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Modern emergency planning and response: Lessons learned after Fukushima

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Abstract

After the Fukushima Daiichi nuclear power plant accident the Nuclear Regulation Authority of Japan issued "Nuclear Emergency Response Guidelines" in 2012 in which a new emergency response strategy was established on the basis of experience and lessons learned from the Fukushima Daiichi accident, as well as international standards and guidance. The paper describes experience and some key lessons learned from the accident on emergency preparedness and response. The new emergency response scheme emphasizes the importance of establishing consistent policies and criteria for implementation of urgent and long-term protective actions including return to normality along the emergency management timeline.

Introduction

The nuclear emergency management system in Japan had been developed incrementally since the accident at the Three Mile Island (TMI) nuclear power plant in the United States of America occurred in 1979. The Emergency Preparedness Guide was issued in 1980 by the Nuclear Safety Commission (NSC) as one of the measures to maintain preparedness for severe accidents. Following the Tokaimura criticality accident in 1999, several weaknesses such as prompt initial actions, a collaboration of national and local governments, strengthening of the emergency response system and the clarification of licensee's responsibilities were identified in the emergency management system. The Act on Special Measures Concerning Nuclear Emergency Preparedness was enacted in December 1999 as an addendum to the Basic Act on Disaster Control Measures, which covers all types of disasters. The Basic Plans for Emergency Preparedness assign the role and responsibilities of the relevant organizations and specifies that the guide by the NSC should be considered as an important technical document for use in establishing an emergency plan and for implementing protective actions.

While the legal framework of Emergency Preparedness and Response in Japan had been established before the Fukushima Daiichi accident, a clear "Concept of operations" in emergency response planning shared between the relevant response organizations had not. The decision making process for implementing protective actions was heavily dependent on the computer-based predictive models. The criteria for terminating urgent protective actions and also for long-term protective actions, such as temporary relocation had not been prepared in the NSC's emergency preparedness guide.

After the Fukushima Daiichi accident, the NSC developed an interim report on the revision of the emergency preparedness guide in March 2012 (NSC, 2012) based on the lessons learned from the Fukushima Daiichi accident as well as consideration of the recent concepts in the international

recommendations and standards. The interim report emphasized the importance of having a common understanding of the emergency management timeline among the relevant organizations, to ensure a consistent and coherent decision-making strategy is developed over time. Based on the interim report, as well as the review of several investigative reports of the Fukushima Daiichi accident, including reports by the National Parliament (Diet), the Government and private sectors, the new Nuclear Regulatory Authority (NRA) issued "Nuclear Emergency Response Guidelines" (NRA, 2012) in October 2012.

International recommendations and standards

A few years before the Fukushima Daiichi accident, ICRP had published a revision and update to its main recommendations as ICRP Publication 103 (ICRP, 2008), which evolve from the previous process-based approach of practices and interventions to an approach based on the characteristics of radiation exposure situations. The principles of justification and optimisation apply in all three exposure situations (i.e. planned, emergency and existing exposure situations) whereas the principle of application of dose limits applies only for doses expected to be incurred with certainty as a result of planned exposure situations. In its previous advice, ICRP recommended the use of intervention levels of averted dose to assist decisions on whether to include certain protective measures in an overall protection strategy. It should be emphasised that the intervention level is understood as a level above which an action is justified and below which no optimisation of protection is needed. However, ICRP now recommends focusing on optimisation of protection with respect to the overall protection strategy, which includes exposures from all exposure pathways simultaneously, rather than individual measures.

Emphasis on optimisation using reference levels in emergency and existing exposure situations focuses attention on the residual level of dose remaining after implementation of protection strategies. This approach provides an increased flexibility in designing the optimum protection by focusing on the combined effects of all individual protective measures than on any single protective measure. Applications of ICRP's recommendations for both emergency and existing exposure situations were issued as ICRP Publications 109 (ICRP, 2009a) and 111 (ICRP, 2009b), respectively, before the Fukushima Daiichi accident.

At the time of the accident, IAEA safety standards and operational guidelines were available in the area of emergency preparedness and response, and were developed based on lessons learned from past emergencies and exercises as well as relevant research. The safety standards relevant to emergency management were the Safety Requirements on Preparedness and Response for a Nuclear or Radiological Emergency, No. GSR-2 which has been superseded by GSR Part 7 (IAEA, 2015) and two related Safety Guides, No. GS-G-2.1 (IAEA, 2007) and No. GSG-2 (IAEA, 2011). The revision of the Safety Requirements on Radiation Protection, No. GSR Part 3 (IAEA, 2014) taking into account the new ICRP recommendations had reached a final status and the interim version was issued in May 2011. This means that at the time of the Fukushima accident, the changes in the approach by ICRP had not yet been incorporated into international standards, as well as national ones, and therefore could have been part of the problem for the response to the Fukushima Daiichi accident.

Lessons from the Fukushima Daiichi accident

Amongst the lessons learned from the Fukushima Daiichi accident, the following are some key lessons on the implementation of protective actions:

- Arrangements should be established for taking predetermined urgent protective actions before a release on the basis of plant conditions.
- Advance preparation needs to be in place for safe evacuation of special facilities (designation of medical teams and hospitals, methods of transportation in advance).
- Sheltering should be implemented only for a short period until either safe evacuation or termination of sheltering is possible.
- Predefined criteria based on operational intervention levels concerning relocation and other early measures are needed to ensure timely response.
- The consistent policies and criteria for implementation of urgent and long-term protective actions, including return to normality, should be established in the preparedness process for severe nuclear emergencies.

Urgent protective actions

Evacuation

On 11 March at 20:50, approximately five hours after conditions at the NPP indicated that actions should be taken off the site to protect the public, the local government initially issued an evacuation order for the area within a 2 km radius. Evacuation was expanded over several days, from 12 to 25 March, from 3 km, 10 km, then 20 km and finally out to 30 km. These actions were taken on the basis of the plant conditions and risks (NERHQ, 2011).

Prior to the Fukushima Daiichi accident, arrangements to determine urgent protective actions were established based on the results of computer-based predictive models that predict the accident progression, source terms of radioactive releases and off-site doses. Data provided by the NPP would be used in the calculations of the accident progression and source terms. However, the data from the NPP could not be used because of the loss of all on-site power. The projections of doses were performed from 11 March onwards using the pre-determined source terms of typical severe accident scenarios and also unit releases. This information was not used to determine urgent protective actions, such as evacuation or sheltering.

Despite various analyses performed after the accident, it was very difficult to reproduce the precise source terms to include the timing, magnitude, composition, duration and location of the releases. Furthermore, a release that warrants protective actions can take place over a prolonged time period, and due to changes in the weather conditions, such as wind direction or rain, result in a complex pattern of deposition. This indicates the significant uncertainty associated with dose projections.

When implementing urgent protective actions, there is no time to undertake detailed dose assessments in real time. There are also extremely large uncertainties associated with predictive models. It is therefore necessary to determine, in advance, a set of internally consistent criteria for taking such actions, and based on these criteria to derive appropriate “triggers” for initiating them in the event of an emergency, as described in ICRP Publication 109. The IAEA also recommends that predetermined urgent protective actions should be taken before or shortly after a major release on the basis of plant conditions and should not wait for a release to start.

Evacuation of special people

More than 2000 patients and elderly people stayed in seven hospitals and 17 nursing homes within the 20 km evacuation zone. There were significant difficulties such as providing appropriate transport and evacuation shelters with medical supplies encountered when evacuating patients from these hospitals and nursing homes. It was reported more than 50 patients died either during or soon after evacuation from hospitals and nursing homes.

Prior to the accident, it was planned that evacuation of residents within the 10 km Emergency Planning Zone was to be undertaken following the local emergency plans. However, no specific emergency plans for hospital patients and elderly people in nursing homes have been established although the investigation committee report on the Tokaimura criticality accident in 1999 emphasized the importance of these arrangement for vulnerable people as well as international standards.

Sheltering

Sheltering within 20 to 30 km radius advised on 15 March caused difficulties and confusion amongst the public. The difficulties encountered were mainly due to the loss of local infrastructures, and the confusion resulting from the government advising the public to voluntarily evacuate on 25 March (NERHQ, 2011). Voluntary evacuation meant that those located in the 20 to 30 km radius could choose whether they would evacuate or not. However, this proved to be problematic as the public was uncertain of how to decide if they should evacuate.

In the previous emergency plan, instructions of evacuation were to be issued to districts with areas that were expected to have very likely high levels of radiation or located in the immediate vicinity of the site. Beyond the geographical limits of evacuation zones, sheltering would be instructed as an urgent protective action to reduce their exposures in case of the possible passage of an airborne radioactive plume above their living places. During the Fukushima Daiichi accident, it was found that sheltering required a very difficult judgment. Sheltering in one's own house can be done quickly, and is also advantageous as it enables rapid and easy access to information such as new instructions on protective actions. Conversely, depending on the structure of the house, an effective method to reduce the dose cannot be expected, and considering efforts to secure food etc. sheltering for longer periods is not practical. Instructions for sheltering are temporary measures to reduce exposure from a release of radioactive material. It requires prompt termination of the instruction or changing to an instruction to obligatory evacuation if it can be done safety, depending on the prevailing circumstances.

Modifying initial protective actions

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). Monitoring beyond the area already evacuated was conducted on the evening of 15 March, and the highest value of ambient dose rate measuring at 170 μSv/h was observed at a point outside the evacuation zone at approximately 30 km from the site. The NSC provided advice to the Government that the residents should be requested to voluntarily evacuate from those areas where a relatively high dose was expected. After reviewing the situation, the NSC has been considering the modification of the urgent protective actions implemented and the process of implementing temporary relocation of residents in those areas. Meanwhile, the IAEA advised the Government to carefully assess the situation on 30 March because one of the IAEA's operational criteria for evacuation was exceeded in Iitate village located more than 30 km from the NPP.

Since there were neither criteria nor OILs for use in long-term protective actions in the NSC's guide, the revised recommendations of the ICRP Publications have been taken into consideration in determining the temporary relocation of the inhabitants in the heavily contaminated areas. On 22 April, an area beyond 20 km from the site where the projected dose over one year after the onset of the accident might exceed 20 mSv was established as the "deliberate evacuation area". Actual movement and relocation of people in the deliberate evacuation areas did not start until May because of the need to consider the opinions of different stakeholders.

Preparing long-term protective actions

The specific policies, guidelines and criteria as well as overall arrangements for long-term protective actions for recovery were developed after the accident. The establishment of a 'Roadmap' in May 2011 by the Government was a process used to characterise the situation in order to take control of the exposures. The Roadmap specified the objectives and conditions to be met for the termination of the emergency phase. It facilitated the transition to long-term recovery operations, enabling a phased return to normality. The application of this graded approach proved to be effective in the preparation for long-term recovery operations.

The Roadmap listed nine groups of actions to be taken that were scheduled to be implemented over different target time periods. The characterisation progressively enabled informed planning and implementation of long-term protective actions, including the establishment of detailed environmental monitoring plans, long-term health surveillance, formalization of the long-term management of radioactive waste, and the establishment of long-term plans for decontamination.

The Roadmap subsequently enabled a review of the areas where protective actions were being implemented, which resulted in the implementation of adjustments to the protective actions, such as lifting the recommendation to shelter in September 2011 and the first lifting of an evacuation order in April 2014.

New strategy

Based on the above lessons learned from the Fukushima Daiichi accident, the interim report on the revision of the nuclear emergency preparedness guide by NSC emphasized the importance of having a common understanding of the emergency management timeline among relevant organizations to develop a consistent and coherent decision-making strategy over time.

Figure 1 shows a view of the emergency management timeline and emergency phases with the lines which indicates uncertainty in an emergency situation and information available or degree of stakeholder involvement. The initial uncertain period of an emergency exposure situation can be characterised as following pre-planned actions as best as possible to manage any emergency consequences. Therefore, protection strategies should include triggers that can be used immediately to initiate appropriate protective actions. Triggers may be expressed in terms of directly measurable quantities such as plant conditions and dose rates. As an emergency exposure situation progresses, and understanding of the exact circumstances increases, decisions will increasingly be based on actual circumstances rather than pre-planned responses. As understanding increases and the need to act becomes less urgent, there will also be an increased need to involve relevant stakeholders in the decision-making processes.

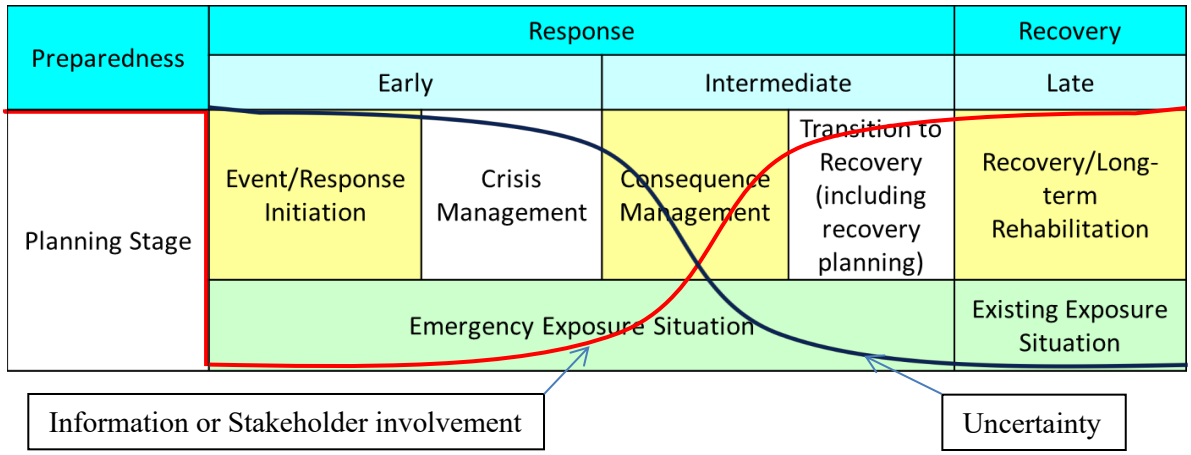

Figure 1. A view of the emergency management timeline and emergency phases

In the first version, the NRA proposed a new emergency response scheme of implementing protective actions. In order to avoid severe deterministic effects and to keep the risk of stochastic effects as low as reasonably achievable, urgent protective actions should be implemented before a release on the basis of predetermined plant conditions (i.e. emergency action levels (EALs)) within precautionary action zone (PAZ), and also an urgent protective action planning zone (UPZ) in the case of severe plant conditions or a risk at multi-units. The PAZ size of about 5 km and UPZ size of about 30 km were suggested from the recommendations provided by IAEA (IAEA, 2007). Radiological monitoring should be conducted following a release to locate additional areas beyond those already evacuated that require urgent protective actions. Decisions on protective actions should be made using predetermined Operational Intervention Levels (OILs).

Figure 2 shows an example of a generic emergency response strategy for implementing protective actions. After declaration of a General Emergency based on EALs, the off-site decision maker starts implementation of the predetermined urgent protective actions in the PAZ and the UPZ. Following a release, the areas not evacuated are promptly monitored. Based on predetermined OILs, areas are identified where additional protective actions are warranted. The goal is to determine areas where specific OILs are exceeded that require; evacuation within a day, relocate within a week to a month, restriction of consumption of local produce within days.

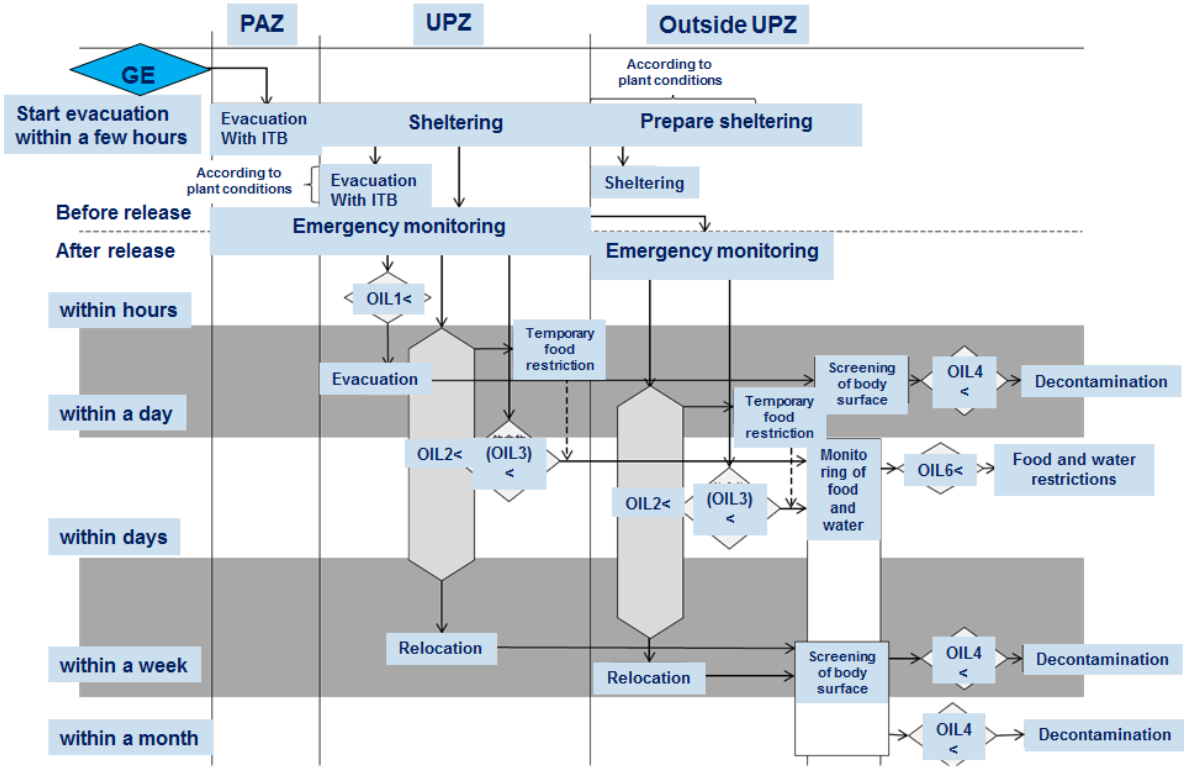

Figure 2. An example of implementing protective actions

NRA has revised the Guidelines thirteen time so far to improve the arrangements for preparedness and response for a nuclear emergency. Further revisions still need to be prepared for arrangements for long-term recovery at the preparedness phase.

Conclusions

A general lesson learned from the Fukushima Daiichi nuclear power plant accident is that there was an implicit assumption that such severe accidents could not happen and thus enough attention had not been paid to preparedness for the accidents by the operators and the regulatory authorities. A clear concept of operations in emergency response planning has not been established and shared by relevant response organizations before the Fukushima Daiichi accident. The new emergency response scheme emphasizes the importance of establishing consistent policies and criteria for implementation of urgent and long-term protective actions including return to normality along the emergency management timeline. Amongst the lessons learned from the Fukushima accident, it is particularly evident that arrangements should be established for taking predetermined urgent protective actions before a release on the basis of plant conditions. It is also suggested that arrangements need to be developed at the preparedness stage for termination of protective actions and long-term protective actions.

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