GAMMA RADIATION SCANNING OF NUCLEAR WASTE STORAGE TILE HOLES

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Abstract

Nuclear waste management facilities at Chalk River Laboratories use below-ground 'tile holes' to store solid waste from various activities such as medical radioisotope production. A silicon PIN (p-type-intrinsic-n-type semiconductor) diode based gamma radiation scanning system has been developed and used to profile the gamma radiation fields along the depth of waste storage tile holes by deploying the sensor into verification tubes adjacent to the tile holes themselves. The radiation field measurements were consistent with expected radiation fields in the tile holes based on administrative knowledge of the radioactive contents and their corresponding decay rates. Such measurements allow non-invasive verification of tile hole contents and provide input to the assessment of radiological risk associated with removal of the waste. Using this detector system, radioactive waste that has decayed to very low levels may be identified based on the radiation profile. This information will support planning for possible transfer of this waste to a licensed waste storage facility designed for low level waste, thus freeing storage space for possible tile hole re-use for more highly radioactive waste.

1. Introduction

Waste Management Areas (WMAs) at AECL's Chalk River Laboratories (CRL) have several arrays of tile holes for storing solid canned waste including waste from medical radioisotope production at CRL and at MDS Nordion, covering a range of relatively short lived to relatively long lived radioisotopes. A miniature detector that could be deployed into narrow verification tubes adjacent to the tile holes and have a fairly wide range of sensitivity to gamma fields is of assistance in detecting waste that has decayed to the point where it could be transferred to low level storage, thus freeing room for possible tile hole re-use for more high level radioactive waste.

A new miniature, inexpensive silicon PIN (p-type-intrinsic-n-type semiconductor) photodiode based radiation detector with a high sensitivity to gamma fields has been developed and tested at CRL for this purpose. A relatively large volume of silicon allows the new photodiode based detector to measure radiation fields from 1 mGy.h^{-1} (0.1 rad.h^{-1}) to 1 kGy.h^{-1} (100 krad.h^{-1}). The detector is small enough to be deployed within guide tubes inserted into the tile holes or the adjacent verification tubes. The instrument system described in this paper allows on-line measurement, logging, display and monitoring of gamma radiation field profiles as the detector is deployed in the field.

2. Instrument system description

2.1 Sensor

The use of Silicon (Si) p-n junction diodes, in unbiased current generation mode of operation, for high radiation field measurements have been demonstrated and a Si diode based detector capable of measuring radiation fields from 0.1 Gy.h^{-1} (10 rad.h^{-1}) to 10^{4} Gy.h^{-1} (1 Mrad.h^{-1}) was developed and successfully used at many facilities at CRL [1][2]. Using the same concept, a large area Si PIN photodiode has been demonstrated to function as a radiation detector in unbiased current mode. The particular model of photodiode was selected for its narrow (6 mm wide) profile that makes it possible to assemble it in a thin capsule, which allows access into small orifices for measurements. Additionally, the depletion region, and therefore the sensitivity of this diode is nearly a hundred times that of the p-n junction diode used in previous AECL diode-based radiation detector systems.

The Si PIN diode based detector system consists of three parts: the detector assembly, a guide tube and a signal readout system. The detector assembly shown in Figure 1 consists of the sensor inside a stainless steel casing, and a low-noise, shielded, coaxial signal cable sheathed in PolyFlow brand polyethylene tubing to provide tensile rigidity. A single pin LEMO connector at the end of the signal cable is the interface to the signal readout system.

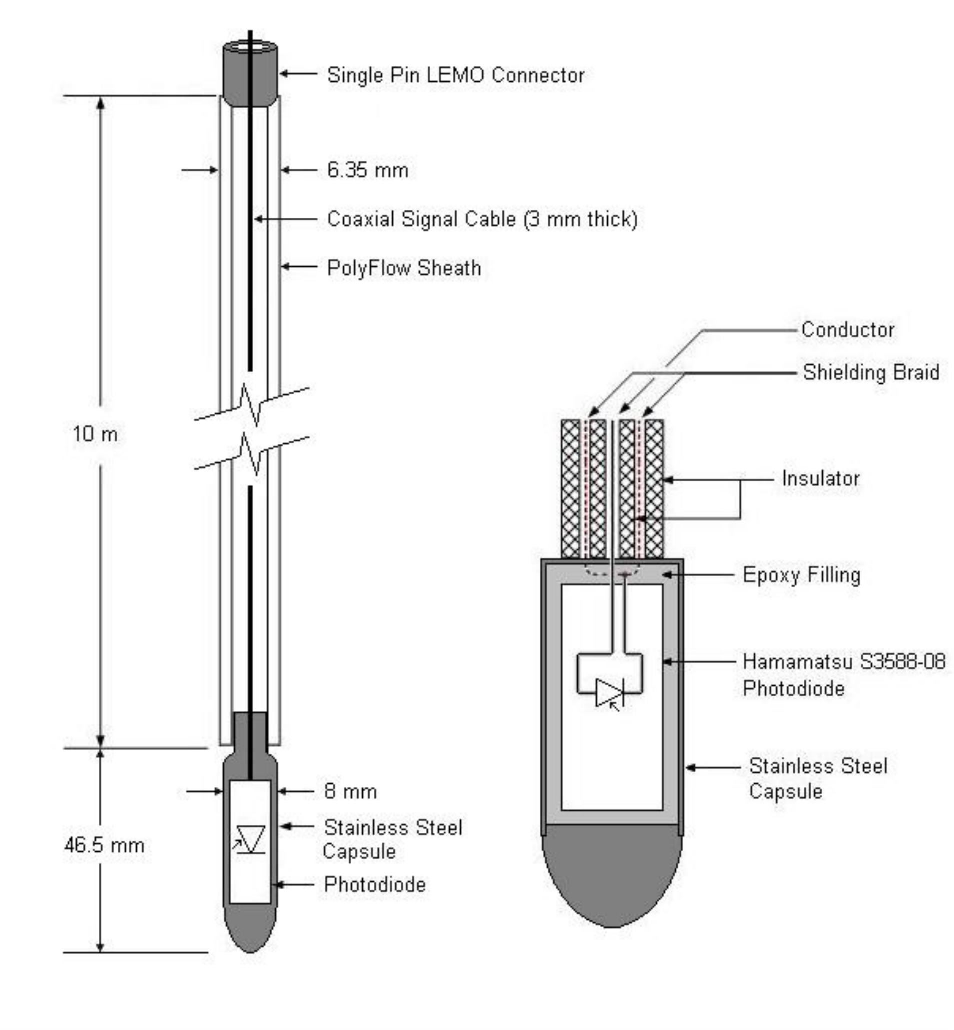

Figure 1 Detector assembly drawing

The sensor is a 6 mm x 34 mm Si PIN photodiode encased in a stainless steel 'capsule' of 8 mm outer diameter and 0.8 mm wall thickness, capped off with a 6.5 mm thick rounded tip. The capsule provides a light-tight seal for the photodiode to minimize photocurrent due to visible light, and protects it from contamination and corrosion.

2.2 Deployment and signal readout system

The probe is deployed inside a guide tube, as shown in Figure 2, to ensure an obstruction-free path and to provide an additional layer of protection from the environment and from radioactive contamination. The guide tube is a 5.3 m long stainless steel tube with 12.7 mm outer diameter and 11 mm inner diameter. The tube has a sealed rounded tip to aid the insertion into, and if necessary, navigating around the contents of the tile hole. The top end of the tube is open and fitted with a Swagelok mating attachment. A 90°-bend elbow (shown in Figure 2) and a 60°-bend elbow are available to mate with the open end of the straight tube using corresponding Swagelok fittings to allow for measurement flexibility. The additional straight guide tube pieces shown in Figure 2 can also be added as required. The 8 mm diameter detector probe is inserted through the open end of the 11 mm inner diameter guide tube assembly to position the sensor. The PolyFlow sheath is rigid enough to be pushed, while being flexible enough to pass through the guide tube elbows. The sensor position inside the guide tube is indicated by external markings on the cable near the end of the guide tube. An encoder equipped driver system that will automatically measure and track the distance traversed by the sensor to provide precise sensor position is under development.

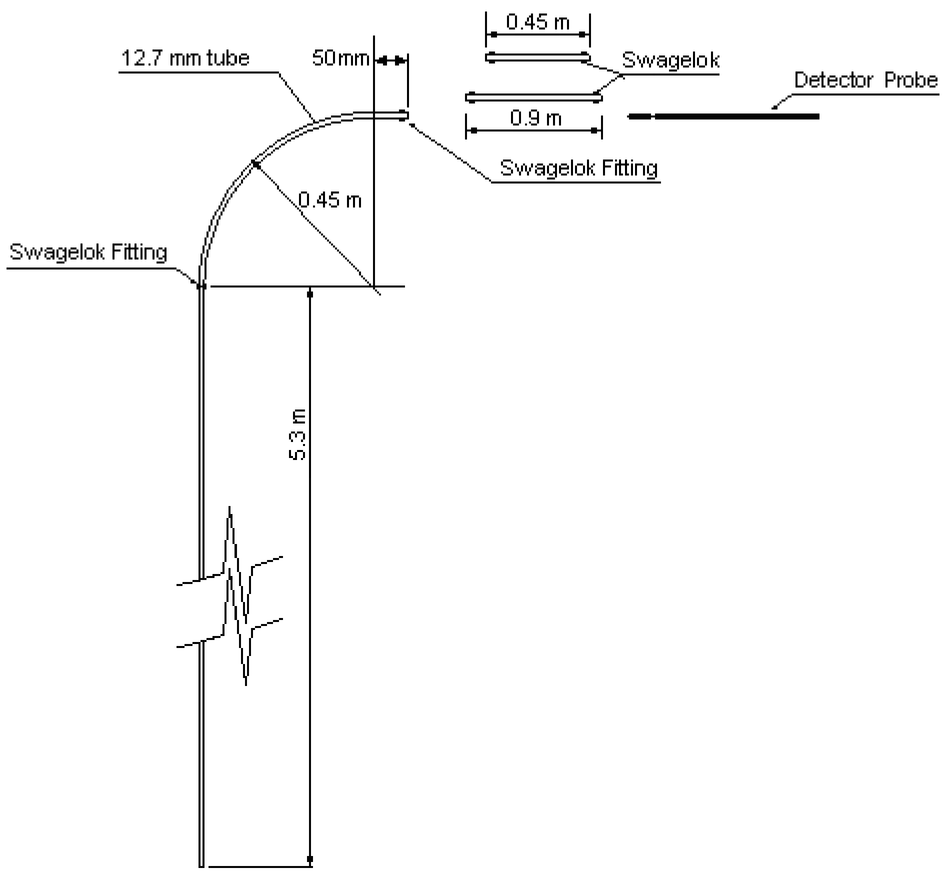

Figure 2 Guide tube assembly for deployment of sensor probe

The radiation field readout system (Figure 3) consists of an amplifier module and a data acquisition (DAQ) module. Both modules are commercial off-the-shelf components and are assembled in an instrument box. The LEMO connector of the detector assembly mates to a LEMO-to-BNC converter provided with the readout system. The analogue amplifier module converts the small input current signal to voltage and scales it with an appropriate gain factor, before it is fed to the Analog-to-Digital

Converter (ADC) in the DAQ system. The DAQ converts the input to a digital data stream and makes it available to the Human-Machine Interface (HMI) application software on a laptop computer. The HMI is a LabVIEW application that displays and logs the readings from the detector.

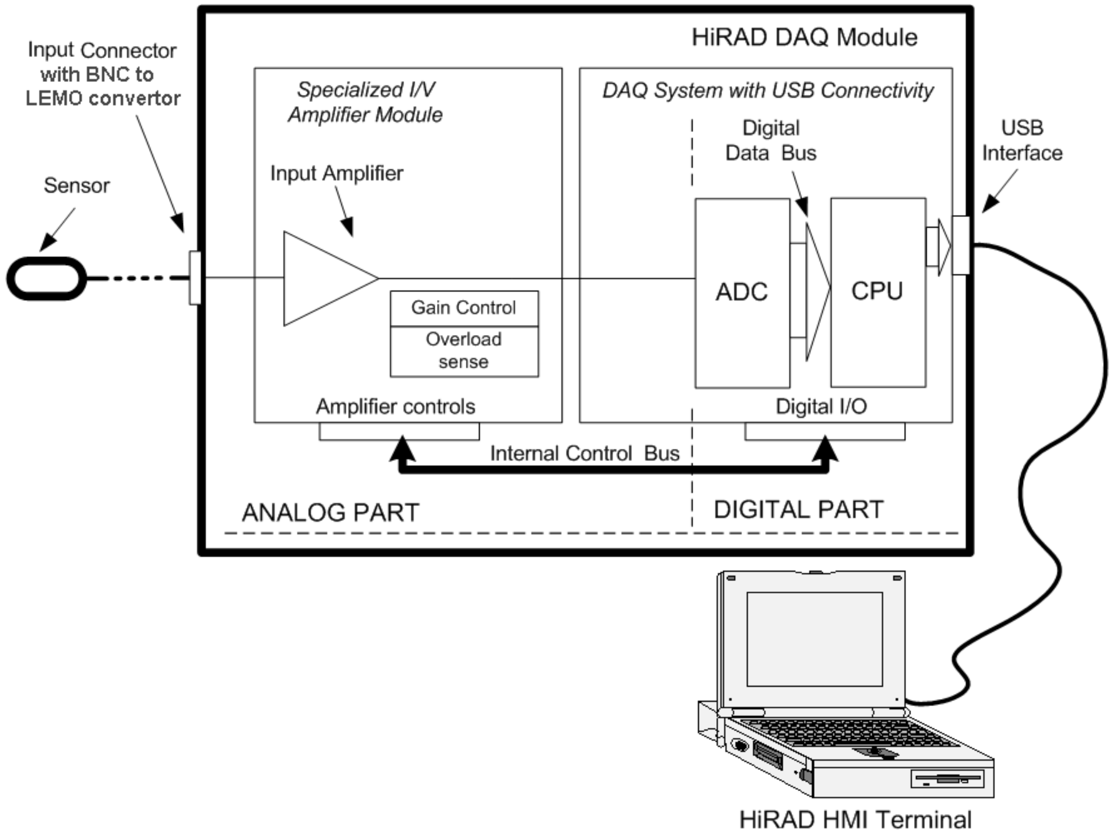

Figure 3 Readout system – equipment layout

2.3 Directionality and sensitivity

Although the stainless steel capsule containing the sensor (Figure 1) is cylindrical, the photodiode sensor within is not axially symmetric and, therefore, not equally responsive to radiation from all radial directions. The radial directional sensitivity of the detector was measured by maintaining it at a fixed location relative to a calibrated gamma beam source and rotating it along its longitudinal axis. The sensor output wanes by 22% from the orientation of peak sensitivity to that of low sensitivity (Figure 4). The orientation of peak sensitivity is marked on the casing for identification during field use.

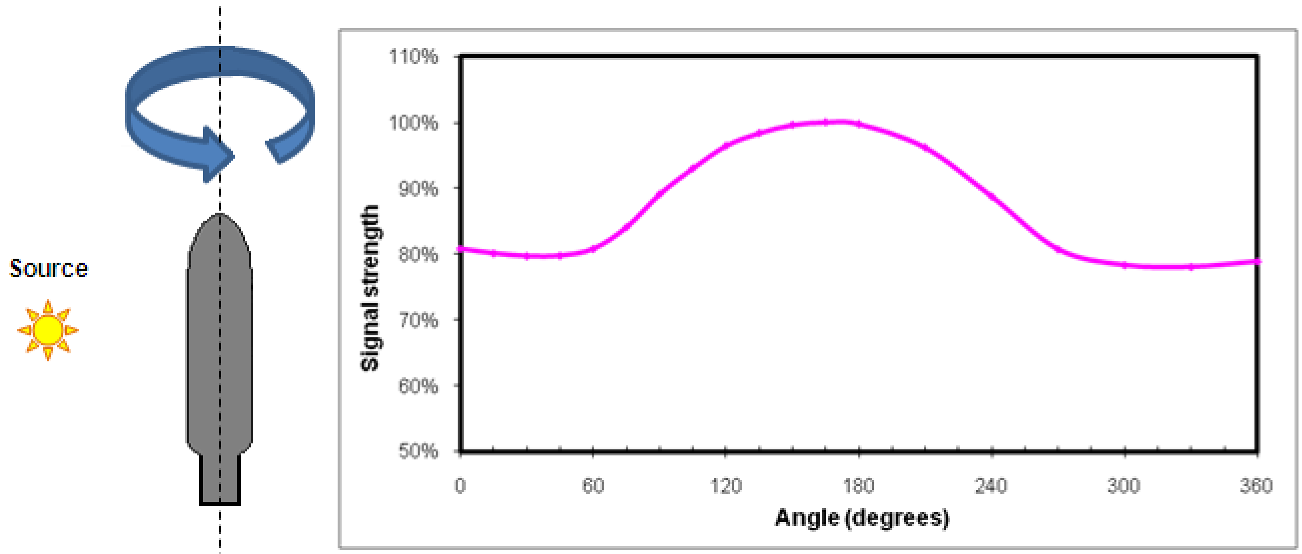

Figure 4 Rotational sensitivity of sensor

In terms of azimuthal sensitivity, about 60% of the radiation field will be measured from a source aligned with the axis of the sensor (Figure 5). At 30° azimuth angle, the signal strength improves to 85% of maximum. Maximum signal strength occurs when the source is at 90° to the direction the sensor tip.

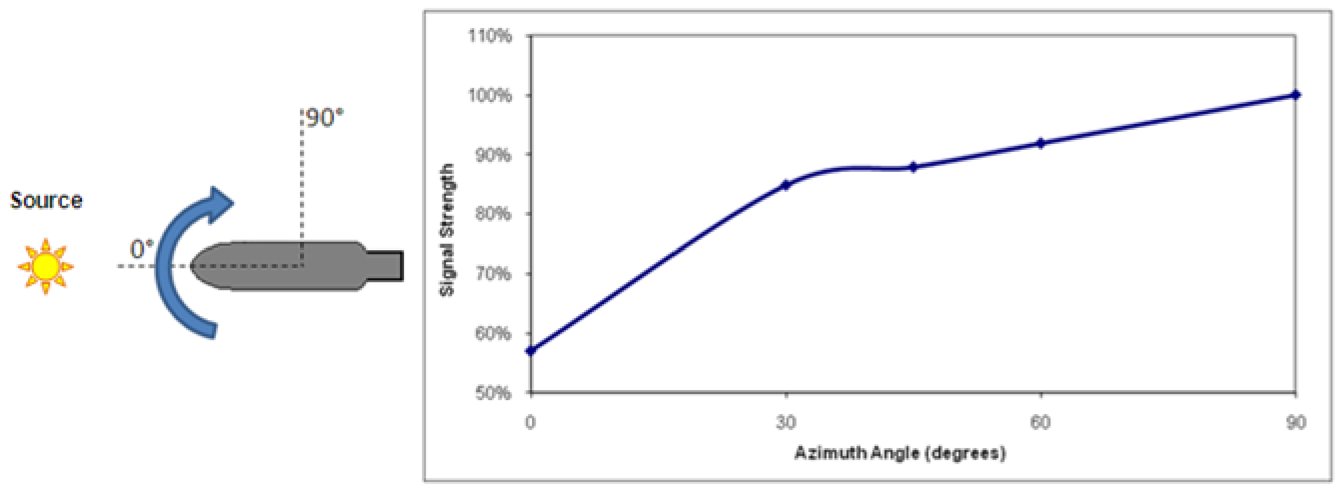

Figure 5 Azimuthal sensitivity of sensor

A dose rate study was performed to determine the relationship between radiation field and the sensor output. A calibrated Cobalt-60 (^{60}Co) gamma source was used, and the source to sensor distance was varied to control the dose rate at the sensor over a range of 1.2 mGy.h^{-1} to 1700 mGy.h^{-1}. The highly linear relationship between the dose rate of the exposed field and the photocurrent measured from the sensor (Figure 6) provides a sensitivity of 5.58 pA(mGy.h^{-1})$^{-1}$ (or 55.8 pA(rad.h^{-1})$^{-1}$). This is nearly 200 times greater than the sensitivity of AECL's p-n junction diode based detector of [1] and [2].

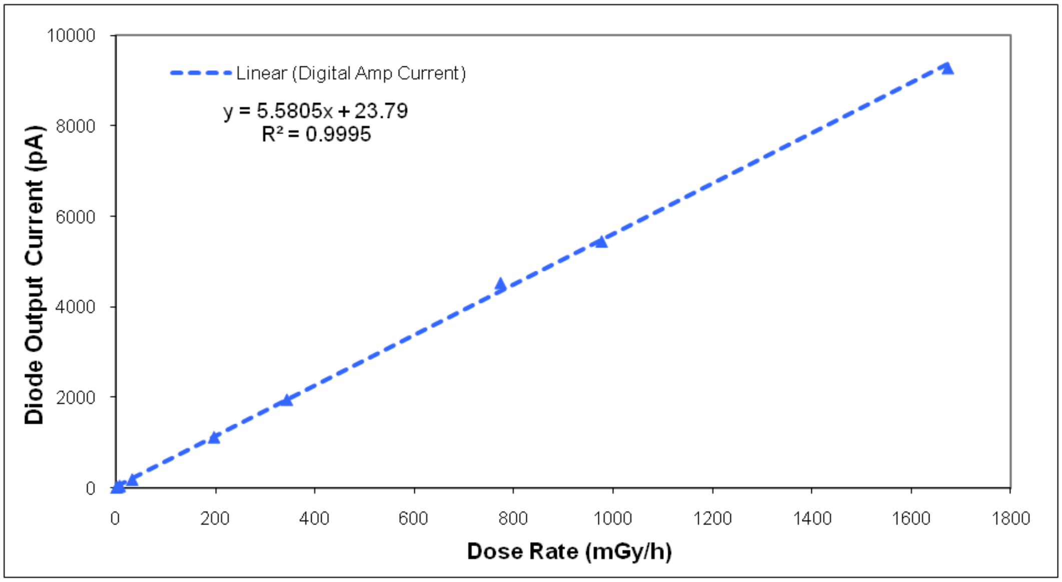

Figure 6 Dose rate calibration - photocurrent vs radiation field showing sensitivity and linearity

The sensitivity of 5.58 pA(mGy.h^{-1})$^{-1}$ is at the direction of 95% of peak sensitivity. The radial and azimuthal sensitivity variation can be accounted for by derating the sensitivity to 5 pA(mGy.h^{-1})$^{-1}$ (a derating of 10%). This is the sensitivity used for the tile hole radiation profile measurements conducted and recommended for general use. The lower threshold of the sensor is around 1 mGy.h^{-1} (100 mrad.h^{-1}). The upper end of the sensitivity range for this system is a few thousand Gy.h^{-1} (hundreds of krad.h^{-1}) and is irrelevant in this application.

The attenuation of gamma radiation due to the guide tube was measured to be 9.7% for a ^{60}Co source. This attenuation must be factored into the sensitivity as the probe is always deployed within the guide tube.

3. Radiation field profile of waste storage tile holes

3.1 Tile holes

Nuclear waste management facilities at AECL's Chalk River Laboratories (CRL) use below-ground 'tile holes' to store highly radioactive solid waste from various activities such as medical radio-isotope production. Administrative records exist detailing the contents of each tile hole, including when each can was deposited and the near-contact radiation fields from each can at the time of storage. Radiation field profiles generated using the Si PIN diode based detector system can be used to verify administrative records and identify tile holes whose contents have decayed to very low levels. This very low level radioactive waste can be extracted from the tile holes and transferred to a licensed above ground storage facility for low level waste, thus freeing space for possible tile hole re-use for more highly radioactive waste.

Figure 7 shows the structure of the tile holes at AECL's WMAs. The tile holes are sealed with a removable cap and concrete plug. A verification tube is built beside each tile hole for performing certain measurements and analysis.

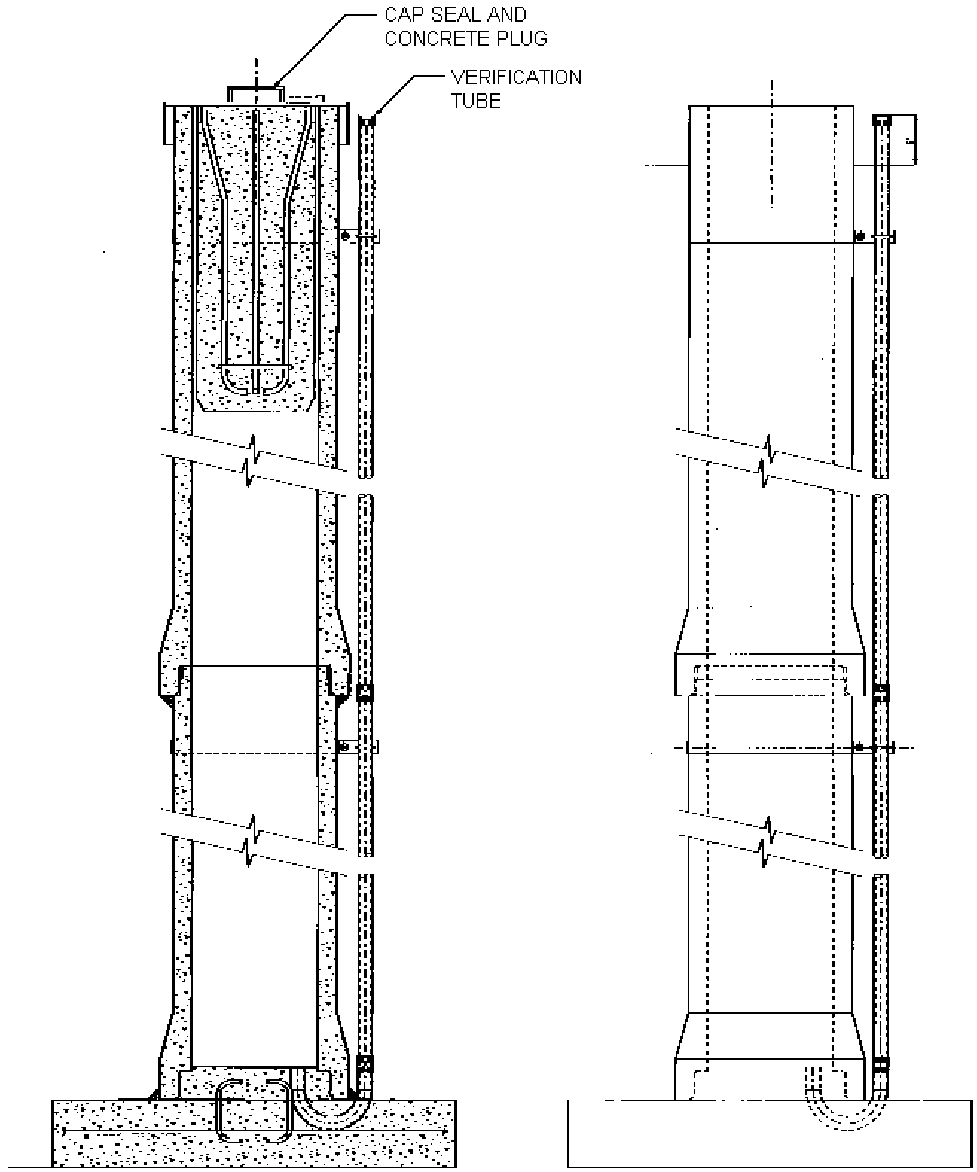

Figure 7 Structural drawing of below ground solid nuclear waste storage tile hole at AECL CRL

Taking readings from the verification tube is a less involved procedure than accessing the tile hole itself; however the accuracy of the readings from such measurements has not been tested. There is a significant amount of concrete between the tile hole interior and the verification hole which acts as shielding. Efforts are underway to calculate the shielding effect, hence the relationship between fields inside the tile hole and those measured in the verification tube. It is intended to confirm this relationship in the future by direct measurement.

3.2 Radiation profile measurement and results

A set of radiation profile measurements were performed via the verification tubes in October 2009. The objective was to measure the radiation fields detectable through the tile hole shielding and verify the general fields from selected tile holes. The detector probe was lowered to the bottom of the verification tube and then brought up in intervals of six inches, while recording the detector signal. The graphs presented in this section plot the measured dose rate against height from the bottom of the verification tube, which is nominally the same level as the bottom of the tile hole. Solid radioactive waste is stored in the tile holes in cans, with 9 cans stacked vertically in each tile hole. The differing content of each can is reflected in the structure of the radiation profiles.

Figure 8 presents the results of the radiation profile scan performed in a verification tube next to a tile hole containing medical radioisotope production waste from MDS Nordion. The contents of this tile hole were expected to be fairly high level, and this is reflected in the radiation profile by the peaks of 200 $mGy.h^{-1}$ at around 0.4 m and 3800 $mGy.h^{-1}$ at around 2.5 m. These values were measured in the verification tube; the radiation levels within the tile hole itself are higher.

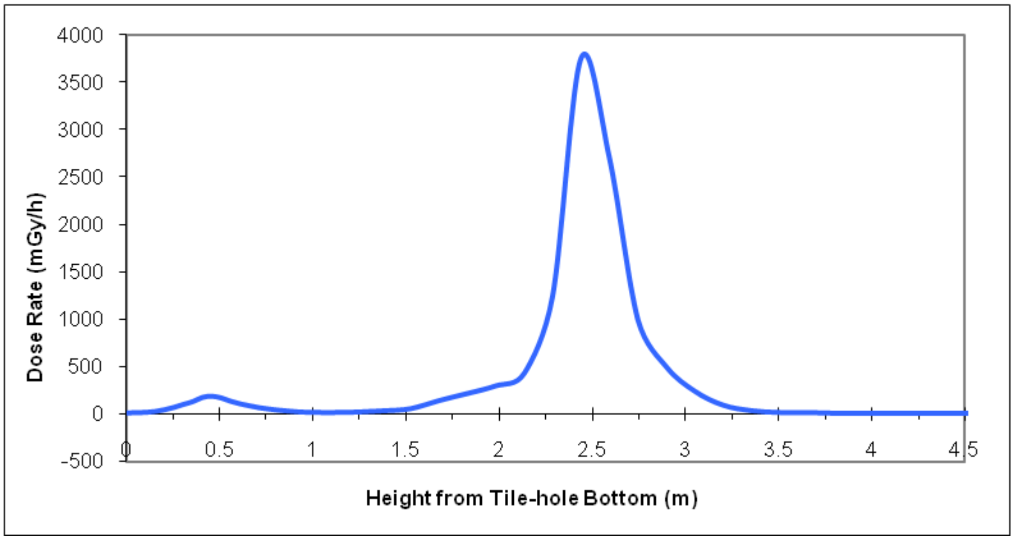

Figure 8 Radiation profile in verification tube next to a tile hole containing Nordion waste

Figure 9 presents the radiation profile measured in a verification tube next to a tile hole that contains low level cell waste from the production of Strontium-82 at MDS Nordion. The highest dose rates recorded are below 5 $mGy.h^{-1}$, i.e. several orders of magnitude lower than those in Figure 8.

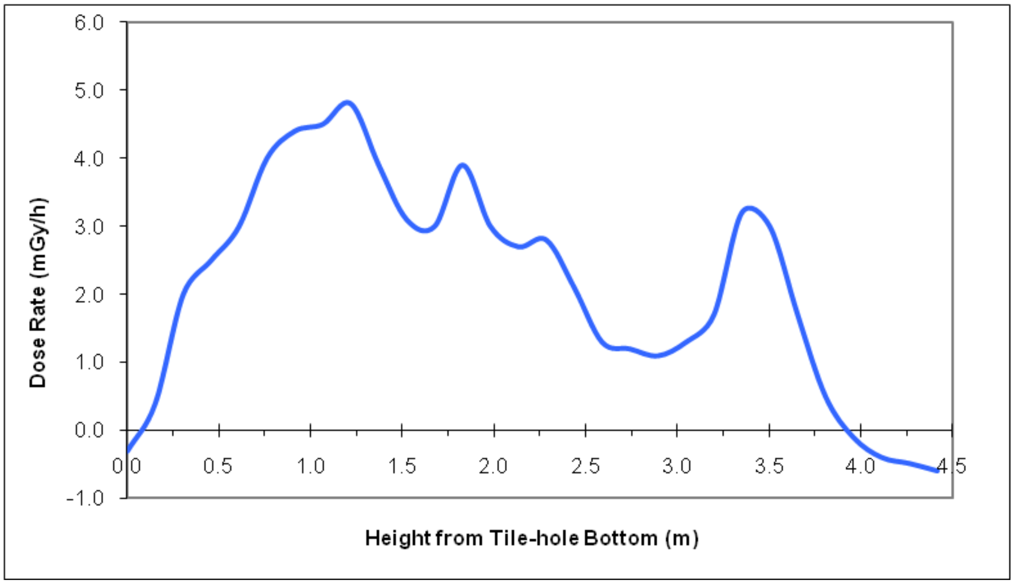

Figure 9 Radiation profile in verification tube next to a tile hole containing low level Strontium waste

The fact that the radiation fields from the Strontium waste storage tile hole are several orders of magnitude lower compared to the Nordion waste in Figure 9 agrees with expectations based on administrative records of the tile hole contents. As noted, the sensor has a low end sensitivity limit of around 1 mGy.h^{-1}, thus readings in Figure 9 below this sensitivity threshold of the instrument are attributable to noise.

4. Conclusions

Nuclear waste storage facilities at AECL use below-ground tile holes to store solid waste from a number of nuclear operations. A miniature detector that could be deployed into narrow verification tubes adjacent to the tile holes and have a fairly wide range of sensitivity to gamma fields is of assistance in detecting waste that has decayed to the point where it could be transferred to low level storage, thus freeing room for possible tile hole re-use for more highly radioactive waste.

A Si PIN photodiode based gamma radiation scanning system has been developed and used to profile the gamma radiation fields along the depth of solid nuclear waste storage tile holes at AECL. The detector assembly consists of the sensor, a signal transmission cable, cable connector, and a PolyFlow sheath for the cable. The detector is always deployed inside a stainless steel guide tube to provide a straight path free of obstacles and an additional layer of protection from contamination. The directionality, sensitivity and linearity of the detector response have been well studied and documented.

The photodiode detector system was used to generate radiation field profiles along the depth of two waste storage tile holes at AECL's Waste Management Area B in Chalk River. The radiation measurements were executed by deploying the sensor into verification tubes adjacent to the tile holes. The measurements were consistent with expected radiation fields in the tile holes, based on administrative knowledge of the contents. This is a successful first step in an endeavour to accurately determine the near-contact radiation fields of low level tile hole contents to assess withdrawal and transfer of the waste to a licensed storage facility designed for low level waste, and free space for possible tile hole re-use for higher level radioactive waste.

5. Acknowledgements

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6. References

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