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Comparative study of nuclear post-accident management doctrines in Europe and North America

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Abstract – The French Nuclear Safety Authority (ASN) issued in 2012 a first version of a doctrine establishing the principles of management of a post-accidental situation following a major nuclear accident. Since this publication, the feedback of the Fukushima-Daiichi accident continued and numerous evolutions occurred, both in French and European regulations and in international recommendations from IAEA and ICRP. This had led to further developments in the French doctrine for management of a post-accidental situation. This will result in the publication of a new version of the French doctrine next year. This evolution also prompted questioning about the existence of such doctrines in other countries, especially in neighboring countries. It appeared also interesting to evaluate the agreement of these doctrines, including the French one, with international recommendations, especially the recently published general safety requirements (GSR), part 11, from IAEA. A benchmark study comparing the different post-accidental management doctrines available was then conducted and is presented here.

Keywords: nuclear accident / post-accidental situation / management / radiation protection

1 Introduction

The Nuclear Safety Authority (ASN) established in 2005 the Steering Committee for the management of post-accidental situation (*COMITÉ DIRECTEUR pour la gestion Post-Accidentelle* [CODIRPA]), in charge of considering the establishment of principles for managing a post-accident situation following a major radiological or nuclear accident. This reflection led to the publication in 2012 of the first elements of doctrine (ASN, 2012), subsequently included in the national plan for the response to a major radiological or nuclear accident and integrated into the French ORSEC (*ORGANISATION des SECOURS*) emergency response plans.

The analysis of the feedback from the Chernobyl accident in April 1986 and from the Fukushima-Daiichi accident in March 2011 (Nirasawa *et al.*, 2021) continued in particular to take into account the impact of long lasting radioactive releases. In addition, European and French regulatory developments (EC, 2013; Code de la santé publique (CSP) 2018a, 2018b, 2018c; Code du travail (CT), 2016) and developments in the recommendations of the International Atomic Energy Agency (IAEA, 2012, 2014, 2015, 2018) and the International Commission for Radiological Protection (ICRP) (ICRP, 2018, 2020), have led to further reflections by CODIRPA and to propose developments in this post-accident

management doctrine, which were recently endorsed by the French Prime Minister¹.

This evolution of the French post-accident management doctrine has led to questions about the existence of post-accident management doctrines in foreign countries and their content, in order to compare them and to learn from them for the further work of CODIRPA. Such a comparative analysis of nuclear accident management doctrines has already been carried out by the European Commission (EC, 2013) and by joint work by the Association of the Authorities responsible for radiation protection in Europe (Heads of European Radiation Protection Authorities [HERCA]) and the association of nuclear safety authorities of Western Europe (Western European Nuclear Regulator's Association [WENRA]). However, this previous work focused mainly on the emergency response phase of a nuclear accident (HERCA-WENRA, 2014). Moreover, the 2013 European Community study does not take into account recent developments, including the IAEA and ICRP recommendations and their consideration by different countries. The study presented here is therefore a comparison of the recommendations published by 15 European and North American countries for the management of the post-accidental phase of a nuclear accident. The aim is to have a general picture of the work in progress and to compare

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¹ Letter from Prime Minister CAB/2020D/11412 as of 18 June 2020.

the strategies implemented by the different countries included in the study.

2 Document collection and analysis

In order to carry out this comparative analysis, research was carried out to collect the doctrines of nuclear accident management from different European countries (priority to the countries bordering France) and from two North American countries. The analysis of the documents was limited by the availability of official documents on the internet and by the language of publication (French or English) in order to avoid the risk of misinterpretation due to translation. As a result, only the following country doctrines have been analyzed: Belgium, Canada, Germany, Ireland, Italy, Luxembourg, Nordic countries (Denmark, Norway, Sweden, Finland and Iceland), Spain, Switzerland, United Kingdom and United States. In a few cases (Canada, Spain, Italy and Luxembourg), the information was supplemented by direct contacts with members of the nuclear safety authorities, *via* the contact points identified by the International Relations Department of ASN. In the case of Switzerland, the information was collected through a direct exchange with the Federal Office of Public Health, supplemented by the review of the documents relating to the management of radiological emergencies (OFPP, 2015), since the post-accident management doctrine of that country is still being developed.

The analysis of post-accident management doctrines has also been limited to accidents at nuclear power plants (NPP), although most existing doctrines may include elements of management of other accidental situations (transport accidents, malevolent actions, etc.). Moreover, although the structure of the doctrines studied incorporates both emergency and long-term management, the study presented here is limited to the long-term management of the post-accident phase of a nuclear accident.

This analysis was complemented by the analysis of the latest IAEA documents on accident management (IAEA, 2012, 2015, 2018), the latest update of the *Codex Alimentarius* (FAO, 2019) and ICRP Publication 146 (ICRP, 2020), dealing with the protection of populations in emergency and post-accident situations.

3 Comparison of national approaches

The countries subject to this comparative analysis have different levels of nuclearization. For example, Luxembourg, Greece, Italy, Ireland and Portugal do not have a NPP in their territory and Germany is currently shutting down the last three NPPs remaining in service in 2021. All the other countries studied have NPP operating in their territory. It should be noted, however, the special case of Luxembourg, which is neighboring a French NPP (Cattenom), the latter being located very close to the Luxembourg territory. This geographical situation has led Luxembourg to develop post-accident management capacity based on the HERCA-WENRA approach (Gouvernement du Grand-Duché de Luxembourg, 2015) and to participate actively in the work of CODIRPA. Ireland is in a similar situation, with facilities in the United Kingdom near Irish territory. Similarly, Italy does not have a

specific text for the management of a nuclear accident, but is currently transcribing the most relevant IAEA recommendations in its national legislation. Thus, Italy will take into account only the IAEA recommendations applicable to a nuclear accident in a third-party country that may have consequences on its national territory. Another particular case is that of the Nordic countries (Denmark, Norway, Sweden, Finland and Iceland) which have a common doctrine (STUK, 2014), transposed at least partially into national legislation, while Norway, Denmark and Iceland do not have NPP. However, this common approach allows them to have a set of recommendations in the event of a nuclear accident in a third country impacting their own territory, as it was the case for Norway with the Chernobyl accident (Skuterud and Thørring, 2012). One country (Spain) with NPP in its territory have not yet developed a specific post-accident management doctrine, but have a set of laws governing a nuclear emergency (BOE, 2004, 2010). In general, the level of translation of IAEA recommendations does not appear to depend on the presence of nuclear reactors in operation in the country concerned, but rather on the estimation of the risk associated with the presence of nuclear facilities, whether on or near national territory.

4 The phases of a nuclear accident and definitions

The breakdown of a major nuclear or radiological accident in several phases, although theoretical, is a structuring framework for the reflection on accident management and particularly for the management of the long term consequences. It should be noted that the names of the different phases of a nuclear accident vary greatly from country to country. In this study, a unique name for each of the phases is used based on the IAEA terminology. The breakdown proposed by IAEA (2018) has four main phases (Fig. 1A): a preparedness phase, an emergency response phase, a transition phase and a long-term phase, *i.e.* the post-accident phase.

The emergency response phase is subdivided into two phases. The urgent response phase (or threat phase) starts from the detection of conditions requiring the potential application of population protection action until the moment when these actions are in place (evacuation and consumption restrictions). The early response phase begins when the radiological situation is sufficiently clearly understood for the decision to implement urgent protection actions such as stable iodine intake, shelter and consumption restrictions taken during the discharge phase. These two phases are referred collectively thereafter as the “emergency response phase” (Fig. 1A), correspond roughly to the period of radioactive discharges and end with the termination of emergency.

The transition phase is a period taking place after the end of the emergency response phase, *i.e.*, a phase during which the facility is stabilized, additional releases are not expected, radiological characterization of the environment is carried out (due to the imprecise knowledge about the extent and importance of radioactive deposits) and long-term protection measures of populations are planned and implemented. The transition phase is then followed by the post-accident phase, starting when long-term protective measures are implemented.

A: Breakdown of a nuclear emergency according to IAEA **B: Breakdown of a nuclear emergency according to CODIRPA**

Fig. 1. The different phases of a major nuclear or radiological accident according to the IAEA (up) (IAEA, 2018) and comparison with the phases used by French doctrine (bottom) (ASN, 2012). The long-term phase is also referred as the post-accidental phase in some countries.

According to IAEA definitions (IAEA, 2018), both the emergency response phase and the transition phase correspond to an emergency exposure situation as defined by ICRP (2007), while the post-accident phase corresponds to an existing exposure situation.

All countries under review including France (ASN, 2012) agree on the existence of the three main phases: the preparedness phase, the emergency response phase and the long-term phase. On the other hand, there are many differences between countries in the details of these phases and more particularly on two points (Fig. 1):

- the separation of the emergency response phase is more or less complex in different countries, with some countries such as Spain considering the emergency response phase as a single phase (BOE, 2004, 2010), while most countries consider that the emergency response phase can be divided into two phases, a threat phase (corresponding to the IAEA urgent response phase) and a release phase (corresponding to the IAEA early response phase);
- the major difference is the positioning of the transition phase within the emergency response phase as recommended by IAEA (case of Belgium, Switzerland and Canada) (Moniteur Belge, 2018; CCSN, 2018) or in the long-term phase (Germany, UK and France, see Fig. 1B) (SSK, 2014; PHE, 2019; ASN, 2012).

All countries agree that the end of the emergency response phase can be pronounced when the facility has returned to a stabilized state and no release is expected, which is in line with the IAEA recommendations. Moreover, all countries agree that the end of the emergency response phase must be formally formalized (IAEA, 2018). Some countries (United Kingdom, United States, France) (NCRP, 2014; PHE, 2019; ASN, 2012)

emphasize that there may be spatial (geographical) and temporal overlaps between the different phases, for example due to a change in wind direction, allowing a territory to be placed in transition and another territory, in the wind of potential new releases, still in an emergency response phase, or due to the preparation of long-term measures from the emergency response phase (Fig. 2).

However, in the examples given by the IAEA on the declaration of the termination of the emergency situation (IAEA, 2018), there appears to be a difficulty linked to the fact that the declaration of the termination of the emergency corresponds both to a state of the accident installation (stabilized state of the facility and no risk of further releases), and to the radiological characterization of the environment and the lifting of emergency measures to protect populations (in particular evacuation and sheltering). This has led the IAEA to place the transition phase in the emergency response phase. For instance, the IAEA estimates that in the case of the Fukushima-Daiichi accident, the termination of the emergency took place in July 2011, based on the end of evacuations or relocations of over-exposed persons. The transition phase continued until 16 December 2011, when a cold shutdown of the reactors was declared and leading to the declaration of the termination of the emergency (IAEA, 2018).

During this transition phase, the following activities were completed:

- radiological characterization of the environment;
- establishment of long-term medical and health follow-up;
- definition of the criteria for the end of emergency measures, in particular the lifting of evacuation orders;
- establishment of the long-term strategy for waste management and decontamination;
- establishment of radiation protection for on-site and off-site workers.

Fig. 2. Variation in the relative importance of population protection measures taken during the different phases of a major nuclear or radiological accident. Red: emergency response phase; grey: transition phase; green: long-term phase (*i.e.* post-accident phase). According to the [NCRP \(2014\)](#).

The French management doctrine ([ASN, 2012](#)) considers that decisions to implement measures to protect populations during the post-accidental phase, *i.e.*, after the end of the releases may follow a different timeframe from that of the management of the facility, as soon as information on the radiological state of the environment is available, either by predictive modelling or by field measurements. Thus, in the case of multiple releases in different directions, some of the long-term protection actions can be taken as soon as possible in a given direction, while a neighboring territory, still under releases, could be subject to emergency protection measures at the same time, regardless of the time of decision-making. Furthermore, once releases have been completed in a given direction, with a state of the facility safe enough to be sure of the absence of further releases, and regardless of the cold shutdown status of the facility, it is essential that the characterization of the radiological status of the environment is undertaken, so that emergency measures can be lifted and long-term measures implemented as soon as possible. Overall, it is considered by several countries (United States, France, United Kingdom) that the implementation and optimization of measures to protect the population appear more as a continuum from the beginning of the emergency response phase to the long-term phase ([Fig. 2](#)) ([NCRP, 2014](#); [ASN, 2012](#); [PHE, 2019](#)), whereas the phase of the accident essentially corresponds to a status of the affected facility, meeting technical criteria.

Phase differences have implications for exposure reference levels, which are adapted to the reference levels proposed by the ICRP according to the phase of the accident, and thus the consequences for the protection of populations, especially during the transition and long-term phases.

It should be noted that the ICRP does not take into account such a transition phase of a nuclear or radiological accident, but merely an emergency response phase and a recovery phase, corresponding to an emergency and an existing exposure situation, respectively (see [Fig. 1](#)) ([ICRP, 2020](#)).

5 Reference exposure levels

The ICRP, in its publication 146 ([ICRP, 2020](#)), proposes reference exposure levels for the population during a radiological or nuclear emergency based on exposure

situations as defined in the recommendations of publication 103 ([ICRP, 2007](#)). During the emergency exposure situation, the ICRP recommends a reference level of 100 mSv for the entire duration of the emergency phase, while recognizing that this level can be quickly exceeded, particularly for emergency responders. For the long-term phase, the ICRP recommends a reference level of between 1 and 20 mSv per year, corresponding to an existing exposure situation, stressing the need for optimization of protection to gradually reduce exposures to values of the order of 1 mSv per year over the long-term.

The transposition of these recommendations into the IAEA scheme leads to considering the entire emergency response phase, including the transition phase, as an emergency exposure situation, with the existing exposure situation taking place only after the declaration of the termination of the emergency ([Fig. 1](#)) ([IAEA, 2018](#)). However, the IAEA introduces an additional exposure reference level for the transition phase, with a benchmark value of around 20 mSv for the duration of this phase, without being linked to an emergency or existing exposure situation as defined by the [ICRP \(2007\)](#). The proposal of two benchmark values before the termination of the emergency creates additional complexity in this scheme and shows that the transition phase is indeed a phase during which the focus must be on measures to protect the population, regardless of the status of the installation.

Most countries with post-accident management doctrine or specific legislation propose exposure benchmarks for each phase of a nuclear accident ([Tab. 1](#)). All proposed values are consistent with the recommendations of the ICRP and IAEA. There are some differences, for example due to the period taken into account for the benchmark value. For example, France, Belgium and the United Kingdom propose a benchmark value of dose for the emergency response phase until the end of discharges, while Germany and Nordic doctrines propose a benchmark for the emergency response phase in the first year. Depending on the duration of releases and the definition of the emergency response phase, this can be considered to be more or less protective. Another difference, related to the phase of the nuclear accident, is the variability of country-to-country benchmark values for the transition phase. On the other hand, there is a high degree of consistency in the benchmark values for the long-term phase ([Tab. 1](#)).

Table 1. Reference exposure levels for the population according to international organizations and countries, taking into account the phase of the accident for each country. Doses are expressed as an effective dose (E), all routes of exposure taken into account.

Organisation or country	Phases of the accident			Reference
	Emergency	Transition	Long-term	
ICRP	100 mSv	–	1–20 mSv	ICRP (2020)
IAEA	100 mSv	≈20 mSv	1–20 mSv	IAEA (2018)
France	100 mSv ¹	1–20 mSv	1–20 mSv	CSP (2018a, 2018b, 2018c)
Germany	100 mSv ²	–	1–20 mSv	SSK (2014, 2015)
Belgium	20–100 mSv	20–100 mSv	1–20 mSv	Moniteur Belge (2018)
Nordic countries ³	20–100 mSv ²	–	1–20 mSv	STUK (2014)
United Kingdom	100 mSv	<100 mSv, with optimisation ⁴	<20 mSv	PHE (2019)
Switzerland	100 mSv ²	100 mSv	1–20 mSv	OFPP (2015)
Canada ⁵	20–100 mSv	20–100 mSv	1–20 mSv	CCSN (2018)
United States ⁶	–	–	–	NCRP (2014)
Spain ⁷	–	–	–	BOE (2004)

¹ With application of the principles of optimization and justification (CSP, 2018a, 2018b, 2018c).

² During the first year, with optimization to be implemented as soon as possible.

³ Denmark, Sweden, Norway, Finland, Iceland.

⁴ The UK's management doctrine insists on optimizing exposure during the transition phase, without providing a baseline.

⁵ Canada relies on the recommendations of the ICRP, with no specific guide value.

⁶ The USA considers that the use of exposure reference levels does not adequately address considerations specific to the nature of the accident and its consequences (NCRP, 2014). The protection strategy is based solely on the guide values for protection actions (EPA, 2017).

⁷ Spain, in its legislation, does not indicate exposure reference levels, but only preventable dose levels for the implementation of protective measures.

6 Long-term protective measures

Only some countries (France, Nordic countries, United Kingdom, Belgium, USA, Canada) have developed a post-accident management doctrine document, which is a non-legally binding document. This is due either to the federal structure of the country concerned (Canada, the United States) or to a willingness to separate the doctrine document from the legislative aspect (France, Nordic countries, United Kingdom, Belgium). The use of a limited number of reference values in legislation, combined with the proposal of a comprehensive non-binding management doctrine, allows for greater freedom of action in the choice and graduation of protective measures. This allows for better adaptation of protective measures to prevailing circumstances and local issues. In line with this, Luxembourg participates in the work of CODIRPA in order to being able to include planning issues, and especially the zoning (see below), in its own emergency preparedness and response. This may allow a better trans-border coordination in case of an emergency situation in a French NPP located close to the border of Luxembourg. In general, post-accident management doctrines are much more detailed than legislation, the latter being sometimes very brief about protective measures for the population. One of the few exceptions is Belgian legislation, which is very detailed on post-accident management.

All the doctrines examined converge on the nature of long-term protective measures for populations, and on the fact that these measures need to be adapted to the results of measurements of radiological contamination of the environment. The French doctrine (ASN, 2012), with the Swiss doctrine (in preparation), are the only doctrines to propose a

structured approach to the protection of populations on the basis of post-accidental zoning. This zoning, consisting of three different area (long-term relocation area, area banning the consumption of locally produced fresh foods and an area with pre-market control, according to French names), enables protection measures to be graded according to local issues within each of these areas. This type of approach makes protection measures more legible for the population concerned, but risks to make the “border effects” more pronounced on both sides of the area boundaries. For other countries, it is the use of operational levels of intervention (OIL) that triggers the introduction of a specific protection measure. Given the discontinuous nature (in leopard stains) of contamination following a nuclear accident, the use of OILs may allow better adaptation of protection measures to radiological contamination and local issues, but the overall protection strategy is thus less easily readable and comprehensible for the population.

The main transitional or long-term measures, which are included in all post-accident management doctrines in more or less detail, are as follows:

- short-term or long-term relocation, which must be distinguished from evacuation. In parallel, this presupposes the establishment of a relocation area, or at least restricted areas due to an excessive risk of external exposure;
- restrictions on the consumption of fresh food locally produced;
- restrictions on non-food goods (materials and manufactured goods);
- radiation protection of stakeholders, whether professionals or volunteers. This reference to the radiation protection of

- volunteers involved in assisting populations in post-accident situations is a Canadian specificity (CCSN, 2018);
- characterization of radiological contamination of the environment;
- medical follow-up, including mental health and psychological support. This aspect of public health also covers the identification of the affected population and an assessment of their exposure. This requires, according to the IAEA (2018), the establishment of a structure to coordinate this monitoring, the establishment of the principles for the management of this follow-up (parameters and follow-up duration), the possible management of biological and non-biological samples as well as ethical aspects;
- the information of the affected population;
- the establishment of waste management principles and the strategy for decontamination actions;
- compensation mechanisms.

Only certain measures (long-term relocation and fresh product consumption restrictions, radiation protection of stakeholders) can be associated with exposure limits or benchmark values (Tab. 1), possibly associated with OIL (Belgium, Germany and Nordic doctrine) (Moniteur Belge, 2018; SSK, 2015, 2019; STUK, 2014). In other countries, it is simply mentioned that these protection measures must be set in place in order to comply with the exposure benchmark values proposed by IAEA or in national texts, but without further details.

Compensation mechanisms are a specific case. Indeed, financial compensation fall under the specific nuclear liability regime. This regime assess the responsibility of the operator, and applies to all countries that have signed the Paris Convention².

For other measures such as restrictions on non-food items, medical follow-up, establishment of waste management strategy, or decontamination strategy, their application is generally not subject to a clearly defined criterion. Most doctrines therefore remain at the level of management and protection principles and exposure benchmarks (as shown in Tab. 1 for the long-term phase) for all other measures. The rare implementation of the long-term benchmarks values into OILs for triggering the application of protection measures is not in line with the IAEA recommendations (IAEA, 2018). This could be due to several factors such as the time required to integrate international recommendations into national doctrines, the fact that the assumptions underlying the calculation of OILs are possibly not considered appropriate, or the fact that OILs can be seen as binding, and thus lack flexibility in adapting protective measures to local issues. This latter point is mentioned in particular as a justification for the non-use of OIL in United Kingdom documents (PHE, 2019).

Population information is regularly mentioned, but there is little evidence on the implementation and form of this information. Most national texts, as well as the IAEA recommendations, stress the need for such information, but it appears that it is rather a top-down information on the

radiological situation and on the protection measures to be put in place than to accompany the population. Only a few doctrines (Nordic countries, France, United Kingdom) explicitly mention the fact that there must be a genuine support for the population, with the promotion of a culture of radiation protection as advocated by the ICRP (2020) and support for citizens' measurement initiatives, etc. The production of communication tools such as the French website www.post-accident-nucleaire.fr or the guide to help the population living on a contaminated territory (ASN, 2020) based on a Japanese example (Kuroda *et al.*, 2020) remain rare initiatives at the stage of preparation. Similarly, the notion of stakeholder involvement is clearly reflected in most of the doctrines examined, but very few indicate the form that such stakeholder involvement could take, despite the importance of such involvement (Naito *et al.*, 2020). Stakeholder involvement at the preparatory stage, as is done within CODIRPA in France, remains an exception (Bertho *et al.*, 2021). Similarly, the description of the role of welcome and information centers as a one-stop shop for those concerned by a post-accidental situation (ASN, 2012) is an originality that is not found in any other country.

On the other hand, it is clear in all post-accidental management doctrines that the principles of optimization and justification must be taken into account in establishing exposure benchmarks, taking into account local issues and economic revitalization of contaminated territories (Schneider *et al.*, 2021). The doctrine of the United Kingdom (PHE, 2019) thus incorporates the principle of optimization described in ICRP publication 146 (ICRP, 2020), which, by focusing on reducing exposures of the most exposed individuals, reduces the overall exposure of the population and thus gradually lowers the exposure benchmark values (Fig. 3).

7 Conclusions

The last 10 years have seen the publication of several post-accident management doctrines, in parallel with the publication of the IAEA recommendations, in particular the publication GSR-11 on the termination of an emergency situation (IAEA, 2018), the publication of the EURATOM Regulation on maximum permissible levels of contamination of production for human consumption (EURATOM, 2016) and the publication of the European BSS (EC, 2013). These publications have profoundly changed the landscape of the protection of populations in a nuclear or radiological emergency and in a post-accident situation, compared to the situation carried out by the European Community in 2012 (EC, 2013). This leads to a much better homogenization of the principles of population protection, reference levels and associated OILs for most of the countries examined in this comparative study. All countries comply at least with the reference levels proposed by the ICRP (2020) and the IAEA (IAEA, 2012, IAEA, 2015, IAEA, 2018), although there may be significant differences between countries in the phase of an accident or in the use of OILs. Thus, for France, the CODIRPA doctrine uses only the benchmark values for the establishment of post-accidental zoning, without involving OIL (ASN, 2012), as does the United Kingdom (PHE, 2019). Similarly, all the measures to protect and accompany the populations involved are very homogeneous from one doctrine to another,

² Paris Convention, 2004, modifying the Paris convention from July 29, 1960 and the additional protocol signed on January 28, 1964 and entering in force as to January 1st, 2022.

Fig. 3. Schematic representation of the application of the optimization principle in an iterative approach. In (A), a baseline, with a majority of individuals with exposure below the exposure benchmark (dotted line). In (B), exposure optimization reduces the number of individuals above the benchmark, allowing for a third step (C) to lower the exposure benchmark. This situation then becomes the new starting situation (A). Based on PHE (2019) and ICRP (2020).

and all agree that the active involvement of local actors in decision-making to manage the post-accident situation is important for a better resilience of the territories.

In this context, the comparison of French doctrine (ASN, 2012), in its version recently validated by the Prime Minister³, with the recommendations of the ICRP and the IAEA, and although being one of the oldest published post-accident management doctrines, shows good consistency and best respects the prerequisites of the IAEA recommendations. This is probably due to the large amount of work made and reports published since 2005 with pluralistic working groups, each being dedicated to one of the numerous aspects of the management of a post-accidental situation. However, some differences appear between the French doctrine and IAEA

recommendations, mainly in the phase of a nuclear accident and in the use of OIL. Moreover, the doctrine of CODIRPA is in very good agreement with the doctrines examined in this analysis, and in particular with the doctrines of border countries, where they have them. This would allow, in the event of an accident with cross-border consequences, a better homogenization of measures to protect populations on both sides of the border.

References

- ASN. 2012. *Éléments de doctrine pour la gestion post-accidentelle d'un accident nucléaire*. <https://www.asn.fr/Prevenir-et-comprendre-l-accident/Gestion-post-accidentelle/Elements-de-doctrine>.
- ASN. 2020. *Guide pour les habitants d'un territoire contaminé par un accident nucléaire*. <https://post-accident-nucleaire.fr/preparation-la-gestion-post-accidentelle-dun-accident-nucleaire>.
- Bertho JM, Gabillaud-Poillion F, Reuter C, Rivière O. 2021. Involvement of stakeholders during the preparedness phase of post-accident situation management. *Ann. ICRP* 50(suppl): 160–166.
- BOE (Boletín Oficial del Estado, España). 2004. *Real Decreto 1546/2004, de 25 de junio, por el que se aprueba el Plan Básico de Emergencia Nuclear*. Última actualización publicada el 03/01/2020. BOE-A-2004-13061. <https://www.boe.es/buscar/pdf/2004/BOE-A-2004-13061-consolidado.pdf>.
- BOE (Boletín Oficial del Estado, España). 2010. *Real Decreto 1564/2010, de 19 de noviembre, por el que se aprueba la Directriz básica de planificación de protección civil ante el riesgo radiológico*. BOE-A-2010-17808. <https://www.boe.es/boe/dias/2010/11/20/pdfs/BOE-A-2010-17808.pdf>.
- CCSN. 2018. *Gestion des urgences et protection-incendie, tome II : cadre pour le rétablissement après une urgence nucléaire REGDOC-2.10.1*. http://www.nuclearsafety.gc.ca/pubs_catalogue/uploads/REGDOC-2-10-1-Emergency-Management-and-Fire-Protection-vol2-draft-eng.pdf.
- CSP (Code de la santé publique). 2018a. *Section 1 : principes généraux, articles L1333-1 à L-1333-6*. https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006072665/LEGISCTA000032010445?etatTexte=VIGUEUR&etatTexte=VIGUEUR_DIFF#LEGISCTA000032044833.
- CSP (Code de la santé publique). 2018b. *Section 4 : gestion des situations d'urgence radiologique articles R. 1333-81 à R. 1333-89*. https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006072665/LEGISCTA000006190974?query=R1333-81&typeRecherche=date&dateVersion=05%2F01%2F2021&nomCode=LHIW4Q%3D%3D&searchField=ALL&tab_selection=code&page=1&anchor=LEGISCTA000006190974#LEGISCTA000006190974.
- CSP (Code de la santé publique). 2018c. *Section 5 : gestion de situations d'exposition durable résultant d'une pollution par des substances radioactives, articles R1333-90 à R1333-96*. https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006072665/LEGISCTA000006191035/#LEGISCTA000037017354.
- Code du travail. 2016. *Chapitre 1^{er} – Prévention des risques d'exposition aux rayonnements ionisants, articles L 4451-1 et suivants*. https://www.legifrance.gouv.fr/codes/section_lc/LEGITEXT000006072050/LEGISCTA000006178087?etatTexte=VIGUEUR&etatTexte=VIGUEUR_DIFF.
- EC. 2013. *Review of current off-site nuclear emergency preparedness and response arrangements in EU member states and neighbouring countries*. ENCO FR-(13)-29; EC/ENER/DI/2012-474.

³ Letter from Prime Minister CAB/2020D/11412 as of 18 June 2020.

- https://ec.europa.eu/energy/sites/ener/files/documents/2014_nep_epr_review_2012-474_main_0.pdf.
- EPA. 2017. *PAG manuel: Protective action guides and planning guidance for radiological incidents*. EPA-400/R-17/001. https://www.epa.gov/sites/default/files/2017-01/documents/epa_pag_manual_final_revisions_01-11-2017_cover_disclaimer_8.pdf.
- EURATOM. 2016. *Règlement 2016/52 fixant les niveaux maximaux admissibles de contamination radioactive pour les denrées alimentaires et les aliments pour animaux après un accident nucléaire ou dans toute autre situation d'urgence radiologique*. JOUE, L13/2 du 20/01/2016. <https://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32016R0052>.
- FAO. 2019. *Codex Alimentarius: general standard for contaminants and toxins in food and feed*. CXS 193-1995, amended 2019. http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXS%2B193-1995%252FCXS_193e.pdf.
- Gouvernement du Grand-Duché de Luxembourg. 2015. *Plan d'intervention d'urgence (PIU) en cas d'accident nucléaire*. https://www.infocrise.lu/documents/20181/22768/PLAN_URGENCE_NUCLEAIRE_VERSION_PUBLIQUE_LR.pdf/f0a69009-136c-497b-a994-b3b216742ba1.
- HERCA-WENRA. 2014. *HERCA-WENRA approach for a better cross-border coordination of protective actions during the early phase of a nuclear accident*. <https://www.asn.fr/Media/Files/HERCA-WENRA-approach-for-better-cross-border-coordination-of-protective-actions-during-the-early-phase-of-a-nuclear-accident?>.
- IAEA. 2012. *Criteria for use in preparedness and response for a nuclear or radiological emergency. General safety requirements 2 (GSR-2)*. Vienna: IAEA ed., STI/PUB/1467.
- IAEA. 2014. *Radiation protection and safety of radiation sources: international basic safety standards (GSR part 3)*. Vienna: IAEA ed., STI/PUB/1578.
- IAEA. 2015. *Preparedness and response for a nuclear or radiological emergency. General safety requirements 7 (GSR-7)*. Vienna: IAEA ed., STI/PUB/1708.
- IAEA. 2018. *Arrangements for the termination of a nuclear or radiological emergency. General safety guide 11 (GSG-11)*. Vienna: IAEA ed., STI/PUB/1796.
- ICRP. 2007. The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann. ICRP* 37(2-4).
- ICRP. 2018. Ethical foundations of the system of radiological protection. ICRP publication 138. *Ann. ICRP* 47(1).
- ICRP. 2020. Radiological protection of people and the environment in the event of a large nuclear accident: update of ICRP publications 109 and 111. ICRP Publication 146. *Ann. ICRP* 49(4).
- Kuroda Y, Koyama Y, Yoshida H, Naito W. 2020. Preparation of an "Information booklet for returnees" – Building trust through collaboration with local communities. *Radioprotection* 55(4): 309–315. <https://doi.org/10.1051/radiopro/2020081>.
- Moniteur Belge. 2018. *Plan d'urgence nucléaire et radiologique pour le territoire belge*. 6 mars 2018, 18847. https://centredecrise.be/sites/default/files/nucleair_noodplan_belgischstaatsblad_plan_durgence_nucleaire_moniteur_belge_0.pdf.
- Naito W, Uesaka M, Kuroda Y, Kono T, Sakoda A, Yoshida H. 2020. Examples of practical activities related to public understanding of radiation risk following the Fukushima nuclear accident. *Radioprotection* 55(4): 297–307. <https://doi.org/10.1051/radiopro/2020086>.
- Nirasawa T, Tsubokura M, Murakami M. 2021. Changes in radiation protection measures after the Fukushima Daiichi nuclear accident: evaluation of meeting minutes of the Nuclear Regulation Authority, Japan. *Radioprotection* 56(2): 153–160. <https://doi.org/10.1051/radiopro/2020079>.
- NCRP. 2014. *Decision making for late-phase recovery from major nuclear or radiological incidents*. NCRP report 175. Bethesda, MD: NCRP ed.
- OFPP. 2015. *Concept de protection d'urgence en cas d'accident nucléaire en Suisse*. Cote: 403. 2-0. <http://www.news.admin.ch/NSBSubscriber/message/attachments/40199.pdf>.
- PHE. 2019. *Public health protection in radiation emergencies*. Report PHE-CRCE-049. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/805655/Advice_for_Radiation_Emergencies_2019.pdf.
- Schneider T, Lochard J, Maître M, Ban N, Croûail P, Gallego E, Homma T, Kai M, Lecomte JF, Takamura N. 2021. Radiological protection challenges facing business activities affected by a nuclear accident: some lessons from the management of the accident at the Fukushima-Daiichi Nuclear Power Plant. *Radioprotection* 56(3): 181–192. <https://doi.org/10.1051/radiopro/2021022>.
- Skuterud, L, Thørring H. 2012. Averted doses to Norwegian Sámi Reindeer Herders after the Chernobyl accident. *Health Phys.* 102 (2): 208–216.
- SSK. 2014. *Basic radiological principles for decisions on measures for the protection of the population against incidents involving releases of radionuclides. Recommendations by the German commission on radiological protection*. https://www.ssk.de/SharedDocs/Beratungsergebnisse_PDF/2014/RadiologischeGrundlagen_e.html?nn=2876422.
- SSK. 2015. *Operational intervention levels (OILs) for measures to protect individuals in the event of environmental contamination with alpha and beta emitters. Recommendations by the German Commission on Radiological Protection*. https://www.ssk.de/SharedDocs/Beratungsergebnisse_PDF/2015/2015-12-03_Empf_AlphaBeta_e.pdf?__blob=publicationFile.
- SSK. 2019. *Operational intervention levels for measures to protect the population against incidents involving releases of radionuclides. Recommendations by the German Commission on Radiological Protection*. https://www.ssk.de/SharedDocs/Beratungsergebnisse_E/2019/2019-10-25_Empf_AbgeleitRichtwerte_e.html?jsessionid=982C93FE65B0C7C84F7A6532B202BE0B.2_cid382.
- STUK. 2014. *Protective measures in early and intermediate phases of a nuclear or radiological accident*. https://www.stuk.fi/documents/12547/103518/nordic_flagbook_february2014.pdf/de016067-7c30-4747-bd63-606bdaad08f7.