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

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TUESDAY, SEPTEMBER 12, 2017
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
I. Introduction: Criticality Accident Dosimetry

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Diameter (mm)</th>
<th>Thickness (mm)</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebonite</td>
<td>22</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>Magnesium</td>
<td>22</td>
<td>10</td>
<td>6.6</td>
</tr>
<tr>
<td>Nickel</td>
<td>22</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Indium</td>
<td>22</td>
<td>1</td>
<td>2.8</td>
</tr>
<tr>
<td>Copper</td>
<td>22</td>
<td>0.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Gold</td>
<td>4.5</td>
<td>0.005</td>
<td>0.015</td>
</tr>
</tbody>
</table>
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 $\phi_M$, the Maxwell fluence, is fixed from copper foil measurements
For 0.1 eV < E < 100 keV, an intermediate component:

$$\phi_K(E) = K \times \frac{E^b}{E} \times (1 - e^{-\frac{E^2}{E_C^2}}) \times e^{-\frac{E}{E_d}}$$

with $E$ in eV

where $E_C^2$ and $E_d$ coefficients are respectively fixed to $0.025$ eV$^2$ and $3 \times 10^5$ eV

and $b$ and $K$ coefficients are fixed from gold and copper under cadmium foil measurements

For $E > 100$ keV, a fast component:

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

with $E$ in eV

where $C$, $\alpha$, $\gamma$ and $\beta$ coefficients are fixed from indium, nickel and magnesium foils measurements
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.
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.
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.
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.
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**.