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Monte Carlo modelling and real-time dosemeter measurements of dose rate distribution at a ^{60}Co industrial irradiation plant

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ABSTRACT

The dose rate distribution in a MDS Nordion JS7500 ^{60}Co industrial irradiation plant has been calculated using the egspp Monte Carlo code. This code is a development of the established EGSnrc code developed and distributed by National Research Council of Canada.

The coding method is described and absolute dose rates given for each of the dwell positions in the path through the irradiator. These calculated dose rates have been compared with measurements made using a radiation resistant electronic dosimetry system. In addition, the integral dose derived from calculated and measured dose rates has been compared to the value obtained using chemical dosimeters.

1. Introduction

Knowledge of the dose rate at each dwell position in a ^{60}Co industrial irradiation plant is important for many reasons. Such information helps in the design of an irradiator and the configuration and subsequent re-loading of the source rack. The dose rate distribution also assists the plant operator with scheduling products of different densities or dose requirements and with setting the irradiator dwell time.

Solid and liquid state dosimeters commonly used to monitor the irradiation process give the integral dose over the plant cycle, but no information on how the dose rate varied with position in the plant. Such information can be obtained by placing dosimeters at each dwell point and exposing the source whilst the totes or carriers are kept static, but this method necessarily utilises a large number of dosimeters and care has to be taken to prevent excessive temperature rise during the irradiation. It is also necessary to account properly for the transit of the source to and from its storage position at the bottom of the source pond.

The dose rate distribution can also be measured using a radiation resistant electronic system. The NPL real-time dosemeter (RTD) (Sharpe et al., 2000; Sephton et al., 2002) uses an ionisation chamber to measure dose rate and a thermistor to measure temperature at each dwell position. The data are stored on magnetic tape for retrieval after the irradiation.

Sephton et al. (2007) investigated the use of point kernel modelling to predict the dose rate variation at a ^{60}Co irradiation plant. The point kernel method is based on line-of-sight attenuation, with approximate build-up factors, on a predetermined coordinate grid. The point kernel code IADCP (MDS Nordion, 2006) was used in the study. Static measurements with alanine and electronic measurements made with the RTD were found to be in good general agreement with predictions obtained from the IADCP model.

The accuracy of point kernel codes is limited by the approximations involved in modelling the radiation transport. Monte Carlo modelling is, in principle, the most detailed modelling method, (ASTM, 2002; Weiss and Stangeland, 2003) and involves tracking simulated particles through a geometrical model of the physical system, taking account of scattering and energy absorption. A large number of histories are simulated to estimate outcomes of interactions based on probability distributions.

This paper describes the use of Monte Carlo modelling to predict the dose rate variation in an industrial ^{60}Co plant. Comparison is made with measurements made with the RTD at each dwell position. In addition, integral dose calculations are compared with measurements made with the RTD and alanine dosimeters.

Knowledge of the temperature variation is also of importance. The use of megacuries of ^{60}Co may lead to significant rises in the temperature of both the product and chemical dosimeters. The temperature profile can be used to correct the response of the dosimeters. The correlation between integral dose and temperature rise is also investigated.

2. Monte Carlo modelling

The Fortran-based EGSnrc Monte Carlo code for electrons and photons delivers very accurate results up to extremely high energies, (Kawrakow and Rogers, 2003). Previously its use was

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effectively limited to situations involving relatively simple geometries. This was because the code describing how far a particle had to move in a given direction before it entered a new region had to be written by the user.

Recently, however, the egspp code (based on C++) has been released as part of the EGSnrc software (Kawrakow, 2006). The egspp code allows much simpler and more intuitive user input. Rather than writing a code for a given situation, the user simply has to write an input file detailing the geometry of the materials involved and a description of the source geometry and spectrum.

The facility used in the study is a MDS Nordion JS7500 ^{60}Co industrial irradiation plant. The product path involves four passes of the source on each of the two levels, this is shown schematically in Fig. 1, where the dwell positions have been allocated sequential numbers that are referred to later. The totes are made of aluminium and are $50 \times 60 \times 120\,cm^3$ in size. The conveyor system carrying the totes past the source rack is not original, having been replaced in the 1990s. It comprises mild steel frames with hollow stainless steel rollers. The source activity at the time of the measurements was approximately 1.4 MCi.

The large number of repeated elements in the geometry and source, such as the rollers of the conveyor, the pencils in the source rack, and the totes placed around the irradiator vault were generated for the input file using simple Fortran scripts. Fig. 2 shows a 3D representation of the plant derived from the egspp input files. The activities of individual source pencils were taken from an Excel file and read into the Fortran code for generating the source rack. They were then incorporated into the input file as probabilistic weights for the individual source pencils.

Typically, a tote will contain several boxes of product, which may not completely fill the tote. The RTD was, however, placed in a tote completely filled with expanded polystyrene, so for these models the mass of product contained on the other totes in a run was simply diffused around the complete tote. This was found to be sufficiently accurate; if the aim had been to simulate the doses delivered to real product then a more accurate model of the tote would have been required, but this would not have involved a significantly more complex model.

The simulation takes approximately 24 h to run on a typical office laptop PC (~1 GHz, 256 MB RAM), to give results with statistical uncertainties in the maximum dose rate positions of approximately 2%.

Dose rates were recorded in small volumes of water ($1 \times 2.5 \times 3\,cm^3$), distributed over up to 175 positions in each tote. Water was used as dosimeters are almost always calibrated in terms of absorbed dose to water. The EGSnrc code calculates dose by scoring directly the energy lost by charged particles in collisional ionisation processes; in this way, an accurate estimate of the doses delivered to these regions is produced, which takes account of incomplete deposition of energy as a result of radiative energy loss processes.

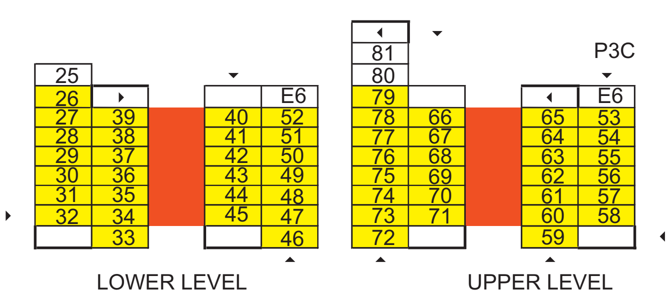

Fig. 1. Schematic diagram of product flow through irradiator showing numbering system used.

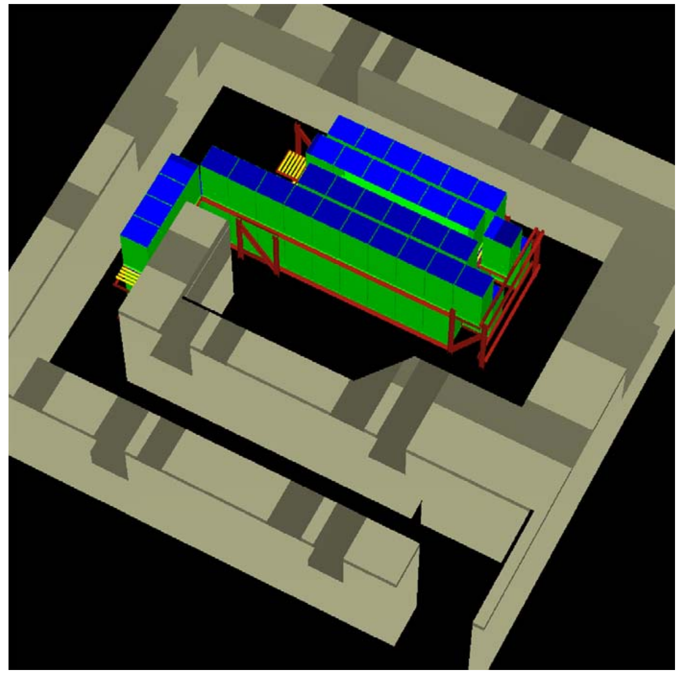

Fig. 2. Representation of plant for MC modelling.

3. Validation techniques

The RTD has been described in previous papers (Sephton et al., 2007) but it may be helpful to give some details here. An ionisation chamber is surrounded by 3 mm of polyetheretherketone (PEEK) to achieve electronic equilibrium in ^{60}Co radiation. The chamber is nitrogen filled and being of aluminium/ceramic construction is inherently radiation hard. The active volume of the chamber is $7\,cm^3$ along an active length of 2.5 cm. The chamber has been calibrated in terms of absorbed dose to water in a degraded ^{60}Co gamma ray field using alanine dosimeters. Temperature is measured with a R-T matched thermistor.

Some improvements were made to the RTD prior to this study. The tape deck was made more rigid and the bearings improved. The transistor-based high voltage power supply was replaced with alkaline cells to improve current capability and radiation resistance.

The alanine dosimeters consisted of pellets in cylindrical holders approximately 12 mm diameter and 17 mm high. The pellets are manufactured from alanine powder and paraffin wax with a mixture ratio of 10:1 by mass. The pellets are approximately 5 mm diameter and 2.5 mm high; four pellets are used in each dosimeter. Three dosimeters were placed at 120° intervals around the sensitive volume of the ionisation chamber.

4. Results

The modelling and measurements were carried out at two positions in the tote: the centre of the tote and the centre of a face parallel to the source rack, see Table 1. For the second position the RTD was operated twice; the second measurement was at a higher electrometer gain setting. This enabled a more detailed study to be made of the dose rates at dwell points furthest from the rack. This was not possible with the "centre of tote" measurements as the irradiation conditions were different for the subsequent run. The dose rate variation is shown in Figs. 3 and 4; integral data is given in Table 1. The error bars shown in Figs. 3