# Training practices for CEA engineers qualified in criticality safety

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# TRAINING PRACTICES FOR CEA ENGINEERS QUALIFIED IN CRITICALITY SAFETY


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## ABSTRACT

Soon after the Tokai Mura criticality accident, the French nuclear authority addressed nuclear operators to take measures regarding criticality safety. In CEA in particular after a thorough assessment of the late 1990's – early 2000's practices, the decision was taken to put up a training program in criticality safety for young (and "old") nuclear safety specialists.

The evolution of the training practices for the IQC (Ingénieurs Qualifiés en Criticité – Engineers Qualified in Criticality safety) are presented hereafter, beginning with the first training session set up in October 2001 until now. This primarily deals with the kind of audience this training addresses (professional background), what is taught, learned, used later on and how one becomes an IQC. Furthermore, a discussion involves who recognizes the qualification, how long does one need to become a real criticality safety specialist on an operational basis, how the staff uses (or not) the knowledge and how this ensemble contributes to the professional careers advancement (criticality safety is a strong "card").
The methodological documents in support of the IQC are also presented, particularly the last version of the "*criticality guide fiches (files, cards, sheets)*" collection which summarizes the main aspects and principles of criticality safety (including the rudiments of neutron physics, criticality control modes, double contingency principle, etc.).


## 1. INTRODUCTION

The Commissariat à l'Énergie Atomique et aux Énergies Alternatives – usually referred to as the CEA has ten research centers in various regions of France, each one specializing in specific areas of research. These research centers / laboratories are located throughout France in the regions of Paris/Île de France, Rhône-Alpes, Languedoc Roussillon (Rhône Valley), Provence-Alpes-Côte d'Azur, Aquitaine, Central France and Burgundy.

Among them, research on nuclear energy is conducted mainly in 3 centers[1]: at Saclay in the region Paris/Île de France, Marcoule in the Rhône Valley and Cadarache in Provence.

[1] Nuclear research at the Grenoble research center ended in early 2000. Today, all of the nuclear facilities there have

In mid-1999, just a few months before the Tokai Mura criticality accident, the CEA decided to review the organization regarding criticality safety in all of its nuclear facilities in order to improve it. Soon after the Tokai Mura criticality accident in September 1999, the French Nuclear Regulator (today's Autorité de Sûreté Nucléaire – more commonly known as the ASN) requested that nuclear operators take measures regarding criticality safety. In the CEA in particular after a thorough assessment of its own practices, the decision was made to establish a training program in criticality safety for nuclear safety specialists other than the high level criticality safety specialist designated as the “ICC” (Ingénieur Criticien de Centre / Center's Criticality Engineer).

It's important to point out that until 2000, the CEA's criticality safety organization had a very simple model. This high level criticality safety specialist, the ICC was in charge of an entire nuclear center regardless of the number of nuclear facilities within. This criticality "officer" function had been formally established in France in 1984 by the ASN. The ICC had a "criticality correspondent" (i.e. a person who had been made aware of criticality issues arising in his/hers facility) in each nuclear facility.

## 2. CEA ORGANIZATION

As presented at the ICNC in 2003, the CEA's organization [2] is based on an operational line, backed up by support resources and a control line. The organization is specified in a CEA internal instruction from the Nuclear Safety and Protection Division (DPSN) with specific instructions for each CEA center.

Regarding criticality safety and in particular the operational line and support resources, a three "level" organization has now been established as follows since 2000: (from "top" to "bottom"):

1. A central (CEA) Criticality Safety Expertise Group (CSEG) in which criticality specialists perform among their other activities, criticality calculations for each of the nuclear facilities. The members of the CSEG are also in charge of criticality accident issues (until 2014, there was a Criticality Skill Team dedicated to criticality accidents located in Valduc within the experimental facilities such as SILENE, CALIBAN, etc.... However, today with its facilities shutdown and its activities have been transferred to the CSEG).
2. At each CEA center, there is a high level expert – the aforementioned ICC (he has a renewable term of 4 years)
3. At every nuclear facility (Installation Nucléaire de Base - INB[3] / Basic Nuclear Facility) where fissile materials are present, there is a local organization which is managed by a local criticality specialist named, the IQC with a renewable term of 4 years as well.

The control line regarding criticality issues (2$^{nd}$ level control) in each CEA center consists of a safety team including one person with sufficient criticality expertise to be appointed the Criticality Specialist (CS).

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been decommissioned and their dismantling has almost ended.

[2] ICNC 2003 - "The Organization of Criticality Hazard Prevention at the CEA" JAERI-Conference 2003-019

[3] the list is available at www.asn.fr

These lines are implemented at every CEA center having licensed nuclear facilities and where fissile materials are present and criticality safety issues can be met.

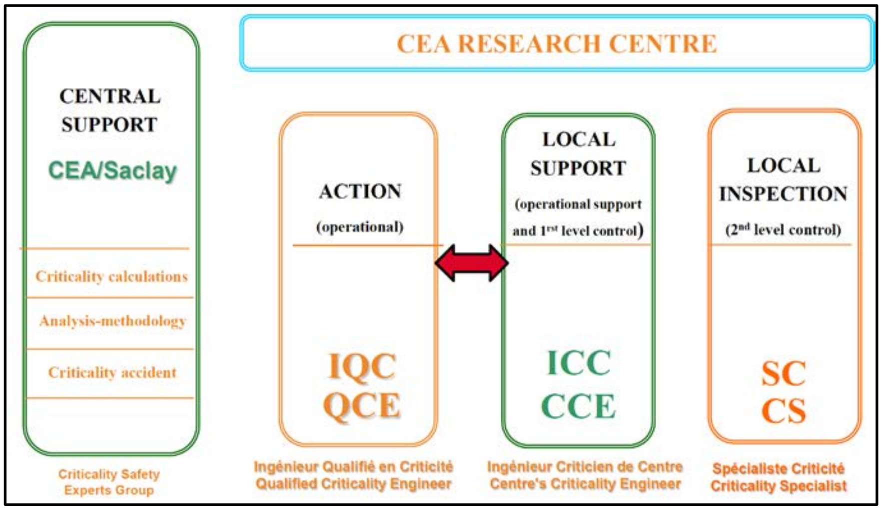


**Figure 1: CEA's organization chart on criticality safety**

## 3. TRAINING FOR THE IQCs', ICCs', SCs'

In order to consolidate this structure, an appropriate training in accordance with the responsibilities of the position is given to the appointees in charge of the operations or the control. Some of these positions require a “qualification agreement”.

### 3.1. Training of the ICCs

On the whole, the ICCs have an overall good professional background in general nuclear safety and in criticality safety if possible. Recruitment is done among the ranks of reactor/neutron physicists, nuclear safety engineers or nuclear chemistry engineers. Sometimes the ICC can be a physicist and former IQC.

Prior to their appointment, they receive an approximate nine-week overall training session which involves theoretical and practical aspects. An ICC applicant must pass a qualifying examination and spend one week as a trainee in a French nuclear facility during which he is required to write an internship report followed by a presentation / oral examination of the report to a committee made up of ICCs and senior French criticality safety experts.

Furthermore, a diploma is issued by the INSTN (training sessions usually take place every two years in France). It is the duty of the director of a CEA research center to request the "qualification" of the ICC for his own specific center and a "qualification agreement" is issued by the Head of the Criticality Safety Experts Group, following the appointment of the candidate by the director of the CEA center as an official ICC.

### 3.2. Training of the IQCs (and the SC's[4])

Training for the IQC's (and SC's[5]) consists of two 1-week sessions. These "*initial training*" sessions are organized by the INSTN (National Institute of Nuclear Sciences and Techniques[6]) at Cadarache.
The first 1-week session is called "CRITICALITY SAFETY" and it consists of:

- Organization of the criticality safety in France (general presentation).
- Physical phenomena and elementary neutron physics necessary to understand criticality accidents.
- Computer codes: input and output data, validation domain and limitations of use followed by the analysis/understanding of a calculation technical report.
- The criticality parameters and critical curves, criticality standards (Maubert guide), guides sheets and other available tools.
- The characteristics of a criticality accident.
- Existing detection means (such as CAAS/Criticality Accident Alarm System).
- Near criticality events and major accidents in plants and laboratories.
- The Tokai Mura criticality accident.
- Radiological consequences of a criticality accident and crisis management.
- The principles of defense in depth and the layout of a safety analysis followed by its application to criticality accidents.
- Elementary safety analysis applied to the transport of fissile material including the criticality study of a transport package, the main transport fissile material regulatory
- Awareness of the criticality risk by the operating personnel.

During the second week session called "CRITICALITY SAFETY ANALYSIS", the IQC's receive:

- "*practical training*" in which they are trained to use criticality reports, technical notes of criticality calculations, procedures, operating practices, etc.
- a quick overview of the regulatory framework governing criticality,
  - dealing with nuclear laws,
  - nuclear regulatory authority decisions,
  - internal CEA recommendations and rules as examples.

At the end of the training session, a certificate of attendance is awarded by the INSTN.

### 3.3. Appointment of the IQCs

The nuclear facility manager in which an IQC is working must submit an application to the ICC for his/her "qualification". This initial qualification at the beginning of a criticality safety "career" is almost always accompanied by obligations and sometimes restrictions. The usual obligation is to stay in close touch with the ICC during the first months after his/her nomination.

[4] the SC's have as a minimum requisite for training the same as that of the IQC's.

[5] sometimes they have had previous ICC training and more thorough experience in criticality safety

[6] more information at http://www-instn.cea.fr/

This time lapse can last from 3 months up to 1 year depending on the professional background of the IQC and his/hers personal involvement with criticality safety more than the minimal one due to professional obligations.

### 3.4. Training of the IQCs: raw statistics and feedback

Since 2001 over 500 scientists / engineers from the entire French nuclear industry have gone through this training process. They can be categorized in 3 sets:

1. scientists / engineers performing general safety analysis/assessment who are unaware of the criticality safety issues and who wish to understand the importance of the risk and who have taken only the "CRITICALITY SAFETY" session courses.
2. scientists / engineers aware of the importance of criticality safety issues due to their professional position and who wish to learn how to go through a criticality safety analysis and who have taken only the "CRITICALITY SAFETY ANALYSIS" session courses.
3. scientists / engineers who have followed both sessions (not necessarily in the order which is presented here even if its recommended at least for CEA employees) and in particular CEA personnel in order to obtain the IQC qualification (compulsory).

The trainees are not required to take an exam. At the end of each session the participants evaluate the course. Data available since 2004 shows that over 80% of the trainees give an appreciation of (+) or (++) and almost 100% answer "***yes***" to the question: "*Do you recommend this training session on criticality safety to others?" (colleagues, fellow workers, etc.).*

Some more recent statistics (software provided) over the last 5 years show that almost 40% of the trainees are CEA employees and –more important – 60% come from other nuclear related companies such as AREVA and various subcontractors with nuclear safety departments.

## 4. GENERAL GUIDES AND DOCUMENTS FOR CRITICALITY ENGINEERS

Criticality engineers (at all levels) have guides which are available everywhere (paper, local servers, intranets). In particular, one finds:

- CEA N – 2051: it's the French criticality standard also known as "the Maubert guide " published in 1976,
- A Guide sheets collection[7]: The guide sheets collection is a set of fact sheets, each dealing with a specific topic of nuclear criticality safety,
- A Guide for Criticality Accident Studies[8]

[7] file collection (ICNC'07 : A guide summarizing the main notions and principles of criticality safety: the criticality guide files collection)

[8] NCSD'05 : Guide in Progress for Criticality Accident Studies

### 4.1. Guide sheets collection

#### 4.1.1. Purpose of the document

The purpose of the criticality guide sheets collection is to summarize in short form the main elements of criticality safety. The document is intended for the local criticality specialists (IQC) to assist them in conducting criticality safety analysis. However, it may also be useful for anyone who wants to learn the basic concepts of criticality safety.

The document was created in 2002 and is now being revised. The first version comprises 27 sheets; the next revision will consist of 22 sheets. The revision process involves the Criticality Safety Experts Group (CSEG) and the ICCs, as high level experts. For the moment, this new version is at its verification stage.

#### 4.1.2. Content of the document

The next revision of the collection contains 22 guide sheets, listed below:

- General principles of criticality
    - Fiche #1: Introduction to criticality
    - Fiche #2: Generals principles for nuclear criticality safety analysis
    - Fiche #3: Bounding fissile medium
    - Fiche #4: Concentration vs H/X parametric curve
    - Fiche #5: Methods of control and Factors Affecting Criticality
    - Fiche #6: Calculation method for criticality safety analysis
- Methods of control of criticality safety (including any one or a combination of the Factors Affecting Criticality)
    - Fiche #7: Criticality control by limitation of the mass of fissile material
    - Fiche #8: Criticality control by limitation of the dimensions or shape of operational equipment
    - Fiche #9: Criticality control by limitation of the concentration of fissile material in solutions
    - Fiche #10: Criticality control by limitation of neutron-moderating material
    - Fiche #11: Criticality control by combination of mass limitation and moderation limitation
    - Fiche #12: Criticality control by combination of two Factors Affecting Criticality (mass + concentration, geometry + concentration, geometry + moderation)
    - Fiche #13: Criticality control by combination of mass limitation and limitation of the dimensions and/or shape of operational equipment
    - Fiche #14: Criticality control by presence of appropriate neutron absorbers
- Fiche #15: Reflection
- Fiche #16: Interaction
- Fiche #17: Actinides
- Fiche #18: Fire hazards and criticality
- Criticality accident
    - Fiche #19: Criticality accident alarm system (CAAS)
    - Fiche #20: Criticality accident scenarios
    - Fiche #21: Description of the Tokai Mura accident
    - Fiche #22: Earthquake

The standard summary of the Fiche "Methods of control of criticality safety control mode" is presented below:

1. Main application areas of this control mode, examples of units and facilities using the method of control
2. Definition of criticality parameters and limits
3. Method to determine the limits of the controlled parameters (calculation …)
4. Description of the normal and potentially abnormal conditions of facility operations or processes that may potentially affect active or passive means for ensuring criticality safety control methods. Examples of criticality safety analysis.

#### 4.1.3. Example of a Guide Fiche

An example of a guide sheet is shown in APPENDIX. It is taken from Fiche #4 (in French): Concentration vs H/X parametric curve

### 4.2. A Guide for Criticality Accident Studies

#### 4.2.1. Purpose of the document

Since 1967, the CEA has assembled a unique body of knowledge and knowhow in the various areas involved in studying the phenomenology of criticality accidents and evaluating their radiological impact (accident dynamics, detection, exposure risk, emergency response, etc.). This was made possible by an ambitious program of experiments conducted in the CRAC and SILENE facilities at the Valduc Criticality Laboratory.

The purpose of the criticality accident study guide being prepared at the CEA is:

- to capitalize on the knowledge acquired to date in this field,
- to make available the data required for criticality accident studies used in elaborating a safety case.

The document is intended for local criticality specialists (IQCs) and high level experts (ICCs).

#### 4.2.2. Content of the document

The guide contains the following sections:

1. Recap of Criticality Risk and General Measures for Preventing it
2. General Considerations on Criticality Accidents and their Phenomenology
   This chapter provides descriptions of criticality excursions and their impact (e.g. overall evolution of a criticality excursion for aqueous fissile media).

3. Current State of the Knowledge Obtained from Experimental Programs and Recorded Accidents
   Experimental results are available in more or less documented form, obtained from the following test facilities:

- in France: CRAC, SILENE, CALIBAN,
- in the US: KEWB, HPRR, GODIVA, SHEBA,
- in Japan: TRACY,
- in the UK: VIPER.

4. Energy Release Estimates and Accident Dynamics Models

This chapter proposes various solutions for evaluating fission yield.

5. Risk of Exposure to Neutron and Gamma Radiation

This chapter supplies the following information for calculating dose estimates:

- Catalogues of dose measurements made in the vicinities of CRAC, SILENE, CALIBAN, HPRR, GODIVA, SHEBA and TRACY critical assemblies, with or without shielding. This experimental data has the advantage of being both realistic and representative;
- Nomograms and/or empirical relationships for estimates made over short or long distances (up to 1 km), to obtain immediate order-of-magnitude data for "typical" media;
- Calculation codes, if the source and its environment are precisely known.

6. Estimation of Radiological Impact

This chapter provides tools to determinate the types and quantities of radionuclides likely to be released in different forms (gas, aerosol, dispersed material), for the purpose of estimating their impact, in terms of exposure, on people and the environment.

7. Criticality Accident Detection and Alarming

This chapter provides guidance related to criticality accident alarm systems (how to identify optimum criticality detector locations, how to identify evacuation routes, how to monitor personal and area doses…).

8. Impact of High Dose Radiation

For didactic purposes, this chapter of the guide provides information on medical problems and symptoms resulting from acute irradiation, according to the extent of exposure.

9. Emergency Preparedness Planning and Response

The guide specifies what provisions to make for emergency preparedness planning and response.

10. Lessons Learned from Accidents Recorded Worldwide

Analysis of criticality accidents recorded worldwide has provided lessons on both the conditions leading to an accident situation and its likely evolution/consequences.

11. Methodology for Criticality Accident Assessment

This chapter proposes a consistent methodology and a set of tools for addressing areas involved in the safety assessment of a hypothetical criticality accident.

## 5. TRAINING PRACTICES – CRITICALITY EXERCISES

Among the training practices, classroom training is the most usual especially when the safety report of a facility changes. A new process implies new RGE/GOR (Règles Générales d'Exploitation/General Operating Rules), new procedures, operational instructions. The IQC is the main player on criticality safety in his facility so when such evolutions occur, the former trainee becomes a trainer for his front line workers/operators. Usually and at least at the beginning of his career as an IQC, he also involves the ICC in the training sessions.

If the nuclear facility is equipped with a CAAS, then periodic alarm tests are performed, the frequency of which is in accordance with the constructor's recommendations. There are also training, exercises and evacuation drills in order to check personnel readiness.

Once a year, the ICC gathers all the IQCs of his center for a one day meeting in order to assess their experience during the past year. In general, specific themes such as technical and regulatory evolutions are always discussed.

## 6. CONCLUSION

The CEA has a strong criticality safety organization in general and in each center in particular (local organization). Regarding the general organization, a homogeneous process of Training, Qualification and Appointment for the different criticality safety functions provides that criticality engineers have the required level of knowledge and skills.

- The CSEG, which is in charge of methodology guides, criticality networks, lessons learned, provides high level information especially about the evolution of the criticality "*état de l'art / state of the art*".
- The ICC is the "*man in the middle*" between the support resources and the control functions (SC) for the entire center. He ensures that the operational resources and control functions are distinctly separated.
- The IQC's receive robust training and they have a complete set of documents available online. They are always supported by the ICC, especially during their first year.

Finally the CEA has an overall criticality safety organization supported by a global training for its criticality safety engineers and a complete set of documents.

**APPENDIX**

**Guide sheet #4 – concentration vs H/X parametric curve (page 2/3)**

## FICHE-GUIDE DE CRITICITE N° 4

LOI DE DILUTION

Projet 2

### Principale loi de dilution théorique : la loi d'addition des volumes

- La loi d'addition des volumes est une loi théorique très fréquemment utilisée
- Principe de la loi d'addition des volumes :

$$V_{tot} = V_{soluté} + V_{solvant}$$

- En conséquence, pour un élément X pur qui se dilue dans de l'eau, la fonction qui relie C(X) à H/X est de la forme :

$$C(X) = \frac{M_X}{\frac{M_X}{\rho_X} + \frac{1}{2} \times \left(\frac{M_{H_2O}}{\rho_{H_2O}}\right) \times \left(\frac{H}{X}\right)}$$

- **Loi « métal-eau »** : elle correspond à un bloc de métal massif qui se désagrègerait et se disperserait de plus en plus dans de l'eau, la concentration en matière fissile variant entre la masse volumique du métal pur et 0. Vis-à-vis du risque de criticité, cette loi conduit aux valeurs des paramètres de criticité les plus faibles (donc présentant les marges de sécurité les plus grandes), aucun autre milieu fissile ne pouvant avoir une concentration ou une densité partielle en matière fissile plus élevée
- **Loi « cristal »** : elle correspond à un bloc d'oxyde, de densité maximale théorique, qui se désagrègerait et se disperserait de plus en plus dans de l'eau, la concentration en matière fissile variant entre la masse volumique de l'oxyde pur et 0
- Cas particulier de la **loi « poudre »** : la loi poudre est identique à la loi « cristal » avec une condition supplémentaire qui est que la concentration est toujours inférieure à la densité apparente de la poudre sèche ($C(X) \leq d_{poudre}$)
  - La partie horizontale de la courbe où $C(X) = d_{poudre}$ est appelée « **palier poudre** »
  - Le point où le palier poudre rencontre la loi cristal est appelé « **troncature** »
- Loi de dilution **« standard » $UO_2F_2$ et $PuO_2F_2$** : c'est une loi qui prend la forme $C(X) = \frac{1}{a + b \times \frac{H}{X}}$ avec a et b variables en fonction de la modération