Updates of the french criticality safety analysis guide and event database (logic)

Fabien Duret, Matthieu Duluc, Aurelie Bardelay

UPDATES OF THE FRENCH CRITICALITY SAFETY ANALYSIS GUIDE AND EVENT DATABASE (LOGIC)

Fabien Duret (1) *, Matthieu Duluc (1), Aurélie Bardelay (1)

(1)*Institut de Radioprotection et de Sûreté Nucléaire (IRSN), B.P. 17, 92262 Fontenay-aux-Roses Cedex, France*
* *fabien.duret@irsn.fr*

ABSTRACT

At ICNC 2011 [1], IRSN presented a guide devoted to criticality risks analysis. In addition to general information (physical phenomena, studies, rules, etc.), this guide included an appendix with diagrams describing the items of the French criticality safety regulations, and the questions to be delt with when performing an analysis or an expert assessment. A new version of the guide, published in 2022, takes into account upgrades of the French regulations since 2010 and includes new topics: reactor loading and unloading operations (also concerned by criticality safety, contrary to operating reactors), measurements of fissile material masses, neutron reflections and interactions, and criticality accidents (detection and alarm, protection, means to stop an accident). New questions have also been added in order to take into account scenarios encountered in reported criticality safety events since 2010 that cannot be described by the 2010 guide scenarios. The Neutronics and Criticality Safety Department (SNC) uses its own database of criticality safety events, so called "LOGIC" (including events that occurred in France and some foreign events), where each event is associated with a scenario to be chosen from a list of scenarios corresponding to the "questions" of the guide. LOGIC also includes elements presented in the operator event reports (chronology, causes, consequences, preventive measures), IRSN experts remarks and complements resulting from the analysis of the event report.
This article presents the 2022 version of the criticality safety analysis guide, the LOGIC event database and the links between the guide and the event database.

KEYWORDS

Guide, analysis, french regulations, events, database

1. INTRODUCTION

The previous version of the IRSN criticality safety analysis guide was presented at ICNC 2011 [1]. Then, at ICNC 2015, evolutions of French regulations dealing with criticality safety [2] as well as a new criticality events database called "LOGIC" [3] were presented. This paper presents an update of the IRSN criticality safety analysis guide that was issued in 2022 [4] and its links wih both the French regulations, issued officially after 2015, and with LOGIC database. Finally, we present summary sheets briefly describing events whose failures illustrate issues presented in the IRSN guide (issues to be considered in a criticality safety analysis and corresponding failures). The IRSN guide is currently available in French, but it will be translated into English and made available on the IRSN website.

2. LINK BETWEEN THE IRSN CRITICALITY SAFETY GUIDE AND FRENCH REGULATIONS

Following the work of a “criticality working group” involving The French Nuclear Safety Authority (ASN), the French licensees (AREVA, CEA, EDF, etc.) and the French Technical Safety Organization (IRSN), a ASN resolution [5] came into force on July 1st, 2015, updating the Fundamental Safety Rule I.3.c. This Fundamental Safety Rule I.3.c had come into force in 1984 and had been used to set out the principles for demonstrating nuclear criticality safety in all the French nuclear facilities, excluding reactors. The new resolution objectives aim at clarifying the scope for reactors loading and unloading operations (since criticality safety issues have to be addressed during these operations) and transport packages of fissile material, developping areas not covered in the Fundamental Safety Rule I.3.c and taking into account the lessons learned from past criticality events. The working group has also drafted a nuclear criticality safety guide (ASN guide n° 26), which is still in a validation process and, contrary to the resolution, is not legally binding (see Figure 1 below).

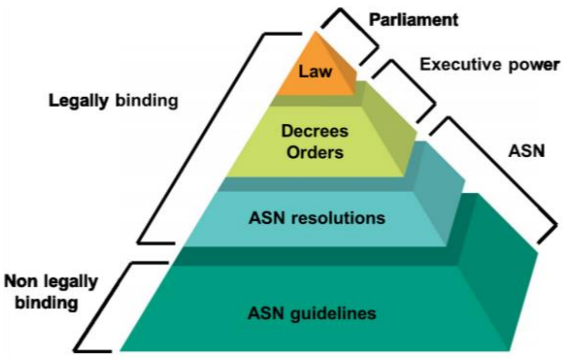

Figure 1. The French regulatory "pyramid"

The ASN resolution adresses the application of the defense in depth principle (prevention, detection and limitation of consequences) to criticality safety, the "double contingency" principle (reminded below), criticality control modes (see section 3), the reference fissile media, the criticality safety organization (in particular the role of the Criticality Engineer), and the acceptable margin to critical conditions (taking into account not only the validation of criticality calculation means as it was the case in the Fundamental Safety Rule I.3.c, but also the margins inherent to the calculated configurations and the sensitivity of k_{eff} to various parameters).

The "double contigency" principle is stated as follows:

- a criticality accident shall in no case result from a single anomaly ;
- if a criticality accident can result from the simultaneous occurrence of two anomalies, it shall then be demonstrated that: the two anomalies are independent ; the probability of occurrence of each of the two anomalies is sufficiently low ; each anomaly is brought to light by means of appropriate and reliable systems, allowing repair or the deployment of compensatory measures within an appropriate time frame".

The ASN resolution deals with civil facilities (INBs). For defense-related facilities (IANIDs), the instruction DSND N°34 [6] was notified by the Defense Nuclear Safety Authority (ASND) on July 24th, 2020. Articles 1 to 4 of this instruction contain elements similar to those of the ASN resolution, applicable to all IANIDs. Article 5 contains elements similar to those of the ASN resolution for organizational aspects (roles of criticality engineers independent of operations and criticality officers among the operating personnel), but is applicable only on IANIDs not under the hierarchical authority of the Ministry of Defense, that is, all IANIDs except for port facilities and Naval Propulsion reactors. The latter are covered by article 6 of the ASND instruction, which has no equivalent in the ASN resolution. This article 6 mentions some specific safety measures, which are:

- the analysis of well-identified situations "beyond the double contingency principle", i.e., resulting from two or more failures and not necessarily respecting the usual admissibility criteria used in other IANIDs in normal and incidental situations ;
- double checks at each stage of loading or unloading a reactor.

The 2022 IRSN criticality safety analysis guide is not binding and provides more details than the ASN resolution and ASND instruction. Most of the diagrams in the IRSN guide appendix address issues related to criticality safety assessment (see sections 3 and 4), but the first four diagrams present principles related to the general approach to criticality risk control, as developed in the ASN resolution and the ASND instruction, and cover the following topics:
- civil nuclear facilities (INBs) or defense facilities (IANIDs) design;
- INBs or IANIDs reactors design for safe loading or unloading operation;
- safety measures in plants and reactors belonging to INBs and IANIDs;
- human organization in some IANID plants or some IANID reactors not under the authority of the Ministry of Defense[1]. This last diagram is presented on Figure 2 below.

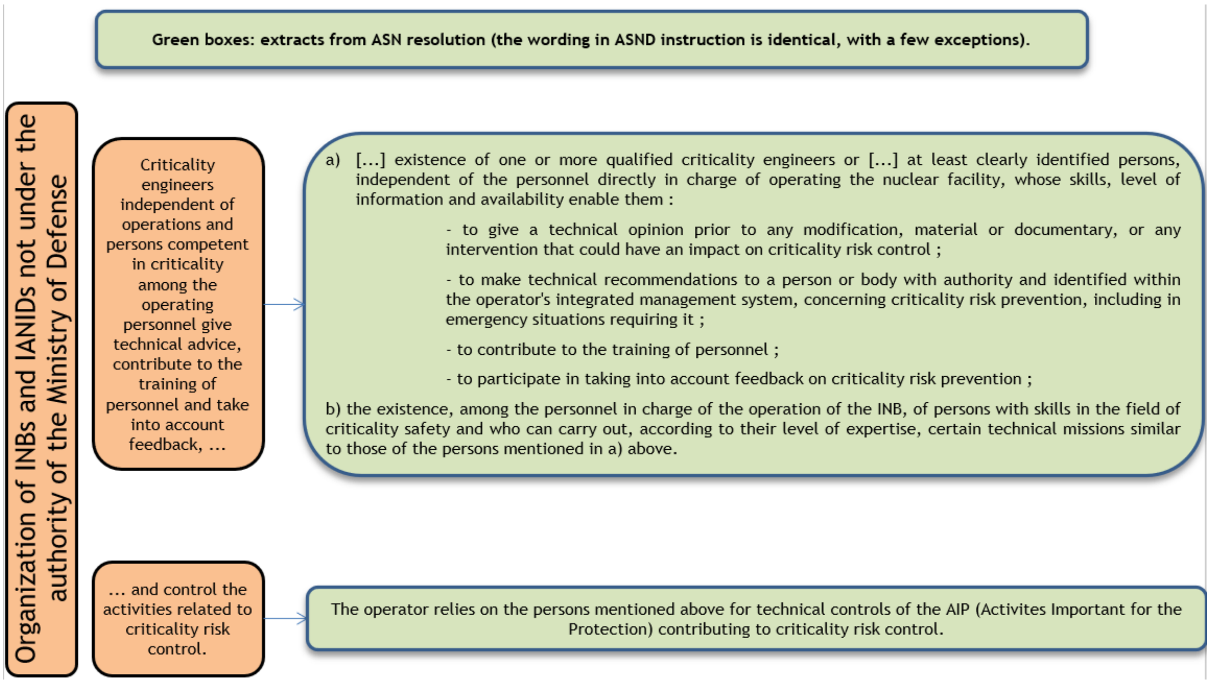

Figure 2. Diagram about the criticality safety organisation in some of the IANIDs

3. ISSUES RELATED TO REFERENCE FISSILE MEDIA AND TO CRITICALITY CONTROL MODES AND PARAMETERS

In France, the phrase "criticality control modes" refers to the main controlled parameters used to ensure subcriticality in non-reactor facilities: mass of fissile material, geometry, fissile concentration in a given homogeneous medium, moderation and homogeneous or heterogeneous neutron poisoning. Other parameters are related to the fissile material (nature of the fissile material and the moderator, isotopic composition, density) and are taken into account by defining a bounding Reference Fissile Medium leading to the most restrictive limits for the chosen control mode(s). Choices of this medium and the control mode are thus strongly linked. Finally, the safe limits of the aforementioned parameters are influenced by neutron reflections (concrete walls, etc.) and interactions (distances between fissile units,

[1] It does not include the organization of IANIDs under the authority of the Ministry of Defense, i.e., port facilities and reactors related to Naval Propulsion, because their organization is currently being developed and must be formalized in an organization note that will be cited in the aforementioned methodological reference guide concerning criticality safety in Naval Propulsion facilities, itself undergoing evaluation at IRSN.

etc.). As they are generic to the control modes, a new diagram showing issues related to neutron reflections and interactions has been added in the 2022 version of the IRSN criticality safety guide, whereas in the 2010 version of the guide, these issues were distributed in the diagrams related to control modes, which led to repetitions (moreover, if, for example, subcriticality is based on two control modes, reflections and interactions influence these two control modes equally).

Also, diagrams of the 2010 guide devoted to Reference Fissile Media and control modes, for non reactor civil facilities, have been updated to take into account the feedback of events that have highlighted failures without corresponding issues in the 2010 diagrams. A part of the diagram devoted to geometry is shown on Figure 3 below.

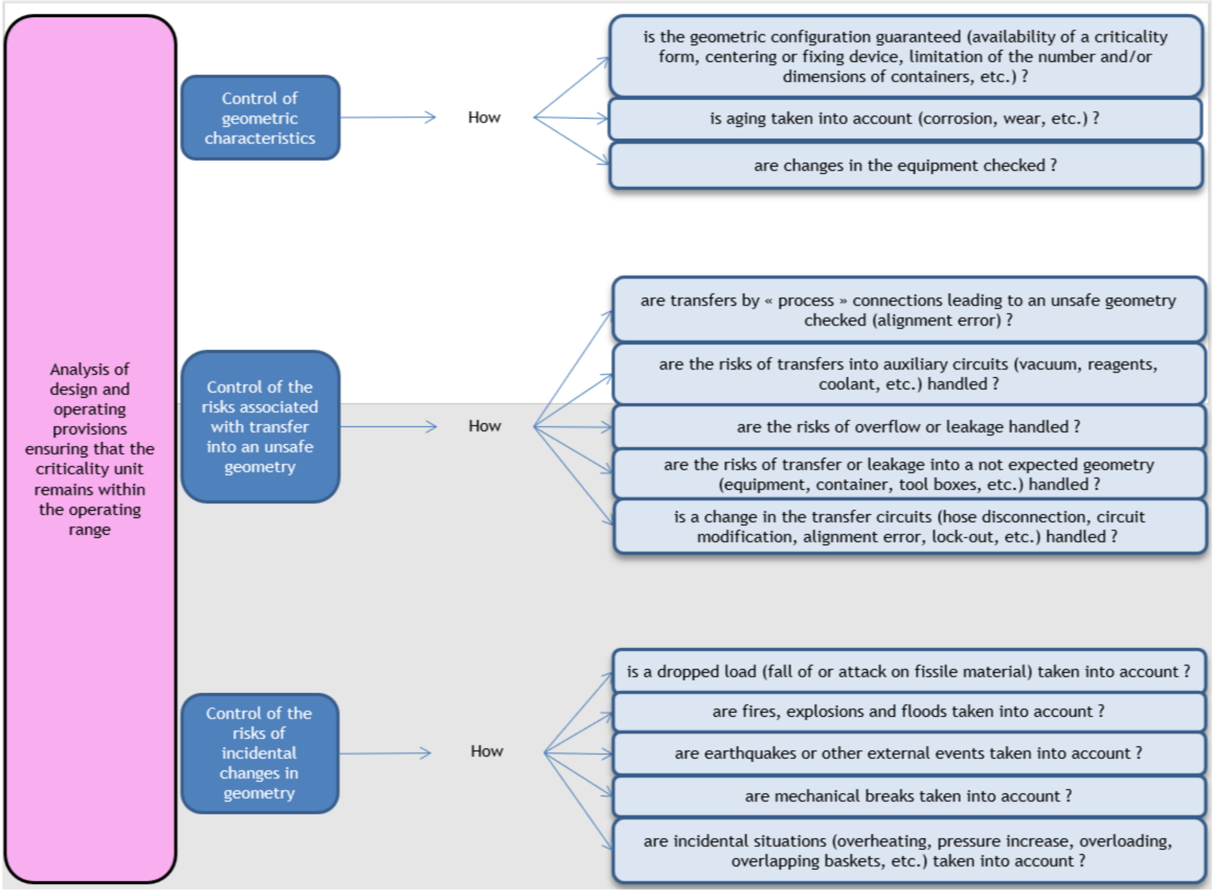

Figure 3. Part of the diagram about the geometry control mode

4. NEW DIAGRAMS SHOWING ISSUES RELATED TO REACTORS, MASS MEASUREMENTS AND CRITICALITY ACCIDENTS

For reactor loading and unloading operations, analysis of criticality safety do not use the so-called "criticality control modes" approach. Nevertheless, reactivity still depends on geometry, moderation (dry or flooded core, nature of the moderator, etc.), homogeneous poisoning (soluble boron), heterogeneous poisoning (absorbent rods for civil reactors, absorbents in fuel element covers and fixed and mobile crosses for naval propulsion reactors, etc.). Also, reactor studies consider fissile media that are realistic, and the notion of Reference Fissile Medium is thus not relevant. In connection with the scope of regulations, which has been extended to reactor loading and unloading operations (see section 2), diagrams devoted to these operations and related issues have been added in the 2022 version of the IRSN criticality safety analysis guide. For the most part (except some issues not relevant for reactors), they derive from their counterparts for non reactor facilities, but the "Reference Fissile Medium" becomes "Fissile Medium" and for example the "control mode including a limitation of geometry" becomes "maintaining subcriticality by a limitation of geometry", and so on for the other control modes, except mass and concentration, which are not relevant for reactors.

The 2022 guide also includes three new diagrams related to criticality accidents (respectively detection and alarm, protection of personnel and population, emergency response and means to stop an accident), and a new diagram related to measurements of fissile material mass (type of measure, calibration, uncertainties, etc). A part of the diagram related to emergency response including the means to stop an accident is show on Figure 4 below.

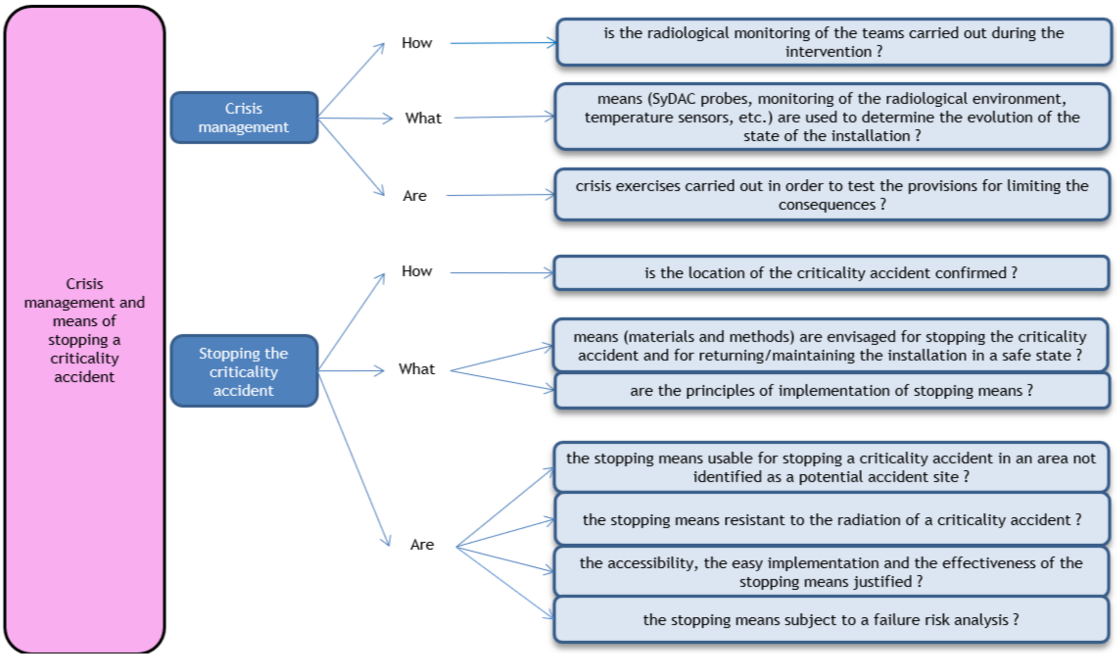

Figure 4. Part of the diagram about emergency response in case of a criticality accident

5. "LOGIC" EVENT DATABASE

Periodic safety reviews (PSR) of nuclear facilities [7] include lessons learned from the events that occcurred during the past period, resulting from human errors, safety organization or technical failures. This specific analysis provides lessons about the operating conditions of the facility and highlights malfunctions that have occurred during operations, maintenance or restart after a shutdown. In addition to the global event database developed by IRSN to gather all the recorded safety events, the so-called "LOGIC" database focuses on criticality safety events, it has been presented at ICNC 2015 [2]. LOGIC database contains about 1000 events and is continuously updated with the declared criticality events from licensees and includes the IRSN analysis. Especially, each criticality event is classified according to one or more types of failures involved. Each type of failure that can be chosen in LOGIC is bijectively linked to an issue described in one of the diagrams of the IRSN criticality safety analysis guide, according to the category of issues involved: criticality control mode (or sometimes multiple control modes) or reference fissile medium for non reactor facilities (nuclear cycle, defense), criticality control parameters or fissile material for reactor loading and unloading operations, neutronic interactions or reflections, or criticality accident categories (detection, protection or means to stop an accident). Moreover, this link between LOGIC and the IRSN criticality safety guide has allowed to identify failures that had no corresponding issues in the diagrams of the 2010 version of the IRSN guide (in particular regarding reference fissile media and control modes in non reactor facilities). Thanks to this feedback from LOGIC database, new features has been including in the new version of the guide. This process enhances safety and is described on Figure 5 below.

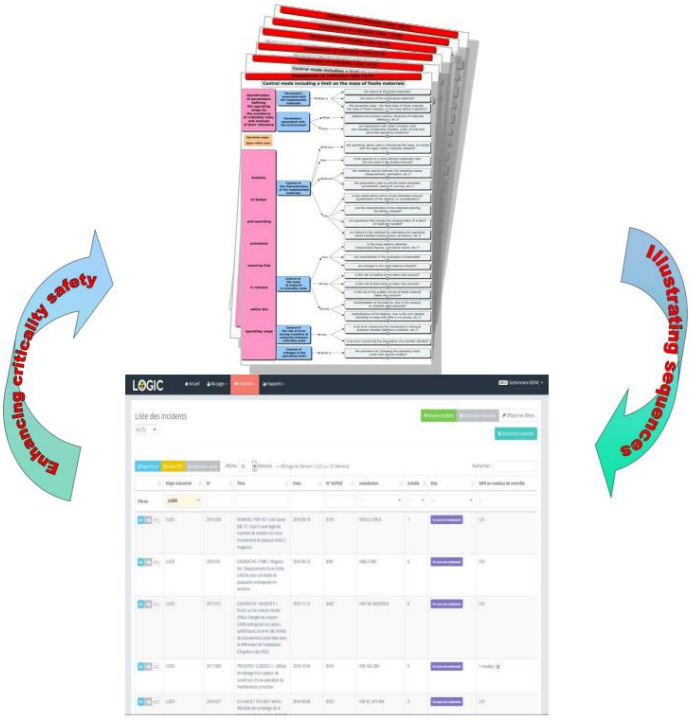

Figure 5. Link between LOGIC database and the IRSN criticality safety guide

LOGIC database will include new types of failures corresponding to the new categories of issues added in the 2022 version of the IRSN criticality safety guide, about reactor loading and unloading operations, neutronic interactions and reflections, and criticality accidents (detection, protection and means to stop an accident). However, only some of the criticality accidents issues of the guide have a corresponding failure in LOGIC. For example, the issue " How are the risks of untimely activation of the criticality detection and alarm system taken into account ?" has a corresponding failure "untimely activation of the criticality detection and alarm system", but the issue "What areas of the facility require monitoring by a criticality detection and alarm system ?" is only relevant for criticality safety analysis and has no corresponding failure in LOGIC. Moreover, the issues in the diagram concerning fissile material mass measurements have no corresponding detailed failures in LOGIC, but can be linked to a more global failure that is "What are the methods used to estimate the operational quantities (measurement, direct or indirect quantification, etc.) ?". The headings in LOGIC database are either fixed-choice menus or free text boxes and the main data provided for each event are shown below:

Table I. Headings in LOGIC database

LOGIC headings	sub-headings	Fixed choice menu or free text box, type of information expected
Document directory	-	Link to a directory containing the documents associated with the incident (declaration, analysis report, follow-up...)
Comments	-	To specify elements not adapted to other headings
General information	Title of the incident	
	Date of detection	
	Operator	Fixed choice menu
	Industrial object	Fixed choice menu: plant (or laboratory), reactor or transport
	Facility	Fixed choice menu (name and number of the facility)
	Near miss	Fixed choice menu (Yes / No / Not Analysed), to identify if the event is a near miss
	INES	Fixed choice menu: number in the International Nuclear Event Scale
	Proposal to add or modify a failure type	Free text box to propose a new failure or a modification of the statement describing an existing failure

General information	Failure previously analyzed	Free text box to indicate if the failure was already considered as an incidental situation in the operator's safety analysis at event's time
	Request addressed to all operators	Free text box to indicate the references of the letters sent by the safety authorities to all operators to ask them to take into account the feedback from the event and to specify the themes of this feedback
	IRSN expert report	References of IRSN expert reports about the event or that mention it (follow-up, periodic safety review, etc.)
	Failure type	Fixed choice menus to choose a failure type (and associated category) corresponding bijectively to a question in a diagram of the criticality analysis guide
	Related event(s)	Fixed choice menu to select other events and free text box to explain their link with the present event (events with strong similarities, or detected during investigations following a first event, etc.)
	Link to an illustrative sheet	See section 6 of the present paper for explanations about summary sheets illustrating questions of the criticality safety analysis guide
Unit(s) concerned	Building - Workshop	Free text box (for example, several criticality units can be concerned if they have received a non-compliant container during its movements)
	Criticality unit(s)	
	Criticality sub-unit(s), container, etc.	
Narrative		Free text box to describe the chronological narrative of the event
Reference Fissile Medium and criticality control mode(s)	Reference Fissile Medium (or Media)	Free text box - If necessary, different Reference Fissile Media under normal or incidental conditions can be described
	Control mode(s)	Free text box to indicate which control mode failed, but also those that did not fail (including secondary modes, i.e., those that are used only in an incidental situation, such as poisoning), with associated limit values, and this for all the units involved in the event
	Means of control used	Free text box to indicate all the control means associated with the failed control mode
	Failed means of control	Free text box to distinguish the control means that have failed
Cause(s) and detection	Cause(s)	Free text box to describe direct or underlying causes
	Description of the failures	Optional free text box to describe a possible complex chain of failures resulting from each other
	Event detection	Free text box to describe detection conditions (alarm, visual observation...)
Consequences	Consequences	Free text box to describe the real and potential safety consequences (potential consequences in case of more unfavorable conditions or aggravating factor)
	Margins compared to a critical configuration	Free text box to describe the numerical values of margins or k_{eff}, in relation to the real and potential consequences.
Corrective actions / feedback		Free text box to describe: - curative actions (acting on event's effect, return to a safe state) ; - corrective actions (acting on event's causes to avoid its recurrence) ; - preventive actions (acting on the probable causes of potential similar events to avoid their occurrence) ; - actions linked to feedback (extended to other facilities concerned by real or potential similar failures). The actions must correspond to the causes of the event.

6. SUMMARY SHEETS OF EVENTS ILLUSTRATING THE ANALYSIS GUIDE

In addition to the contents of the LOGIC database headings, which can be very detailed, the Neutronics and Criticality safety Department at IRSN also produces summary sheets to illustrate the questions listed in the diagrams of the criticality safety analysis guide with events related to the corresponding failures.

Each sheet consists of a single page of text, briefly presenting the chronological narrative, causes, consequences and corrective actions of an event, and a page of illustration (concerned process or other type of illustration). Figures 6 and 7 below show these two pages for an event involving a geometry-related failure that corresponds to one of the issues listed in the geometry-related diagram of the IRSN guide, shown earlier on Figure 3 of this paper.

Criticality control mode	Risk	Typical Sequence
Geometry	risk of incidental modification of geometry	How are incidental situations (overheating, pressure increase, overloading, overlapping baskets, etc) taken into account ?

References

Title of the incident:	Dispersion of about 300 g of plutonium oxide inside a glove box when filling a container
Date of the incident:	September 24, 2008

Description of the incident

At the beginning of the packaging operations of a lot of plutonium oxide, a block from the materials handling was found by the operator, which has continued operations through the "automatic" mode to "slave manual" mode of the controller, till the fill of the twenty-second container. The operator has performed a maintenance operation on the controller, leaving a full container accosted at the filling head of the process.
Once this operation, the operator has activated the remote control "recovery" on the controller, which has had the effect of re-filling the already full container accosted at the filling head (it's at this point that the fissile material has accumulated in the equipment of the glove box). The operator having found the lack of evolution in the weighing of the container, the decision was made to stop the filling operation.
Assuming a defect of the weighing system, the operator has proceeded to the undocking of the container, operation during which the plutonium oxide powder spread on the bottom of the glove box. The operator has immediately proceed to the redocking of the container and, after consulting the criticality Engineer, the powder was recovered with monitoring the glove box.

Cause of the incident

Technical causes:	The level sensor in the filling head has not worked. Moreover, the filling head is not in the general operating rules and is not subject to periodic inspections and tests.
Organizational causes:	The operator was not been attentive after switching the "recovery" mode on the controller and did not change the mass as provided in the set for the twenty-second container. The controller has resumed filling the container ignoring the plutonium oxide already in the container.

Consequences of the incident

Approximately 600 g of plutonium oxide powder were dispersed in the glove box and about 15 kg of plutonium oxide were accumulated in the equipment of the filling process, at the filling head and piping. This configuration was not likely to induce a criticality risk, given the geometry is the criticality control mode of these equipments.
The possible incidental configuration is the spillage in the glove box of the entire mass of plutonium oxide upstream of the filling head. This mass, estimated at 24.5 kg, is much lower than the permissible mass (40.6 kg total reflection with water) for plutonium oxide containing 3% moisture and a density equal to 3.5.

Corrective measures

Preventive:

- Presentation of the event to the entire staff of operators as a feedback
- Change the remote control "recovery" on the controller
- Study to ensure the detection of the filling container, provided by the lead implanted in the filling head
- Reflection about the conditions for achieving the modifications of equipment requiring interruption cycles of the process
- Add the scenario of a dispersion of fissile material in the glove box, in the demonstration of the subcriticality of the filling unit (recommended by IRSN)

Figure 6. Example of a criticality event summary sheet, text part

Illustration

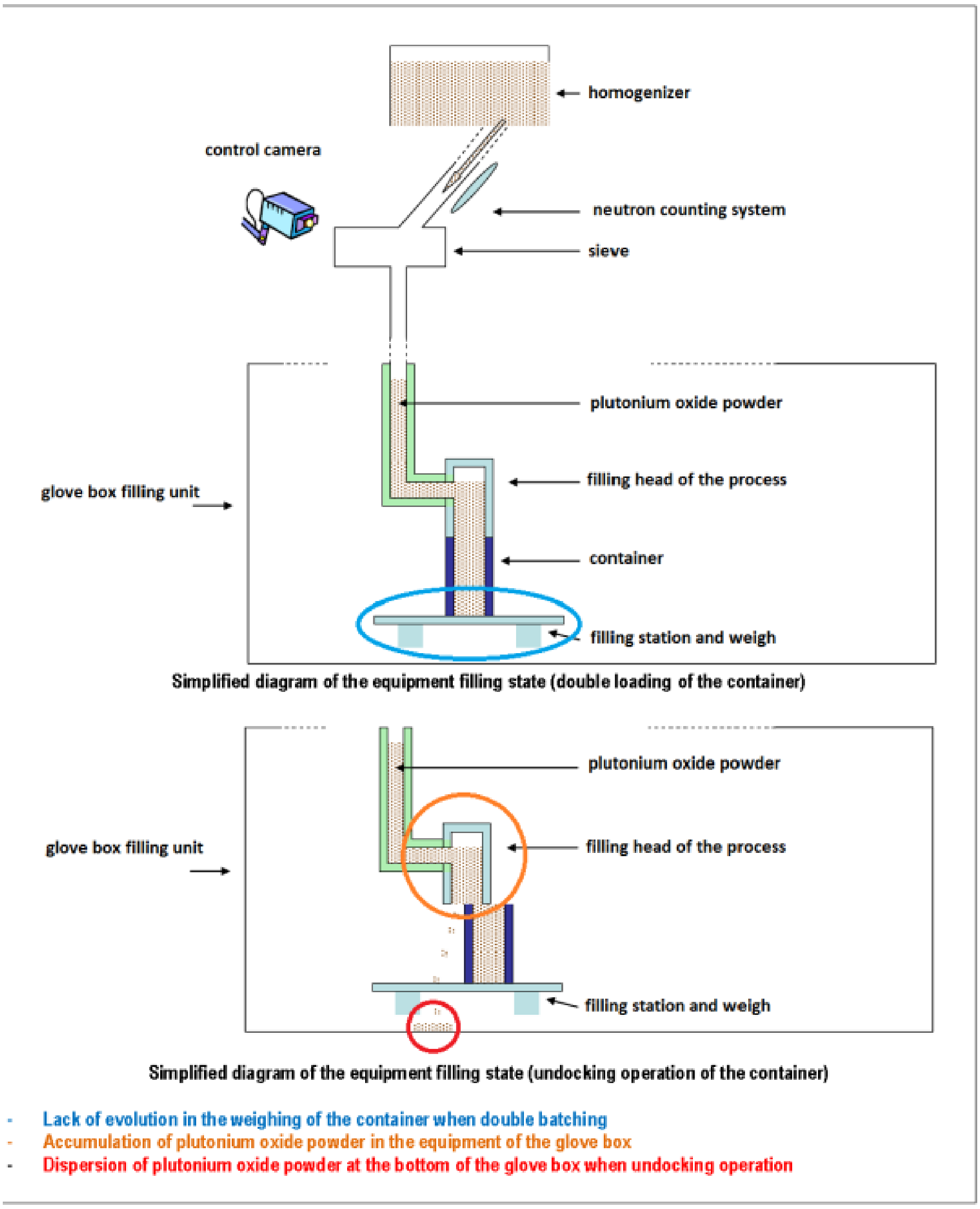

Figure 7. Example of a criticality event summary sheet, illustration part

7. CONCLUSIONS

The IRSN criticality safety analysis guide has been updated in 2022 following the evolutions of French regulations, but also to take into account the feedback of criticality events resulting from failures that had no corresponding questions in the diagrams of the initial version of the guide. In addition, to facilitate the integration of lessons learned to better understand criticality events, with the aim to prevent later occurence of similar events, the new IRSN guide version illustrates the interest of a cross cutting safety analysis linking events database use and systematic safety analysis process.

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