

## **Report yearly test criticality dosimetry**

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## **Contract information**

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# 1 Introduction

In places where fissile materials are being handled and processed, there is always a certain risk that, due to human error or failure of a safeguards system, a critical mass or volume is reached; a situation ending up in a criticality accident. Examples of such criticality accidents can be found in (IAEA report, 1982). Although these accidents almost stopped occurring as a result of a high level of today's safety technology, the risk of criticality is never absolutely excluded.

In such an accident situation, specialized dosimetry techniques are necessary, which differ markedly from those used in routine radiological protection. In the first place, the technique must allow a quick separation of exposed and non-exposed persons after the accident. In the second place, the technique must be able to separate the neutron and the gamma component of the dose. Another feature of the criticality dosimetry system is that doses must be reconstructed within an uncertainty of less than 50% within 48 hours and less than 25% four days later, and this should be done for a broad dose range spanning from 100 mGy up to 10 Gy. Since, in the case of neutrons, the sensitivity of detectors usually strongly depends on the neutron energy, the system must be able to reconstruct the neutron spectrum or at least estimate the average neutron energy (IAEA, 1982).

## 2 SCK•CEN criticality dosemeters

SCK•CEN developed criticality dosemeters based on the activation of gold and indium foils and sulfur pellets:

- $^{197}\text{Au}(n,\gamma)^{198}\text{Au}$  (with and without cadmium cover)
- $^{115}\text{In}(n,n')^{115m}\text{In}$
- $^{32}\text{S}(n,p)^{32}\text{P}$

Due to the differences in neutron activation cross-sections of the activation detectors, which are illustrated in Figure 1, an estimation of the original neutron spectrum can be reconstructed. This neutron spectrum is used to calculate both  $D^*(10)$  and  $H^*(10)$ .

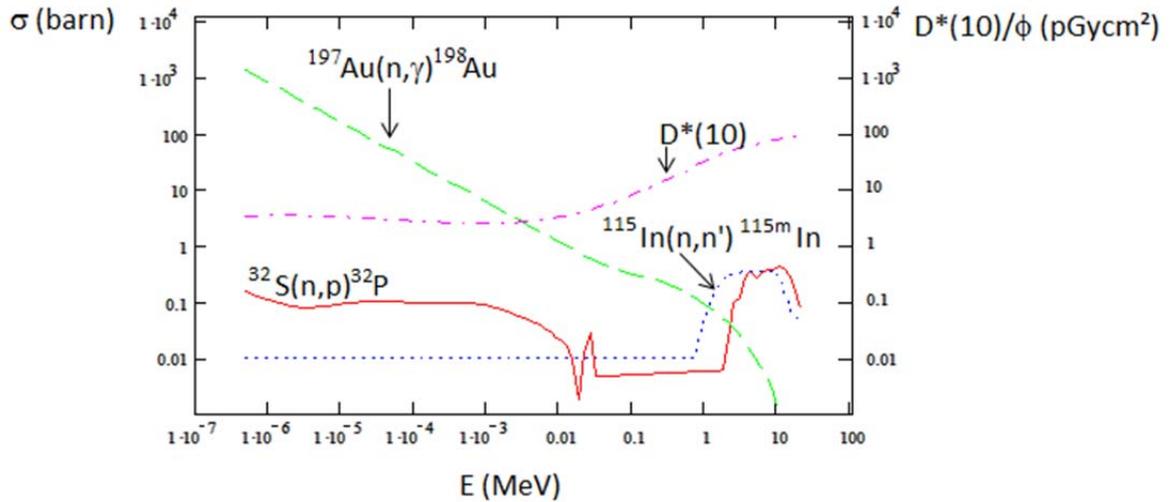


FIGURE 1: NEUTRON ACTIVATION CROSS SECTIONS OF THE ACTIVATION DETECTORS, TOGETHER WITH THE  $D^*(10)/\phi$  CONVERSION COEFFICIENTS.

The activation of  $^{198}\text{Au}$  (412 keV,  $T_{1/2} = 2.7$  days) and  $^{115\text{m}}\text{In}$  (335 keV,  $T_{1/2} = 4.5$  hours) are measured by gamma spectrometry using a Germanium detector. The activity of  $^{32}\text{P}$  is measured via liquid scintillation counting after chemical separation from  $^{32}\text{S}$ .

Next to  $^{115\text{m}}\text{In}$ , also  $^{116\text{m}}\text{In}$  is formed during irradiation with neutrons.  $^{116\text{m}}\text{In}$  has a short half-life of 54 minutes and can be used for fast separation of irradiation from non-irradiated people. The activity of  $^{116\text{m}}\text{In}$  can be measured easily with a simple dose rate meter in close contact with the dosimeter badge. Roughly for a neutron dose of 0.1 Gy, a dose rate of 4  $\mu\text{Sv/h}$  can be measured 10 minutes after irradiation.

There are no detectors for gamma dosimetry radiation present in the criticality dosimeter since in principle every person wearing a criticality dosimeter will also be wearing a standard TLD-badge.

### 3 Description of the experiments

Since our criticality dosimeters do not require any maintenance, a yearly test is incorporated in the quality assurance program. For this yearly test, conducted on March 8, 2012, 2 dosimeters are irradiated to a known dose in a fission spectrum in the BR1 reactor. The sulphur pellets and gold and indium foils are sent for analysis to the responsible laboratories and the results of their analysis are used to calculate the neutron spectrum and  $D^*(10)$  and  $H^*(10)$  using an algorithm described by Doroshenko et al. (1977). Sulphur is analysed by the laboratory for liquid scintillation counting and the gold and indium foils are analysed by the laboratory for gamma spectrometry. Both laboratories are part of the Expert Group for Low

Level Radioactivity Measurements. The calculation of the neutron dose is performed by the Expert Group Radiation Protection Dosimetry and Calibration.

The main goal of the experiments is to avoid loss of knowledge in the different laboratories and the validation of the dose reconstruction technique.

## 4 Results

Dosimeter 1 was irradiated during 30 s in the reactor, dosimeter 2 for a period of 90 s. The dose received by the dosimeters was equal to respectively 0.323 Gy (4.4 Sv) and 1.002 Gy (13.4 Sv). The activation of  $^{116m}\text{In}$  was determined with a Radiagem in close proximity of the criticality dosimeter at different times after irradiation. The measured dose rates 10 minutes after irradiation were equal to 22  $\mu\text{Gy/h}$  for dosimeter 1 and 60  $\mu\text{Gy/h}$  for dosimeter 2. The results of the different measurements are presented in Figure 2, showing a decay for both dosimeters with a half-life of 46 minutes for dosimeter 1 and 39 minutes for dosimeter 2, approaching the expected value of 54 minutes. The results confirm the average dose rate of roughly 4  $\mu\text{Sv/h}$  for a neutron dose of 100 mGy.

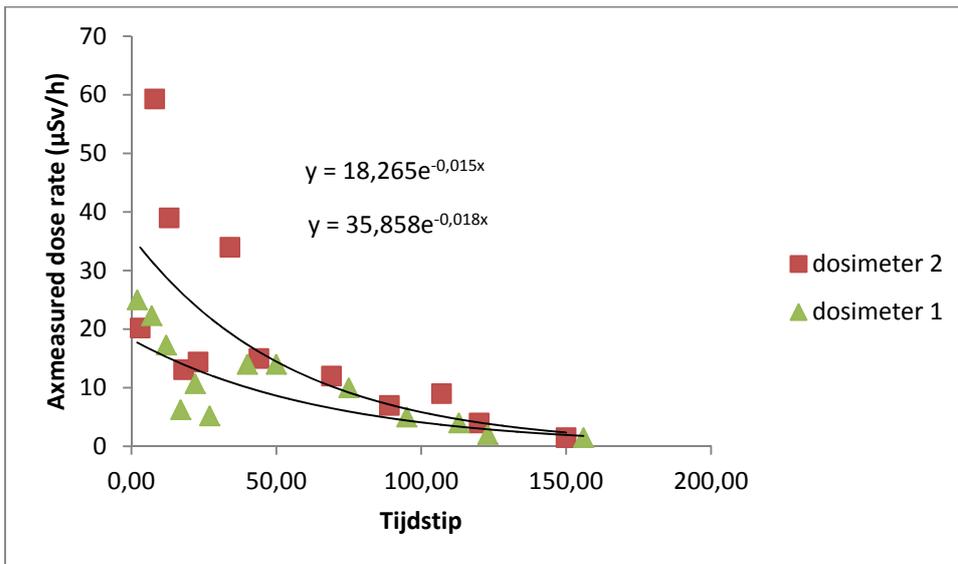


FIGURE 2: THE ACTIVATION OF  $^{116m}\text{In}$  WAS MEASURED USING A RADIAGEM IN CLOSE PROXIMITY OF THE CRITICALITY DOSEMETER AT DIFFERENT TIMES AFTER IRRADIATION. THE RESULTS SHOW FOR BOTH DOSEMETERS SHOW A DECAY WITH A HALF-LIFE OF 46 (DOSEMETER 1) AND 39 MINUTES (DOSEMETER 2), APPROACHING THE EXPECTED VALUE OF 54 MINUTES.

The activities of the gold and indium foils and sulfur pellets are shown in Table 1. The results are presented in Bq/g and represent the initial activities from the moment of irradiation.

TABLE 1: MEASURED ACTIVITIES OF THE ACTIVATION DETECTORS AT THE MOMENT OF THE IRRADIATION. THE RESULTS ARE PRESENTED IN BQ/G

Dosemeter	Au	Au(Cd)	In	S
1	1460	560	252.0	2.50
2	3580	1470	660.0	5.96

The specific activities of the different foils and pellets are translated into detector's responses and used in the algorithm for calculation of the neutron spectrum and neutrons doses. The calculated neutron spectra for both dosimeters are presented in Figure 3.

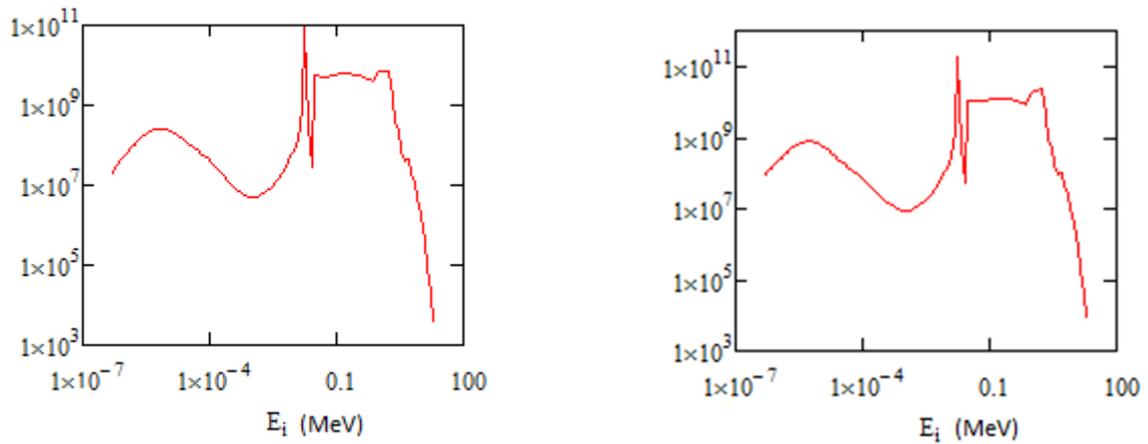


FIGURE 3: RECONSTRUCTED SPECTRA FOR DOSEMETER 1 (LEFT) AND DOSEMETER 2 (RIGHT)

The calculated neutron doses, in comparison with the reference values, are presented in Table 2. The results for dosimeter 2 are nearly perfect (max 4% deviation from the reference value). For dosimeter 1, the calculated dose differed for more than 30% from the reference value, but this might be explained by the fact that this dosimeter was inserted relatively slow in the reactor core, which increased the uncertainty on the reference value up to 10%.

TABLE 2: CALCULATED NEUTRON DOSES, COMPARED TO THE REFERENCE VALUES

Irradiation (s)	Reference dose		Calculated dose		Calculated/reference	
	[Sv]	[Gy]	[Sv]	[Gy]	[Sv/Sv]	[Gy/Gy]
30	4.41	0.32	5.50	0.43	1.25	1.33
90	13.23	0.97	13.42	1.01	1.01	1.04

#### 4.1 Conclusions

The yearly test confirmed the quality of the dosimetry system. The experiment was conducted without irregularities and all laboratories were able to deliver their result within 48 hours of irradiation. The calculated dose for dosimeter 2 approached the reference value within an uncertainty window of 4%. The results for dosimeter 1 differed for more than 30% from the

reference value, but this can be explained by the fact that this dosimeter was inserted relatively slow in the reactor core, which increased the uncertainty on the reference value.

In general, it can be concluded that the criticality dosimetry system from SCK•CEN has a good quality assurance plan. Moreover in general the dosimeters are able to reconstruct neutron doses within the required uncertainty level of 25% within 48 hours after a criticality accident.

The QA system for the entire dosimetry system has been updated and a validation file is drafted. The system of criticality dosimetry will be submitted to BELAC for accreditation according ISO17025 within the next months.