ON THE DISTINCTION OF SMALL EXTRA DOSES FROM THE NATURAL BACKGROUND

DESIGN AND TESTING OF A SENSITIVE TL-DOSEMETER

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INTRODUCTION

An important issue in environmental dosimetry is the detection of artificial doses added to the environmental dose by installations, working with ionising radiation (e.g. hospitals, reactors, in this article called a 'facility'). Dutch legislation sets a limit for the extra radiation dose rate added to the environment by a facility to a maximum of 40 μSv/a (1). Straightforward environmental dosimetry isn't able to distinguish such a small artificial dose from the fluctuating natural background within a reasonable measuring time.
A special method and dosimetry system, SEAD (Sensitive Extra Ambient Dosemeter) (2) which takes into account fluctuations in natural background and is sensitive enough to detect an extra dose rate of 40 μSv/a is presented in this study.

FLUCTUATIONS IN NATURAL BACKGROUND

Natural background radiation is build of three components: cosmic radiation, terrestrial radiation and radiation due to airborne and deposited radioactivity (radon and progeny). Terrestrial radiation varies in the Netherlands from 105 μSv/a to 683 μSv/a (3). Temporal fluctuations in airborne radioactivity and cosmic radiation occur on an daily basis and depend on rainfall, temperature, air-pressure and windvelocity; short risings due to rainfall can be up to 80 nSv/h compared to an average of 70 nSv/h. Typical temporal fluctuations are shown in figure 1. Due to temproal fluctuations weekly ambient doses can differ more than 2 μSv. Translated to a dose per year, this gives a difference of 100 μSv.

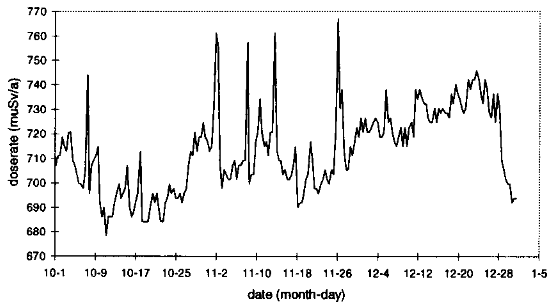

Figure 1: Fluctuations of the natural background based on 10-hour measurement periods at Delft. Dose rates are converted into yearly doses.

CUSTOMARY METHODS TO DISTINGUISH ARTIFICIAL DOSES FROM NATURAL BACKGROUND

There are a few different methods in use to detect an artificial dose added to the environment by a facility, all with the purpose to estimate the natural background and subtract this estimation from the measured dose rate around the facility, leaving an estimation of the artificial added dose rate.

The first way to estimate the natural dose rate is by measuring the dose rate at a place where there's no influence of the facility on the background radiation. Because the terrestrial component of the natural background differs strongly form place to place, this method is unlikely to produce an unbiased estimation of the 'natural background around the facility'. The second method is only usable in the case of facilities where the source(s) of ionising radiation can be switched off. In this case the background can be estimated by a measurement at a time the facility doesn't contribute to the natural background. Figure 1 shows clearly that it's rather unlikely that also this method provides an unbiased estimation within a practical measuring period (2 weeks). A reasonable improvement, but only for facilities where the sources can be switched off, can be made by combining these two methods. Two different measurements at the facility can be corrected for temporal fluctuations by measurements on a reference location (outside the influence of the facility). A last method estimates the fluctuations in natural background by mathematical modelling. This estimation needs a lot of precise meteorological data on air-pressure, rainfall, temperature at a high spatial resolution and is particularly difficult in the case of rainfall (wash-out of radon-progeny).

A NEW METHOD FOR MEASURING THE EXTRA ARTIFICIAL DOSE

Considering the disadvantages of the customary methods a different method is introduced. This method doesn't give an estimation of the natural background but uses the angle dependence of the incoming radiation and is based on the application of a radiation shield. By placing two detectors on both sides of a *radiation-shield*, one side faced to the facility and one to the opposite side, it's possible to measure a natural component (*not* natural background) and a natural component + artificial component in the same time and on the same place. In this way temporal and spatial fluctuations are taken into account and the difference between the two detectors provides a unbiased estimation of the extra dose added to the environment by the facility

DETECTOR DESCRIPTION

The detector SEAD (figure 2) is composed of two dosemeters of ten TL- samples each. The TL-material is LiF: Mg, Cu, P (GR200A), which is very sensitive to photons and has some other outstanding properties for ambient dosimetry (like low-fading-rate and low hygroscopicity). Using ten samples in each dosemeter improves the statistics of the experiment and thus lowers the lowest artificial dose which can be discriminated from the dose due to natural background. The samples are shielded with 5 mm PTFE .The shielding materials consist of 10 cm thick lead, which is enough to shield 6 MeV gamma-radiation for 98,7%. The lead is specially selected for its low specific activity (old) and is covered with 4 mm Copper to provide for as less signal as possible due to the lead-shielding. The cover of the detector is made of 1,5 mm Aluminium which transmits more than 80% of 30 keV photon-radiation and isn't a impediment for higher energies. The cover protects the dosemeters against extreme weather conditions.

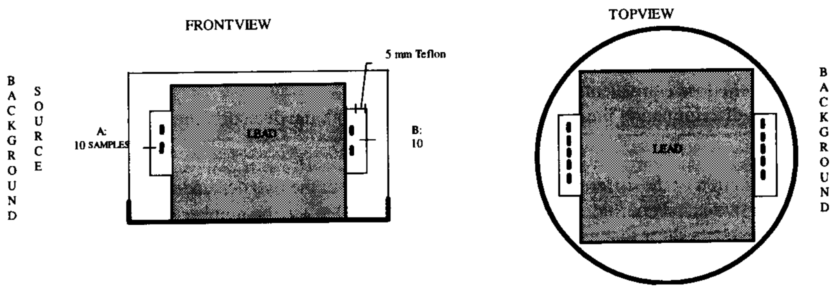

Figure 2: Schematic view of the Sensitive Extra Ambient Dosedetector

PERFORMANCE

Annealing and read-out The TL-material GR200A has an excellent performance, but only when specific and highly reproducable annealing and read-out procedures are applied. It's shown that an annealing temperature 240 °C for 10 minutes followed by fast cooling (>150 K/min) gives a good sensitivity. The *read-out procedure* consists of a plateau on 150°C for 5 seconds, followed by a heating-rate of 3 K/s to 240°C and a second plateau at 240 °C for 13 seconds. The integrating limits for TL-light are from 155°C to *the end* of the second platform. In this way the, non-stable peak 2 (peak temp ≈120 °C) is left out of the integration and peak 4 (peak temp 220 °C) is included as much as possible.

Uniformity and reproducibility To gain a batch of GR200A-samples with a great uniformity a selection of these 40 samples is made out of 100 'new' samples with a manufacturer-guarantee of max. 5% deviation. The standard deviation of the readings of 40 samples after equal irradiation with 10 mR is 0.8%. The standard deviation of 6 readings of each sample after 6 equal irradiations with 60 μGy is less than 2%.

Fading Three groups of 4 samples were placed outdoors for 14 days. One group was irradiated with 3,65 mR before the storage and one group was irradiated after the 14 days with 4,35 mR. After accounting for the different doses and the environmental dose in 14 days (measured with the third group) a fading of (2 ± 4) % (1 st.dev. of the mean) was calculated.

Zero-dose. The zero-dose of all samples was measured by reading them directly after annealing. Most of the readings of the zero-dose didn't exceed the minimum detectable value (determined by the variance in reader-background). The samples which did have a detectable zero-dose were left out of the selection.

Length of field-cycle. The length of the field cycle was determined by irradiating a group of 6 samples which different (low) doses. It was proven that the relative standard-deviation of the mean of 6 readings remained constant when the samples were exposed to 4 mR or more. This can be explained by writing the relative standard deviation σ_N as a function of the total counts n and standard deviation of the reader-background σ_B.(4)

$$\frac{\langle \sigma_N^2 \rangle}{N^2} = b + \frac{1}{n} + 2\frac{\sigma_B^2}{n^2} \qquad (1)$$

where b is a constant. In the case of GR200A and the used reader (modified Harshaw 2000) b>0.001, σ_B=10 and n > 4000 counts for a dose of 4 mR, leaving b, a constant, as the only significant contribution to the relative standard deviation. A dose of 4 mR is equal to the environmental background in 14 days. Fig. 4 shows the relative standard deviation of a TL-measurement as a function of the measurement time in a natural background.

Hygroscopicity. After 14 days storage the difference of the mean between 5 samples placed in a closed can, filled with water and five samples placed in a dry environment was non-significant (0 ± 2)%.

Energy response The relation of measured counts and irradiated dose (mR) is plotted in fig. 3. The defined dependence between ambient dose equivalent (cSv) and exposure (R) as given by ICRU (5) is plotted in fig. 3.

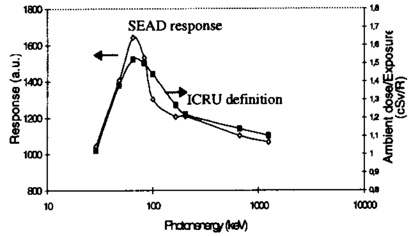

fig 3: TL-response of SEAD and ICRU definition

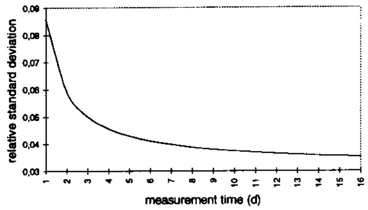

fig 4: Relative standard deviation as a function of measuring time

From fig 3 it's clear that the combinaton of lead, 1,5 mm Al and the 5 mm PTFE gives an excellent agreement with the ICRU definition of ambient dose equivalent.

Discrimination limit The discrimination limit, O_D, (not to be confused with the detection limit) is defined by

$$O_D = t_{\alpha/2}(n+m-2)S_d \qquad (2)$$

Where S_d is the standard deviation of the difference of the mean readings from the two dosemeters and $t_{\alpha/2}$ is the Student-t critical value for a two-sided confindence interval of 1-α and n and m are the number of samples in dosemeter A and B. Measurements show that n=m=10 is sufficient to reach the desired discrimination limit.

Field measurements Results of 4 measurements with SEAD are shown in table 1, two of them at one place at the site boundary of a research reactor and three at different places at the site boundary of a hospital in which radiation facilities are operated.

Table 1: Resluts of measurements with SEAD.

	Reactor	Reactor	Hospital 1	Hospital 2
Extra artificial dose (mSv/a)	0.032	0.037	-0.017	-0.032
'Background' (mSv/a)	0.73	0.68	0.86	0.87
Discrimination limit (95%) (mSv/a)	0.030	0.021	0.033	0.029

DISCUSSION AND CONCLUSION

SEAD is capable of distinguishing an artificial dose rate of 40 μSv/a from the natural background in a measuring time of 14 days. The performance tests show that SEAD shows excellent stability, in particular because of the use of (well-selected) GR200A-samples. Table 1 shows, however, that in absence of any artificial radiation source a difference in natural dose rate can be up to 32 μSv/a (hospital 2). This difference isn't a result of diffence in soil-type (both dosemeters are virtually on the same spot) but is due to diffences in surrounding elements (buildings, trees etc.) on both sides of the detector. This difference can only be established precisely when measurements around a facility can be performed with 'the source switched off'. In other cases the artificial dose rate as established by SEAD must be considered as best estimate, because it eliminates by far more biasing factors than methods used up to now.

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