Safety Science 101 (2018) 155–163

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Analyzing nuclear expertise support to population protection decision making process during nuclear emergencies

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ARTICLE INFO

Keywords:
Nuclear crisis management
Population protection
Crisis exercises
Decision making
Expert

ABSTRACT

Nowadays, strategies to protect population in the early phase of a nuclear crisis consist in three main actions: sheltering, evacuation and iodine pills ingestion. These actions are supposed to be guided by two successive decision-making strategies: triggering reflex actions in pre-planned perimeters in the near field around the accident and then, achieving spatial estimation of doses received by the general public (expressed in Sievert) along the situation development to adapt the actions. Through the observation of four nuclear exercises in France, this paper aims to study the population protection decision making process in the early phase of a severe nuclear accident. This study underlines the existence of a potential intermediate episode in the population protection strategy and how it is currently managed by civilian security and nuclear experts in an emergency situation. We argue that in case of a large nuclear accident, nuclear expertise is essential and not sufficient to take decisions for protecting population.

Chapter 1: Context

Twenty-five years apart, Chernobyl and Fukushima nuclear accidents demonstrated the need to strengthen capacities to cope with such events in parallel of the continuous improvement of safety in nuclear facilities. In this order, nuclear emergency planning, preparedness and management are essential aspects of any country's nuclear power program. Nuclear emergency management strategies are mainly based on a good coordination between the nuclear power plant owner's actions to bring back the situation under control and the public authorities' actions regarding population and environment protection duties. This paper focuses on this last aspect.

In the case of a severe nuclear or radiological accident, efforts are oriented to avoid uncontrolled release of radiological materials in the environment. This aim is mainly achieved by a technical defense-in-depth approach, which implies the design of several physical defense barriers between radioactive elements and the environment. However, a radiological release can occur when the situation is such that the last physical barrier (such as the containment) is threatened (deliberate controlled venting can be switched on to avoid containment explosion) or already damaged by events such as explosions or fires. In this case, radiological elements are emitted in the form of gas or aerosols firstly transported by atmospheric or water vectors, thus threatening public health. When the nuclear emergency situation is such that a release cannot be excluded in the following hours, general public countermeasures are set up with the aim to avoid short-term deterministic effects (acute harmful tissues reactions) and keep long-term stochastic effects as low as possible (cancers or hereditary effects) (ICRP, 2007).

In a radiological or nuclear emergency, general public protection strategy relies on three main urgent countermeasures: evacuation, sheltering, and ingestion of stable iodine tablets. The two first protective actions aim at getting the population off the exposition to radiations and radioactive particles that can be emitted in the environment in case of a severe nuclear accident; the third especially aims at reducing the risk of thyroid cancer. The decision to implement these countermeasures is based on two strategies illustrated in Table 1.

Population sheltering action can be ordered as reflex action in an emergency context. When the situation assessment states that a radiological release can occur quite soon (less than 6 h in the French response), sheltering reflex action can be triggered by the radiological facility owner acting on behalf of and under the control of the local government according to the emergency regulation. In this case, sheltering reflex action perimeter is defined during risk analysis prior any emergencies.

However, as evacuation and iodine tablet prophylaxis, sheltering decision can also be implemented based on forecasted doses reference

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http://dx.doi.org/10.1016/j.ssci.2017.08.017
Received 1 April 2016; Received in revised form 1 June 2017; Accepted 17 August 2017

Table 1
Population protection countermeasures decision strategies during a radiological or nuclear emergency situation in the regulation (Decree of November 20th 2009 regarding approval of decision 2009-DC-0153 of the French Nuclear Safety Authority of August 18th 2009 on intervention levels in radiological emergency).

Population countermeasures	Implementation decision strategy and associated area	
	Decision based on reflex actions	Decision based on forecasted exposure dose assessment
Sheltering	Based on pre-planned perimeters	From 10 mSv all body. Perimeters are defined in situ from dose consequence assessment.
Evacuation	–	From 50 mSv all body. Perimeters are defined in situ from dose consequence assessment.
Iodine stable tablet dose	–	From 50 mSv to the thyroid Perimeters are defined in situ from dose consequence assessment.

Table 2
Summary and main criteria of the four national nuclear exercises.

Exercise	Nuclear facility impacted	Meteorological conditions	Duration
A	Nuclear Research Centre	Real	1 day
B	Nuclear Power Plant	Simulated	2 days
C	Nuclear Waste Treatment Plant	Real	1 day
D	Nuclear Material Road Transport	Real	1 day

values. Indeed, in nuclear emergency situations, population protection countermeasures actions aim at avoiding acute effects relating to high dose exposure but also at reducing the probability of emergence of cancers or hereditary effects induced by radioactivity in the long term. For this purpose, protection countermeasures in a nuclear emergency are mainly implemented in relation to absorbed doses reference values expressed in Sievert (mSv, μSv) that take into account: (i) energy deposited in organs and tissues in the human body by radiations; (ii) the biological impact of different radiation types; (iii) organs and tissues sensitivity to ionizing radiation. Reference values contribute to the radiological situation assessment by providing a landmark to which real-time information regarding the situation and protective actions can be compared (ICRP, 2007). Nowadays, recommended dose guidance values play a crucial role in the population protection strategy in a nuclear or radiological emergency. However, the choice to order one or another of these emergency countermeasures need also to take into account several other factors such as additional risks, situation on the field, local data (population density, economical stakes, etc.). These data, in regards to dose exposure, are not related to guidance values that trigger decision about population's protection countermeasures. By consequence, they play a critical role in the emergency decision process.

One of the main difference between the management of nuclear accidents and other emergencies (such as chemical accidents) comes from the fact that the absorbed doses corresponding to population protection decisions cannot be measured directly during the emergency phases (in human tissues or in the field (ICRP, 2007)). The risk assessment is mainly based on calculations allowing assessing internal and external dose exposure of general public for a given exposure time; from 24 h in the emergency phase to a month in the first post-accidental phase (ASN, 2012). These calculations are performed with radio-ecological modeling systems (analysis of radionuclides transfer in the environment by air, water, soil, sediment, plant, toward human) to assess equivalent and effective doses that can be compared to reference values for population protection. First responders and decision makers are thus facing a situation in which risk is more difficult to assess than for other kinds of accidents (fire, explosion, flood, …). When available, field sensors values such as radionuclides activities are used together with modeling systems to refine dose estimation in a continuous process. By consequence, population protection countermeasures are mainly taken on recommendations of nuclear expert organizations that perform public dose estimation based on the assessment of the installation state, present or future radiological releases in the environment and scalable meteorological forecasts.

By consequence, population protection response consists in two main processes that can be called "episodes" and occur separately or successively as a function of the situation and its dynamics. The first one is based on a reflex strategy based on a first evaluation of the plant state and the kinetic of its evolution and population protection areas pre-planned in the near field of the Nuclear Power Plant (NPP). The second one is based on spatial and temporal forecast dose assessment and perimeters are established in situ.

Thus, through the observation of four nuclear exercises in France, this paper aims to study how strategic decisions are implemented in situ during a simulated nuclear emergency, including the contribution of nuclear experts and the coordination with the civilian security decision makers.

Chapter 2: Research methodology

2.1. National nuclear exercises

Data used in this study were collected during four national-level nuclear exercises conducted from 2012 to 2014 (Table 2). National nuclear exercises aim to test all or a part of the emergency plans prescribed to cope with a radiological emergency situation. They contribute to the training of emergency stakeholders by putting into practice emergency procedures and plans in realistic (as far as possible) emergency settings. They allow to study difficulties experienced by stakeholders and to identify improvement in emergency plans and procedures or in exercise scenarios. Processes of communication and coordination between various response organizations that take part in the response system at different levels are getting special attention. In addition, they also aim to develop pedagogical approaches towards the population in order that everyone can take part more efficiently in the emergency response.

The four exercises are based on common principles. They involve the mobilization of both public local authorities and radiological facilities owners regarding fictive accident scenarios and are conducted in real-time. In addition, as they simulate the first phase of a nuclear or radiological emergency, they mainly focus on the emergency phase and do not address implementation of post-accidental countermeasures.

2.1.1. Exercise A: Earthquake on a nuclear research center

Exercise A that occurred on January 2012 was designed in a post-Fukushima learning process and consisted in the occurrence of an earthquake at 09:00 AM that impacted 25 municipalities as well as a nuclear research center. The scenario required from the public authorities to manage simultaneously an earthquake and its nuclear consequences. The fictive earthquake magnitude of 5,5 on Richter scale was chosen near the Maximum Historically Probable Earthquake (MHPE) (5,3 on Richter scale). The scenario implied the collapse of electricity and communication networks as well as partial or total destruction of 1200 buildings and transportation infrastructures in the area. Several facilities of the nuclear research center were also impacted leading to the release of radioactive materials in the atmosphere and the loss of the centralized radiological monitoring. Real meteorological conditions were used during the exercise.