Toward Enhancing Preparedness and Response Arrangements and Capabilities for a Nuclear Emergency(1)

−Emergency Preparedness and Response "Concepts in International Standards and Fukushima Experience"−

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The Nuclear Regulation Authority (NRA) has enacted the Guide for Emergency Preparedness and Response (hereafter, "NRA EPR Guide") by taking heed of the lessons learned from the Fukushima Daiichi Nuclear Power Plant (NPP) Accident in line with international standards for emergency preparedness and response that were established mainly by the International Atomic Energy Agency (IAEA). This commentary explains the safety requirements established by the IAEA, along with the underlying basic concept of the protection strategy for an emergency response.

I. Introduction

In March 2013, the Nuclear Safety Subcommittee of the Atomic Energy Society of Japan (AESJ) published a report (subtitled "What Went Wrong and What Should Be Done?") based on discussions that took place during the eight rounds of seminars on the Fukushima Daiichi NPP Accident that were held in 2012 [1]. To further these discussions, the AESJ held an organized session at its Spring Annual Meeting 2014 to feature challenges involving nuclear emergency preparedness and response as an important means of defense in depth. Nuclear emergency preparedness and response is aimed at fully mitigating the impact of any loss of control at nuclear facilities or radiation sources to protect people and the environment from radiation. Specific measures were discussed in detail through presentations given by experts from various organizations and at the overall discussion session.

The organized session, entitled "Toward Enhancing Preparedness and Response Arrangements and Capabilities for a Nuclear Emergency," consisted of the following three presentations: (1) Emergency preparedness and response—Concepts in international standards and Fukushima experience, which was presented by Toshimitsu Homma (author); (2) A desirable system for nuclear preparedness and response, which was presented by Yasushi Morishita, Director of the Nuclear Regulation Policy Planning Division, NRA Secretariat; and (3) Current state of evacuation plans and challenges ahead, which was presented by Noriaki Shimada,

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Director of the Office for Evacuation, Nuclear Safety Subcommittee, Disaster Management Department, Shimane Prefecture, followed by the overall discussion chaired by Takashi Nitta from the Japan Atomic Power Company. Commentary (1) provides an overview of the presentation (1), while Commentary (2) provides an overview of the presentations (2) and (3).

II. Lessons Learned from the Fukushima Daiichi NPP Accident and the NRA EPR Guide

An overview of the report published by the Nuclear Safety Subcommittee has already been provided in this commentary series. Addressing challenges associated with nuclear preparedness and response [2)], the fifth commentary drew the following seven lessons from the Fukushima Daiichi NPP Accident in relation to challenges involving urgent and long-term protective actions as well as emergency management and operation.

Lesson 1: Implementation of urgent protective actions: Arrangements should be made to promptly implement precautionary urgent protective actions within a predetermined zone before radioactive material is released into the environment based on predefined criteria for plant conditions.

Lesson 2: Evacuation and sheltering: Prior arrangements should be made to ensure the safe evacuation of persons in need of assistance from special facilities such as hospitals. Sheltering should be implemented only for a short period until such persons can be safely evacuated or relocated.

Lesson 3: Immediate restrictions on food and drink: Operational intervention levels (OILs) should be prepared based on immediately available data, such as ambient dose rates for restrictions on food and drink during crisis management in the early phase of the response.

Lesson 4: Long-term restrictions on food and drink: Practical recommendations should be made concerning long-term restrictions on food and drink with due consideration given to the actual situation in the affected areas and international harmonization.

Lesson 5: Protective actions over the timeline: The concept and criteria for urgent and long-term protective actions should be established, including actions aimed at facilitating the resumption of normal life in the preparedness stage. Such actions should include providing advance guidance on the application of the principles of radiation protection to the possible emergency conditions that correspond to the protective actions.

Lesson 6: Operational intervention levels (OILs): OILs provide essential guidelines for making decisions in an emergency. More detailed international guidelines on preparing OILs are necessary.

Lesson 7: Preparedness against combined emergencies: Arrangements should be put in place for the full range of possible events, including those with a very low probability, taking into account the combination of a nuclear accident with a conventional emergency, such as an emergency following an earthquake.

In line with these lessons, the following practical challenges should probably be considered as well.

- In the aftermath of the Fukushima Daiichi NPP Accident, critical information was not shared among the organizations involved, especially those from the accident site, municipalities, regulatory bodies, and the national government. The assignment of roles and the chain of command must be clarified to ensure information sharing and proper coordination.

- Basically, the national and local governments have roles to play in the off-site arrangements, while the operator has roles to play in the on-site arrangements. Nonetheless, it is important for the operator to coordinate its arrangements with the national and local governments to ensure a prompt and effective response. In addition, both sides may be required to cross such boundaries when considering their roles.
- In the crisis management phase, the initial response should be guided by predetermined methods. At the same time real experts must be trained and constantly deployed to assist the decision makers so that flexible responses can be taken even in unexpected circumstances.
- The fire service, police, Self-Defense Forces, and other emergency response professionals should be mobilized to facilitate evacuation and other protective actions at the scene. Instead of treating nuclear emergencies as something exceptional, local governments can prepare for the necessary operations effectively under the same framework as that applied when responding to other conventional emergencies.
- It is questionable whether a facility in which responders work only in the event of a nuclear emergency will actually function. Consideration should be given to integrating such a facility with one used for responding to a conventional emergency.

One of the major lessons to be learned from the Fukushima Daiichi NPP Accident is that both the operators and the national and local governments made an implicit assumption that such severe accidents could not happen, resulting in them paying insufficient attention to preparedness for such accidents. The Regulatory Guide on Emergency Preparedness for Nuclear Facilities issued by the Nuclear Safety Commission (hereafter, the "NSC Guide") specified various technical indicators, such as "areas in which arrangements for emergency preparedness and response should be intensively implemented (emergency planning zones (EPZs))" and "criteria for protective actions (dose criteria)," for implementing urgent protective actions. However, this guide did not clarify the concept of operations for protective actions or explain the specific steps required. For this reason, in the emergency response drills that were conducted frequently after the JCO Tokaimura criticality accident, an approach was established in which the areas for evacuation and sheltering were decided by comparing the dose projections obtained using two emergency simulation systems: the Emergency Response Support System (ERSS; source term predictions for accident progress, released amounts, etc.) and the System for Prediction of Environmental Emergency Dose Information (SPEEDI). Although such an approach was different from the basic concept used for implementing the urgent protective actions commonly adopted by the international community, the necessary review of this approach had been neglected.

Immediately after the accident, the NSC established a working group on the Emergency Preparedness Guide under the Special Committee on Nuclear Disaster to discuss issues to be reflected in the NSC Guide. The working group summarized an approach for revising the guide. These revisions were sought in order to take into account the basic concept of protective actions in emergencies in line with the latest international considerations. Moreover, based on the lessons learned from the Fukushima Daiichi NPP Accident, the working group has considered the basic concept of protective actions against all reasonably foreseeable events (even those with a very low probability of occurrence) to protect human life, health, property, and daily life as well as the environment. They produced an interim report in March 2012 [3).

The NRA, which was established in September 2012, issued the new EPR Guide [4) in October 2012 based on the review of the NSC Guide and the interim report as well as reports from commissions assigned to investigate the Fukushima Daiichi NPP Accident. This commentary explains the international standards that were taken into account during the process of establishing the NRA EPR Guide.

A particular focus is placed on the basic concept of emergency preparedness and response, as adopted by the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP).

III. International Standard Developments at the Time of the Fukushima Daiichi NPP Accident

In 2011, when the Fukushima Daiichi NPP Accident took place, the IAEA published two important documents related to nuclear preparedness and response: GSR Part 3 (Interim, 2011)[5], which is a revised version of the Basic Safety Standards (BSS) issued in 1996 that defined the safety requirements for radiation protection; and General Safety Guide No. GSG-2 in 2011[6], which defines the "Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency." These documents reflected the ideas behind the new recommendations issued by the ICRP in 2007 (ICRP Pub. 103)[7]. The concept of radiation protection has evolved from a process-based approach using practices and interventions to an approach based on the characteristics of three kinds of exposure situations; namely, planned exposure, emergency exposure, and existing exposure situations. In particular, guidance for the necessary responses to emergency exposure and existing exposure situations were respectively compiled in 2009 (ICRP Pub. 109[8] and 111[9]). In this respect, the year 2011 marked a transition to this new way of thinking about radiation protection. It is fair to say that when the Fukushima Daiichi NPP Accident took place, none of the emergency response plans produced by Japan or any other country had adopted the radiation protection concept for emergency exposure and existing exposure situations after an accident, as recommended by the ICRP.

Nonetheless, prior to the Fukushima Daiichi NPP Accident, the IAEA had developed the safety requirements *Preparedness and Response for a Nuclear or Radiological Emergency* (GS-R-2, 2002)[10] based on the lessons learned from incidents such as the nuclear reactor accidents at the Three Mile Island (TMI) plant in the United States and the Chernobyl plant in the former Soviet Union, the radiation source accident in Goiânia, Brazil[11], and the criticality accident in JCO Tokaimura. These safety requirements have been valued by many countries as a basic concept of emergency response. The IAEA is currently revising GS-R-2, which will be published in the near future as GSR Part 7. The discussions held so far have not led to any substantial changes to the basic concept of emergency response, while the requirements incorporate lessons learned from the Fukushima Daiichi NPP Accident and the new concept of radiation protection.

IV. Basic Concept of Emergency Response Adopted in International Standards

1. Overview of the Emergency Management Timeline

In an emergency, various activities are required of operators, local governments, and the national government to effectively mitigate the impacts on the health and infrastructure of local residents as well as the environment and support the return of affected areas to normal social and economic activity as far as possible. In responding to an emergency, it is important for the relevant organizations to establish a common and consistent decision-making scheme throughout the emergency management timeline. **Figure 1** presents the concept of emergency management for each phase along the timeline [12]. In Figure 1, the solid line represents the amount of information or the involvement of stakeholders, while the dotted line represents the level of uncertainty. An emergency can be broadly divided into three stages: preparedness, response, and recovery. The response stage can be further divided into response initiation and crisis management in the early phase and consequence management and transition to recovery in the intermediate phase.

In the early phase, event/response initiation includes recognition of the emergency situation and initiation of the response. Together with measures for mitigating the accident's progression and gaining control over the source, urgent protective actions are implemented from the perspective of crisis management. Owing to the greater uncertainty caused by the limited availability of information during crisis management, an extremely urgent response is required even before reliable information on the emergency becomes available to achieve the radiation protection goal of avoiding severe deterministic health effects and keeping the stochastic health effects as low as reasonably achievable. For this reason, urgent protective actions are taken according to a planned procedure for a scenario assumed in the preparedness stage. The necessary coordination should be undertaken with stakeholders beforehand in the preparedness phase. More information becomes available over time and coordination with stakeholders will be more important during consequence management and the transition to recovery.

In the intermediate phase, consequence management is identified as the period of time after a certain degree of control has been regained over the source or the major release has been terminated and radioactive contamination is in the environment. During this phase, adequate dialogue should be conducted with stakeholders to modify and lift any protective actions taken in the early phase and to consider long-term protective actions, such as restoring agriculture or decontaminating affected areas. These actions should be taken based on an adequate characterization of the radiological situation by environmental monitoring or analysis. In the transition to recovery, specific plans are developed to initiate the recovery/long-term rehabilitation of affected areas, and support is provided to return social and economic activities to normal.

The concept of an emergency exposure situation recommended by the ICRP in 2007 can be adopted in the early and intermediate phases of a response. Similarly, the concept of an

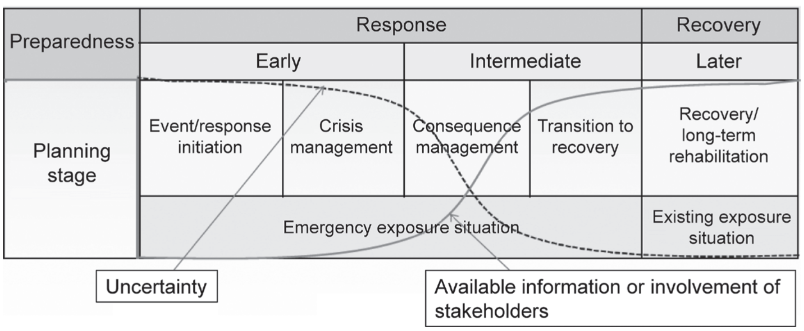

Figure 1 Timeline of emergency management and the emergency phase

existing exposure situation can be applied to the later recovery management. The concepts adopted by the ICRP are explained later in Section IV-5.

2. Emergency Response Goals

In the safety requirements established in GS-R-2, the IAEA has taken a management approach to ensure the substantial achievement of emergency response goals by developing an emergency management system based on the most efficient and effective method. The approach sets forth the following goals for the first step:

(1) to regain control of the situation;
(2) to prevent or mitigate consequence at the scene;
(3) to prevent the occurrence of deterministic health effects in workers and the public;
(4) to provide first aid and manage the treatment of radiation injuries;
(5) to prevent, to the extent practicable, the occurrence of stochastic health effects in the population;
(6) to prevent, to the extent practicable, the occurrence of non-radiological effects on individuals and among the population;
(7) to protect, to the extent practicable, property and the environment; and
(8) to prepare, to the extent practicable, for the resumption of normal social and economic activity.

Next, a response strategy is considered based on the experience of past emergencies and emergency response drills, detailed analysis and understanding of emergency situations, and principles derived from international law as well as principles of justification and optimization of protective actions. Detailed preparedness and response requirements are derived from the strategy.

This approach puts a clear emphasis on the importance of preparedness to ensure an effective response and achieve these goals rather than responding to a de facto situation reactively. An emergency involves various uncertainties, but before such uncertainties can be substantially reduced, decisions on protective actions must be taken based on an analysis of the given situation. For this reason, the IAEA points out the importance of employing a strategy for protective actions that gives due consideration to uncertainties with the aim of ensuring that decisions on protective actions that produce more benefits than harm can be taken when they are most effective.

3. Protective Action Strategy in the Early Phase

Past experience of accidents, such as those that occurred at the TMI and Chernobyl plants, as well as studies on severe accidents and probabilistic safety assessments (PSAs) demonstrate the extreme difficulty involved in assessing the situation resulting from an ongoing accident and predicting the accident's progression. Even greater uncertainties can complicate estimations of the following: the release and transport of radioactive material inside a facility; the resultant source terms for the environment; the dispersion and deposition of radioactive material in the environment; and the resultant doses. It is virtually impossible to predict sufficiently precise source terms quickly enough to enable decisions to be made on urgent protective actions. Bearing in mind the uncertainties that prevail during an emergency, the IAEA justifies the adoption of a precautionary approach to take urgent protective actions in all directions within a predetermined range whenever a severe condition is detected at a facility in order to prevent any deterministic effects even if the condition does not lead to radiation exposure. The type of protection strategy adopted by the IAEA in the early phase is based mainly on an idea developed by the Nuclear Regulatory Commission (NRC) of the United States. According to the underlying American principle, operators are primarily responsible for any accidents. Because operators are presumably the most knowledgeable about accidents, they are required to issue protective action recommendations for off-site areas. State governments at the subnational level are, of course, ultimately responsible for the judgments and decisions taken with respect to protective actions. The NRC reviews the recommendations of the operators and offers adequate counsel. The protection strategy adopted by the IAEA in the early phase is outlined below along the lines of a paper presented at an international symposium entitled *Emergency management in the early phase* [13].

(1) Aspects of severe accidents at nuclear power plants

[1] Uncertainty about the amount and duration of a radioactive release caused by core damage

In the event of any trouble at a reactor facility, operators try to mitigate the impact of any ensuing accidents by shutting down the reactor to stop a fission reaction, cooling the core to remove any decay heat, and implementing other measures to protect the reactor core. Nonetheless, any failure of a safety system designed to protect a reactor core may lead to cladding damage in several minutes to several hours from fuel overheating (note that the fuel temperature is not evenly distributed and that the rate of temperature increase depends on the availability of cooling systems and the level of the Zircaloy-steam reaction). In addition, the time of the core exposure can only be roughly estimated. Therefore, it is nearly impossible to predict precisely how radionuclides released from a core will change over time and when their release will end.

Operators may be able to predict, or at least detect, extremely severe fuel damage by using direct indicators of impending cladding damage (e.g., a reduced core water level and a temperature increase) and an increase in radiation associated with cladding damage. Only an extremely inaccurate estimate can be made concerning the amount of radioactive material released from a nuclear reactor into the primary containment vessel (PCV).

[2] Uncertainty about environmental releases from damaged primary containment vessels

A severe accident can escalate in a reactor cooling system through various sequences, and it can cause various modes of damage to a PCV. The most likely sequences of an accident and the probabilities of different modes of PCV damage are assessed by conducting PSAs. For instance, the NRC has conducted an extensive study of nuclear power plants in the United States to estimate the probabilities of early PCV damage being caused by factors such as station blackouts or a loss of coolants (NRC, 1990) [14]. They have also studied various modes of PCV damage, including the following: damage caused by high pressure or high temperature; damage caused by a possible direct containment heating of a PCV if a molten core melts through the lower head of a reactor vessel under a high reactor pressure; and damage caused by a failure to close the valve that isolates the interior of the PCV immediately.

Although PSAs do cover such damage, the reality is that few operators can accurately predict whether and when a PCV will suffer damage and how much radioactive material will leak out as a result. There are safety systems that can reduce the release of radionuclides from PCVs, such as sprays, filters, pools, and ice-condensers. However, it is difficult to predict to what extent a release can be reduced under extreme and uncertain conditions. To complicate matters, the safety systems could fail, or a containment bypass could occur, resulting in a radioactive release.

According to the NRC's risk study, PCV damage that occurs in the early phase due to core damage is estimated to release between 1% and 20% of the iodine that has accumulated in the reactor core. This range can be much larger for other major nuclides. This uncertainty is extremely important. Indeed, the release of less than 1% of the iodine may not produce any severe deterministic effects off-site, but the release of 20% within a short period of time may cause deaths if no protective actions are taken.

The typical sequences for accidents that could lead to a massive release are as follows: 1) a system failure or operator error; 2) failure of the safety systems designed to protect the fuel; 3) the core gets uncovered; 4) the fuel heats up and fails; 5) radioactive material is released from the fuel into a PCV or other plant areas; 6) the containment fails or is bypassed resulting in a release to the atmosphere; and 7) actions are taken to mitigate the accident, slow and stop the release, and stabilize the plant. Instruments in the control room can detect events up to the fifth stage of these sequences, but they cannot accurately predict events in the sixth stage that would significantly influence the timing and magnitude of any release. As is the case with PCV damage, most large releases take place in undetectable locations. The control room is probably unable to measure the timing and extent of such a release.

[3] Uncertainty about the impact of an environmental release

Despite recent improvements that have enabled extensive atmospheric dispersion to be predicted much more accurately, predictions in regional or local areas remain uncertain due to limited knowledge of the atmospheric parameters for such ranges. Without any environmental measurements, predicting the radionuclide concentration is extremely difficult given the uncertainty about the rate and location of the release, continuous changes in meteorological parameters, and the initial migration of released material according to the local terrain and weather conditions. Once a release is detected through monitoring, it may be possible to estimate how long it will take before the released material reaches residents in nearby communities. However, it would be too late to make any decisions on the protective actions needed to avoid any severe deterministic effects from a fatal release involving massive exposure.

In most sequences for severe accidents, the exposure pathway that produces the most severe deterministic effects is external exposure from surface deposition. For this reason, the effects depend significantly on the occurrence and scale of precipitation. An assessment of the Chernobyl Accident demonstrated that the distribution of the deposition of radioactive material was extremely ununiform. The concentration could differ by over an order of magnitude between two different locations that were only a few hundred meters apart. It is impossible to predict such variations. In a study conducted with assistance from the European Commission (EC) and the NRC [15)], the various degrees of uncertainty were estimated using the key factors involved in estimating the dose after a nuclear accident. Combined with these environmental uncertainties, even accurately determined source terms would only enable the initial dose estimation to be within a factor of 10 to 100 at best from the actual doses.

(2) Prevention of deterministic effects

An assessment of severe accidents [14)] suggests that severe deterministic effects are produced off-site by either critical fuel damage or PCV damage in the early phase. Effective protective actions in the early phase require a swift response before any exposure occurs. In practice, an emergency support team must be established and organized to carry out the necessary measures, which inevitably leads to some delay. Clearly, alerts based on the plant conditions are vital. If operators report a failure that has been detected by a system employed for protecting a reactor core, they can alert the relevant agencies off-site a few hours before any release.

As mentioned earlier, core damage can be predicted through observable conditions, but it is much harder to foresee PCV damage. Due to the considerable uncertainties involved, it is virtually impossible to estimate the amount of release and doses off-site accurately when decisions need to be made. After the core suffers damage, this degree of uncertainty does not change until the scale of the release is indicated by environmental measurements. Precious time would be lost by delaying decisions or waiting for information that would not improve the quality of decisions anyway. Ensuring the prompt protection of residents crucially requires clear criteria for initiating the necessary activities in response to predicted or actual core damage.

This idea forms the basis for emergency classifications in many countries, and it has been incorporated in GS-R-2 as well. The emergency classifications used in GS-R-2 are in line with the four categories presented in Section IV-4. The classification criteria are specified according to predetermined emergency action levels (EALs), which depend on abnormalities in the condition of the facilities, safety-related matters, the release of radioactive material, environmental measurements, and other observable indicators. The scheme provides the basis for alert requirements and defines the authority and duties of relevant agencies according to the emergency classification. Thus, it enables all relevant agencies to take action swiftly according to the declared emergency category.

(3) Minimization of stochastic and non-radiological effects

Another goal of radiation protection during an emergency response is to reduce any resultant stochastic effects. Protective actions that are intended to reduce the stochastic effects can often produce conflicting effects in relation to public finances, society, the economy, and psychology. Damage caused by a severe accident that poses both radiological and non-radiological effects persists for a long time. The pace of recovery from such an accident depends on various factors, including the need to regain and maintain public trust, signs of the emergence of deterministic effects and an increase in the stochastic effects, the number of people who undergo health surveillance, the public perception of government activities during an emergency, and compliance with international standards.

Based on the experiences from the Chernobyl Accident and other past events, the IAEA recommends the following: (1) restrictions on food intake; (2) distribution of iodine thyroid blocking agents; (3) health surveillance; (4) planning of protective activities; (5) operational intervention levels (OILs); and (6) advice for residents. Space limitations prevent us from going into detail, but further information can be found in Reference Material [13].

(4) Strategy for protective actions

In light of the above, the IAEA has recommended the following approach as a means of substantially reducing the human health effects of severe accidents.

(a) Residents within 3 to 5 km should evacuate or shelter in place before or immediately after any major release. In addition, iodine thyroid blocking agents should be distributed to residents who sought shelter near the site before or immediately after the major release. Decisions should be made based only on the conditions of the site facilities, without waiting for the release.

(b) Before or immediately after the major release, warnings must be issued in all areas located within 300 km or more to avoid any intake of potentially contaminated food.

(c) After a release, monitoring should be swiftly carried out around the evacuated areas to allow people to avoid hot spots left by radioactivity deposition. Decisions on protective actions should be made swiftly by applying predetermined OILs to the monitoring results.

4. Basic Requirements Established in GS-R-2

The IAEA established basic requirements for emergency preparedness and response in GS-R-2 based on the protective action strategy in the early phase. **Figure 2** outlines the procedure to be taken in the planning and response stages of responding to an emergency. These requirements essentially adhere to the US approach to emergency preparedness and response. According to these requirements, the following arrangements should be implemented in the planning stage.

(1) Hazard assessments

Operators assess hazards in each category according to the type and scale of the radiation source and facility. Hazards are classified into categories to ensure that preparedness and response measures can be properly prepared and maintained through a graded approach according to their potential magnitudes and nature. Although this classification is not described in detail, its five categories cover the most hazardous nuclear power plants and various other sources of hazards.

In a hazard assessment, accident sequences leading to an emergency can be considered based on the findings of the safety analysis conducted during the designing of the facilities. To do this, all reasonably foreseeable postulated incidents must be taken into account. A hazard assessment must also identify which facilities and sources require the following actions and how extensively in response to an emergency.

a. Precautionary urgent protective actions to prevent severe deterministic health effects by keeping doses below a certain limit under any circumstances
b. Urgent protective actions to prevent stochastic effects by averting doses in accordance with international standards
c. Restrictions on food intake, measures related to agriculture, and long-term protective actions in accordance with international standards
d. Protection for the workers in accordance with international standards

(2) Setting of criteria for emergency classification

Operators must prepare the relevant criteria for classifying emergencies. The IAEA has adopted four categories for the classification of emergencies: (1) general emergencies, which require urgent protective actions both on-site and off-site; (2) site area emergencies, which require actions on-site and preparations in the vicinity of the site as necessary; (3) facility

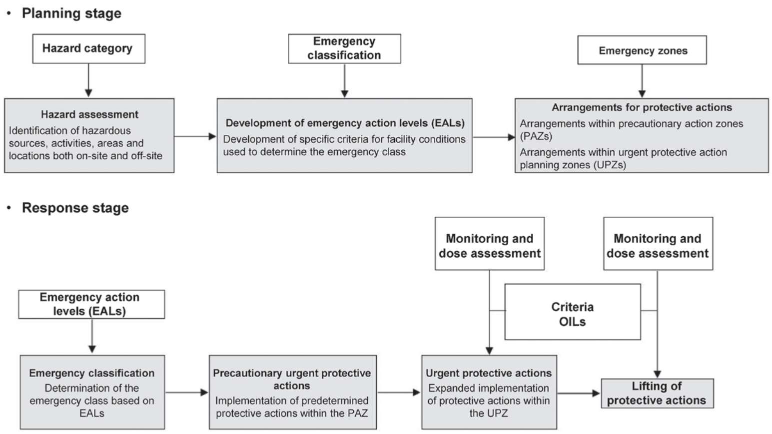

Figure 2 Basic concept of emergency preparedness and response in the IAEA GS-R-2

emergencies, which require the protection of people on-site; and (4) alerts, which are issued at facilities involving an uncertain or significant decrease in the level of protection for the preparation of protective actions. By defining the authority and responsibilities of the relevant agencies in accordance with this classification, all relevant agencies can promptly take action according to the declared emergency category. EALs serve as the criteria for this classification.

(3) Assignment of planning zones for urgent protective actions

Planning zones must be assigned to nuclear power plants and other facilities that are classified as highly hazardous in order to allow the necessary actions to be promptly performed off-site in response to an emergency.

a. Precautionary action zones (PAZs): Necessary arrangements are made according to the facility conditions so that precautionary urgent protective actions can be taken before or immediately after the release of radioactive material to substantially reduce the risk of severe deterministic health effects.

b. Urgent protective action planning zones (UPZs): Necessary arrangements are made so that urgent protective actions can be taken to avert doses in accordance with international standards.

After due preparations have been made for emergencies in the planning stage, actions are taken in response to an actual emergency as shown in Figure 2.

- Emergencies are classified according to EALs
- Urgent protective actions are taken in PAZs as prepared in advance for a general emergency.
- Appropriate urgent protective actions are taken in UPZs while the measurement results from monitoring are compared against OILs.
- Similarly, judgements on the lifting of protective actions are made by comparing the measuring results from monitoring against the relevant criteria.

5. Concept of Radiation Protection in an Emergency

Let us take a brief look at the basic concept of providing radiation protection against emergency exposure situations as recommended by the ICRP in 2007. A more in-depth explanation is available in Serial Lecture, *New ICRP Recommendation—New Radiation Protection Principle and Standards (6); Emergency Exposure Situations* [16]. The recommendations stress the importance of justification and optimization in a protection strategy against emergency exposure situations. A process of optimization based on the reference level is applied to plan protective actions and ensure optimal levels of protection. Such optimization facilitates more comprehensive protection and flexible responses by simultaneously considering all exposure pathways and all relevant protective options. In the planning stage, optimization may also facilitate effective resource allocation by providing a framework of reference on the ways in which protective actions influence one another.

Optimization based on a reference level focuses on the levels of residual doses after the implementation of a protection strategy. This is the main difference in relation to the optimization of a single protective action to avert doses based on the recommendations made by the ICRP in 1990. As shown in **Figure 3**, for example, the conventional optimization of a single protective action is carried out to plan an evacuation if a project dose exceeds an avertable effective dose of 50 mSv, which requires an evacuation unless any other actions are taken.

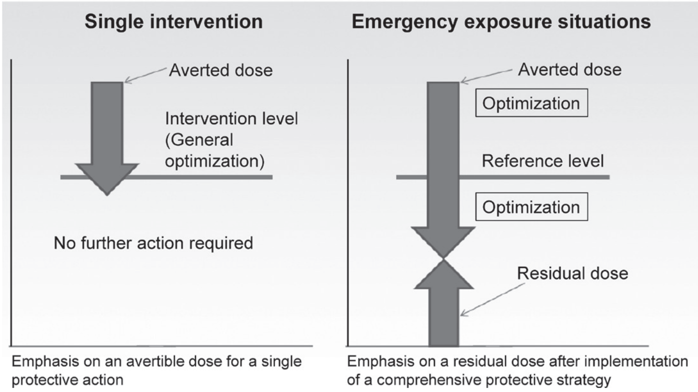

Figure 3 Intervention and optimization under emergency exposure situations

Optimization performed based on a reference level considers all exposure pathways and all relevant protective options. In the planning stage, protective options that reduce residual doses to below the reference level are selected. In response to any emergency exposure situations, the estimated residual dose is assessed against the reference level to consider the effectiveness of a protection strategy and determine whether there is a need to modify specific protective actions or take additional actions. Although it is somewhat more complicated in practice compared to the optimization of a single protective action against emergency exposure situations, such a concept enables optimal protective actions to be planned more flexibly by emphasizing the synergy among all of the actions.

According to the recommendations made by the ICRP in 2007, the reference level for the effective residual dose in relation to a protection strategy under emergency exposure situations should be selected from between 20 and 100 mSv. Any dose beyond 100 mSv increases the likelihood of deterministic effects and carries a significant risk of cancer. The maximum value for a reference level is therefore an acute or annual dose of 100 mSv. The ICRP additionally recommends that all viable protective actions be taken if severe deterministic health effects may exceed the threshold. In the planning stage, the reference level can serve as a criterion for judging the soundness of a protection strategy. In the response stage, the reference level is used as a benchmark for judging the effectiveness of a protection strategy and determining whether there is a need to modify specific protective actions or take additional actions.

6. Criteria for Implementing Protective Actions

As mentioned in Chapter IV, GS-R-2 presents a decision-making procedure for emergency responses. To avoid severe deterministic health effects, precautionary protective actions are taken according to the facility conditions, which are defined by EALs and the emergency classification. Meanwhile, urgent protective actions are taken after the environmental release of radioactive material mainly to reduce the occurrence of stochastic effects. Rather than relying on criteria expressed in terms of doses, judgements are made according to OILs that can be measured in the environment, such as the dose rates and concentration levels of radioactive material in the environment. Examples of these criteria are presented along with the decision-making scheme in General Safety Guide No. GSG-2 [6)].

GSG-2 is mainly intended to define consistent generic criteria (GC) that can form the basis for developing EALs and OILs as operational criteria. The guide recommends that GC be first set for precautionary urgent protective actions to prevent any severe deterministic health effects. When this is done, the optimization principle for protective actions must be followed to apply the reference level for the residual dose as presented by the ICRP with the aim of allowing the GC to be set without any inconsistency with the reference levels in the range of 20 and 100 mSv. Once a set of GC has been established, default values must be set with EALs and OILs for initiating protective actions. Under emergency exposure situations, the default values should be adjusted according to the rapidly changing conditions in a pre-determined way.

More specifically, TABLE IV-1 of Schedule IV in GSR Part 3 [5)], which is a revised version of BSS, defines the GC for acute exposure doses for which protective actions or other response actions are expected regardless of the circumstances in order to prevent or minimize any severe deterministic health effects. Similarly, TABLE A-1 in the Annex defines GC for protective actions and other response actions aimed at reducing the risks of stochastic effects. **Tables 1** and **2** present the GC for preventing deterministic health effects and the GC for reducing stochastic effects, respectively. They are expressed in terms of the given organ doses or effective doses.

Further information can be found in the appendices of GSG-2 entitled "Development and examples of EALs for light water reactors" and "Examples of default OILs for deposition, individual contamination, and contamination of food, milk and water."

Table 1 Generic criteria for avoiding severe deterministic effects

Generic criteria	Examples of protective actions and other response actions
Acute external exposure (less than 10 h) Red marrow*1: 1 Gy Fetus: 0.1 Gy Tissue*2: 25 Gy at 0.5 cm Skin*3: 10 Gy to 100 cm^2	If the dose is projected: • Take precautionary urgent protective actions immediately (even under difficult conditions) to keep doses below the general criteria • Provide public information and warnings • Carry out urgent decontamination
Acute internal exposure due to an intake (Δ = 30 d*4) Red marrow: 0.2 Gy for radionuclides with atomic number Z ≥ 90*5 2 Gy for radionuclides with atomic number Z ≤ 89*5 Thyroid: 2 Gy Lung*7: 30 Gy Colon: 20 Gy Fetus*8: 0.1 Gy	If the dose has been received: - Perform immediate medical examinations, consultations, and indicated medical treatment - Carry out contamination control - Carry out immediate decorporation*6 (if applicable) - Carry out registration for longer term medical follow-up - Provide comprehensive psychological counseling

*1: External dose to red bone marrow, lungs, small intestine, gonads, thyroid, and lens of the eye caused by exposure in a uniform field of strongly penetrating radiation.

*2: A dose delivered to 100 cm^2 at a depth of 0.5 cm under the tissue surface due to close contact (e.g., with a radiation source carried in a hand or pocket)

*3: A dose delivered to the 100 cm^2 dermis, the skin structure at a depth of 40 mg/cm^2 (i.e., 0.4 mm) below the surface.

*4: AD (Δ) denotes an absorbed dose delivered over a period of time Δ by an intake (I_{05}) that will result in a health effect in 5% of exposed individuals.

*5: Different criteria are used to take into account differences in the intake thresholds among radionuclides.

*6: General criteria for decorporation are based on projected doses without decorporation.

*7: In this commentary, the term "lung" refers to the alveolar-interstitial (AI) region of the respiratory tract.

*8: An absorbed dose to fetus during utero development.

Table 2 Generic criteria for reducing stochastic effects

Generic criteria		Examples of protective actions and other response actions
Projected dose that exceeds the following generic criteria: Take urgent protective actions and other response actions.		
Thyroid equivalent dose	50 mSv (first 7 days)	Iodine thyroid blocking
Effective dose Fetal equivalent dose	100 mSv (first 7 days) 100 mSv (first 7 days)	Sheltering, evacuation, decontamination, intake restriction on food, milk, and water, contamination control, reassurance of the public
Projected dose that exceeds the following generic criteria: In the early phase of an emergency, take urgent protective actions and other response actions.		
Effective dose Fetal equivalent dose	100 mSv (annual) 100 mSv (entire period of utero development)	Temporary relocation, decontamination, substitution of food, milk, and water, reassurance of the public
Received dose that exceeds the following generic criteria: Take long-term medical actions to detect and effectively treat radiation induced health effects		
Effective dose	100 mSv (in a month)	Health screening of specific radiosensitive organs based on equivalent doses (as a basis for long-term medical follow-up) and counseling
Fetal equivalent dose	100 mSv (entire period of utero development)	Counseling to allow informed decisions to be made in individual circumstances

V. Conclusions

This commentary began with a brief review of the lessons learned from the Fukushima Daiichi NPP Accident with respect to preparedness and response in a nuclear emergency. It then provided an overview of international standards that the NRA referenced in its development of the NRA EPR Guide. The focus of this commentary was GS-R-2, which defines the safety requirements established by the IAEA, along with the underlying basic concept of the protection strategy for an emergency response. As an emergency response involves many organizations, sufficient coordination is required to ensure its effectiveness. The prerequisite is the development of a plan based on the established principles and basic concept of radiation protection and safety as explained in this commentary. As a further step, an arrangement should be reached to clearly divide the various responsibilities among all of the relevant organizations and deliver an integrated and coordinated response under a sufficiently clear agreement. Drills should be conducted so that the arrangements can be constantly modified to ensure an effective response in practice.

References

1) Nuclear Safety Subcommittee, Atomic Energy Society of Japan: Report from the Seminar on the Fukushima Daiichi Nuclear Accident [in Japanese], March 2013.
2) Toshimitsu Homma, et al.: A Digest of the Nuclear Safety Subcommittee Report on the Fukushima Daiichi NPP Accident, Seminar (5); Lessons learned on Emergency Preparedness and Response and Related Issues [in Japanese], Journal of the Atomic Energy Society of Japan, 55 (10), 568 (2013).
3) Nuclear Safety Commission: Interim Report for Reviewing “Regulatory Guide: Emergency Preparedness for Nuclear Facilities” [in Japanese], March 22, 2012.
4) Nuclear Regulation Authority: Guide for Emergency Preparedness and Response [in Japanese], fully revised on September 5, 2013.
5) IAEA, Safety Standards Series No. GSR Part 3, IAEA, 2014.
6) IAEA, Safety Standards Series No. GSG-2, IAEA, 2011.
7) ICRP, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, ICRP, 2009.
8) ICRP, Application of the Commission’s Recommendations for the Protection of People in Emergency Exposure Situations, ICRP Publication 109, ICRP, 2013.
9) ICRP, Application of the Commission’s Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency, ICRP

Publication 111, ICRP, 2012.
10) IAEA, Safety Standards Series No. GS-R-2, IAEA, 2002.
11) IAEA, The Radiological Accident in Goiânia, IAEA, 1988.
12) OECD/NEA: Strategic Aspects of Nuclear and Radiological Emergency Management, Radiation Protection 2010, OECD, 2010.
13) M. Crick, et al.: Emergency Management in the Early Phase, Radiat. Prot. Dosim., 109 (1–2), 7–17, 2004.
14) NRC: Severe Accident Risks: An Assessment for Five US Nuclear Power Plants, Final Summary Report, NUREG-1150, Vol. 1, 1990.
15) L. H. J. Goossens and F. T. Harper: Joint EC/USNRC Expert Judgement Driven Radiological Protection Uncertainty Analysis, J. Radiol. Prot., 18(4), 249–264, 1998.
16) Toshimitsu Homma: New ICRP Recommendation—New Radiation Protection Principle and Standards, (6); Emergency Exposure Situations [in Japanese], Journal of the Atomic Energy Society of Japan, 52 (9), 578 (2010).