RADIOLOGICAL ENVIRONMENTAL MONITORING WITH LIF700H DOSEMETERS

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ABSTRACT

Since 2008 a radiological environmental monitoring with LiF700H has been carried out as a result of increasing the RA-6 research reactor core power.The information obtained is used to evaluate and to quantify analytically the air kerma rate, the fading and the associated uncertainty by developing software tools (deconvolution and uncertainty algorithms).

LiF700H dosemeters were chosen because of their high sensitivity to low air kerma rates. They show a very good stability and a negligible fading for two-month working periods. The air kerma rate detection limit (based on the 3σ criterion) during these working periods is about 0.4 nGy/h. Air kerma rates of about 70 nGy/h are measured with this detection limit.

Following the NIST guidelines, an algorithm was developed in order to find the associated uncertainty. It considers several aspects, such as the source activity decay, distance source-dosemeter during the calibration procedure, irradiation time, calibration factor, dosemeter readout, dosemeter sensitivity, TLD reader stability and fading. The associated uncertainty is found to be about 25% for a 95% confidence interval (k = 2.025), which can be considered acceptable when taking into account the very low air kerma rates estimated.

The LiF700H response to different energies and its relationship with climate changes over the calendar year are planned as future tasks.

INTRODUCTION

The main goal of environmental monitoring is to provide data on natural background radiation and to dermine the contribution to the dose to public from man-made sources. In order to fulfil this purpose measurements are carried out starting at the nuclear or radiological facility limits to country-wide locations. A permanent country-wide background monitoring with passive dosemeters serves as a basis for the calculation of the contribution to dose in accidental situations.

The use of thermluminescence dosimetry to environmental monitoring, particularly in the vicinity of nuclear facilities, is attractive to such applications because of their small size and the absence of any need for servicing while in use, among others.

In addition to general properties of thermoluminescent dosemeters (TLD), LiF700H dosemeters were chosen because of its high sensitivity (about ten times higher than that of LiF700) to very low air kerma rates, like those found in environmental dosimetry. By using these solid state detectors and by applying the methodology described below, the air kerma rate was measured with an expanded uncertainty of about 25% (k = 2.025).

MATERIALS AND METHODS

The environmental dosemeters used at Bariloche Atomic Centre consist of three chips of LiF700H (LiF:Mn,Cu,P) placed in a plastic device and inside a plastic box at one metre above ground level. The middle chip is sandwiched by two 1 mm copper layers for a future energy dependence analysis.

The dosemeters are annealed at 240ºC during 15 minutes and then divided into two groups: one for calibration and the other one is distributed in fifteen measurement points. After a two month period, they are collected and read at the dosimetry laboratory. The readout cycle consists of three steps: firstly, they are preheated at 140ºC during 10 seconds; then, the temperature is increased from 140ºC to 240ºC with a ramp of 20ºC/seg, and finally they remain at 240ºC during 20 seconds. It is all done with a Harshaw TLD 3500 reader in a constant flux nitrogen atmosphere (2 l/min).

The calibration is performed by using a 3.7E10 Bq ^{137}Cs point source and the calibration line is obtained with three points: 30, 60 and 90 µGy. The irradiation is done at 1 metre from the source. In order to find the calibration factor and the minimum detectable kerma two methods were employed: a standard method, where every dosemeter is read twice; and a deconvolution method, where the dosemeters are read once and the background signal is estimated analytically. The standard method applies the 3σ (standard deviation) criterion, whereas the deconvolution is carried out by substracting the background signal and by using a non-linear minimization method.

Following the NIST guidelines, an algorithm was developed in order to find the associated uncertainty. It considers several aspects, such as the source activity decay, distance source-dosemeter, irradiation time, calibration factor, dosemeter readout, dosemeter sensitivity, reader stability and fading. Some user-defined spreadsheet functions were written; they all were adapted from [4].

RESULTS

Calibration and kerma calculation. The calibration straight line was obtained for three values of air kerma: 30, 60 and 90 µGy. By using the standard method (each dosemeter is read twice) the calibration factor was calculated with an uncertaintity lower than 10% and the doses were estimated with an uncertaintity lower than 1%. This is the algorithm currently used and it can be considered very accurate since it was several times successfully validated in national dosimetry intercomparisons organized by the Nuclear Regulatory Authority of Argentina.

From the calibration procedure, the following parameters are obtained:

$\Delta L_0 = \frac{\sum_{1}^{j}(L_{0,1}^{i} - L_{0,2}^{i})}{j}$, average of non-irradiated dosemeters, and $\sigma\Delta L_0$, its standard deviation. $L_{0,1}^{i}$ and $L_{0,2}^{i}$ are the first and second readouts of the *i*-th non-irradiated dosemeter.

p: calibration straight line slope, obtained by least squares between the three calibration doses minus ΔL_0. That is, the least squares method is applied to the $\left[\frac{\sum_{1}^{j}(L_{K,1}^{i} - L_{K,2}^{i})}{j} - \Delta L_0 \; ; \quad K\right]$ pair, where $L_{K,1}^{i}$ and $L_{K,2}^{i}$ are the first and second readout of the irradiated dosemeters at a *K* μGy dose.

$Kmd = 3 \cdot \sigma \cdot \Delta L_0 \cdot p$, minimum detectable Kerma.

The kerma is calculated as: $K_i = \overline{\Delta L_i}\, p$, where $\overline{\Delta L_i} = \frac{\sum(L_i^1 - L_i^2)}{2} - \Delta L_0$, the readout average of the two naked dosemeters of the *i*-th station minus the zero readout. The kerma from the dosemeters placed between the copper layers is found as: $K_i = \Delta L_{i,Cu}\, p_{Cu}$, where $\Delta L_{i,Cu} = (L_{i,Cu}^{1} - L_{i,Cu}^{2}) - \Delta L_0$. The *Cu* subscript refers to the copper filters. In both cases, the value obtained is divided by the working-period hours. Thus, the kerma rate is estimated in μGy/h.

The calibration straight line slope found with the deconvolution algorithm showed a difference with the standard method lower than 5%. An analytical approach to the background signal and the reduction of the readout time to the half are the deconvolution algorithm most important contributions. This method is currently being implemented for further evaluations.

In the following paragraphs the factors contributing to uncertainty will be described.

Source activity decay. From [10] the source half life is obtained with an uncertainty of almost ten days and the activity uncertainty is found in the manufacturer certificate [1], being 1%. By assuming a rectangular distribution, the relative standard uncertainty is 0.51%. (52 degrees of freedom).

Calibration Kerma. In this case two conversion factors were taken into account: the conversion from exposure to kerma (F_K), and the conversion from R/h to Gy/h (F_U). The calibration kerma is found like:

$$K = \frac{\dot{X}_{1m}}{\left(d/d_o\right)^2} t \cdot F_K \cdot F_U$$

The uncertainty in the time measurement is estimated in about a tenth of second (the chronometer used is triggered by the source command).

Calibration factor. It is obtained from a linear regression of the readouts by applying weighted least squares. Some spreadsheet functions were written ad hoc and the uncertainty is calculated for every period (usually about 1%).

Calibration dosemeters readout. Ten dosemeters are read as zeros and nine dosemeters for each calibration dose. By doing it, ΔL_o, the average readout of zeros, and $\sigma_{\Delta L_o}$, the standard deviation of the average, are obtained. Similarly, ΔL_k and $\sigma_{\Delta L_k}$ (K = 30, 60 and 90 µGy) are calculated. Typical uncertainty values are $u\Delta L_o \approx$ 6% (zeros) and $u\Delta L_k \approx$ 3% (30, 60 and 90 µGy). A net readout for each *k* is estimated as the difference between ΔL_k and ΔL_o, with a combined relative uncertainty of about 7%. These dose values are used to determine the calibration straight line, and according to the Welch-Satterthwaite formula, they have 16 degrees of freedom each.

Dosemeter readout. The dosemeter readout is the average of the three detectors making it up. The uncertainty is found to be typically lower than 0.4% with 2 degrees of freedom. By using this uncertainty, the zeros readout uncertainty and that obtained in the previous paragraph, the kerma uncertainty can be estimated. Typical values are 7% with 5 degrees of freedom.

Detectors individual sensitivity. The dosemeters were verified before using them. Also, since August 2008 groups of 26 detectors have been used, every two months, for calibration and since March 2009 every single detector has been identified. This data analysis has shown that individual sensitivities have a normal distribution with a standard deviation of 5% (339 degrees of freedom).

Fading. In order to estimate the fading some tests have been made since March 2009. An additional dosemeter was placed in two stations (every dosemeter consists of three LiF700H chips irradiated at a 90 µGy gamma dose). No fading has been observed, being the relationship average between them and those of calibration: 1.08 ± 0.03 with 95% of confidence (k = 2.025 and 27 degrees of freedom). That is, a relative combined uncertainty of 1.4%.

TLD reader stability. Since the calibration detectors are read two months before those arranged in the stations, a correction due to the TLD reader stability must be made. This is done by comparing the equipment light tests. Assuming a triangular distribution with an amplitude of 5%, these corrections are normally between 1% and 2% (this is the relation between the averages of calibration and readout light tests).

Variation due to energy. According to references [2, 3] it introduces an uncertainty lower than 10%. Therefore a rectangular distribution is assumed. The relative uncertainty is 5.8%.

Expanded uncertainty. When taking into account the listed effects, a final relative combined uncertainty of 11.6% is obtained (38 degrees of freedom). Thus, for a 95% confidence interval, a coverage factor of 2.025 should be used. As a result, a relative expanded uncertainty of 25% is found.

CONCLUSIONS

As shown above, the expanded uncertainty is found to be 25% for a 95% confidence interval and a coverage factor *k* of 2.025. Since we deal with very low kerma rates, this value can be considered acceptable.

LiF700H dosemeters were chosen because of their high sensitivity to low air kerma rates. They show a very good stability and a negligible fading. All these characteristics are very desirable in these working conditions.

An association between kerma rate variations and season climate changes is trying to be found. Nevertheless, this uncertainty is being a very defiant challenge since these variations are within the margin of error.

The LiF700H response to different energies is planned as a future task by using the relationship between the naked dosemeters and those under the copper filters.

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