MONTE CARLO CALCULATIONS OF CALIBRATIONS OF CALIBRATION COEFFICIENTS OF ATL MONITORS INSTALLED AT NPP TEMELIN

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The contribution describes a technique of determination of calibration coefficients of a radioactivity monitor using Monte Carlo calculations. The monitor is installed at the NPP Temelin adjacent to lines with a radioactive medium. The output quantity is the activity concentration (in Bq/m^3) that is converted from the number of counts per minute measured by the monitor. The value of this conversion constant, i.e. calibration coefficient, was calculated for gamma photons emitted by ^{60}Co and compared to the data stated by the manufacturer and supplier of these monitors, General Atomic Electronic Systems, Inc., USA. Results of the comparison show very good agreement between calculations and manufacturer data; the differences are lower than the quadratic sum of uncertainties.

INTRODUCTION

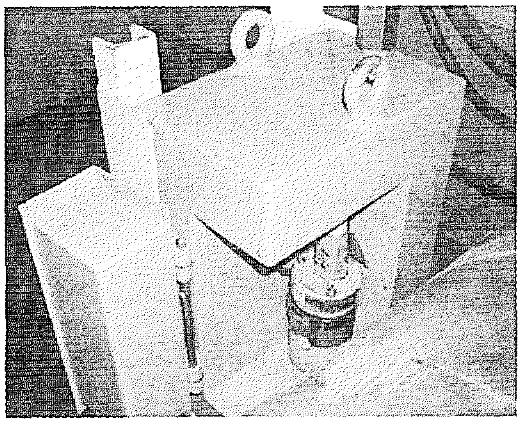
The study was initiated by the fact that it is very difficult to calibrate and verify these types of monitors due to complex geometry hence it would be much easier to use computational methods for determination of calibration coefficients. Unfortunately, the present definition of the calibration denies determining calibration coefficients by computational methods because it requires the consecutive chain of measurements. That is why any calculations can only support results of measurements at present. This study shows that calculations based on Monte Carlo methods could be, in some cases, used for determination of calibration coefficients as well.

MATERIALS AND METHODS

1. ATL monitors

Five types of ATL monitors (Adjacent-To-Line monitors) are used at the NPP Temelin; some of them contain Geiger-Müller detectors (GM detectors) only, some of them scintillation detectors only, and some of them both types of these detectors. For this study one monitor containing a GM detector only was chosen. The monitor incorporates a small GM detector (4.4 cm high, 1.2 cm in diameter, both values including an energy compensation made of 2 mm thick Sn, 1.4 cm^3 inner volume filled with neon gas) fixed inside an aluminum can. The can is enclosed by 8 cm thick lead shielding from all sides except one that is faced to a line with a radioactive medium. Figure 1 shows a photograph of the monitor. This monitor is used for measurement of the activity concentration of (a) steam inside a line (87 cm total outer diameter, 63 cm outer diameter of inner line with steam) between steam generator and turbine and (b) coolant in the primary circuit (57 cm total outer diameter of the line, 43 cm outer diameter of inner line with coolant).

Figure 1. Photograph of the modeled monitor

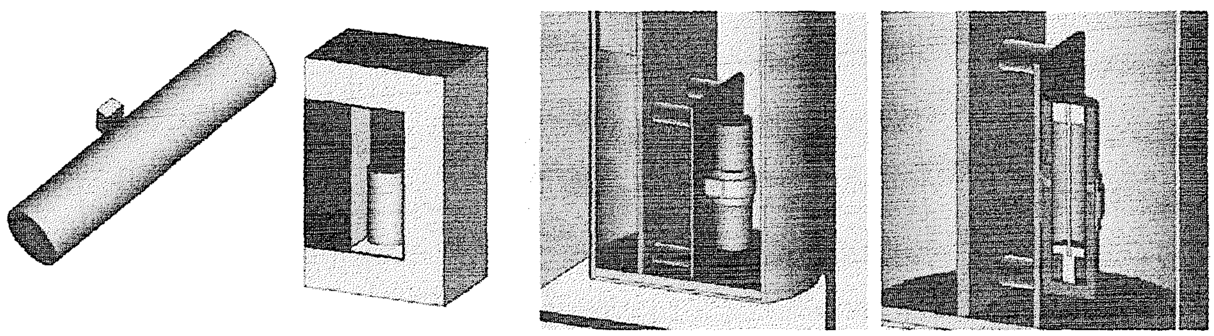


2. Monte Carlo Calculations

The model

Monte Carlo calculations were performed using the general-purpose code MCNPX in version 2.6f [1.]. A detailed model of the monitor has been created according to all available information supplied by both the manufacturer and the NPP Temelin staff. The model is shown in Figure 2. Calculations were done for gamma photons from ^{60}Co emitted uniformly from a radioactive medium inside a line 300 cm long. Due to very low probability of photon reaching the GM detector, several variance reduction techniques were used, including source bias and cell-based weight windows computed using a weight window generator.

Figure 2. Model of the monitor. From left to right: the monitor adjacent to a line, a can among shielding, view inside the can, and a cut through the GM detector.



GM detector sensitivity

The main problem and challenge was a question how to determine the number of pulses created inside the GM detector. In this type of detectors, a pulse is created by a cascade ionization initialized by one or several electrons originated from a photon interaction. This number depends on many parameters including detector voltage, position of an electron origin, etc. This problem was solved by comparison of the sensitivity of the GM detector stated by the manufacturer (TGM Detectors, Inc.) and determined from calculations. The result of the calculation was a pulse-height energy spectrum whose sum is the total number of "ideal" detector pulses, i.e. when every electron, that left any energy inside the GM detector, creates a pulse. But in the real case, this ideal behavior is deteriorated in the lower energy region because there is much lower probability that an electron creates a pulse. That is why the calculated pulse-height spectrum has to be multiplied by a probability function and then its sum - the total number of "real" detected pulses - can be used for determination of the sensitivity. The probability function was chosen (a) to have a reasonable behavior and (b) to change the value of the "ideal" sensitivity to correspond to the value stated by the manufacturer. The chosen probability function was then used in all cases for conversion from "ideal" pulses to "real" detected pulses.

Calibration coefficient

The calibration coefficient K in units (Bq/m^3)/(imp/min) was determined from results of calculations as follows:

$$K = \frac{1}{tVFY}$$

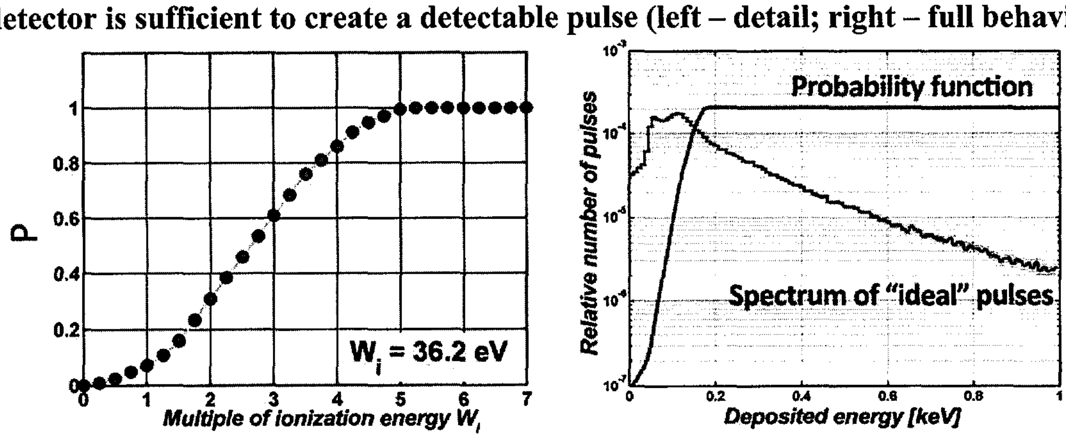
where t is the conversion from seconds to minutes (t = 60 s/min), V is the source volume, F is the calculated number of detected pulses, and Y is the photon yield per atom disintegration.

RESULTS AND DISCUSSION

1. GM detector sensitivity

The chosen probability function is shown in Figure 3. It can be seen that the probability function has a reasonable behavior: it is smooth and 100 % probability is reached when the deposited energy is equal to 5 times the value of mean ionization energy in neon (W_i = 36.2 eV [2.]). With this probability function very good agreement of measured and calculated sensitivity was obtained. Without the probability function, the calculated sensitivity was 32 % higher than the value stated by the manufacturer and with the function showed in Figure 3, the calculated sensitivity was only 5 % higher which is sufficient with regard to input data uncertainties.

Figure 3. A function representing the probability P that the energy deposited inside the GM detector is sufficient to create a detectable pulse (left – detail; right – full behavior).



2. Calibration coefficients

Table 1 shows comparison of calibration coefficients for ^{60}Co stated by the manufacturer [3.] and calculated by MCNPX.

Table 1: Comparison of calibration coefficients

Radioactive medium	GA-ESI [*1] [3.]		MCNPX		Difference[*2]
	Calibration coefficient (Bq/m^3)/(imp/min)	Uncertainty 1σ	Calibration coefficient (Bq/m^3)/(imp/min)	Statistical uncertainty 1σ	
Tube 1: coolant, water with H_3BO_3	2.37E+5	±14.5 %	2.55E+5	±4.7 %	+8 %
Tube 2: vapor	1.59E+5	±8 %	1.78E+5	±7.2 %	+12 %
Tube 2: vapor [*3]	1.59E+5	±8 %	1.71E+5	±6.1 %	+7 %

*1 General Atomic Electronic Systems, Inc.
*2 Difference is calculated as follows: (MCNPX-GAESI)/GAESI
*3 Monitor is rotated by 90°

The results show very good agreement; in all cases the differences are lower than the quadratic sum of uncertainties. It indicates that the MCNPX calculations are able to give very reasonable results for problems with GM detectors which are a little bit tricky to model.

CONCLUSIONS

A detailed model of one of the ATL monitors installed at the NPP Temelin has been created. The model has been used with two different types of radioactive sources containing ^{60}Co for determination of calibration coefficients – a conversion constant from the number of detected pulses to the activity concentration in the radioactive medium. Results have been compared to values stated by the manufacturer and supplier of the monitor. It was found that in all the studied cases the difference has fallen into the interval of uncertainties.

ACKNOWLEDGEMENT

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