Preparedness and Response to Radiological Emergencies

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Abstract

Radiological emergencies, caused by various reasons, will be faced by societies also in the future. Therefore all nations must have arrangements to response to these emergencies. Especially after the accident at the Chernobyl nuclear power plant in 1986 major progress was made internationally and nationally in management of response to and recovery from nuclear and radiological emergencies. Notwithstanding the broadly adequate provisions now in place in most countries and internationally, complacency would be misplaced and continuing vigilance remains important. Improvements, of a technical, organisational or political nature, are still needed in emergency management. The Fukushima accident put these issues on the forefront of political debate and public opinion will certainly increase the need for developing preparedness strategies for emergency response and recovery all over the world in the following years. Radiological emergency may come about not only through an accident but also through nuclear terrorism or other malicious acts with radioactive materials. Addressing these challenges requires that nations set up arrangements to secure their territory from malicious and illegal acts and to protect their citizens' health and welfare from harmful effects of radiation. Safety and security arrangements have common goals and the systems and measures used to achieve these goals need to be complementary. Therefore, a well-coordinated approach in nuclear safety and security is essential.

Introduction

There are several types of events that could result in dispersion of radioactive substances into the environment. These include both intentional and unintentional events. Releases of radioactive substances could range from major accidents at nuclear facilities or explosion of a nuclear weapon to small events such as a transportation accident. The extent of the contamination and radiological impact on the environment and people depend greatly on the type of an event and the radionuclides involved. However, many aspects of responding to the situation and of protecting people will be similar regardless of the spatial scale and involved radionuclides.

The first goal in a radiological or nuclear emergency is to protect the affected people. From radiation protection point of view this means striving to avoid all deterministic (harmful tissue reactions) health effects of radiation and to minimize the appearance of stochastic health effects in the affected population to a level which is practically achievable [1]. There will be also other health effects which are related with people's worry and anxiety about their own and relatives' health. These psychological impacts might need more attention than the radiological health impacts.

The planning and implementation of protective actions in a case of nuclear or radiological emergency is co-operation of several authorities and expert organisations. Composition of the groups planning decisions on countermeasures depends on the type of an emergency and also on the phase of the situation. There are several potential pathways of people's exposure to radiation in a radiological emergency situation. In the early phase of an emergency people can be exposed to external radiation from the contaminated air and to internal radiation from inhaled radionuclides. Soon after, different surfaces in the environment and the ground will be contaminated and people will be exposed to external radiation from deposited radionuclides. Later on, the local foodstuffs and drinking water might be contaminated and people will be exposed to internal radiation from ingested radionuclides. For example in a case of a severe nuclear power plant accident, there is always a certain time before any radioactive releases to the environment take place. In this threat phase, decisions are normally made by the operator and the local rescue officers, and the decisions are based on 'best estimates' about the development of the plant condition. In later phases of the accident also other organisations will be involved in decision making and planning of countermeasures and protective actions. Also the grounds on which the decisions are based will change when more information about the accident and the radiological situation in the environment is available.

The past six decades have shown that various accidents with the use of radioactive and nuclear materials must be taken into consideration although today the likelihood of major accidents is small and releases of radioactive substances into the environment are minimized with effective safety and security systems. As the consequence of the terrorist attacks during the past few years, political leaders and authorities have become more aware of a need to re-assess existing threats and our preparedness to them. There are several lessons learned from the recent attacks and other events where radioactive or nuclear materials have been involved. Terrorists' intent to stage multiple events simultaneously must be taken into account in emergency planning today. Suicide scenarios and the fact that terrorists deliberately choose improbable or unexpected events lead to the conclusion that we can no longer rely on historical factors such as the probability of failure rates of various components to predict the likelihood of an event. One lesson is also to realize that multiple hazardous agents may be combined in an attack. Thus, planning for a radiological incident alone is an outmoded concept and authorities need to be able to recognise and respond to a situation where there is a combined chemical, biological, and radiological/nuclear hazard (CBRN).

There are more than 400 commercial nuclear power reactors, 10-20 reprocessing plants, almost 300 nuclear research reactors and more than 200 nuclear powered ships and submarines in operation around the world [2]. Most of these facilities are situated quite close to residential areas and accidents happened with them might have severe consequences to the local population. Hundreds of accidents and incidents have occurred with small research reactors and nuclear powered ships and submarines. Some of them have resulted in loss of lives and human exposure to radiation at different levels. Accidents at nuclear submarines and vessels may lead to serious consequences to population only if they happen at harbours. Damaged reactor of a nuclear submarine and vessel may result in dispersion of radioactive materials within an area of few tens of square kilometres calling for protective actions, and later on also clean-up actions. Small research rectors are normally close to or inside inhabited areas and their severe accidents may also contaminate areas of few tens of square kilometres and protective and clean-up actions might be needed.

Few severe accidents have happened with nuclear power reactors, the most well known at the Fukushima Daiichi plant in Japan in 2011 [3], the Chernobyl plant in Ukraine in 1986 [4], the Three Mile Island plant in Pennsylvania in USA in 1979 [5], and the Windscale plant in Cumbria in Northern England in 1957 [6]

Highly radioactive sources are used for a variety of purposes, such as medicine, research, industry, and instrument calibration. Experience worldwide shows that, despite the existence of a regulatory framework, control of such high-active sources may nevertheless be lost, even in countries with rigorous regulatory systems. A large number of incidents involving the loss of control have been reported over the last 50 years. Following the terrorist attacks during the past few years, there have been heightened concerns about terrorist activity on, *inter alia*, radioactive sources, and level of control and regulation has been raised. For example in the European Union, the member states have implemented control of high-active sealed radioactive sources and orphan sources in their national legislation, based on the directive on high-active sealed sources and orphan sources of the Council of the European Union in 2003 [7]

This paper aims to describe issues which will be faced by the organisations being involved in management of nuclear or radiological emergencies. The paper does not purport to be a complete description of the task field, but rather to give a general description of the measures to be taken and the methods needed in radiological emergencies. The paper also tries to identify targets for development of preparedness and response to and recovery from radiological emergencies.

Decision making in emergency situation

In a nuclear or radiological emergency the affected people are exposed to radiation at variable rates depending on time after the accident. Figure 1 tries to illustrate development of the dose rate after a major accident of a nuclear facility and factors affecting decision making. In early phase of an accident the decision are based normally on technical condition of the accident plant and the prevailing weather condition, and decisions are based on 'best estimates'. Later on, radiation measurements will be available and decisions on protective actions will more and more be based on them. The figure also indicates the key actors being involved in decision making in different phases of an emergency. In late or recovery phase the number of actors or stakeholders may increase substantially due to the complexity of the situation.

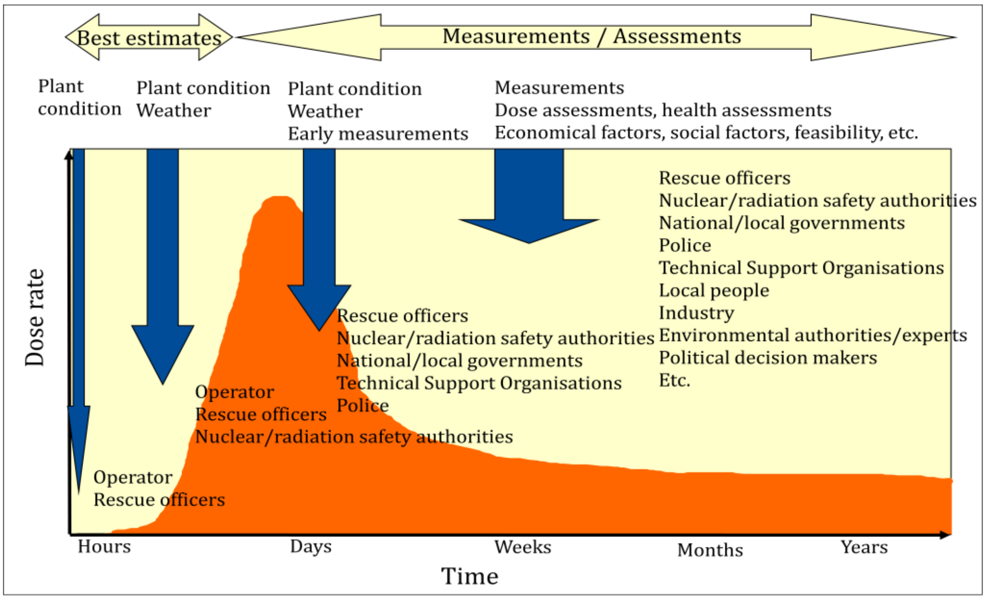

Figure 1. Temporal variation of dose rate to which the affected people are exposed after a major accident at a nuclear facility, the grounds on which the decisions are based, and actors being involved in decision making.

Figure 2 illustrates what kind of decision support tools and methods are needed in different phases of an emergency. In the threat phase, in a very early phase of an emergency, pre-planned procedure are the only available methods to be applied. These procedures shall be part of emergency preparedness plans of the operator and other first responders. In later phases various technical tools, assessment methods and working procedures are needed in decision making. In principle all these tools and methods are available today thanks to extensive research and development performed after the Chernobyl accident in 1986. The only questions are how they can be used in an effective way and if the decision makers are willing to use them.

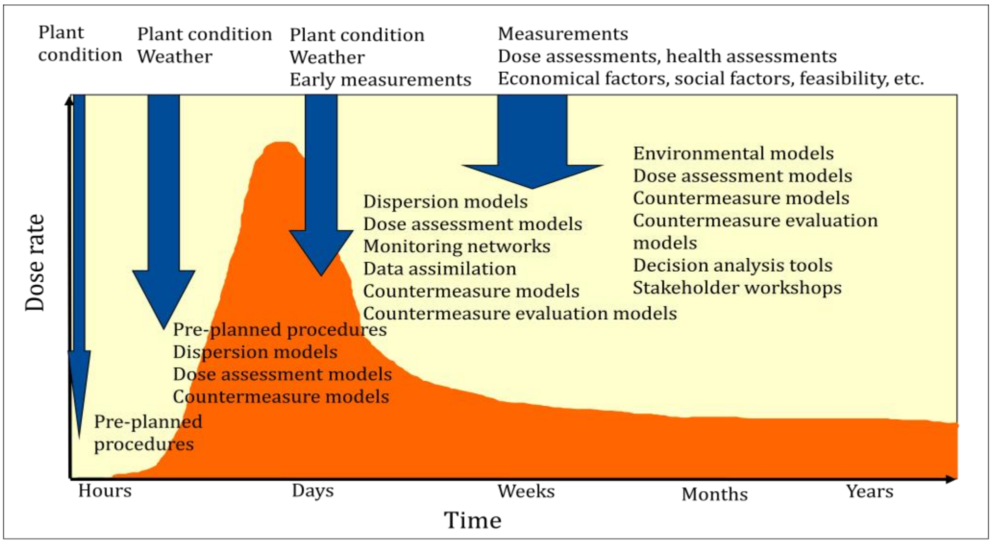

Figure 2. Decision support tools and methods needed in different phases of a radiological emergency.

Special Decision Support Systems (DSS) have been developed for management of radiological emergencies. A DSS is a computer-based information system that supports business or organisational decision making processes. Comprehensive DSSs developed especially for management of nuclear or radiological emergencies are e.g. RODOS [8] and ARGOS [9] used in Europe, RECASS used in Russia [10], ARAC used in US [11] and SPEEDI used in Japan [12]. All these systems are able to make predictions on dispersion of radionuclides in the atmosphere, terrestrial and water environment, dose assessments of people exposed to radiation through different pathways, presentation of radiological data in different forms, etc.

Of course the exposure situation described in Figures 1 and 2 is not valid in a case of a malicious and intentional dispersion of radioactive material into the environment. Normally in that kind of situation there is no warning time but radioactive material will spread out immediately if an explosives are used, or radioactive material or strong radiation source may already be hided in the environment and the first indicators are e.g. unusual number of symptoms of illness in the area, unexpected amount of sick or dying animals, e.g. birds, insects or fishes, etc. Even small groups of individuals have the ability to cause massive damage and extensive human suffering with little or no warning. Predictably, firefighters, police officers, other emergency management personnel, and civilian volunteers will respond and be on the scene soon after any such event. Because, in addition to radioactive material, also chemical and biological agents may be involved in this kind of attack, all first responders should be well trained and alert to potential risks associated with them. In principle the protective actions and countermeasures are similar to those within an accident situation, but the rescue and other personnel should keep in mind that they are part of a crime scene and they should preserve all evidence when possible.

International harmonisation of criteria

The International Commission on Radiological Protection (ICRP) revised its basic recommendations for a system of radiological protection in its Publication 103 [1]. The previous process-based protection approach using practices and interventions was replaced with an approach based on exposure situations, i.e. planned, emergency and existing situations. The fundamental principles of justification and optimisation of protection are applied to all controllable exposure situations. Application of the Commission's recommendations for the protection of people in emergency and post-emergency existing exposure situations were later described in the ICRP Publications 109 and 111, respectively [13, 14].

The reference level, introduced by the ICRP, is a level of residual dose or risk above which it is generally judged not to be appropriate to plan to allow exposures to occur. Therefore, any planned protection strategy should at least aim to reduce exposures below this level, with optimisation achieving still lower exposures. Protection against all exposures, above or below the reference level, should be optimised. In the context of developing response plans for emergency exposure situations, the ICRP recommends that national authorities should set reference levels between 20 mSv and 100 mSv effective dose (acute or per year, as applicable to the emergency exposure situation under consideration). Reference levels below 20 mSv may be appropriate for the response to situations involving low projected exposures. There may also be situations where it is not possible to plan to keep all doses below the appropriate reference level, e.g. extreme malicious events or low-probability, high-consequence accidents in which extremely high acute doses can be received within minutes or hours. For these situations, it is not possible to plan to avoid such exposures entirely, and therefore, the ICRP advises that measures should be taken to reduce the probability of their occurrence, and response plans should be developed that can mitigate the health consequences where practicable. The best possible protection will be achieved by considering simultaneously all exposure pathways and all relevant protection options when deciding on the optimum course of action. Each individual protective measure must be justified by itself in the context of an overall protection strategy, but also the full protection strategy must be justified.

In addition to the reference level, the ICRP recommends to set, in advance, internally consistent dose criteria for protective actions that need to be taken promptly in order to be effective, and, based on these criteria, to derive appropriate triggers, expressed as readily measurable quantities, for initiating them in the event of an emergency [13].

The basic principles of radiation protection and the recommended criteria issued by the ICRP have been implemented in the international Basic Safety Standards (BSS) and adopted also in directives of the European Union. The international BSS and the European BSS are at the moment under revision based on the latest ICRP recommendations [15, 16]. These basic safety standards and the ICRP recommendations lay down the bases for international harmonisation of criteria and actions taken in a radiological emergency. National authorities in several countries are at the moment setting their national criteria to be applied in radiological emergencies. Because the reference levels are not directly measurable quantities, operational criteria will also be needed.

Soon after the Chernobyl accident in 1986, some international criteria were set. For example concerning foodstuff contamination, the European Council set regulations on maximum permitted levels of radioactive contamination of foodstuffs and feedingstuffs following a radiological emergency [17, 18, 19]. These levels are shown in Table 1.

Table 1. Maximum permitted levels of radionuclides in various foodstuffs and drinking water in the European Union.

	Activity concentration, Bq/kg		
Radionuclides[1]	**Baby food**	**Dairy products and liquid foodstuffs**[2]	**Other foodstuffs**[3]
Strontium isotopes in total	75	125	750
Iodine isotopes in total	150	500	2 000
Plutonium and transplutonium isotopes in total	1	20	80
Other radionuclides in total[4], with half-life over 10 days, e.g. ^{134}Cs and ^{137}Cs	400	1 000	1 250

1) Activity levels for different groups of radionuclides are not dependent on each other. Each level is applied separately.
2) Concerns also drinking water.
3) For some, not frequently used, foodstuffs, e.g. certain spices, the activity levels to be enacted are ten times higher than the values in this table for basic foodstuffs.
4) Does not concern H-14 (carbon), K-40 (potassium) and tritium

Due to Chernobyl accident, the European Council issued in 1990 the regulation concerning import of agricultural products originating in third countries [20]. The recommended maximum concentrations of ^{134}Cs and ^{137}Cs together for dairy products and baby food is 370 Bq/kg and for other foodstuffs 600 Bq/kg. In 2003, the European Commission issued the recommendation, that natural products (game meat, mushrooms and fish) in internal trade of the EU shall not exceed the sum concentration of ^{134}Cs and ^{137}Cs of 600 Bq/kg [21]. These levels are still valid in the EU. The activity levels due to Chernobyl accident are disabled if the activity levels of Table 1 are put into force due to a new nuclear or radiological emergency.

The international trade of foodstuffs follows recommendations of the Codex Alimentarius standard [22]. The aim of Codex Alimentarius is that annual effective dose from foodstuffs is below 1 milliSv. Codex Alimentarius limit values are not lowered in the later years either because it is assumed that the amount of contaminated products in international trade is decreased due to, among others, market mechanism and measures to decrease the activity concentrations in foodstuffs.

Striving to achieve consistency between the decisions and actions taken at national levels in an emergency is the most advisable because divergent national decisions on protective actions would cause unnecessary confusion and concern among the population. The accident at the Fukushima Daiichi nuclear power plant is a good example of diverging decisions taken by foreign authorities protecting their citizens in Japan, e.g. regarding evacuation of foreign citizens in Japan, iodine prophylaxis of foreign citizens in Japan, and monitoring of passengers returning home from Japan.

Protective actions and decision making in a radiological emergency

There are plenty of actions which can be taken to protect people in a radiological emergency. Of course, actions to be taken depend on the type and scale of the radiation situation and also the feasibility of actions. The feasibility in turn, is dependent on many factors, such as the time being available for the action, phase of an emergency situation, resources being available, etc. The list below contains some protective actions, which will be weighed if significant amount of radioactive substances are dispersed into the environment.

- sheltering indoors (partial sheltering, lifting the sheltering)
- iodine prophylaxis (children, adults)
- evacuation of people (before or after the contamination of the environment)
- control of access to contaminated areas
- temporary relocation of people
- permanent relocation of people
- clean-up of the environment (grass cutting, soil removal, ploughing, fire-shooting, vacuum sweeping, road planing, tree removal, cleaning interiors, sandblasting buildings, high pressure hosing, etc.)
- decontamination of people (self-decontamination, controlled decontamination)
- treatment of contaminated people in hospitals
- actions on foodstuffs, feedingstuffs and drinking water (use restrictions, prohibition of use, etc.)
- actions concerning livestock production, other raw materials and production facilities
- handling of radioactive waste
- etc.
- no actions

It goes without saying that people who participate in decision making of these protective measures represent various population groups and authorities. For example in the exercises in seven European countries focusing on clean-up actions of inhabited areas after a nuclear accident [23], the decision making panels represented the following fields of activities;

- Ministries of interior, public health, environment, economy, defence
- Provincial governments
- Affected cities
- Environmental protection and management
- Waste management
- Consumer services
- Police
- Rescue services
- Nuclear power companies
- Radiation protection authorities
- Nuclear safety authorities
- Health authorities
- Defence forces
- Food control
- Local government and agencies

All partners and stakeholders participating in the decision making will bring their own values to the decision making process, and weighing these values against each other is not an easy task. Therefore it is recommended to use formal decision analyzing tools in decision making panels. Today there are several computer based decision analyzing tools available and these tools make decision making transparent. Transparency is a key issue in decision making, because decisions on protective actions will affect every person's normal life in the affected area. Especially in the late and recovery phases of a radiological emergency, when there is time enough to arrange decision making meetings, the use of decision analyzing tools is important to make the process transparent. All participants in the decision making leave their fingerprint in the process and afterwards it is possible to figure out the values they presented and how theses values were weighed against each other. The values can vary from side to side, but normally they can be grouped in the following categories;

- Health related issues (public/workers' radiation doses, workers' physical safety, etc.)
- Social/political aspects (political acceptability, public reassurance and confidence, socio-psychological effects, equity, environmental protection, etc.)
- Technical feasibility (costs, available resources, waste management, etc.)

Effectiveness and overall benefit of the protective measures depend greatly on how the taken measures are communicated to the public. Risk communication is a key element in all crisis management. Communications should be as open as possible, timely, and presented in a way that the average citizen is able to understand it. Also the bases for the protective measures should be communicated in order to maintain public trust and confidence in authorities. Therefore the transparency in decision making is essential. In a case of malevolent and intentional dispersion of radioactive material into the environment there might be certain things which shall be kept confidential, because these situations are under criminal investigation.

Future challenges in emergency management

Everyone should take a stand so that the radiological emergencies will arise also in the future. We just don't know when and where, and what are the reasons for future emergencies. We have thousands of nuclear reactors and other facilities handling major radioactive and nuclear materials all around the world. Being aware that every man-made facility or equipment is always at risk for malfunction or an accident, it is more than likely that bigger or smaller nuclear incidents and accidents will happen from time to time. Risk for nuclear accidents is today very small, but when the risk comes true it will have multidimensional consequences in the society. In addition to nuclear facilities, there are in the world tens of thousands of smaller installations using radioactive sources and materials. Of course incidents and accidents in connection with them would have more limited radiological consequences compared with big nuclear facilities. However, sources could possibly be stolen or bought by persons with malicious intent, and applied in devices purposely designed to harm people and create anxiety and disruption.

Terrorism with nuclear and radioactive materials and illicit trafficking of radioactive and nuclear explosive devices and materials threaten the safety and security of all nations. Effective intelligence and radiation detection systems, intended to improve the capability to detect and interdict nuclear and radiological threats, are becoming increasingly important to all nations. International co-operation is necessity to success in this task and will strengthen national and international capabilities to combat nuclear terrorism.

International co-operation is a requirement also in the traditional emergency preparedness and response. Globalisation can be seen as a challenge, when people are travelling more and more, and all nations try to protect them also when being abroad. But globalisation can be seen also as an opportunity if nations exploit the modern information technology and co-operate with each other. The challenges we have in the near future in management of nuclear or radiological emergencies are related e.g. to the following issues;

- use of compatible methodologies, taking into account the experiences we have from the past emergency situations,
- how to develop the existing decision support tools and methods to take into account long-lasting releases of radioactivity into the environment, releases of radioactivity into water bodies, etc.,
- how to guarantee access to reliable information about the situation, when the accident site is far from our own country,
- how to deal with contaminated goods,
- what kind of radiation detection techniques we need in combating nuclear terrorism,
- information to and communication with the public,

These issues have been under living discussion in Europe when the European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery (NERIS Platform) was established in 2010-2011 [24]. The greatest challenge facing emergency and post accident management of a nuclear or radiological event in Europe is to organise an effective joint European cooperation in a complex social and political situation resulting from a major nuclear accident or malevolent act involving nuclear or other radioactive material. European countries have various cultural backgrounds and there are differences in administrative cultures and legislations. The NERIS Platform will promote transparent decision making and compatible technologies and methods to be used for prevention and consequence management of nuclear or radiological emergencies. Transparency and broad participation of different stakeholders in decision making is the basic condition for effective cooperation at the European, regional and national levels and is now largely acknowledged by European organisations and national/international conventions. The Platform is open to all European organisations concerned with nuclear and radiological emergency response and recovery preparedness having expressed their interest in the activities of the Platform and having signed the Terms of Reference.The general goal in Europe should be that people are equally protected in case of a radiological emergency regardless of their residence.

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