



HAL
open science

Criticality accident dosimetry at CEA facilities use of snac2 type neutron zone spectrometer

P. Casoli, E. Gagnier, M. Laget, L. Lebaron-Jacobs

► To cite this version:

P. Casoli, E. Gagnier, M. Laget, L. Lebaron-Jacobs. Criticality accident dosimetry at CEA facilities use of snac2 type neutron zone spectrometer. ANS NCSD 2017 Nuclear Criticality Safety Division Topical Meeting, Sep 2017, Carlsbad, United States. cea-02417317

HAL Id: cea-02417317

<https://cea.hal.science/cea-02417317>

Submitted on 18 Dec 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

DE LA RECHERCHE À L'INDUSTRIE



www.cea.fr

CRITICALITY ACCIDENT DOSIMETRY AT CEA FACILITIES: USE OF SNAC2 TYPE NEUTRON ZONE SPECTROMETER

PIERRE CASOLI, EMMANUEL GAGNIER, MICHAEL LAGET,

DEN, SERMA, CP2C
CEA, PARIS-SACLAY CENTER

LAURENCE LEBARON-JACOBS

DRF, D3P, POSITON
CEA, CADARACHE CENTER

ANS NCSD | 2017 NUCLEAR CRITICALITY SAFETY DIVISION
TOPICAL MEETING | CARLSBAD (NM, USA)

TUESDAY, SEPTEMBER 12, 2017

CP2C: CEA CRITICALITY SAFETY EXPERT GROUP

- **CP2C** is a CEA-unified **Criticality Safety Experts Group** which:
 - performs **criticality calculations** and **criticality-related methodology analysis** for CEA nuclear facilities;
 - and is in charge of **any issue regarding criticality accident**.

- **4 CP2C talks at NCS D 2017:**
 - “Evaluation of SCALE 6.1.2 Tsunami Module for Selection of Representative Benchmarks for Validation of Criticality Safety Studies”, D. Noyelles, E. Gagnier
 - “Criticality Accident Intervention: a Slide-Rule for Dose Estimation”, M. Laget, E. Gagnier
 - “Study of the Possibility of Having Means of Stopping a Hypothetic Criticality Accident in Orphee Reactor Transfer Canal”, D. Noyelles, E. Gagnier
 - “Criticality Accident Dosimetry at CEA Facilities: Use of SNAC2 Type Neutron Zone Spectrometer”, P. Casoli, E. Gagnier, M. Laget, L. Lebaron-Jacobs (CEA/DRF)

- **CP2C is a part of CEA SERMA unit**, which is in charge of **reactors and applied math studies**. See the following NCS D 2017 talk:
 - “Results of TRIPOLI-4 Version 10 on TRIPOLI Criticality Validation Suite, Thermal Spectra”, J.-C. Trama, F. Malouch

- I. Introduction: Criticality Accident Dosimetry**
- II. Criticality Accident Dosimetry in CEA Facilities**
 - I. Dosimetry System Currently Used at CEA**
 - II. SNAC2 Neutron Spectrometer Composition**
 - III. Neutron Spectrum Rebuilding**
 - IV. SNAC2 Use and Exploitation**
- III. System Evolution Possibilities**
 - I. Drawbacks of a Zone Spectrometer**
 - II. New System with One or Several Personal Spectrometers**
 - III. Difficulties Linked to the Use of Personal Spectrometers**
- IV. Conclusion**

I. INTRODUCTION: CRITICALITY ACCIDENT DOSIMETRY

- **Criticality accidents** are induced by **uncontrolled chain reaction initiations**.
- Such a chain reaction produces potential **intense neutron and gamma ray emissions**.
- The **risk of exposure** for people present near the accident location **has to be assessed and limited**.
- Therefore the **dose received** by the involved people **has to be evaluated**:

Firstly, **as early as possible**, so that:

- the people can be **sorted**,
- the victims can be **identified**,
- and a medical action plan can be **organized**;

Secondly, **as accurately as possible**:

- to define **medical treatments**,
- to **record doses**,
- and to **document** the accident.

Several dosimetry technics can be used, **potentially simultaneously**, to estimate the doses.

- **The clinical dosimetry** is the observation of **symptoms** and provides a **preliminary estimation** of the dose.
- **Biological dosimetry** technics can give **additional information** about the level and the heterogeneity of the dose:
 - the **activation of body elements**, such as **sodium 23 in the blood**, or **sulfur 32 in the hairs and the nails**;
 - the evolution of **biological parameters**, such as **blood count**, **chromosome analyses** or **electroencephalograms**.
- **Physical dosimetry** technics can be used to **improve dose evaluations**:
 - **activation** reactions;
 - use of **diodes**;
 - **thermo-luminescence**;
 - **free radical** measurements.

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: DOSIMETRY SYSTEM CURRENTLY USED AT CEA (1/2)

- To carry out the dosimetry in **facilities where a criticality accident** can occur, the **teams in charge of operational dosimetry for CEA** (French Alternative Energy and Atomic Energy Commission) use a **dosimetry system composed of three types of devices:**

Criticality Belts:

Giving information about the **orientation of victims** in relation to the direction of the incident neutron flux

Neutron Zone Spectrometers:

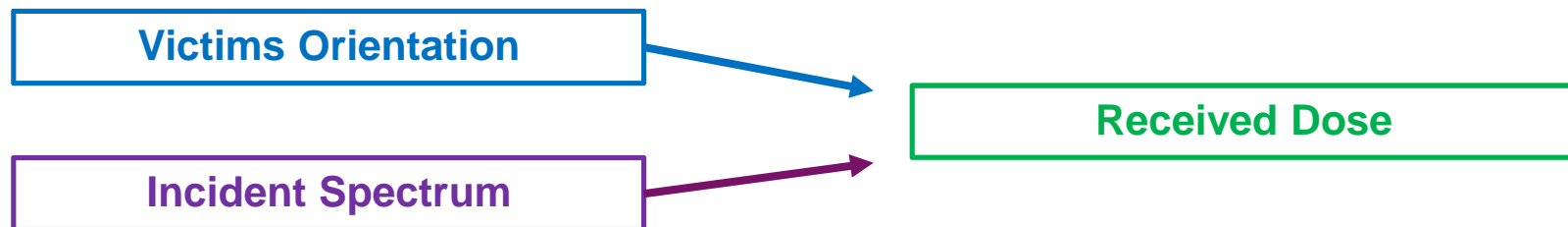
Providing information about the **incident neutron spectrum** at fixed points of the facility

Personal Dosimeters:

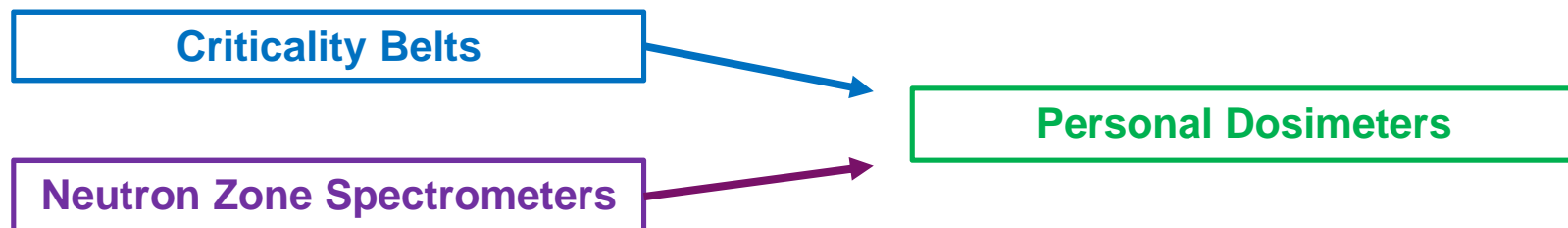
Assessing **neutron and gamma doses** received by people

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: DOSIMETRY SYSTEM CURRENTLY USED AT CEA (2/2)

- The **dose** received by the involved people **depends at the same time**
 - on the **orientation of the body** in the neutron flux,
 - and on **the spectrum** of the incident neutrons.



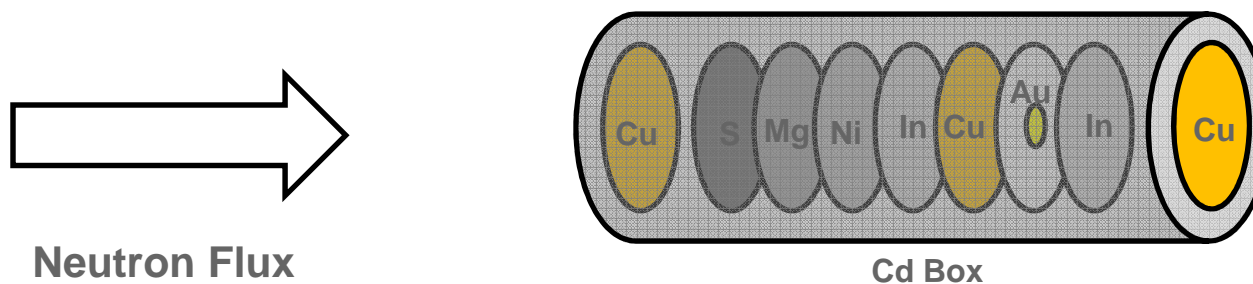
- Therefore **each of the three devices of the system is essential** so that a correct evaluation of the dose can be obtained.



- In particular, the **characterization of the neutron spectrum** is needed to perform simulation calculations **to estimate the doses received by the organs** of the exposed people.

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: SNAC2 NEUTRON SPECTROMETER COMPOSITION (1/2)

- CEA currently uses a device named “**SNAC2**” as a **neutron zone spectrometer**.
- It means “**Spectromètre Neutron par Activation et Comptage**”, i.e. “**Spectrometer for neutron by activation and counting**”.
- This spectrometer is made of a **pile of foils** of various materials which can **be activated by exposures to neutron fluxes**.
- The foils of the SNAC2 are made of the following materials:
 - in a **cadmium box**: **ebonite** (sulfur), **magnesium**, **nickel**, **indium**, **copper** and **gold**;
 - **in front** of the cadmium box, **and behind** the cadmium box: **copper**.



II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: SNAC2 NEUTRON SPECTROMETER COMPOSITION (2/2)

- **Dimensions** and **masses** of the foils used in SNAC2 spectrometers :

Material	Diameter (mm)	Thickness (mm)	Mass (g)
Ebonite	22	3	1.5
Magnesium	22	10	6.6
Nickel	22	3	10
Indium	22	1	2.8
Copper	22	0.5	1.7
Gold	4.5	0.005	0.015

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: NEUTRON SPECTRUM REBUILDING (1/3)

- The **activation reactions** on the foils elements provide **information** on different parts of the incident neutron spectrum, and allow to **rebuild the spectrum** following **three components**.
- For $E < 0,5 \text{ eV}$ (where E is the incident neutron energy), a Maxwell thermal component:

$$\phi_M(E) = \phi_M \times \frac{E}{E_0} \times e^{-\frac{E}{E_0}}$$

- with E in eV
- where E_0 , the **most probable energy** of the Maxwell spectrum, is fixed to 0,025eV
- and ϕ_M , the **Maxwell fluence**, is fixed from copper foil measurements

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: NEUTRON SPECTRUM REBUILDING (2/3)

■ For 0,1 eV < E < 100 keV, an intermediate component:

$$\Phi_K(E) = K \times \frac{E^b}{E} \times \left(1 - e^{-\frac{E^2}{E_c^2}}\right) \times e^{-\frac{E}{E_d}}$$

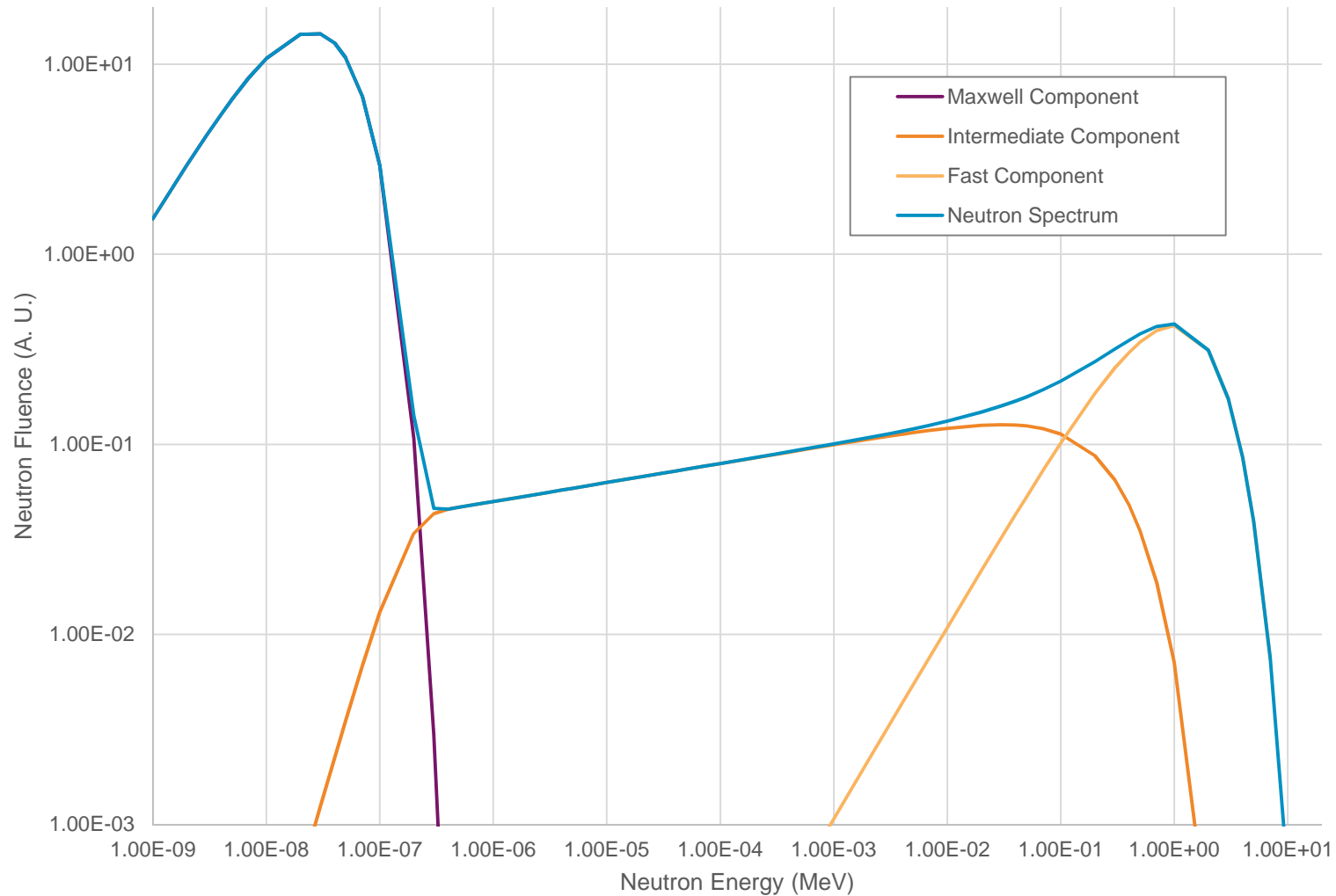
- with E in eV
- where E_c^2 and E_d coefficients are respectively fixed to **0,025 eV²** and **3x10⁵ eV**
- and **b and K** coefficients are fixed from gold and copper under cadmium foil measurements

■ For E > 100 keV, a fast component:

$$\Phi_R(E) = 10^{-6} \times C \times E^{\alpha\gamma} \times e^{-\beta E}$$

- with E in eV
- where **C, α, γ** and **β** coefficients are fixed from indium, nickel and magnesium foils measurements

II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: NEUTRON SPECTRUM REBUILDING (3/3)



II. CRITICALITY ACCIDENT DOSIMETRY IN CEA FACILITIES: SNAC2 USE AND EXPLOITATION

- **Several hundred of SNAC2** spectrometers are currently used in **CEA facilities** where there is a risk of criticality accident.

- When a criticality accident occurs **radiation protection units** of **each facility** have to:
 - **measure the foil activation**;
 - and to **interpret the results**;
 - in order to **characterize the neutron spectrum**.

- This neutron spectrum can be exploited:
 - on one hand, to **estimate conversion coefficients** needed to interpret the biological dosimetry, and especially the measurements of **the activation of the sodium in the blood**, which can provide an estimation of the **whole body dose**;
 - on the other hand, together with **criticality belt** and **personal dosimeter** measurements, to estimate the **organ doses** and dose **heterogeneity** using a **numerical rebuilding** of the irradiation.

III. SYSTEM EVOLUTION POSSIBILITIES: DRAWBACKS OF A ZONE SPECTROMETER (1/2)

- A **study** is currently **under progress at CEA** to analyze the opportunity to change our criticality accident dosimetry system, and particularly the SNAC2 spectrometer, into a **new system** which could even better **fulfill the needs of the medical staff** in charge of the treatment of the victims, providing **more information about the neutron spectrum**, allowing a **new dose evaluation** with a more **accurate resolution** in energy and a more accurate spatial resolution.
- The SNAC2 device is a **zone spectrometer**: in case of criticality accident, the people in the facility should **catch the spectrometers** and **take them with them during the evacuation** so that the foils can be rapidly measured.
- A **rapid measurement** of the foils is decisive:
 - on one hand because **the half-life of some activation products is short** : a few hours only;
 - on the other hand because the medical staff needs an **estimation of the doses** received by the exposed people **as soon as possible**, to be able to make a diagnosis and if needed to define a treatment for the victims.

III. SYSTEM EVOLUTION POSSIBILITIES: DRAWBACKS OF A ZONE SPECTROMETER (2/2)

- However, **taking zone spectrometers** during an evacuation can be **difficult** because the priority is **to evacuate the facility as quickly as possible**.
- The spectrometer should be **placed at appropriate locations**:
 - they should allow to rebuild **a neutron spectrum typical of the spectrum received** by a person at his working place;
 - they should also, if possible, be **close to evacuation paths**, so that it is easier to take them during the evacuation.
- Unfortunately **such a compromise is not always possible**, and there is a significant probability that the spectrometer cannot be taken soon enough, or that it is not located at the best place to be correctly interpreted.

III. SYSTEM EVOLUTION POSSIBILITIES: NEW SYSTEM WITH ONE OR SEVERAL PERSONAL SPECTROMETERS

- To avoid the drawbacks of the zone spectrometer, the use of a **personal spectrometer** worn by people working in the facility can be considered.

- With such a spectrometer:
 - **the real neutron spectrum received by the exposed people is characterized;**

 - **there is no difficulty to collect the spectrometer during the evacuation.**

- Another possibility could be that people wear **several personal spectrometers** placed **at appropriate locations on their clothes**, to **take into account the incident neutron flux direction**.

III. SYSTEM EVOLUTION POSSIBILITIES: DIFFICULTIES LINKED TO THE USE OF PERSONAL SPECTROMETERS

- Nevertheless, such systems with one or several personnel dosimeters could have **drawbacks** too.
- One of them is the **albedo effect of the body**, which has to be taken into account during the interpretation of the foil measurements.
- Another problem would be the **high number of foils** that have to be measured:
 - activation **measurements** can be **long** and the **number of measurement devices** available in each facilities is **limited**;
 - it is **useless** to collect a high number of foil **if you cannot measure** them in a reasonable time.
- This is why it should also be interesting to perform **sensitivity studies**, to determine **the number of required foils** to achieve **the accuracy for the target dose evaluation**.

IV. CONCLUSION

- The criticality accident dosimetry system currently used at the CEA facilities has been presented. The **SNAC2 zone spectrometers** are **efficient** but have also some **drawbacks**, such as the **difficulty of collecting them** during the criticality evacuation.
- The possibility of using **personal spectrometers** instead of zone spectrometers seems to be a **promising solution** to solve these problems. Nevertheless, some difficulties, such as **the albedo** effect or the **foil number optimization** will have to be fixed.
- **CEA is currently discussing these technical issues** with French and international criticality experts. It may be **useful to perform experimental studies** and **to develop collaborations** with other laboratories in the future to finalize **a new criticality accident dosimetry system**.
- The **SNAC2** zone spectrometers are **still currently used** in the CEA facilities. A **work is in progress** to decide if the SNAC2 should **be kept or** if they should **be replaced** by a new system. Ultimately the dosimetry system will have to be selected **taking into account the medical needs and priorities**.

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex

Direction de l'Energie Nucléaire
Direction déléguée aux Activités Nucléaires de Saclay
Département de Modélisation des Systèmes et Structures

Service d'Études des Réacteurs et de Mathématiques
Appliquées