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## ► To cite this version:

F Barbry, M Laget, M Prigniau. Criticality accident safety analysis: questions and partial answers provided by dedicated experiments conducted on CRAC and SILENE. ICNC 2019 - 11th International Conference on Nuclear Criticality Safety, Sep 2019, Paris, France. cea-04491847

**HAL Id: cea-04491847**

**<https://cea.hal.science/cea-04491847v1>**

Submitted on 6 Mar 2024

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# CRITICALITY ACCIDENT SAFETY ANALYSIS: QUESTIONS AND PARTIAL ANSWERS PROVIDED BY DEDICATED EXPERIMENTS CONDUCTED ON CRAC AND SILENE

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## ABSTRACT

*Many studies and models in different fields concerning criticality accidents have already been carried out in different countries, notably based on experiments carried out in France on the CRAC and SILENE installations [1][2]. However, some of the more sensitive issues in safety analysis, such as the triggering of the criticality alarm and the management of the post-accident phase, are difficult to address.*

*These questions are part of what could be called the "Criticality Accident Problem". Specific experiments described below have been conducted on SILENE to help provide information on the post-accident phase that would be encountered following the triggering of the criticality alarm in order to be better equipped to manage any urgent actions to be managed.*

## KEY WORDS

*Criticality accidents, emergency response, SILENE*

## 1. THE CRITICALITY ACCIDENT PROBLEM: INTEREST OF QUESTIONS TO ASK AND OF PROVISIONS TO ANTICIPATE

The development of a hypothetical criticality accident scenario is a paradoxical task, given that the objective of the criticality risk prevention approach is precisely to make the probability of such an eventuality as low as possible. There is therefore a major difficulty in defining an accident scenario, the choice of which is nevertheless decisive in estimating its potential consequences.

Moreover, if such an accident were to occur, its cause would probably lie in malfunctions that would have been missed by the safety analysis. This accident would probably occur somewhere it was not anticipated, hence many uncertainties on the studies and calculations to produce in various fields: neutronics, dosimetry, radiation protection, atmospheric releases...

Not denying the interest of preventive studies, one major and fundamental concern should be to anticipate questions and difficulties to be expected in accidental conditions, such as:

- Would it be possible to detect the accident, to monitor it, to locate it?
- Which minimal accident of concern (MAC) should be considered?
- Is it conceivable to stop the accidental process through an intervention, in order to return it to a subcritical state?
- How high a radiation dose would be received by the team, in the eventuality of a reentry due to an extreme necessity, during this unpredictable "post-accidental" phase?

The following sections describe how selected SILENE experiments, for some previously unpublished, could provide partial answers to these questions.

## 2. DEMONSTRATION OF THE CRITICALITY ALARM TRIGGERING

Current relevant standards (ANSI 8.3 and ISO 7753) provide a minimal framework, but they are not fully satisfying and are complex to implement. How to, indeed, define a MAC satisfying the requirements of these standards, from a hypothetical criticality accident scenario, and then deduce from this MAC that the detectors will trigger the alarm as expected?

Low reactivity experiments (between  $3\phi$  and  $1\phi$ ) performed on CRAC and SILENE [3][4] would allow to define a MAC – not on the basis of a hard to define hypothetical scenario, but on the basis of a total number of fissions produced in a given time. Proposals have already been made to this effect [5].

## 3. LONG DURATION EXPERIMENTS AND RADIATION DOSES ESTIMATES

There exists only a few experimental results regarding the measurement of radiation doses around the fissile solution for long durations (several hours), during both the over-critical phase – which generally does not spontaneously end without intervention – and the subcritical phase – during which a residual radiation is emitted. This information is, however, capital to obtain a first estimate of the order of magnitude of the radiation doses associated with each of these phases, but also for the qualification of calculation codes.

SILENE experiments have been performed for such long durations [6] with various goals; they are presented in the following sub-sections.

### 2-2 Absence of spontaneous stop of the excursion

Some of the selected experiments aimed at demonstrating that in the general case the excursion - the over-critical phase of the accident – does not spontaneously stop if no internal or external mean is used to bring the system to a subcritical state. Such an experiment is illustrated in Figure 1 below.

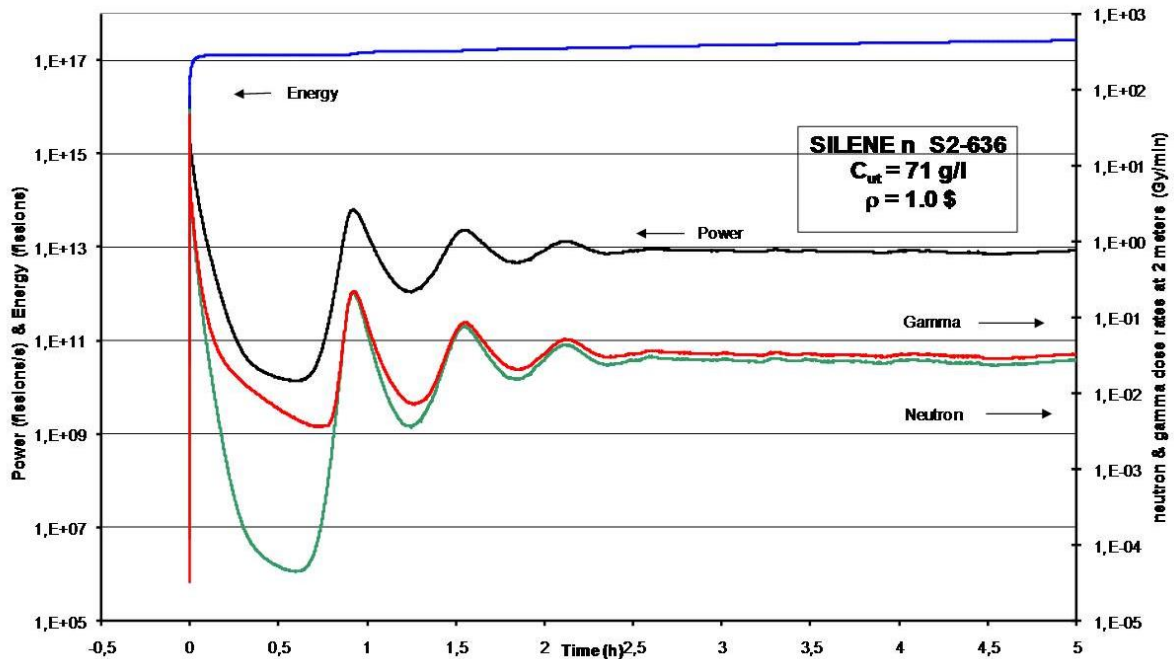
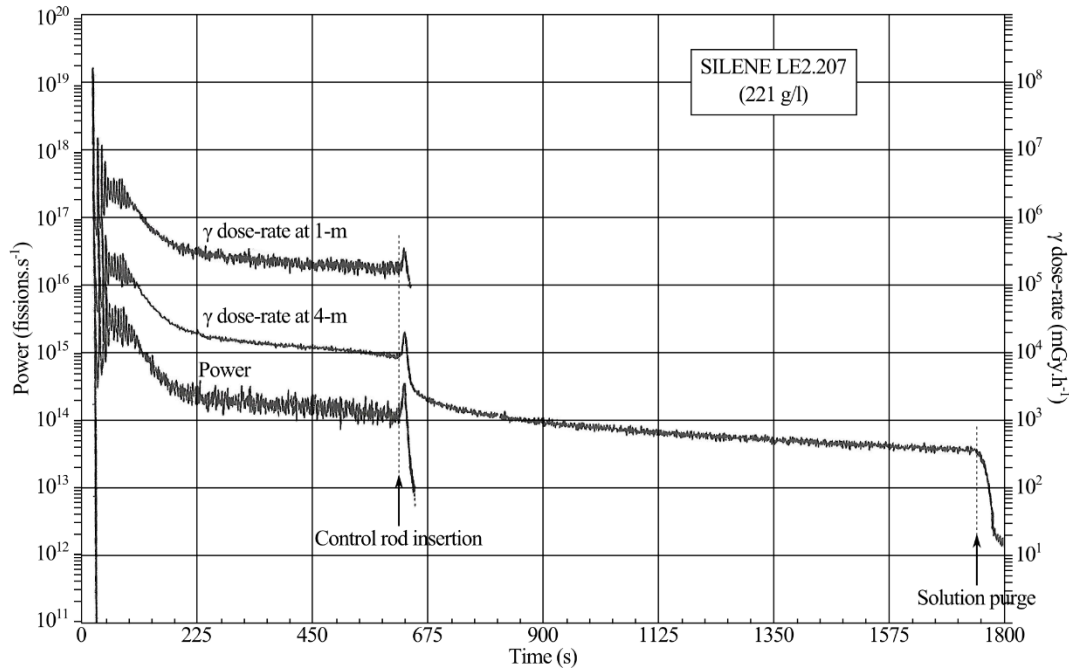


Figure 1 - SILENE S2-636 – long duration experiment.

2-3 Radiation dose-rates due to fission products

During some of the selected experiments, the dose-rate due to the residual activity of the fissile solution, as well as due to the gaseous fission products, confined in a vessel built to this effect [7], were measured. These measurements took place not only during the over-critical phase, but also after, during the post-accidental, sub-critical phase, obtained by the insertion of a control rod in SILENE. Such an experiment is illustrated by figure 2 below.

This kind of information is decisive in the planning of an absolute emergency reentry, in order to be able to assess the potential dose-rates at which a rescue team could be exposed.



**Figure 2 - SILENE experiment with control rod insertion for dose rates measurements during the subcritical post-accidental phase.**

Numerical results synthetizing several experiments with fission products dose-rates measurements are presented in table I below.

**Table I. Numerical results for a selection of SILENE experiments with control rod insertion for dose rates measurements during the subcritical post-accidental phase.**

SILENE experiment	Concentration (gU/l)	Volume (l)	Time over criticality (min)	Reactivity (β)	Total number of fissions	γ dose-rates at 4-m from the core center (sub-critical phase) - Normalized to 10 <sup>18</sup> fissions - mGy/h			
						11 min	30 min	1h	2h
D1-208	221	22.7	6	0.4	3.50E+16	3.71E+03	1.03E+03	4.29E+02	-
S1-208	221	25.1	9	4.1	3.50E+17	3.71E+03	1.00E+03	-	-
LE2-207	222	25.1	10	4.1	3.80E+17	-	1.00E+03	-	-
S2-258	71	38.6	7	1.31	1.50E+17	2.80E+03	1.00E+03	4.00E+02	1.67E+02
S4-259	71	40.5	7	2.86	2.90E+17	3.10E+03	1.03E+03	4.48E+02	1.83E+02
<b>Average over experiments</b>						<b>3.33E+03</b>	<b>1.01E+03</b>	<b>4.26E+02</b>	<b>1.75E+02</b>

For each instant considered, the dose-rates recorded are remarkably homogeneous once normalized to  $10^{18}$  fissions. The last line of table I presents the dose-rates values averaged for the selected experiments.

Those results were obtained in representative experimental conditions, since the fissile solution volumes were small (between 22 and 40 l), for uranium concentrations between 221 and 70 gU/l, and for a wide range of inserted reactivity, between 0.4 and 4 \$ (for this last value, the solution boiled).

#### 2-4 Simulate the conditions of an emergency response [8]

During such an experiment, the SILENE reactor simulated an accidental criticality excursion. A mobile cart was programmed to move from a 10-m distance from the core center to a 1-m distance, simulating the intervention of a team. This cart was equipped with a phantom (a dummy built in a biological tissue simulating material) on which a number of dosimeters and radiation-sensing equipment were arranged.

Three round-trips from 10-m to 1-m of the reactor center, at a speed of  $1 \text{ m}\cdot\text{s}^{-1}$ , were performed at times 6, 14 and 19 minutes from the beginning of the excursion – it can be considered that the beginning of the excursion would correspond to the criticality alarm triggering, or to the first power peak, of a criticality accident.

The processing of the dosimetric devices placed on the cart then allowed obtaining an estimate of the integrated dose, as well as the neutron and gamma dose-rates, during the post-accidental phase. An example of experimental results is presented in figure 3 below. Corresponding numerical values are presented in table II.



**Figure 3 – Dose-rates measurements of the “intervention simulation” SILENE experiment**

**Table II. Numerical doses and dose-rates values obtained for the “intervention simulation” SILENE experiment.**

	Dose-rate at 1 m from the reactor core (Gy.h <sup>-1</sup> )		Integrated dose-rate during a round-trip (Gy)	
	Neutrons	Gammas	Neutrons	Gammas
1 <sup>st</sup> intervention (t = 6 minutes)	4.5 10 <sup>1</sup>	1.2 10 <sup>2</sup>	3.2 10 <sup>-2</sup>	6.7 10 <sup>-2</sup>
2 <sup>nd</sup> intervention (t = 14 minutes)	5.2 10 <sup>1</sup>	1.1 10 <sup>2</sup>	3.8 10 <sup>-2</sup>	6.3 10 <sup>-2</sup>
3 <sup>rd</sup> intervention (t = 19 minutes)	4.5 10 <sup>1</sup>	9.0 10 <sup>1</sup>	3.1 10 <sup>-2</sup>	5.2 10 <sup>-2</sup>

Neutron dose	< 4.10 <sup>-2</sup> Gy
Gamma dose	< 7.10 <sup>-2</sup> Gy

Results of these experiments, carried out on SILENE in the conditions described above, let foresee that an intervention in case of absolute necessity may not be totally excluded.

#### 4. CONCLUSION

Even if radiological consequences outside the facility of a criticality accident are very limited compared to those of a reactor accident, media impact would probably be out of proportions to the real hazard, and thus detrimental to the whole nuclear energy industry.

Results of experimental programs carried out in France on CRAC and SILENE would have contributed to a better understanding of criticality accidents phenomenology, as well as of the related risks assessments necessary to limit such accidents consequences for workers, populations, and environment.

As for the SILENE results presented in this communication, they are unique and very representative of realistic situations; their processing contributes to provide some partial answers to the sensitive issues related to the detection of a criticality accident, but also to the radiation risks associated to any emergency response in accidental or post-accidental phase, being it critical or sub-critical, in the context of crisis management, with external pressures of all kinds.

#### ACKNOWLEDGEMENTS

We wish to thank our colleagues from the IRSN/BERAC (*Bureau d'Évaluation des Risques de Criticité et des Accidents de Criticité*/Criticality Risks and Accidents Assessment Section), as well as the IRSN/CRIS (*Centre de Ressources en Information Scientifique*/Scientific Information Resource Centre), for their help in the completion of this review.

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