Innovation at the UK's National Nuclear Laboratory: Development of the HiRAD Technology – 10377

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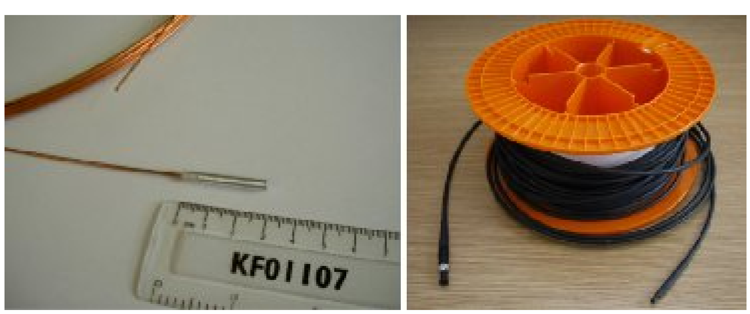
ABSTRACT

This paper presents the results of the first plant trial of the National Nuclear Laboratory (NNL) HiRAD technology (patent pending) which has been developed using the NNL's own Internal Research and Development (IR&D) fund. The HiRAD technology has been developed as a non-electrical radiation detector suitable for deployment on nuclear facilities with elevated levels of radiation (i.e. thousands and tens of thousands of Gray per hour). The technology has the potential to offer customers increased insight into their process operations with cost effective, timely radiation level mapping with reduced radiation exposure to man. Moreover, the HiRAD's resistance to radiation allows it to be used for radiation based plant monitoring on highly active waste processing and storage facilities.

The HiRAD has been successfully demonstrated on the breakdown cell of line 1 in the Highly Active Waste Vitrification Plant (WVP) on the UK Sellafield site. Prior to deployment in the breakdown cell, the HiRAD device was calibrated with low and high level radiation sources at Tracerco Ltd (UK) laboratories and the National Physical Laboratory respectively. During this calibration the HiRAD technology was shown to be sensitive over the radiation range of 0.01 to 8,580 Gy hr^{-1} (currently the highest dose calibration facility HiRAD has been tested in). Although un-tested, the HiRADs upper radiation limit is estimated at 100,000 Gy hr^{-1}. The HiRAD radiation results from the deployment trial have been presented on a 3D visualisation of the breakdown cell. The HiRAD deployment trial has identified that the radiation levels in the breakdown cell are of lower magnitude than previously estimated by the customer and it is concluded that the dose rate estimates were too conservative and pessimistically evaluated cell conditions.

INTRODUCTION

Decommissioning challenges in the worldwide nuclear industry require the development of innovative new technology to enable the characterisation of radiation hazards in a wide variety of scenarios. These unique challenges are being addressed by the NNL through its self investment Internal Research and Development (IR&D) programme. HiRAD does not require any electrical components which gives it the ability to operate in elevated levels of radiation. Hi-RAD is a real-time, remotely deployed, radiation detector developed to operate in elevated levels of radiation (i.e. thousands and tens of thousands of Gray per hour). The device consists of a small scintillating crystal coupled to a variable length metal coated fibre optic cable. Scintillation light produced from the crystal in a radiation field is transmitted down the fibre optic cable, detected by a suitable photon detection system, recorded on PC software and used to infer the radiation levels of the environment that the device is deployed in. Figure 1 illustrates the HiRAD used for the WVP technology deployment trial.



(a) (b)

Figure 1: Photographs of: (a) HiRAD 'Head' (b) HiRAD fitted with protective sheath.

The small dimensions and flexibility of the device allow it to be deployed down small, difficult to access areas (such as pipe work). The HiRAD technology can be deployed as a single detector, a chain, or as an array giving the ability to monitor large process areas. The device is seen a key enabler to reduce project costs with timely radiation level mapping and reduced radiation exposures to man.

This report details the deployment trial of the HiRAD technology in the breakdown cell of line 1 in the Highly Active Waste Vitrification Plant (WVP) on the Sellafield Site in the UK.

HiRAD CALIBRATION

In order for the device to be accurate and operational in detecting unknown radiation levels, the device must be fully calibrated prior to deployment. For the purposes of this investigation, two laboratories were selected to conduct both low and high radiation calibration experiments:

- Tracerco Laboratory: Calibration of the device was performed using low dose ^{60}Co and ^{137}Cs sealed sources. Estimated to give doses between 0.01 - 4 Gy hr^{-1}.
- UK National Physical Laboratory: High dose ^{60}Co irradiator with a dose of 8,580 Gy hr^{-1}.

Low Level Radiation Calibration: Tracerco Laboratory

Three HiRAD devices (A, B & C) were calibrated using sealed ^{60}Co and ^{137}Cs sources at Tracerco Ltd. Multiple devices were constructed to gain experience in determining the ability of different devices to deliver consistent results. Figure 2 shows the count rate from the light detection system for low dose radiation levels for HiRAD devices A, B and C. It is noted that the total count rate (area under the curve) differs by ± 15% between the devices. This difference is due to manufacturing variations in the HiRAD devices (most probably caused during the procedure of securing the crystal to the fibre optic cable). However, because each device is calibrated individually, this does not pose an issue during actual deployments.

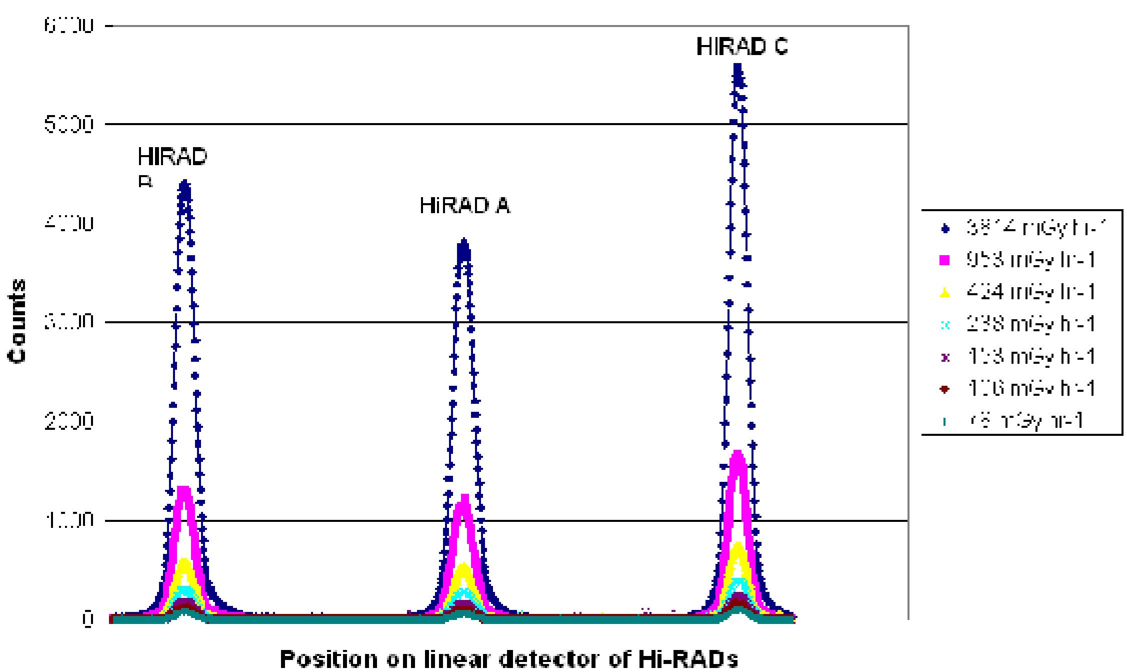


Figure 2: Calibration Graphs of HiRADs (A, B & C) With Low Dose Sources (Tracerco Laboratory).

Figure 3 is a calibration graph of the total counts vs. dose for HiRAD devices A, B and C (plotted on a log scale). The results demonstrate a linear relationship between radiation dose and the scintillation light.

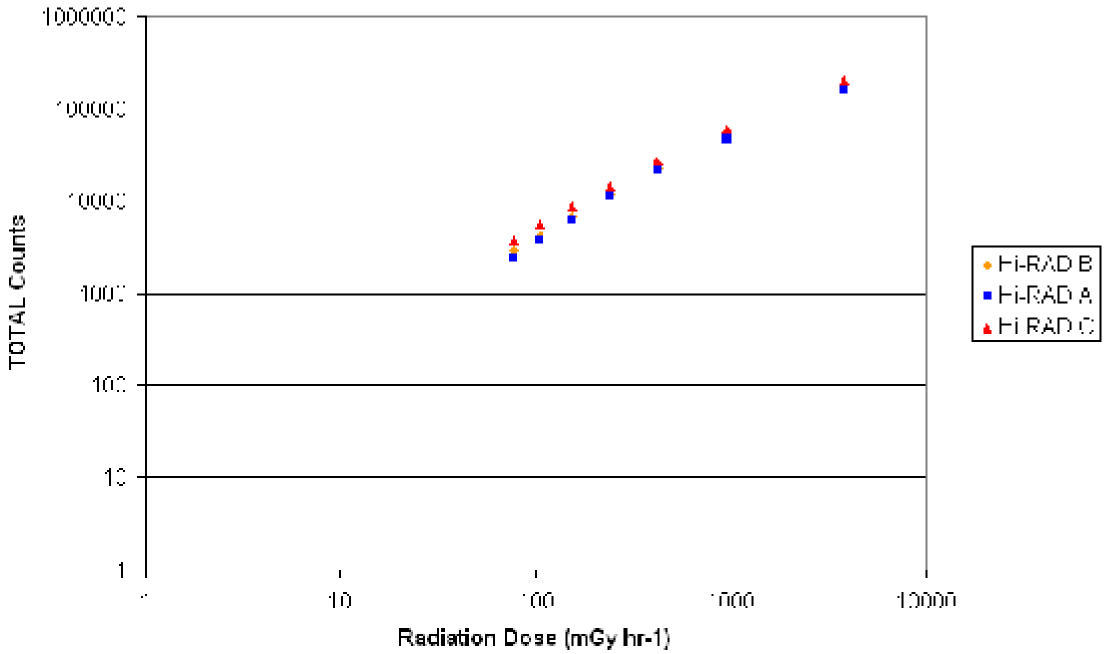


Figure 3: Calibration Graph (Log Scale) for HiRAD at Low Radiation.

High Level Radiation Calibration: National Physical Laboratory (NPL)

High radiation calibration of the HiRAD device was completed with a ^{60}Co Gammacell Irradiator at the NPL. The NPL Co-60 Gammacell Irradiator delivers a maximum radiation dose of 8580 Gy hr^{-1}. One additional data point was also recorded by positioning the HiRAD at a raised position above the chamber pot inside the irradiator. The radiation dose was estimated at this position with the use of chemical dosimetry alanine pellets that were wrapped around the HiRAD head. The radiation dose recorded with the alanine pellets at this position was calculated at approximately 200 Gy hr^{-1}.

For HiRAD operation in elevated levels of radiation it is necessary to connect a fibre optic patchcord to the end of the fibre optic cable before attachment to the light detection system. The smaller diameter patchcord limits the amount of scintillation light reaching the camera and avoids saturation of the light detection equipment. Figure 4 shows the effect of connecting a fibre optic patchcord to the same HiRAD device at a dose of 200 Gy hr^{-1}). The pink curve (max. count rate approx. 55000) is with no patchcord connected to the HiRAD device. This radiation dose corresponds to the upper limit of the HiRAD device without a patchcord. However, the reduced count rate blue curve (max. count rate approx. 300) represents the HiRAD device with the patchcord fitted. The slight noise associated with this curve is due to the reduction in light being transmitted to the camera and is reduced when the HiRAD is exposed to increased radiation levels.

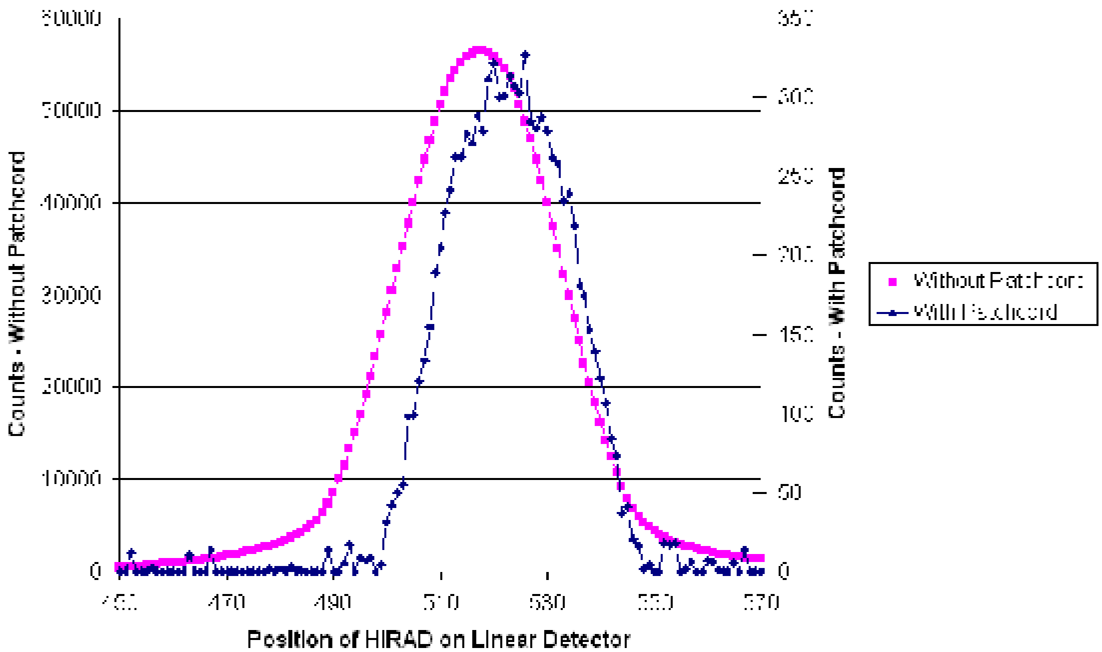


Figure 4: HiRAD Performance at 200 Gy hr^{-1} Fitted With & Without Patchcord.

Figure 5 is a plot of the count rate for a HiRAD deployed four times in a 8580 Gy hr^{-1} radiation environment. It is noted that the total recorded light count for each of these repeat deployments are within 4% of each another. This uncertainty is considered negligible when interpreted into a radiation dose rate.

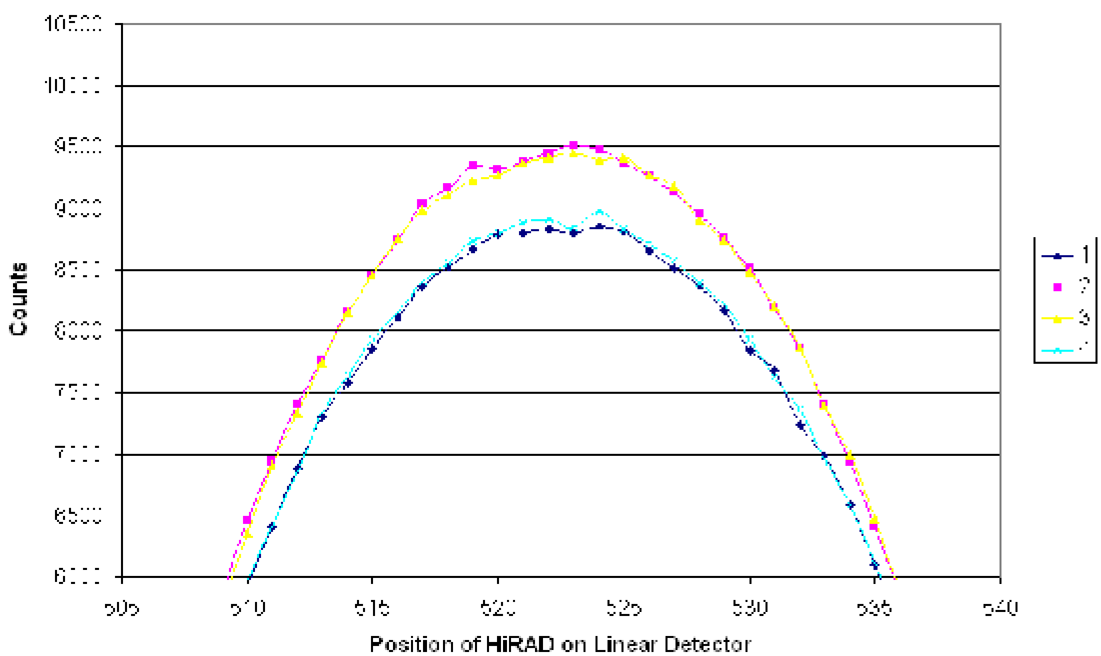


Figure 5: Counts for HiRAD Deployed Four Times in a 8580 Gy hr^{-1} Radiation Environment.

Figure 6 is a calibration graph plot of the two radiation exposures completed at the NPL using the ^{60}Co irradiator. Whilst there are only three data points available (including data point 0, 0) for the plot it is assumed that the linear relationship can be extrapolated up to these increased radiation level environments.

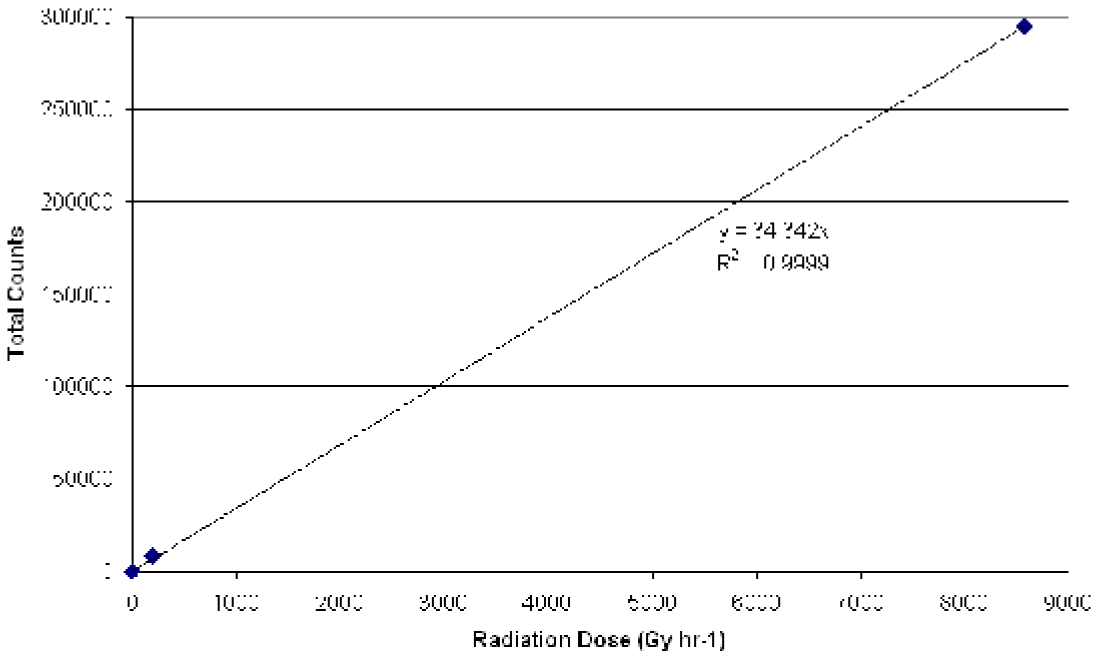


Figure 6: Calibration Graph for NPL Irradiations.

Figure 7 shows the combined calibration graph for all calibration experiments completed during this technology trial. For radiation doses between 0.01 and 10 Gy hr^{-1} the left hand side of the graph is utilized. For radiation doses anticipated to be above 10 Gy hr^{-1} it is advised to fit the fibre optic patchcord to the HiRAD device and use the right hand side of the graph to interpret the unknown radiation levels.

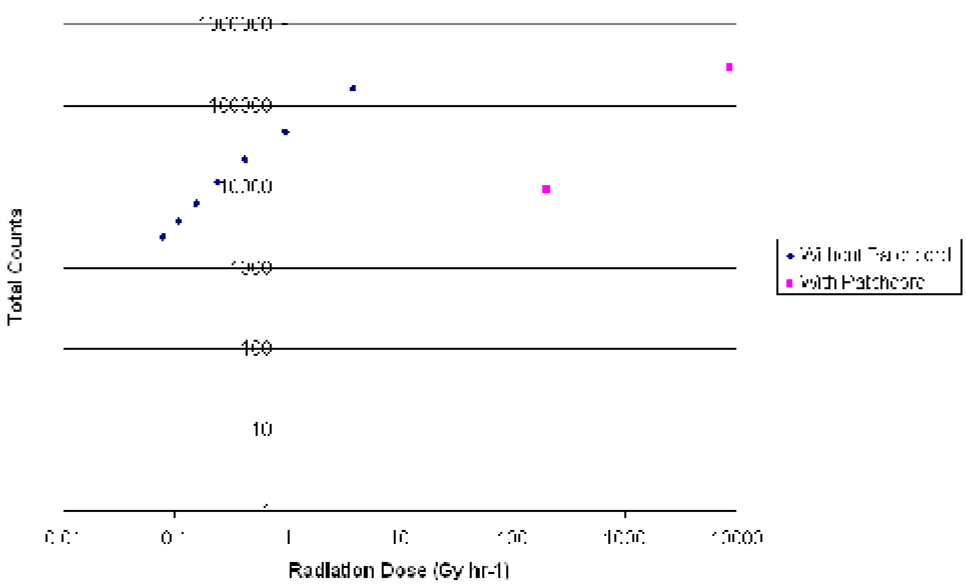


Figure 7: HiRAD Calibration Graph for Low & High Dose Radiation Experiments (Log Scale).

HiRAD DEPLOYMENT: WVP BREAKDOWN CELL LINE 1

Figure 8 is a photograph of the operating area of the breakdown cell in line 1 of the WVP.

Figure 8: Photograph of the Operating Area of the WVP Breakdown Cell Line 1.

The largest single source of radiation of concern is a full product container of PWR fuel. Breakdown cell high activity (HA) waste is also present in the form of used plant items such as dust scrubbers, filter systems, melter heels and used plant equipment. For guidance, WVP Technical provided an estimation of the dose within line 1 breakdown cell well in excess of 1000 Gy hr^{-1} however, to date no other radiation detector has been able to be deployed in this environment.

A single HiRAD device was used to map the radiation intensities over a given volume within the breakdown cell of line 1 in the WVP. The HiRAD was posted in to the breakdown cell via an existing access point. More specifically the HiRAD device was deployed into the cell using an existing traverse which consists of a tube of ~30 mm diameter which feeds wires from the cell face into the cell. Figure 9 shows the deployment port used for insertion of the HiRAD device into the breakdown cell. Then, the device was 'picked up' by a Master Slave Manipulator (MSM) and manoeuvred around the breakdown cell (to a number of heights and depths) thus providing multiple point measurements of radiation intensity.

(a) (b)

Figure 9: Photographs of Deployment Port (a) Low Magnification (b) High Magnification.

After initial completion of recording radiation dose measurements, the HiRAD technology was re-tested after 24 hours and then 2 weeks later to determine if there was any degradation in signal over these time periods. Upon completion of the trial the HiRAD was sacrificed and retained in the breakdown cell. Figure 10 shows images taken from the cell windows during the deployment. Annotated on these images are the points at which radiation measurements were made with the HiRAD technology.

Figure 10: Photographs of the WVP Breakdown Cell Taken from the Operating Windows.

The NNL constructed three-dimensional images of the breakdown cell in Autodesk Inventor and the HiRAD recorded radiation doses overlaid (see Figure 11 and Figure 12). These images have been created from a basic schematic drawing of the cell, images taken through the cell windows and general arrangement drawings. Due to the operational nature of the breakdown cell and lack of detailed reference data, the images have not been drawn to scale and are designed only to be an effective visual representation of the breakdown cell for the customer.

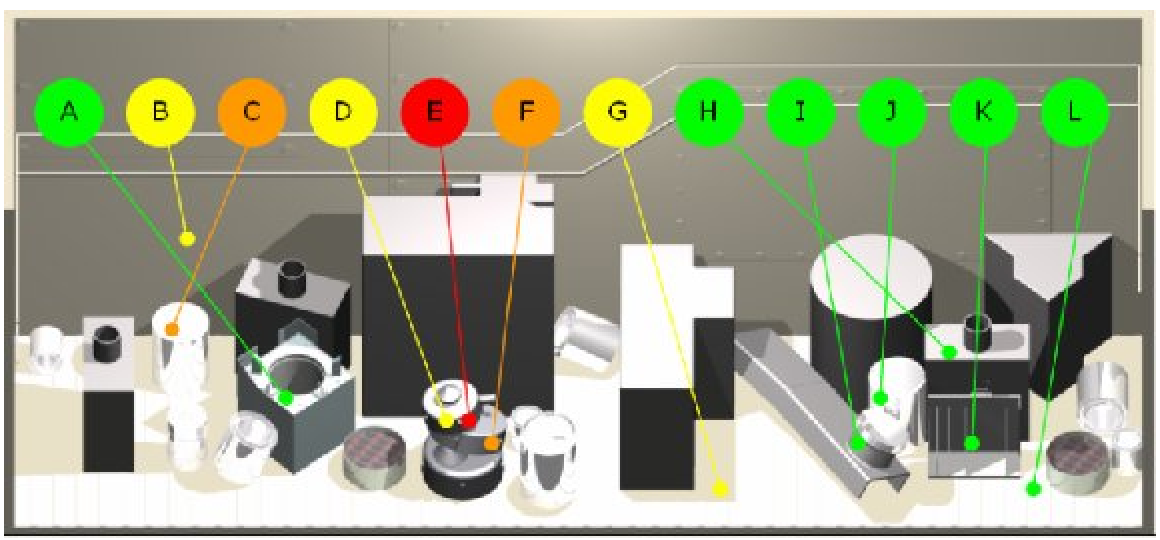


Figure 11: 3D Visualisation of WVP Line 1 Breakdown Cell - Image 1.

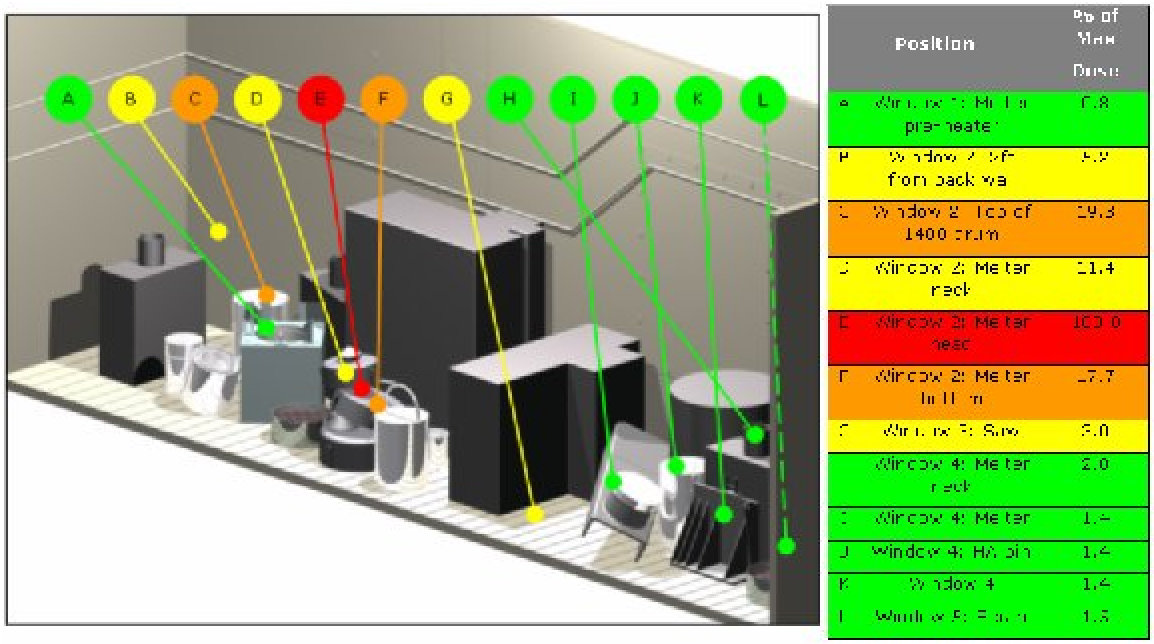


Figure 12: 3D Visualisation of WVP Line 1 Breakdown Cell - Image 2.

HiRAD radiation readings were obtained by calculating the total light count rate at each of the desired positions in the breakdown cell. With the aid of the HiRAD calibration graphs the total count rate data is interpreted into a radiation dose rate. The HiRAD responded well to the levels of radiation in the breakdown cell. The actual recorded dose rates for the equipment items monitored during the trial are classified as restricted information however, for the purposes of this publication the radiation doses have been illustrated in the above figures as percentages of the maximum recorded dose: Colours: Red = 100%, Orange = 15 – 25%, Yellow = 2 – 15%, Green = 0 – 2% of the maximum recorded dose.

The HiRAD was left in position for a period of 24 hours and re-testing after this time period indicated that there was no detrimental effect to the technology and the recorded results. The HiRAD was also left in-situ for a further 2 weeks. A re-test of the technology after this time period proved inconclusive as during the interim period, equipment in the breakdown cell had been relocated and positioned on top of the HiRAD leaving it unable to be moved around the cell by MSMs. It is a reasonable assumption that this movement of equipment left the HiRAD device damaged at the head/fibre optic connection and thus further testing was not possible.

At the end of the technology trial the fibre optic cable was cut and the cable sacrificed in the breakdown cell. The subsequent removal of the remaining HiRAD equipment (camera, laptop etc) from the operating plant posed no issues or challenges.

CONCLUSIONS

The HiRAD technology trial has demonstrated that the HiRAD can easily and effectively be deployed in the breakdown cell of line 1 in the Sellafield Waste Vitrification Plant. With the appropriate pre-deployment paperwork and job preparation work completed, the time from arrival at the operating face to obtaining first results can be completed within 30 minutes.

The successful HiRAD deployment trial has shown that the radiation levels in the breakdown cell are of lower magnitude than previously estimated. It is concluded that the previous radiation dose estimation calculations were too conservative and pessimistically evaluated the conditions in the breakdown cell.

The HiRAD device remained fully operational after 24 hours. Further re-test work was planned after a time period of 24 hours, however further data collection was impossible due to damage sustained to the device during breakdown cell operations during the interim time period.

The HiRAD device has a calibrated range of between 0 to 8580 Gy hr^{-1} and an estimated working range of between 0 to 100,000 Gy hr^{-1}.

HiRAD devices can be manufactured with suitable operational accuracy as demonstrated by calibration graphs, although this uncertainty is eliminated by calibrating individual devices. The technology is easy to transport on and off site with the detector head being sacrificial in order to reduce the risk of contamination.

ACKNOWLEDGMENTS

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