THE USE OF IONISATION CHAMBERS FOR DOSE RATE MEASUREMENTS AT INDUSTRIAL IRRADIATION PLANTS

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The use of ionisation chambers to measure dose rate at industrial irradiation plants has been studied as part of a wider project on real time dosimetry. The characteristics required of such a chamber are discussed. These include the ability to withstand operation at high cumulative doses (up to 5MGy) and dose rates of up to about 150 kGy h\textsuperscript{-1}. Other desirable features are water equivalence and immunity to environmental conditions such as temperature, pressure and humidity. A number of chambers have been assessed experimentally and a suitable chamber selected. The dosimetric characteristics of the chosen chamber have been assessed by comparison with absorbed dose measurements made using chemical dosimeters.

**Introduction**

Measurement of dose rate at specific locations in an industrial gamma processing plant can provide valuable information about the irradiation process and complements the data on total absorbed dose obtained from conventional integrating dosimeters. It is also a vital component in the validation of computer codes, which are designed to model dose delivery in industrial irradiation plants (Oliveira et al., 2000).

Typical dose rate monitors are devices such as semiconductor diodes and ionisation chambers that produce an electrical current proportional to the applied dose rate. The current from these devices can either be measured via a fixed cable or through a mobile device, such as the NPL Real Time Dosemeter (Sharpe et al., 2000). Semiconductor detectors are commonly used for dose rate measurements in applications such as radiotherapy where the total accumulated dose is low, but radiation damage, both transient and permanent, precludes their use in industrial applications, where lifetime doses of several megagrazy may be received. Ionisation chambers are potentially more resistant to radiation damage, although structural failure of components is still an important consideration. In this paper, we present the results of an investigation into the selection of ionisation chambers for use at high doses and dose rates and detail the performance of a selected chamber.

**Selection of ionisation chamber**

A number of factors were considered in the selection of a suitable ionisation chamber and these are summarised below:

- **Total accumulated dose.** An ability to withstand 5 MGy was felt to be desirable as this would allow the chamber to be used for in excess of 100 passes through a typical sterilisation cycle.

- **Dose rate.** Dose rates in industrial Co-60 plants may be of the order of 150 kGy h\textsuperscript{-1} close to the source. The response of ionisation chambers at high dose rates can be affected by saturation. This happens when the electric field strength is no longer sufficient to sweep all the ions across the gas before recombination occurs and results in a reduction in measured current. Careful design of the electrode system is needed to minimise such effects. Saturation effects are closely linked with an observed variation in current with applied polarising voltage (Delaney and Finch, 1992).

- **Sensitivity.** Intense radiation fields can induce noise on the cables, connectors etc involved in the measurement of chamber current and it is therefore desirable to use a chamber with a high sensitivity (current per unit dose rate) to give a good signal to noise ratio. Sensitive chambers may, however, be more prone to saturation effects, as the active volume
will be larger and the electric field strength, consequently, less intense.

and C are sealed and so will be unaffected by factors such as air pressure, temperature and humidity. The polymer based construction of the other chambers

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>BODY MATERIALS</th>
<th>GEOMETRY</th>
<th>CABLE INSULATION</th>
<th>GAS</th>
<th>OVERALL DIAMETER (mm)</th>
<th>OVERALL LENGTH (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber A</td>
<td>steel/ceramic</td>
<td>cylindrical</td>
<td>polyetheretherketone</td>
<td>Xe (1 bar sealed)</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>Chamber B</td>
<td>Shonka/plastic</td>
<td>thimble</td>
<td>not known</td>
<td>air (unsealed)</td>
<td>16</td>
<td>53</td>
</tr>
<tr>
<td>Chamber C</td>
<td>steel/ceramic</td>
<td>cylindrical</td>
<td>polyetheretherketone</td>
<td>N₂ (1 bar sealed)</td>
<td>16</td>
<td>68</td>
</tr>
<tr>
<td>Chamber D</td>
<td>polymethyl methacrylate</td>
<td>thimble</td>
<td>polyethylene</td>
<td>air (unsealed)</td>
<td>13</td>
<td>50</td>
</tr>
<tr>
<td>Chamber E</td>
<td>polyetheretherketone</td>
<td>thimble</td>
<td>not known</td>
<td>air (unsealed)</td>
<td>10</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 1 Constructional details of chambers selected for study

Spectral dependence. The quantity of interest in radiation processing applications is absorbed dose to water and it is important that the chamber response is close to that of water over the wide range of scattered radiation spectra experienced in industrial plants. This imposes constraints on the thickness and atomic number of the body materials.

Five chambers were selected for study, based on the criteria given above. Their constructional details are given in Table 1, and Fig. 1 shows the general form of

![Cathode Anode](Cathode.png)

![Cylindrical chamber](Cylindrical chamber.png)

![Thimble chamber](Thimble chamber.png)

Fig. 1 Schematic diagrams of cylindrical and thimble chambers

Cathode

Anode

Cylindrical chamber

Thimble chamber

the chambers. The steel/ceramic construction of Chambers A and C was expected to result in a very high degree of radiation resistance. The use of PEEK (polyetheretherketone) insulated cable is also of benefit, as this material is known to be capable of withstanding doses of several megagray. Chambers A makes them more likely to sustain radiation damage, but has the potential advantage of lower energy dependence. The five chambers were tested for various characteristics, and the results are summarised in Table 2.

Only Chambers A and C survived irradiation to several megagray without sustaining damage, and, apart from some stiffening of the cables, there were no apparent effects. The sealed chambers have higher active volumes and are therefore more sensitive. The unsealed chambers require correction for temperature and pressure and are, consequently, less convenient to use. The variation of chamber current with applied polarising voltage at a dose rate of approximately 15 kGy h⁻¹ was determined for each chamber. Such curves typically feature an extensive “plateau” region where the current increases only slightly with voltage because very little recombination is taking place. The degree of plateau slope can therefore be used as an indication of the tendency of a chamber to saturate.

Chamber C, from LND⁠¹, had the best overall performance and chambers of this general design were selected for this study. Preliminary results involving comparison of ionisation chamber C and chemical dosimeters indicated a possible spectral dependence of the steel walled chamber in degraded Co-60 radiation spectra and the decision was taken to use a modified version with 0.15 mm thick aluminium body for this study. The manufacturer’s designation of the chamber is LND 52138. The chamber has an active volume of 7 cm³ along an active length of 2.5 cm.

¹ LND, 3230 Lawson Boulevard, New York 11572, USA.
Chamber calibration

The ionisation chamber was calibrated by measuring the current when irradiated in the standard radiation field of NPL’s MDS Nordion Gammascell 220 irradiator. The dose rate in the Gammascell had been determined using chemical dosimeters and was directly traceable to the NPL primary standard therapy level calorimeter. The chamber was mounted coaxially in the cylindrical irradiation chamber and surrounded by 25 mm of water equivalent material to ensure conditions of electronic equilibrium. The dose rate in the Gammascell varies significantly over the active length of the chamber. To correct for this it was necessary to determine the relative response profile of the chamber at discrete positions along its length using the collimated Co-60 beam of a therapy irradiator. The relative response could then be combined with the known dose rates in the Gammascell at the various positions, to derive a calibration factor representative of the response of the chamber when irradiated uniformly along its length. The dose rate in the Gammascell 220 irradiator was approximately 12 kGy h⁻¹ and the polarising voltage of the chamber was 300 volts. The calibration factor derived using the above procedure was 7.7×10⁻⁹ A kGy⁻¹ h⁻¹.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Nominal Response (A kGy⁻¹ h⁻¹)</th>
<th>Plateau Slope (% 100V⁻¹)</th>
<th>Radiation Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber A</td>
<td>5×10⁻⁷</td>
<td>0.69</td>
<td>Undamaged at 6.2 MGY</td>
</tr>
<tr>
<td>Chamber B</td>
<td>5×10⁻⁷</td>
<td>0.29</td>
<td>Insulation failure at 1.9 MGY</td>
</tr>
<tr>
<td>Chamber C</td>
<td>1×10⁻⁷</td>
<td>0.13</td>
<td>Undamaged at 6.2 MGY</td>
</tr>
<tr>
<td>Chamber D</td>
<td>1×10⁻⁷</td>
<td>0.09</td>
<td>Casing failure at 2.6 MGY</td>
</tr>
<tr>
<td>Chamber E</td>
<td>3×10⁻¹⁰</td>
<td>0.69</td>
<td>Cable failure at 6.2 MGY</td>
</tr>
</tbody>
</table>

Table 2 Measured characteristics of chambers

High dose rate response

The response characteristics of the LND 52138 chamber have been studied using the high dose rate irradiation facilities at MDS Nordion’s Kanata site. Twelve Co-60 pencil sources, each with an activity of about 480 TBq (13 kCi), were used in various configurations to provide radiation fields covering the range from 14 to 166 kGy h⁻¹. Alanine dosimeters were substituted for the ionisation chamber and irradiated for a known time (≈10 minutes) to determine the dose rate experienced by the chamber when irradiated by all twelve sources. The relative activities of the pencils were known and so it was possible to use the alanine data to infer the dose rates arising from all the pencil configurations. Fig. 2 shows the variation of chamber current with dose rate at polarisation potentials of 300, 600 and 900 volts. At the two higher voltages the chamber current increases linearly with dose rate but with 300 volts the function is only linear up to about 55 kGy h⁻¹. Fig. 3 shows the variation of chamber current with chamber voltage at a dose rate of 166 kGy h⁻¹. A potential of 600 volts is again shown to be sufficient. The dose rate with all 12 pencils exposed was also calculated from the measured chamber current at a polarising voltage of 1000 V and using the Gammascell derived calibration factor described above. The resultant dose rate of 162 kGy h⁻¹ was in good agreement with the alanine derived dose rate, the difference of 2.5% being well within the uncertainties inherent in the procedure.

Validation measurements at an industrial plant

The validity of the Gammascell derived calibration factor when the chamber is used in an industrial Co-60 irradiation plant was determined at the Canadian Irradiation Centre (CIC), Laval, Canada using the NPL Real Time Dosemeter (Sharpe et al., 2000). The ionisation chamber and associated electronics unit were placed in a standard product carrier. Two alanine dosimeters were attached to either side of the chamber adjacent to the centre of the active volume, and the chamber and thermistor were taped to the inner wall.
of a carrier. The dose rate and temperature profiles obtained are shown in Fig. 4. The carriers pass on both sides of the source on a single level. Positions 1-5 are on one side of the source and positions 6-9 on the other. The Real Time Dosemeter (RTD) registered an integral dose of 10.2 kGy, which was in good agreement with the alanine reading of 10.1 kGy. The total uncertainty associated with the RTD measurements is estimated to be ±5% (2σ) and that associated with the alanine measurements ±2.5% (2σ).

Conclusions

Dosimetry measurements at high dose rates impose a considerable number of constraints on the selection of an ionisation chamber. The work described here demonstrates that accurate dose rate measurements using ionisation chambers can be carried out in an industrial environment up to dose rates of at least 160 kGy h⁻¹.

References


Fig. 4 Dose rate and temperature profiles at CIC measured with Real Time Dosemeter.

Fig. 4  Dose rate and temperature profiles at CIC measured with Real Time Dosemeter.

Acknowledgements

The authors would like to thank Yves Doyle and his staff at CIC, Richard Goddard and his staff at MDS Nordion, Kanata and Robert Lehnert at LND for their help with this work.