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

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DE LA RECHERCHE À L'INDUSTRIE

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

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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 NCSD 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 NCSD 2017 talk:
  - "Results of TRIPOLI-4 Version 10 on TRIPOLI Criticality Validation Suite, Thermal Spectra", J.-C. Trama, F. Malouch

OUTLINE

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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.

I. INTRODUCTION: CRITICALITY ACCIDENT DOSIMETRY

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:

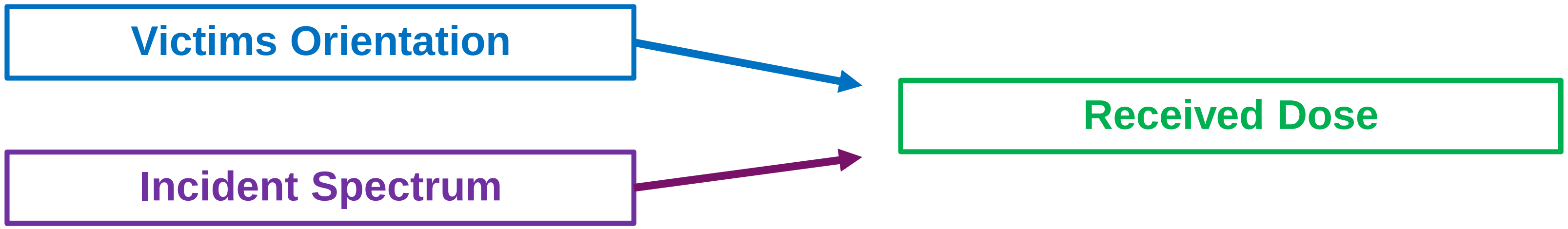
Providing information about the **incident neutron spectrum** at fixed points of the facility

Personal Dosimeters:

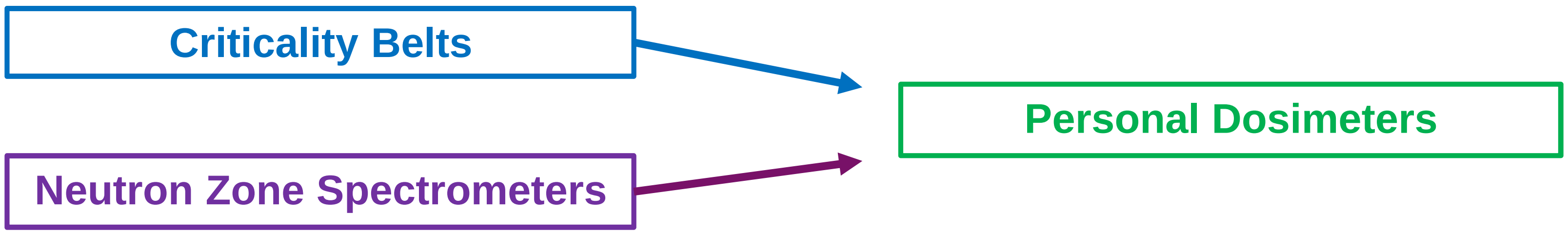
Assessing **neutron and gamma doses** received by people

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.



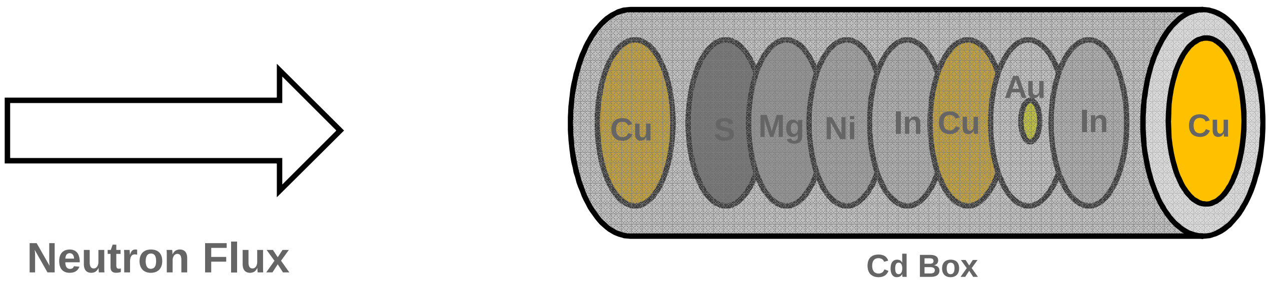
- Therefore **each of the three devices of the system is essential** so that a correct evaluation of the dose can be obtained.



- 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 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:**

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

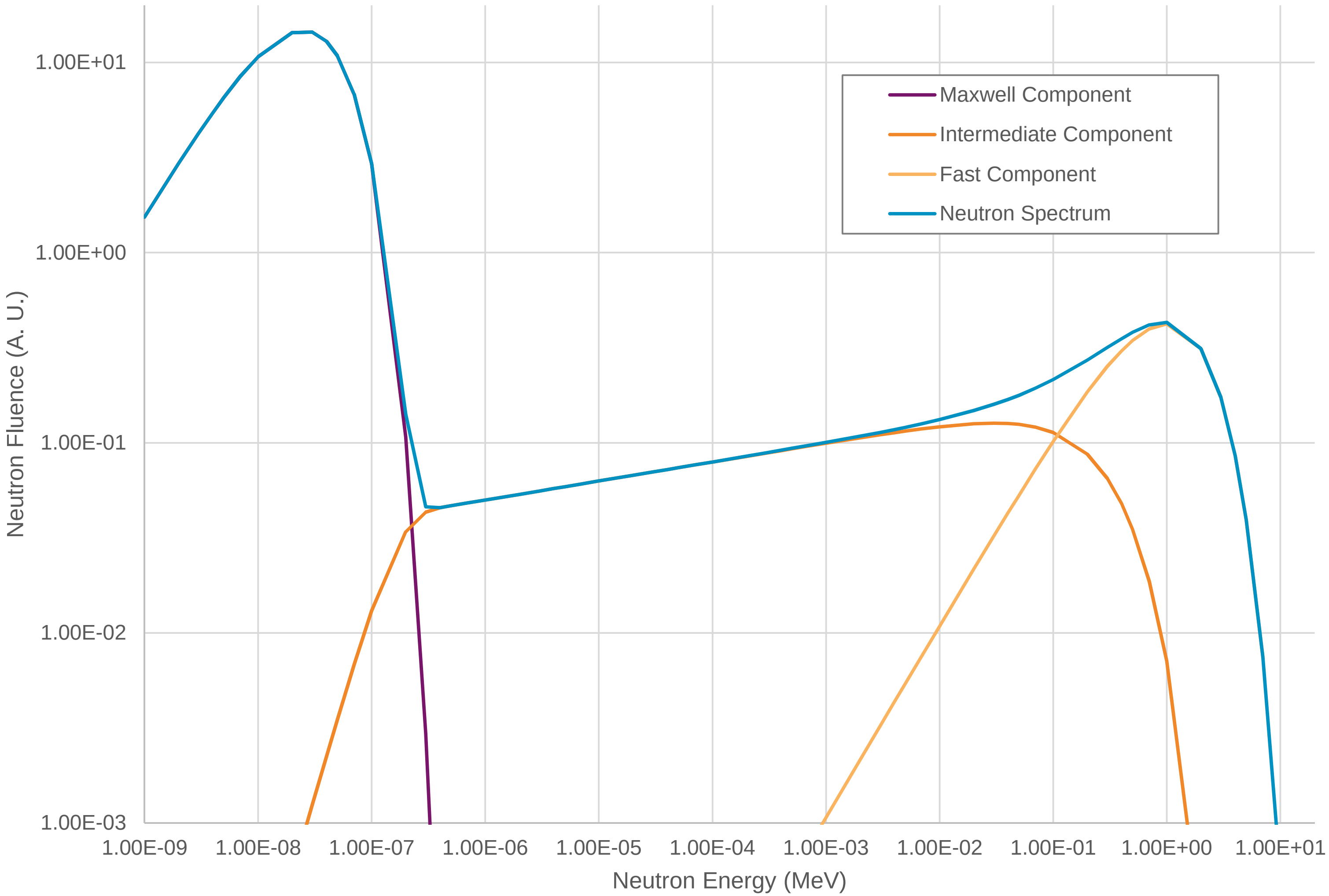
  - with E in eV
  - where E_C^2 and E_d coefficients are respectively fixed to **0,025 eV^2** and **3x10^5 eV**
  - and **b and K** coefficients are fixed from gold and copper under cadmium foil measurements

- **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.**

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