French nuclear facilities criticality safety training approach: reflections and testimonies

Veronique ROUYER\textsuperscript{1}, Igor Le BARS\textsuperscript{1}, Stéphanie PERRIN\textsuperscript{1}, Antoine DEVITA\textsuperscript{2},
Eric GUILLOU\textsuperscript{1}, Eric TORLINI\textsuperscript{4}

\textsuperscript{1} Institute of Protection against radiation and Nuclear Safety, France
veronique.rouyer@irsn.fr, igor.lebars@irsn.fr, stephanie.perrin@irsn.fr

\textsuperscript{2} AREVA NC – MELOX, France
adevita@melox.fr

\textsuperscript{3} AREVA NC La Hague, France
eric.guillou@areva.com

\textsuperscript{4} AREVA NP – FBFC, France
eric.torlini@areva.com

Introduction

Criticality safety is based on two main concepts:

- the safe operating range, as large as possible, defined in the reference safety documents by criticality studies and safety analyses, which take into account normal and abnormal operations and accidental conditions,

- provisions (design, procedures…) guaranteeing that the plant remains in this safe operating range, according to the principle known as “double contingency principle”.

For this last aspect, the personnel are key actors to guarantee safety even if the nuclear process is automated. Indeed, operators, supervisors or managers take part in criticality safety in their daily task, directly or indirectly. In addition, facing with an abnormal event or an equipment failure, these actors play a paramount part and their reactions will have direct consequences on the evolution of the situation. Consequently, the safety criticality training they receive is essential.

The administrative framework in France

In 1984, the French nuclear safety authority published the basic safety rule I.3.c, a fundamental rule applicable to nuclear facilities other than nuclear reactors criticality risks. This Standard, still in force, describes the measures to be taken in order to prevent a criticality accident in nuclear facilities other than nuclear reactors, in which fissile materials are handled. The paragraph devoted to the criticality operators training rules states that “Given the importance of the human factor in the prevention of criticality risks, the operators working on installations which present such risks shall be trained accordingly by a criticality engineer”.

This basic safety rule doesn’t give any details about the training courses objectives and contents. Indeed, they depend on the profile of personnel to train (the responsibilities they have and the context in which they work, especially the impact their work can have on the criticality safety). In addition, the criticality safety in a plant is based on a limited number of criticality control modes (mass, geometry, concentration, moderation or neutron poisoning) and fissile mediums. That often leads to homogeneous constraints on one plant (for example a limited amount of water allowed in nuclear rooms), which is favourable, but also to important differences between plants. The criticality safety training must take into account these specificities and fit each profile of attendees, in order to deliver
the most operational ability. Besides, the objectives have to be defined for each training course according to the specificity of the plant process (manual or automated process for example).

The French rule I.3.c clearly identifies a key actor in the organisation of nuclear criticality safety, especially in nuclear fuel cycle facilities: the criticality safety engineer in a plant (ICC : Ingénieur Criticien de Centre). Every industrial site subjected to criticality risks needs to have a criticality safety engineer specialist to manage criticality prevention training. The ICC, who generally have a first experience in their plant, have attended themselves a specific 6 weeks training provided by a national training organisation.

This paper aims to describe how three experienced AREVA group ICC achieve their training mission, namely ICC from research reactors fuel fabrication plant (CERCA FBFC), from MOX nuclear fuel fabrication plant and from reprocessing plant (AREVA NC). The purpose is not to present the systematic "on the job training" of operators by an experienced one.

**Personnel specificities and topics of the criticality safety training**

In the field of criticality safety, three main categories of personnel could be defined:

- The personnel operating directly on nuclear process (operators, operator leaders, production engineers). They have to follow the procedures, to identify abnormal conditions and to warn their hierarchy.

  The first message of the training is to strictly follow the procedures. But, it is also necessary for personnel to understand the technical reasons for the procedures, their limits of validity and when a particular task impacts criticality safety. This knowledge also may improve the efficiency of feedback loops, particularly to adjust the procedures and the working methods.

  Lastly, the knowledge of the procedures in case of a criticality hazard is essential to mitigate its potential consequences,

- The personnel not operating directly on nuclear process but having responsibilities concerning the plant safety (safety engineers, heads of installation, heads managers…),

  They have to ensure that all operations remain within the safe operating range, defined in safety documents. Moreover, they lead the safety culture and the efficiency of safety feedback loops. They prepare and follow the process modifications and can have to manage abnormal situations,

- The personnel working in the plant but not directly concerned by the nuclear process or criticality safety (maintenance…). They have to follow the different general procedures related to the criticality safety and must know the elementary rules of safety.

The various topics of the training are:

- presentation of the criticality risk, the main principles of nuclear safety and of the criticality safety file
- general information and principles of prevention
  - Concepts of nuclear physics referring to neutronics
  - Parameters contributing to the under criticality of a unit
  - Phenomenology of the accident of criticality
- presentation of the potential causes of a criticality hazard,
- procedures for criticality safety,
- the criticality detection, alarm and measurement system.

**Training in industrial plants**

- AREVA NC/La Hague
The mission of the AREVA NC La Hague plant is to reprocess spent nuclear fuel. This site is mainly composed of two plants (2 x 800 t/year), divided into facilities where the various steps of the process are implemented (dissolution of fuels, clarification of the dissolution solutions, uranium plutonium and fission products extraction, uranium and plutonium purification, conversion and calcination of plutonium, waste conditioning…).

Table 1 summarises the fissile media and criticality control modes of each step of the process:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Fissile medium</th>
<th>Criticality control mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolution</td>
<td>UO$_2$ rod taking into account limited burn up</td>
<td>Geometry</td>
</tr>
<tr>
<td>Clarification Control of the solution</td>
<td>UO$_2$-PuO$_2$</td>
<td>Mass</td>
</tr>
<tr>
<td>Separation</td>
<td>Pu(NO$_3$)$_4$</td>
<td>Mass</td>
</tr>
<tr>
<td>Plutonium Purification ConversionCalcination</td>
<td>Pu(NO$_3$)$_4$</td>
<td>Mass</td>
</tr>
<tr>
<td></td>
<td>PuO$_2$F$_2$</td>
<td>Geometry</td>
</tr>
<tr>
<td></td>
<td>PuO$_2$</td>
<td>Geometry</td>
</tr>
</tbody>
</table>

Table 1

The process is continuous and some capacities are introduced in order to maintain a sufficient hold-up. The production cycle for a treatment campaign (200 t of uranium) can be summarised as follows: creation of a sufficient hold-up to start each unit, start up of the process, its monitoring, draining of the equipments and ending of the process.

A great number of operators lead and supervise the process with centralized control systems. States of each equipment of the unit, of the process parameters and of the alarms are checked on control monitors. The operators are located in the control room, far from nuclear equipments.

Under normal conditions, the process is maintained in the safe operating range by regulation systems. The operators following the process on control screens are able to detect potential upset configurations before the warning thresholds. Most of these configurations are covered by specific procedures (reflex forms) describing the way operators have to react. If the safety analyses conclude that the operators are not able to adjust parameters in case of a quick drift, the monitoring system trips the unit automatically. The procedures concerning criticality safety are gathered in a specific document approved by the ICC. This document is available for operator leaders in the control room.

Among the three categories listed above, two have to attend a specific criticality safety training:

- First category: the personnel operating directly on nuclear process,
- Second category: the personnel not operating directly on nuclear process but having some responsibilities linked with the plant safety.

The first category is trained every 5 years. This “operator - training” lasts approximately 4 hours and is carried out by the ICC. It is planned in such a way that only small groups of operators working in the same facility (5 different trainings) are trained together, in order to have homogeneous set of information. During the training, the criticality safety procedures used are discussed. As far as possible, the potential precursory risk, the limit not to be exceeded, the in-service surveillance and the requested traceability are identified for each procedure. About twenty such training courses are carried out per year. Special training courses can also be organized in case of specific modifications or events.

Training of the second category of personnel is specifically organized in case of new appointment and recruitment. This “in-charge “ criticality safety training, which lasts 2h30, is included in a general safety training course. This training course is devoted to the general plant safety approach independently of the facility.
In addition, some computer-based training (type e-learning) has been developed. These new tools make training more attractive, easy to broadcast and moreover make possible self-training. They have been carried out for the “operator trainings” and for the “in charge trainings”. The “operator training” is specific to each facility. The “in charge training” deals with the whole plant and is a little more theoretical. However, these two tools are built on the same progression way. They complete the classical training and treat more topics and is easy to consult by a largest staff of personnel.

Finally, every 3 years, the personnel working in the plant but not directly concerned by the nuclear process has also a general criticality presentation in the frame of a specific radiological protection training. Indeed, the fissile material is not accessible and removed from the equipments which are insulated before any intervention. In that case, specific procedures are written and the intervention is systematically supervised by an operator.

- AREVA NC/MELOX

The mission of the AREVA NC/MELOX is to manufacture MOX fuel (mixture of uranium and plutonium oxides) for PWR or BWR nuclear power plants (capacity of 145 ton of heavy metal).

The initial fissile material form is plutonium and uranium oxide powders. Then, these powders are mixed and homogenized in order to obtain an homogeneous mixture with the required plutonium content. This mixture is pressed into pellets which are sintered in a furnace. After rectification, they are introduced into claddings. Finally, the fuel rods are put together to form an assembly. Until the fuel rods making-up, all the process is conducted in equipments implemented in glove boxes. The operators lead and supervise the process with a centralized control system. The states of each equipment, of the process driving and of the alarms are checked on control screens. In case of a mechanical breakdown or an upset configuration, the operators intervene in the glove boxes.

The plant is divided into working areas inside which the main criticality control modes are similar (limitation of fissile material mass and of the moderation for example). In these areas, the process is divided in several working units.

The safe operating range is defined in the safety documents, validated by the nuclear safety authority. Inside this range, the normal operating range, which is more restricted, is defined by the criticality operating procedures. Only the persons in charge of safety can authorize other operations within the safe operating range.

The criticality procedures are gathered in a specific document approved by the ICC. This document is available for the operator leaders in the control rooms. Since people have to work in glove boxes, the criticality procedures, using a specific form easy to be distinguished, are also displayed in process rooms.

Thus, two types of personnel have been defined for the criticality safety training:

- the personnel operating directly on nuclear process and workers not directly involved in the nuclear process but likely to enter rooms where fissile material is handled. This personnel has to respect the criticality procedures, especially concerning the limitation of moderation;
- the personnel not directly in contact with the nuclear process but having some responsibilities linked with the plant safety, who can authorized the operations within the safe operating range.

The first category of personnel is trained every 3 years and the second every year. The training lasts approximately 4 hours and is carried out by the ICC. The trainees from all the services concerned by criticality safety are mixed. The training course presents all parameters important for the criticality safety in the plant (fissile medium, plutonium content of the different mixtures,...), the criticality control modes and the criticality hazard independently of the work areas. In addition, short informal tests concerning criticality safety procedures have been developed. They enable a self-testing and
develop the critical acumen. A computer software (type e-learning) is under development and will allow some traceability of the knowledge. Special training courses can also be organized in case of specific modifications or events.

- AREVA NP / CERCA

The CERCA plant, located in "Romans sur Isère", manufactures fuel elements for research nuclear reactors. It is divided into areas corresponding to the different forms of the matter (powders, cores, plates, elements).

Table 2 summarises the fissile medium and the criticality control modes for each area.

<table>
<thead>
<tr>
<th>Area</th>
<th>Fissile medium</th>
<th>Criticality control mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powders</td>
<td>U metal</td>
<td>Mass and Moderation</td>
</tr>
<tr>
<td>Cores</td>
<td>Plates of UAl</td>
<td>Mass</td>
</tr>
<tr>
<td>Plates</td>
<td>U metal</td>
<td>Mass and Moderation</td>
</tr>
<tr>
<td>Elements</td>
<td>Plates of UAl</td>
<td>Mass</td>
</tr>
<tr>
<td>Storages</td>
<td>U metal or plates of UAl</td>
<td>Mass and geometry</td>
</tr>
</tbody>
</table>

Table 2

The batch process is mainly hand-operated. The areas are divided into working units (approximately 200). Two types of working units are defined in the safety documents:
- standard working units in which only one standard batch of matter is handled,
- specific working units in which several standard batches can be handled.

The criticality procedures approved by the ICC are displayed in working units.

Concerning the criticality safety training, two types of personnel have been defined:
- the personnel operating directly on nuclear process and workers not directly involved in the nuclear process but likely to enter rooms where fissile material is handled;
- the personnel not directly in contact with the nuclear process but having some responsibilities linked with the plant safety.

The two criticality safety training courses have the same keystones (presentation of the criticality risk, principles of prevention, criticality control modes, presentation of the precursors likely to lead to a criticality risk, criticality procedures and criticality detection, alarm and measurement system). During these training courses, the Tokai Mura accident (origin, failures, consequences, and management of the accident) is detailed. The trainees from all the services concerned by criticality safety are mixed in order to give them the same sensitivity to the risk. These training courses last approximately 3 hours. The personnel is trained every 2 years. The understanding is tested after each training course.

The engineers and executives applying criticality requirements or in charge of modification documents linked with criticality safety follow an additional training focused on the following items:
- the French regulation,
- the plant safety documents,
- the safety analyses carried out for plant modifications and/or procedures.

These training courses are organized in case of new appointment and recruitment.

Objectives of trainings and reflections
Concerning the training objectives, the main questions the trainers have to answer are “How to build, during the training, the strongest link with the field? How to be sure that the operator will be able to do the best analysis facing an event? How to make the operators aware of the criticality risk when the process operating parameters deviate from the operating range?”.

In a unanimous way for the three plants, the important message for the criticality safety is that the procedures validated by the ICC must be strictly followed. The training aims at developing the knowledge of the personnel operating directly on nuclear process but the purpose is not to urge them to analyse alone an abnormal situation in order to avoid inappropriate actions. They should be able to identify potential upset parameters and warn the right hierarchy level.

The training aims at clarifying the procedures and the links between the procedures and the criticality risk. These links are complex because they are the result of technical studies using a large range of technical domains (neutronic, process…). The understanding of these links becomes more difficult if the process is managed through control monitors, uses centralized monitoring or alarms systems. Indeed, these systems keep the operators far from the process and the operations.

Those are the reasons why the criticality safety training of the personnel having to follow the criticality procedures must be focused on their tasks and the potential consequences of inappropriate actions. Besides, the personnel should be able to clearly identify the range defined by the criticality procedures and to apply the right procedure in the right situation.

Consequently, the training courses should be specific to each plant. The above presentation of three examples of training concepts highlights significant discrepancies concerning "who", "how" and "what" consistent with the main characteristics of the plants:
- AREVA NC La Hague: automated process - centralized systems - no accessibility to the nuclear equipments,
- AREVA NC MELOX: automated process - centralized systems - accessibility to the nuclear equipments,
- AREVA NP CERCA: manual process - accessibility to the nuclear equipments and to the fissile materials.

These points demonstrate that the ICCs should be entrusted with the management and the content of criticality safety training, instead of following a rigid standard. Indeed, beyond their criticality practice, the ICCs have the best overview of the process and of the plant’s organization. Thus, the ICCs can take into account the trainees knowledge and needs. It is also important that the training courses are carried out by the ICCs themselves, so that they answer questions, explain the new or modified procedures, and constantly improve the efficiency of messages. For example, after the Tokai Mura criticality accident, many training courses were reviewed in order to introduce this accident feedback and to answer the associated questions.

Moreover, the ICCs can give, maintain and follow the personnel competences thanks to this training work.

Testimonies’ statement: “The right training for the right man at the right place using the right procedures.”