEA 2013). Prior to the accident, projected dose criteria had been established for sheltering. During the response to the accident the projected dose criteria were not used, instead the decision to shelter was based on the conditions at the NPP (IAEA 2015).

On 15 March sheltering was advised within 20 to 30 km radius and remained in place for 10 days, ending on 25 March, when voluntary evacuation was recommended (IAEA 2015; NAIIC 2012). Voluntary evacuation meant that those located in the 20 to 30 km radius could choose whether or not to evacuate. However, this proved to be problematic as the public was uncertain on how to decide if they should evacuate (AESJ 2015; IAEA 2015; NAIIC 2012).

Insight: ITB agents were not pre-distributed, even though stocks were available within the 10 km emergency planning zone and instructions on the intake of ITB were provided too late to be effective.

ITB is the ingestion of stable (nonradioactive) iodine to reduce the dose to the thyroid from principally inhalation of radioactive iodine released from the NPP. Inhalation of radioactive iodine can be a major source of health effects, in particular for those located close to the NPP. ITB agents need to be taken before, or shortly after (within 1 to 2 hours), inhalation of radioactive iodine (Il'in et al. 1972). The fuel in the plant was damaged at about 18:10 on 11 March and therefore a major release of radioactive iodine could have been possible. The principle issues with the implementation of ITB were:

- ITB agents were not pre-distributed, despite available stockpiles within the 10 km emergency zone (Investigation Committee 2012a) and it probably would not have been possible for the population close to the NPP to take the ITB agents within the required timeframe;

- The response organization did not have the knowledge of when the public should be instructed to take ITB agents and depended on advice that was to be provided by the national government (Investigation Committee 2012a);
- When the advice for implementing ITB was provided by the national government on 16 March (Investigation Committee 2012a), it was too late for ITB to be executed by the local response organizations because: (a) the reduced effectiveness of ITB after intake of radioactive iodine (Il'in et al. 1972), and (b) evacuation had already been completed (Investigation Committee 2012a); and
- There was widespread and undue concern among the local governments over the side effects of taking ITB agents (Investigation Committee 2012a). However, it is important to remember that ITB is both safe and effective if the stable iodine is provided in the correct dosages (WHO 2011).

The lessons identified for taking urgent protective action are:

- Dose projection models have proven to be an unreliable tool for deciding on the implementation of actions to protect the public that need to be taken before, or shortly after, the release of radioactive material in order to be most effective;
- Protective actions need to be implemented in all directions immediately when conditions at the NPP indicate actual or projected damage to the fuel, since the timing, direction and duration of a release are not predictable (IAEA 2013, McKenna 2000);
- Arrangements need to be in place for the safe evacuation of special facilities (e.g. hospitals, prisons or schools), with priority given to ensuring necessary medical care is provided (IAEA 2015);
- The measurement value for screening should be appropriate for emergency conditions (i.e. consideration should be given when establishing the value that screenings will be undertaken in areas that are above background levels of radiation);
- Sheltering should only be implemented for a short period (1 to 2 days) and advising the public to voluntarily evacuate was problematic. The decision on lifting the order to shelter or to evacuate should be made by the authority (IAEA 2013; 2015); and
- Due to the inability to know the timing of a release, as failure of the containment cannot be predicted (McKenna 2000), ITB should be implemented together with evacuation or sheltering. Therefore, ITB should be predistributed for the population close to the NPP to ensure that it can be taken without delaying evacuation, with additional ITB made available at evacuation centers or shelters. The organization responsible for ITB distribution should have the knowledge and authority to issue the instructions without requiring prior approval.

Assessing the initial phase

This section discusses monitoring and environmental sampling and assessment for deciding on urgent and early protective actions.

Insight: Evacuation and relocation of areas contaminated by deposition was delayed.

As shown in Table 1, on 11 April 2011 the criterion for relocation was established at 20 mSv (NAIIC 2011). No assessments were carried out during the selection of the criterion to ensure that it was also justified and did more good than harm, taking into consideration the overall impact of the actions taken to reduce the dose (ICRP 2007).

On the morning of 15 March 2011 there were indications that a major release was taking place, which resulted in deposition due to rain (NERHQ 2011). The deposition meant that the public living in these areas could be exposed to greater than 100 mSv total effective dose in 7 days, and the public would need to be evacuated according to international guidance (IAEA et al. 2011). Monitoring was conducted in the evening of 15 March, beyond the area already evacuated, and the USA performed aerial monitoring on 17 to 19 March, which provided sufficient information to identify the affected areas (NERHQ 2011; US DoE 2011).

The IAEA provided information to the Japanese counterpart on 30 March that measurements of ^{131}I in soil taken from Iitate village (more than 30 km from the NPP) had exceeded one of the IAEA operational criteria for evacuation, which corresponded to 100 mSv total effective dose in 7 days (IAEA 2011b; IAEA 2015). However, there were no predetermined operational levels for dose rates from deposition to use to determine if evacuation/relocation was warranted (IAEA 2011a). Implementation of relocation did not begin in the affected areas until 15 May (NAIIC 2012). A delay in relocation was due to:

- An absence of predetermined operational criterion for relocation/evacuation;
- Local governments concerned that extending the evacuation zone would cause apprehension among the public; and
- Consideration given to the opinions of different stakeholders (IAEA 2015; NAIIC 2012).

The lessons identified for assessing the initial phase are:

- Arrangements need to be in place to ensure that, after a release of radioactive material, environmental monitoring is performed promptly beyond those areas already evacuated based on conditions at the NPP;
- Operational criteria for environmental monitoring need to be predetermined to ensure the implementation of evacuation or relocation after a release (IAEA et al. 2011); and
- The opinions of different stakeholders, including local governments, need to be taken into consideration and their concerns addressed at the preparedness phase.

Managing the medical response

Insight: Medical staff refused to treat patients that were possibly contaminated, despite the fact that contaminated patients could be treated safely. A low-dose criterion established prior to the emergency delayed necessary activities being undertaken during the response, with the criterion being considerably below that at which any radiation-induced health effects would be observed.

Those who had been injured on the site while assisting with the response at the NPP encountered problems locating suitable medical facilities that were prepared to treat patients possibly contaminated with radioactive material (Tominaga et al. 2012). It was also reported that some medical staff at other medical facilities refused to treat patients that were possibly contaminated (Vano et al. 2011). A rescue team that returned to the restricted zone to assist with the evacuation aborted their mission to comply with the occupational dose limit of 5 mSv for females (Investigation Committee 2012a).

The lessons identified for managing the medical response are:

- Arrangements need to be in place to train medical staff that universal precautions against infection (i.e. masks, gloves) provide sufficient protection when handling patients possibly contaminated with radioactive material (IAEA 2013); and
- Dose criteria need to be established that take into consideration the criteria specified in international guidance (IAEA et al. 2011) ensuring these criteria are consistent with the occurrence of radiation-induced health effects that would allow response activities to be undertaken.

Keeping the public informed

Insight: Conflicting information provided by different official sources resulted in confusion and uncertainty of the public.

Information was provided to the media and public from several different official sources, which were uncoordinated until 25 April 2011 when joint press conferences were held between all response organizations (Investigation Committee 2012a). Inconsistent messages were provided to the media and the public (IAEA 2015), including at press conferences from staff of the same official source (Investigation Committee 2012a).

Insight: Protective actions were advised by other countries that conflicted with official recommendations provided by Japan.

On 17 March, the United States embassy in Tokyo issued instructions for American citizens within 80 km to evacuate, or shelter if safe evacuation is not practical (Embassy of the United States in Tokyo 2011). This conflicted with the official recommendation to evacuate out to 20 km and shelter within 20 to 30 km, which had been advised by the Japanese authorities at that time. In addition, some embassies temporarily relocated most or all of their staff from the offices in Tokyo to run operations in locations almost 700 km from the accident (Ministry for Foreign Affairs of Finland 2011). At one point, some countries advised their citizens to avoid all travel to Japan, provided special flights to leave Japan and made ITB agents available (Ministry of Foreign Affairs Norway 2011). Some foreign nationals were recommended to take ITB agents if they were located within 250 km from the NPP. This conflict with the official recommendations provided by Japan was a source of confusion and uncertainty among the public.

Insight: A diagram of dose projection model results was misinterpreted and the public and decision makers mistakenly thought the diagram could have been used to avoid evacuation to locations that were significantly contaminated.

A diagram of dose projection model results that depicted areas of significant contamination was released to the public on 23 March 2011. The diagram showed results calculated using environmental monitoring data obtained after the order to evacuate issued on 12 March. The calculation performed was backdated and the diagram dated as 12 March. It was not made clear to the public that this diagram presented results that had been backdated, and therefore not available at the time the decision to evacuate was made (IAEA 2015; NAIIC 2012). Some members of the public moved to a shelter located in an area that was significantly contaminated after they had been instructed to evacuate on 12 March (IAEA 2015). As noted in references (IAEA 2015; NAIIC 2012), the lack of an explanation before publishing the diagram resulted in misunderstanding and confusion among the public. It was alleged that failure to disclose the diagram, caused people to evacuate to significantly contaminated areas that could have been avoided (IAEA 2015; NAIIC 2012). This is despite the fact that the diagram was not available at the time of the evacuation.

The lessons identified for keeping the public informed are:

- A joint public information centre should be established promptly for the coordination of information from all official sources (IAEA 2013);
- Arrangements need to be in place in order for the affected country to be able to explain any differences in protective action recommendations that are being advised by other official sources. In addition, there is a need for the international harmonization of EPR arrangements among States (IAEA et al. 2002); and
- Any technical information that is released to the public needs to include a plain language explanation, including cautions concerning the results.

Taking agricultural countermeasures, countermeasures against ingestion and longer-term protective actions

This functional requirement addresses those protective actions that can be implemented within days to weeks and still be effective. The requirement includes longer-term agricultural countermeasures, preventing ingestion of contaminated water or milk, and relocation of the population to avoid radiation-induced health effects from long-term exposure from living in contaminated areas.

Insight: Criteria for food restrictions were developed *ad-hoc* during the emergency, their implementation was delayed and their application inconsistent.

Criteria for applying or removing food restrictions were adopted by the government on 17 March 2011. Prior to the accident, criteria had been developed but not adopted as regulatory limits (NAIIC 2012). It was necessary later to extend these criteria to consumables that had not been considered, such as seafood (Investigation Committee 2012b). In some cases, restriction of consumption and/or distribution of drinking water and milk took five or six days after it had first been detected to have exceeded the criterion for ^{131}I concentrations (Hamada and Ogino 2011).

Insight: Local response organizations encountered problems in being able to meet the demand for environmental monitoring that needed to be performed.

The local response organization was not prepared to monitor a wide range of food and beverages, due to the limited resources available (Investigation Committee 2012a). Leafy vegetables and raw milk could not be monitored due to the limited number of instruments and equipment available (Investigation Committee 2012a). Food monitoring data were only available for samples taken on 16 March or later (Hamada and Ogino 2011). This finding is consistent with the experience from the Chernobyl NPP accident (FAO et al. 2006). The patterns of deposition were so complex that it was impossible to monitor enough of the area to effectively identify all the locations for which food restrictions applied.

Insight: Contaminated beef entered the food distribution chain due to insufficient instructions on protecting animal feed.

On 19 March and 14 April 2011 the Japanese government issued instructions on restrictions of animal feed to cattle farmers (Investigation Committee 2012b). However, contaminated beef was found to have entered the food distribution chain. The meat contamination was due to the fact that cattle had consumed contaminated feed – rice straw that had been stored outdoors (Investigation Committee 2012a). This was caused by: (a) instructions were only provided to cattle farmers and did not include grain farmers (producers of animal feed); and (b) the instructions that were provided to the cattle farmers were insufficient and lacking comprehensive information (Investigation Committee 2012a).

Insight: Problems in establishing justified criteria as a basis for decision making

As shown in Table 1, dose rate monitoring results for schools were submitted by the local response organizations at the start of April 2011 and the national government advice was requested on whether schools should re-open (NAIIC 2012). On 19 April 2011, the national government established 20 mSv y^{-1} as the criterion to determine whether schools should re-open. However, there was significant uncertainty and mistrust among the public that children were not being adequately protected by this criterion (NAIIC 2012). This concern culminated in an announcement of a long-term goal to reduce contamination levels of schools to 1 mSv y^{-1} and to provide dosimeters to schools (NAIIC 2012). The difficulty in establishing criteria at the time of the emergency is consistent with experience gained from the accidents at the Three Mile Island and Chernobyl NPPs. These accidents showed it was impossible to establish criteria for justified actions to protect the public, as it was during a period of heightened emotions and mistrust of officials and of the scientific community (McKenna et al. 2007). It is also important to remember that any action taken to reduce the dose to the population below the generic criteria provided in international guidance (IAEA et al. 2011) will not have any observable impact on the radiation-induced health effects among the public.

The lessons identified for taking agricultural countermeasures, countermeasures against ingestion and longer term protective actions are:

- Food restrictions may need to be implemented based on conditions at the NPP, or the possibility of an environmental release, before monitoring and sampling results are available in order to ensure the effective protection of the public;
- Instructions on agricultural countermeasures need to be sufficient to prevent the possibility of contaminated food entering the distribution chain; and
- Criteria for implementing and removing protective actions should be established in advance to ensure its prompt use during an emergency.

Mitigating the non-radiological consequences of the emergency and the response

The non-radiological consequences are the adverse psychological, societal or economic consequences of an emergency and can be some of the most severe consequences (IAEA 2012; IAEA et al. 2015). This is principally caused by the absence of an effective process in place to ensure that actions taken do more good than harm (i.e., the risks from radiation-induced health effects are balanced against the negative consequences of the protective actions that are implemented). The public and those implementing protective actions need to be able to understand when the situation is safe and when no health effects from radiation exposure can be expected, which would help to identify whether an action is justified based on the health hazard from radiation. Currently, there is no clear agreement in the health physics community when these health effects would be observed and when protective actions would be justified. The public and decision makers need to understand when the radiation risks outweighs the risk of taking protective actions and this would need to be agreed on in advance so that all parties understand.

Insight: The principle concerns of the public (i.e., 'Am I safe?' and 'What should I do to be safe?') were not addressed effectively.

The public was provided with technical terms such as dose rates, radionuclide concentrations or doses. In many of these cases, the quantities and doses were: (a) used incorrectly, and (b) not placed into perspective in terms of the possible health hazard from radiation (McKenna et al. 2015). This failure to clearly communicate to the public how protective actions ensure their safety and the possible health hazards, resulted in inappropriate and damaging actions that were not justified based on the radiological hazard (Hamada et al. 2012, NAIIC 2012, Tanigawa et al. 2012, Vano et al. 2011).

Insight: A testing and certification system was required to reassure interested parties (i.e., importing countries).

On 27 March, the European Union (E.U.) restricted food and animal feed from Japan and required confirmation of monitoring or analysis, or a certificate of origin (Food Standards Agency 2012). Most feed and food products from the affected prefectures intended to be imported to the E.U. had to be tested before leaving Japan and were subject to random testing in the E.U. The restrictions also required feed and food products from the remaining prefectures to be accompanied by a declaration stating the prefecture of origin and be randomly tested upon arrival in the E.U. (Food Standards Agency 2012).

The lessons identified for mitigating the non-radiological consequences of the emergency and the response are:

- Arrangements need to be in place to answer the principle concern of the public – 'Am I safe?' – and placing the radiological health hazard in perspective, as provided in IAEA (2013) and McKenna et al. (2015);
- Arrangements need to be in place to ensure that all tradable goods meet international standards and to reassure the public and interested parties (such as importing States) of this (IAEA 2015); and
- Establishing a testing and certification system as soon as practical helps to mitigate the impact on international trade (IAEA 2013).

Conclusions

This paper has provided insights into the reality of decision making on actions to protect the public during the accident at the Fukushima Daiichi NPP, from the point of view of emergency preparedness and response. It has highlighted shortcomings of the response, such as

ITB agents not being pre-distributed or the absence of operational criteria, as well as good practices, such as prompt notification of off-site decision makers by the operators and the decision to take actions to protect the public based on conditions at the NPP.

Many of the lessons from this paper have already been identified from past emergencies (IAEA 2012) and incorporated into international guidance (IAEA et al. 2002), such as the need for predetermined emergency zones and associated protective actions, provisions for promptly conducting monitoring beyond areas already evacuated and the importance of predetermined criteria for applying and removing restrictions.

New lessons warranting the enhancement of international guidance have also been identified, such as answering the principle concern of the public (i.e., ‘Am I safe?’) by placing the radiological health hazard in perspective and reassuring interested parties by using a testing and certification system for international trade.

Footnotes

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‡   15, 894 people and 2, 562 missing, as of 10 February 2016 according to the National Police Agency of Japan (2016).

§   146, 520 people as of 29 August 2011, according to NAIIC (2012).

**   Superseded by IAEA et al. (2015).

††   Food could be contaminated out to large distances (beyond 300 km) and therefore would need to be restricted before monitoring results identify where restrictions are warranted (IAEA 2013).

‡‡   Six minutes after the impact of the tsunami flooding the NPP.

§§   Estimated to be the morning of 15 March - indicated by the maximum dose rate measured (approximately 12 mSv h^{-1}) (IAEA 2015; TEPCO 2012a).

***   i.e., severe damage to the core in the reactor.

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