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

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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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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.

2.1.2. Exercise B: Accident in a NPP

Exercise B took place during two days on June 2013. The nuclear crisis scenario consisted in a NPP severe accident leading to an immediate and long release of radiological materials. In addition to the situation management by the local level, this exercise also aimed to test the national capacity to cope with a nuclear crisis and the cooperation between both levels. The national crisis center (CIC) was activated.

2.1.3. Exercise C: Accident in a nuclear waste recycling facility

This exercise took place on April 2014 on a nuclear facility specialized in the recycling of NPPs nuclear wastes. The fictive scenario implied a starting fire in a local of reconditioned plutonium at 08:00 AM. The fire was detected 30 min later and simultaneously, radioactivity was detected at the local ventilation shaft. The fire was extinguished at 10:00 AM and two local emergency operators were injured and contaminated. The radioactive release lasted 1 h (8h30-9h30) but as real time meteorological conditions were used during the exercise (weak and changing direction winds), radioactivity was detected after the ending of the release.

2.1.4. Exercise D: Accident of a radiological material transport

Regarding the three previous exercises, the June 2014 exercise took place on a territory that has no nuclear facilities. However, it is one of the main European trunk roads regarding hazardous material transport. The fictive scenario implied a road accident on a radiological material transport (RMT). The transport contained 80 barrels of about 200 kg of UO_2. Explosion and fire following the road accident led to the loss of sheltering on 10 barrels and the release of radioactive material in the environment.

2.2. Observation methodology

The observations of the four exercises took place at the local command center (LCC) of the *Préfecture*, in charge of defining population protection actions in the vicinity of the radiological facility impacted. In the crisis organization, the strategic decision level is ensured by the Rescue Operation Director in charge of strategic decisions regarding population protection countermeasures. During a large-scale accident that threatens several municipalities such as a nuclear accident, this role is insured by the Prefect (or his/her Cabinet Director) supported by the Local Command Center (LCC); in the following text, we'll use the term "decision maker" for that role. The LCC has a modular structure i.e. allowing a gradual mobilization to strengthen the civilian protection response. The decision maker is generally assisted in his decision maker's role by his Office Director and Prefecture staff. The civilian protection and defense service supports the decision team and ensures activation and coordination of the LCC actions. The LCC also gathers stakeholders from several organizations involved in the civilian protection and security (police forces, health services, fire brigades, education representatives, etc.), which need to coordinate rapidly. Additional competencies can be required at the LCC to respond to specific situations. It is especially the case regarding the attendance of representatives of the impacted radiological facility (NPP's owner or other) contributing to assess technical situation and its management. The experts assist the decision maker regarding radiological situation assessment and health protection recommendations. The decision maker can also require the contribution of the meteorological organization (Météo France). In the rest of this paper, we'll use the generic term "experts" for those who contribute to facilitate understanding technical aspects of the accident and its consequences: nuclear safety autority, institute for nuclear protection, NPP owner, meteorological institute, …).

Data were collected by "in-situ" observers and from available reports of the exercises. Observations aimed to better assess how LCC teams achieve a certain level of collective situation awareness and how develops the decision making process. Decision makers need to size up the situation they cope with, get the "big picture", and be proactive with regards to the possible development of the situation. The role of situation awareness in the decision making process has been underlined by Natural Decision Making (NDM) theory.

> *"…making decisions in realistic settings is a process of constructing and revising situation representations as much as (if no more than) a process of evaluating the merits of potential courses of action".*
>
> Lipshitz, 1993

Consequently, the achievement of a situation representation is one of the main challenges for strategic level, generally located in crisis command centers away from the field.

> *"On the ground, workers face a crisis, but at the crisis center, managers face a "representational crisis"*
>
> de Saint-Georges et al., 2004

The concept of Situation Awareness (SA) is based on the observation that it is possible to find a gap between how the operator understands the system status and the "real" status of the system (Woods, 1988). SA at individual level has been studied through several approaches such as a product or a process (see. Durso and Sethumadhavan, 2008) or regarding theoretical aspects. The information processing theoretical approach can be illustrated by Endsley (1995) three layers structure of SA: perception of the elements of the environment in a volume of time and space, the comprehension of their meanings and the projection of their status in the near future. Other approaches such as the work of Smith and Hancock (1995) place SA as a dynamic interaction between humans and their environment. SA can then be defined as adaptive, externally directed consciousness that can be represented as a cycle in which environmental information altering individual's knowledge. This knowledge directs the activities and actions of the individual in his environment and in turn, activity and actions create information used as raw material for the construction of meaning and understanding (Weick, 1988).

SA can also be studied through an organizational approach as crisis is mainly managed by groups of individuals who put their efforts into achieving a common goal. Shared situational awareness can be defined as the ability of collective members to share, at least in part, a common operating picture of the situation in addition to cognitive representation constructed mainly beforehand of task requirements, procedures, and role responsibilities that individuals hold in common (Artman and Garbis, 1998). Thus, the propagation of collective situation awareness during an emergency mainly occurs via communication processes between organizations in temporal coherence with the situation's dynamics and information lifetime (Artman and Garbis, 1998; Wybo, 2013). At the beginning of an event, LCC trade cells receive information on their own services on the field or at the upper level of their organization and information are distributed between LCC stakeholders.

> *« When we say that meanings materialize, we mean that sensemaking is, importantly, an issue of language, talk, and communication».*
>
> Weick et al., 2005

Thus, observations were focused on interactions between LCC members during crisis management. As LCC can gather from 30 to 50 individuals, observation was mainly focused on the interaction between the decision maker and the experts and not on the overall organization and functioning of the LCC. Coordination mechanisms can be analyzed as a function of their levels of explicitness or implicitness (Espinosa et al., 2002; Kolbe et al., 2009; Boos et al., 2011). Implicit coordination refers to coordination mechanisms that are not consciously product and that are expressed through the sharing of situation awareness which enable them to better understand the actions and needs of the others groups members (Wittenbaum et al., 1996; Kolbe et al., 2009). Explicit coordination is defined as the behavior that is intentionally used for the purpose of the team coordination and mostly executed by using task organization (procedure, rules, plans, schedules, division of labor, etc.)

Table 3
Social contexts classification .
adapted from Seppänen et al. (2013)

Face-to-face/virtual	Face to Face: interactions conducted as the protagonists are located in the same space and can communicate directly	Virtual: interactions that occurred as people are not located in the same space and used communication tools such as phone, talky-walky, audio or video conference
Individual/ collective	Individual communication regards the communication of one team to another. Information is not shared with all the crisis center	Collective communication, such as broadcasting mechanisms, allows one team (police for instance) to transmit information simultaneously to all LCC stakeholders.
Formal/informal	Formal communication occurs during official briefing points or audio-conferences at the LC	Informal interactions occurs out of briefing points or audio- conferences at the LCC

and by communication (verbal or written). The verbatim of the exchanges were written on research textbook. The authors were allowed to take one audio recording of the verbal exchanges between the participants of exercise C. In addition, in order to preserve the proper conduct of the exercise we were not allowed to interrupt participants by asking them questions to assess their situation awareness through the exercise. By consequence, taking into account these limitations in our analysis, this study focuses on explicit coordination through the verbal communication channel.

The social interactions were studied using an adaptation of the social context typology developed by Seppänen et al. (2013). The method classifies social contexts as a function of three interaction dimensions: face-to-face/virtual; individual/collective; formal/informal. The three dimensions are presented in Table 3.

Chapter 3: Results

As presented in Chapter one, radiologic strategic decision-making in the crisis organization is mainly based on public dose exposition assessment provided by nuclear expert organization. However, observations underline that the availability of this information to the decision maker can be delayed at the beginning of the crisis management although emergency actions need to be undertaken. The analysis of observation data shows the emergence of a temporal structure divided in three main episodes that affect the population protection decision making process based on the communication of population dose exposure (Table 4).

Episode 1 covers the time from the beginning of the emergency situation to the arrival of a nuclear expert in the LCC. Observation focuses on oral communication between the decision maker and LCC teams.
Episode 2 covers the period from the start of collaboration with nuclear experts until dose exposure (expressed in mSv) calculations are available.
Episode 3 starts when dose exposure calculations are available at the LCC.

3.1. Episode 1: No nuclear expert and no population dose calculations

When an emergency occurs, the first interaction between the crisis command center and scientific expertise can be delayed in time and first decision will not wait for this interaction to take place. A number of factors may cause this delay, for instance the difficulty to identify the relation between an event and the related radiological risk or the difficulty to achieve the warning phase as a consequence of the collapse of communication infrastructures.

Table 4
Interactions with experts and availability of population protection perimeters to the Decision Maker.

	Episode 1	Episode 2	Episode 3
Interactions with nuclear experts	No	Yes	Yes
Availability of population dose calculations (mSv)	No	No	Yes

In the case of April 29th exercise, the first official interactions between the LCC and nuclear experts took place two hours after the beginning of the warning phase. In the case of the TMR exercise, Experts reached the LCC less than thirty minutes after the beginning of the exercise due to stakeholders pre-position bias. However, we were not allowed to begin the observation before the LCC was established. By consequence, the TMR exercise cannot be used for the description of the first episode.

3.1.1. Initial social context

During exercise C, episode 1 contains two main social contexts: a virtual one and a face-to-face one in informal ways.

Virtual interactions took place at the individual level of the LCC teams, which are mainly focused on information communication and exchange with their own services at lower and upper level of the response organization. The main situation assessment information came from two sources: the facility owner and emergency services in the field.

Percolation of this information through the LCC was ensured by a two-step informal and face-to-face communication process. First, information is communicated from one team to the decision team in an individual context. Then, the decision team uses a broadcasting mechanism to share important information with all LCC members in order to achieve a collective situation awareness regarding the event.

During this event, the decision maker was mainly interacting with the other members of the decision team as well as with fire services, the police representative and population protection team.

3.1.2. Population protection decision making process

Even if the contact with the nuclear experts is not yet established in the LCC, the situation may require to take quick decisions in this first phase, especially when situation assessment turns toward an immediate release scenario. In this case, reflex decisions are mainly based on emergency pre-planning perimeters around the facility (or accident location) allowing a rapid reaction in the first hours of the event, while waiting for public-absorbed doses forecasts.

Regarding an emergency in a NPP, pre-planned emergency perimeters are implemented with continuous public information regarding nuclear risk and attitude recommendations during a nuclear emergency. In the case of an immediate release scenario, the plant owner can trigger reflex population protection decisions, based on a pre-planned delegation of action by the decision maker. This reflex decision corresponds to the sheltering in a radius from 2 to 5 km around the NPP. Another 10 km radius is also pre-planned if the situation gets worse.

Pre-planned areas are also established in case of an accident with a radiological material transportation (RMT). The method was elaborated in connection with the one used for chemical hazardous material transport. Emergency reflex areas are based on exclusion and sheltering radius ranging from 100 to 1000 m as a function of the nature of radiological package transported. It was the case during the RMT exercise during which first reflex exclusion area was decided and implemented by firefighters at their arrival on the accident scene.

By consequence, first population protection decisions in the case of a nuclear or radiological emergency may not be decided "*in situ*" by the decision maker and its LCC, especially in an immediate radiological release scenario requiring quick actions to protect population in the near field of the release. They are mainly taken and implemented by stakeholders in the field based on pre-planned areas elaborated beforehand by nuclear experts and civilian security representatives during safety and security analysis. At the LCC level, the information of the implementation of these first actions mainly contributes to its first situation assessment of the most plausible occurring scenario regarding potential dynamics and risks of the current radiological situation.

3.2. Episode 2: Availability of nuclear expert advisors but no population dose calculations available yet

3.2.1. Evolution of social contexts

When the contact is established between the National Nuclear experts, NPP representatives or radiological transport owner, and the local command center (LCC), the interaction mainly occurs by two main social contexts. The first one is a face-to-face and mainly informal interaction when experts arrive at the LCC. However, Nuclear advisor contribution to the decision making process also comes from recommendations emitted by the experts and facility owner respective national crisis centers. By consequence, a virtual and formal interaction also takes place between the LCC and nuclear advisors by audio-conferences. Decision audio-conferences aim to assess the situation state regarding the impacted facility, the potential evolution of the situation and to discuss population protection countermeasures based on projected dose exposure evaluation. In addition to the LCC and Nuclear advisor crisis center they also gather both local and national crisis centers of the facility owner.

3.2.2. Consequence on LCC collective situation assessment and decision making process

During exercises, audio-conferences structure the communication process inside the LCC regarding the percolation of information. Decision audio-conferences constitute the main opportunity to share and build collective situation awareness between LCC stakeholders and the nuclear experts. Indeed, when an event occurs on a fixed plant (exercise A, B and C), the main LCC information sources regarding NPP state and public risk assessment come from nuclear experts. This distribution can evolve slightly when the facility impacted is mobile such as in Exercise D. Indeed, even if the radiological risk assessment is provided to the decision maker by the transport owner and by the Nuclear Safety Authority, emergency services such as firefighters are generally the first source of information regarding the state of the radiological transportation. By consequence, for the LCC, decision audio-conferences constitute a main opportunity to build a radiological situation assessment and achieve a consensus with the nuclear experts in regard to population protection decisions, the latter contributing to the radiological situation assessment of the LCC.

However, observations underline different strategies regarding the percolation of the radiological situation assessment built during decision audio-conferences towards all LCC members.

The first strategy, implemented during exercise C, consists in implementing decision audio-conferences in the LCC allowing all LCC teams to get the same level of information regarding the radiological situation and the current state of the decision-making process. However, the observation suggests that decision audio-conferences are rarely used “in situ” to collect information from LCC teams to be shared with nuclear experts. Thus, this functioning mode requires beforehand setting up additional communication systems to collect data and share situation awareness from LCC teams with the LCC decision team. One main pattern was observed in the continuity of the social context already observed in the first episode, i.e. individual face to face interactions from functional teams to the decision teams and then the information is shared between the decision making team and the LCC teams by broadcasting mechanisms.

The second strategy implemented during exercise D, implied the localization of decision audio-conferences in a separate LCC room in order to avoid difficulties that can occur with the first strategy such as the running LCC activities and high level of background noise. In this configuration, only some LCC teams representatives were present at the audio-conference, which can reduce the level of collective situation awareness inside the LCC. During exercise D, this was in part mitigated by the alternating organization of several formal LCC internal briefings in order to share information with LCC teams. However, it seems that few summaries of decisions taken during decision audio-conferences were transferred toward teams during these briefings. They were mainly used by the decision team to gather information from the LCC functional teams. Observations also underline that one issue is to find a balance between audio-conferences with nuclear experts and the natural tendency of the LCC to set up periodic internal briefings. Moreover, additional audio-conferences can be required between the LCC and the lower and upper levels of the crisis organization: mayors of impacted municipalities and national–level crisis center (CIC).

3.2.3. Public dose assessment

From the moment of the first contact with scientific advisers, the availability of the public dose assessment perimeters can be somehow delayed in time. This is what happened during exercise C, in which the nuclear facility owner’s population doses evaluations were quickly available and communicated to the LCC. However, national nuclear experts could not yet validate them as the second independent opinion. National nuclear experts results regarding dose estimations were transmitted to the decision maker at 4:00 PM (8 h after the beginning of the event). One main contributor of this delay is the dose calculation process itself. In the case of a differed release (more than 6 h) the first dose evaluations are based on forecast prognostic scenario for which measurements are not yet available. However, in the case of an immediate release such as the one that occurred in Exercise C, measurements become available and are naturally used in order to better assess public dose. By consequence, the process - not solely based on calculation - takes more time.

Observations illustrate that the delay to obtain public dose perimeters stresses the decision-making process and especially interactions between the nation-level Nuclear Expert and the decision maker, as no further decisions can be made. In nuclear expert’s frame of reference, the calculations delay during immediate release scenario do not trigger population protection actions as they are already implemented by pre-planned actions. Furthermore, even if dose calculations are not available, nuclear experts assess the severity of the radiological situation based on the radiological facility state and on first available environmental measurements. Based on this data they assess if population countermeasures took in episode 1 need to be extended or modified.

However, in the decision maker perception, dose calculations results expressed in mSv that can be compared with the population protection guidance of 10 and 50 mSv are the main reference values in order to adapt population protection decisions took during episode 1. By consequence, LCC stakeholders can be focalized on their availability. Furthermore, decision-making regarding population protection countermeasure is as important as the way to communicate on the situation.

During Exercise C, the reflex sheltering actions lasted seven hours with few situation assessment communications towards the public. This implied many issues regarding school food supplies and the question of the parental pressure that would have increased inexorably. The same issues took place at a higher level in Exercise B during which sheltering actions were implemented and could not be suspended in a short time after the event. By consequence from the moment when first decisions are taken, the need of explanation increases quickly over time in order to favor population adhesion to countermeasures. Thus, even though dose assessment is not yet available, the decision maker needs to characterize the order of magnitude and dynamics of the radiological situation he copes with, allowing a better communication to the public.

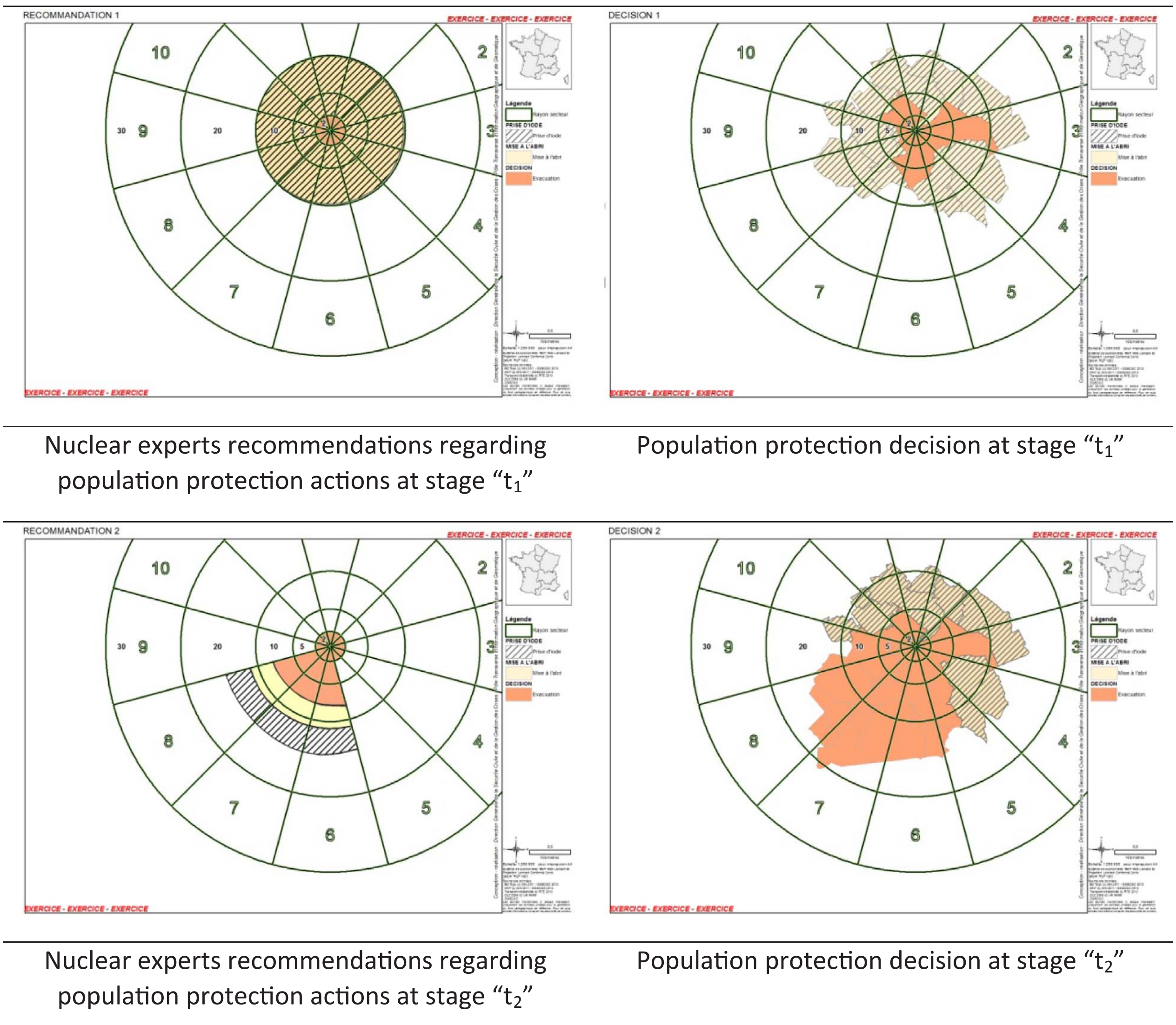

Fig. 1. adaptation by the decision maker of nuclear experts protection perimeters during two successive decision stages "t_1" and "t_2" (left: initial; right: adapted). Stripped area: Iodine pills prophylaxis. Yellow area: Sheltering. Orange area: Evacuation.

These examples illustrate the possible difficulty regarding the separation of decision-making process and public communication stakes in a radiological emergency. In this context, dose assessment that can be compared to threshold values that aimed to guide population protection decision in radiological situation seems to be crucial to nuclear decision-making but also to the communication processes and stakeholders can be focused on their availability.

The observation also underlined that during this episode, when public dose-related perimeters are not yet available, the perception of the decision team and LCC stakeholders can also be bothered by the quick availability at the LCC of environmental radioactivity measurements. Some of these measurements, expressed in Bq/m^3, cannot be understood by LCC stakeholders, for which the frame of reference uses Sievert-scale threshold values. By consequence, the availability of environmental measurements at the LCC level can also create confusion for LCC stakeholders in the way to use these data for situation management. If these measurements can contribute to assess the contamination distribution in the environment, they cannot be always directly used in the decision-making process. In other words, due to the lack of population dose calculations, this episode, depending on its length can impact the decision-making process as it doesn't allow taking decisions regarding the current doctrine.

3.3. *Episode 3: Availability of public dose calculations*

In this episode, population protection perimeters based on dose exposure calculations are transmitted to the decision maker and its crisis center. Observation of exercises shows this expertise is essential but not sufficient to take decisions.

3.3.1. *Social context*

In this episode, the social context stays relatively the same than in Episode 2. Main discussions regarding radiological situation assessment and decision-making occur during decision audio-conferences. However, as the expert perimeters require adjustments regarding their operational application in the real context of the area, the LCC functional cells are more and more solicited by the decision maker to complete the nuclear expertise. The same process occurs when the LCC begins to anticipate the swing into post-accidental phase, the LCC expertise is more and more involved regarding production of decrees related to agricultural areas, water supplies, food distributions and the next steps regarding population health care.

Interactions that mainly occur between decision team and nuclear expertise can also be slightly extended to contacts between LCC functional cells and nuclear experts outside decision audio-conferences, i.e. in an informal communication way. This happened during Exercise D in which the decision maker wanted to better assess the chemical risk regarding health symptoms and epidemiological protocols. To answer this question, the Nuclear Safety Authority and the Regional Health Agency (ARS) representatives in the LCC worked together in order to provide an answer to the decision maker.

3.3.2. Decision making process

When exposure dose perimeters (10 and 50 mSv) and associated recommendations are available, decision become possible but observations underlined that their direct implementation is not always possible. Indeed, these recommendations don't take into account the local reality regarding stakes such as population distribution, infrastructures, and means available to implement protection actions. By consequence, the main role of the LCC stakeholders is to adapt expert technical propositions into operational decisions taking into account a cost/benefice analysis based on several criteria analyzed hereafter.

For example, during Exercise B, population protection areas are adjusted to the reality of the field taking into account municipality administrative zoning in the first place as well as roads, highways or natural limits such as rivers. Previous decisions can also be taken into account in the decision process. Fig. 1 illustrates this adjusting process. Fig. 1-left represents the recommendation of the nuclear experts on two successive decision stages ("t_1" and "t_2" during exercise B and Fig. 1-right shows the population protection decision by the LCC following these recommendations. Three protection areas around the source term are represented:

- In yellow: sheltering actions.
- In orange: evacuation actions.
- In hatched: stable iodine prophylaxis.

Fig. 1-right shows that during both decision stages, the decision maker completed experts recommendations with civilian security own knowledge.

Indeed, at the "t_1" decision stage, he decided to extended and adapted nuclear expertise areas (Fig. 1-left "t_1") to the administrative boundaries of the municipalities (Fig. 1-right "t_1"). Indeed, nuclear expertise recommendations of population protection areas (evacuation in one hand and sheltering and stable iodine prophylaxis in the other hand) could both involve the population of a same municipality. The LCC analyzed that this particular configuration could imply difficulties to explain the differences in protection actions to the people living in the same town. As civilian security means were available to do it, the LCC decided to evacuate all the population of the impacted town and adapted expert protection areas to each municipalities boundary.

During the second decision stage "t_2", observations highlighted three factors that aimed to adapt and extend nuclear expert protection areas recommendations to the field. We found again that the municipalities' boundaries were still a main factor in the adaptation of population protection areas by the LCC. The second one regarded the decision to choose the most protective action (evacuation) and to extend it to the biggest area recommended by the nuclear experts (stable iodine prophylaxis on Fig. 1-left "t_2"). Indeed, sheltering and iodine distribution were not considered compatible with people expectations facing major nuclear accident. Furthermore, the multiplicity of protection instructions was also seen as likely to impact the efficiency of communication toward the public and by consequence the efficiency of protection countermeasures. The third factor consisted in taking into account previous decisions. Indeed, nuclear experts recommended lifting sheltering actions taken in the decision stage "t_1" in the North of the source-term. However, the LCC estimated that it was not possible to simply lift up the previous sheltering order as a nuclear emergency is still ongoing and evacuation actions will be conducted in the south of the source-term area.

Co-existence of risks can also delay the decision making process. During Exercise A, the decision maker and LCC stakeholders were balancing the pros and cons of evacuation or sheltering. The nuclear accident was caused by the 5,5 Richter-Scale earthquake that also damaged several buildings and infrastructures. In this situation, reflex population countermeasures in the case of nuclear emergency (sheltering) and in the case of an earthquake (evacuating) are in opposition. The decision maker had difficulty to obtain the radiological impact on the population regarding the radioactive release and an assessment of buildings that should resist to an earthquake. This inconsistency in the population protection countermeasures delayed the decision making process. Following Exercise A, a national working group was set up to address risk co-existence issues.

During Exercise D, risk co-existence also occurred. According to the experts, it seems that the main risk linked to the RMT accident and the release of uranium oxide powder were not the risk linked to the radioactivity but its chemical health impact. Nuclear national experts were quickly aware of this element and gave this information during the first LCC internal situation briefing. However, it seems that this information remained in the background of LCC situation awareness during the four next hours. It was raised again during the third decision audio-conference when national nuclear experts recommended urine tests for people in a 300 m radius. The updated perimeter of 300 m did not correspond to a radiological risk expressed in mSv as it could have been expected. Indeed, as nuclear experts assessed that the chemical risk was more important than the radiological one, chemical dose calculations were conducted. As the atmospheric release was by then already stopped, no additional countermeasure such as sheltering or evacuation actions were recommended. However, medical tests for the population living in the 300 m perimeter (calculated threshold for irreversible health effects) were recommended in order to be sure they would not suffer from this exposure. From this time, the decision maker aim was oriented towards getting clear communication elements to distinguish chemical risk from the radiological one in order to be able to communicate in an effective way with the population when the medical tests started.

Difficulty to implement actions can also take place during the swing from emergency phase to post-accidental phase. First post-accidental protection areas are generally based on forecasts of population exposition levels to the ground and food chain radiological contamination. Usually it is assumed that first post-accidental restrictive areas are activated at the end of the emergency phase and thus require anticipation. One difficulty in the swing from emergency to post-accidental restrictive areas can be the fact that post-accidental areas can be larger than emergency ones. This can be explained by the fact that territories impacted by radioactive deposition can be more extensive than emergency population protection areas. It is generally the case with the "territory strengthened monitoring area" that takes into account the monitoring of food production, commercialization and consumption in the area. This zone is thus characterized by a low environment contamination that does not justify population protection actions. Nevertheless, the contamination forecast calculations are assessed to be significant as they can exceed the maximal acceptable values (Bq/kg) fixed by EURATOM regulation (ASN, 2012). During Exercise C, post-accidental area recommended by modeling forecasts was estimated to 10 km while emergency-sheltering area was 2 km. During exercise C, post-accidental area was assessed by the nuclear experts at 1 km while first perimeter was 300 m. If decision to implement National nuclear advisor recommendation doesn't seems to cause difficulties to the LCC, the main issue is how to explain efficiently the differences between emergency and post-accidental restrictive areas to the population and especially to a population that was not affected by emergency decisions and which is concerned by the post-accidental countermeasures.

During this episode, decisions addressing population protection are possible but cannot be taken only on the basis of nuclear expertise; they must also account for and knowledge of the local context in which the accident occurs and develops.

Chapter 4: Discussion and conclusion

Although they cannot be considered as representative of all nuclear and radiological crisis management exercises, the four ones observed in this study contributed to enrich the understanding of the co-construction of a situation assessment between nuclear experts and civilian protection decision makers.

The first outcome of this paper is to underline, that an intermediate management episode can take place during the crisis when managers are still waiting for dose calculations. This episode appears in addition to the two main population protection strategies defined in the nuclear response plans: reflex actions and decisions based on dose calculations. During a nuclear emergency situation, first population decisions are based on pre-planned perimeters. These pre-planned perimeters are based on the use of *national-level* nuclear expertise beforehand; they allow a quick reaction of emergency managers in the absence of expertise. The analysis illustrates that reflex actions may be triggered by local stakeholders for the population protection response to match the event kinetic. By consequence, at the decision maker level, the implementation of these first actions mainly contributes to its situation assessment of the most plausible scenario occurring regarding the potential dynamics and risks of the current situation.

After first pre-planned population protection decisions have been taken and when the communication process occurs between national-level nuclear experts and the population protection decision maker, observations underlined that it does not mean an immediate availability of the dose exposure perimeters allowing guiding further population protection decisions (evacuation and sheltering). Although it exists a delay that cannot be shortened for dose assessment by national-level nuclear experts, it can be extended due to operational constraints. In the case of immediate and brief radiological releases as those studied in this research, the longer the delay to obtain dose results, the greater the difficulties to take decisions during the interaction between nuclear experts and decision makers. In our opinion, these difficulties can be explained by the fact that nowadays crisis management is a decision making process as well as a crisis communication process. In this context, radiological dose thresholds guiding population protection decisions seem to be well integrated in the frame of reference of LCC stakeholders and they focus on the availability of this crucial information in their decision making process. However, while waiting for these calculation results, the nuclear experts' analysis of radiological situation are mainly based on a number of "measurable" or "observable" data such as facility state, weather conditions or radiological environmental measurements when available. These elements in addition to stakes regarding population density, organization, and civilian security means, contribute to achieve a consensus in the situation assessment regarding population protection actions. However, as communication to the public has an increasing role in crisis management, it seems that dose assessment also plays an increasing role in the public communication as it can contribute to population sensemaking and adhesion to countermeasures already implemented. By consequence, this result suggests that this potential intermediate episode should be taken into consideration in the population protection decision strategy plan. As seen in this study, nuclear experts, based on their own background knowledge and plant and environmental data available, play a crucial role during this intermediate episode to help the decision maker and operational teams in situation assessment, understanding what is happening and in supporting population decision making and communication to the public and media.

The authors think that the potential existence of this episode in the decision making should be introducing during nuclear emergency management preparedness. Highlighting what issues can occur in the population protection strategies and what kind of implicit mitigation strategies have been developed by stakeholders to try to overcome these issues may facilitate management of this intermediate episode. This awareness may also help to look after additional decision support tools and guidance to hence the population decision making process during this episode.

The second outcome of this study is to show that population protection decision process during a nuclear emergency depends on nuclear expertise but also on civilian protection parameters that may become priorities.

Nuclear expertise main outcome is (and sometimes too restrictively) seen as based on doses calculation while it is based on several kinds of data and expertise that allows to contribute to the assessment of the situation and population recommendation even if dose calculations are not still available. This expertise has a crucial role to play to help the decision maker and operational teams in situation assessment, understanding what is happening and in supporting the decision maker to communicate to the public and media. However, as illustrated in Chapter 3.3 decisions addressing to populations must also take into account the context in which the accident occurs and develops. Analysis of the Fukushima accident (see Gisquet and Older, 2015) illustrated the difficulty and length that can occur for stakeholders to make sense of the situation on the field and thus at the public authority crisis command center. In the same time, the decision making process needs also to embed civilian stakeholder's own knowledge and experience regarding the diversity of territories and people who live in, the local context or the existence of other hazards (earthquake, flood). The aggregation of a nuclear risk with other risks (tsunami, earthquake, chemical accident) and the real context of the threatened territory (demography, urbanism, networks, vulnerable population) require the achievement of a consensus. Thus, in case of a large nuclear accident, technical analysis is essential and not sufficient to take appropriate decisions for protecting population and one of the main challenge is to achieve the balance between priorities of the local context and nuclear stakeholders' expertise during all phases of the nuclear crisis management.

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