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Control Testing of the UK National Nuclear Laboratory's RadBall Technology at Savannah River National Laboratory - 10080

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ABSTRACT

The UK National Nuclear Laboratory (NNL) has developed a remote, non-electrical, radiation-mapping device known as RadBall (patent pending), which offers a means to locate and quantify radiation hazards and sources within contaminated areas of the nuclear industry. To date, the RadBall has been deployed in a number of technology trials in nuclear waste reprocessing plants at Sellafield in the UK. The trials have demonstrated the successful ability of the RadBall technology to be deployed and retrieved from active areas. The positive results from these initial deployment trials and the anticipated future potential of RadBall have led to the NNL partnering with the Savannah River National Laboratory (SRNL) to further underpin and strengthen the technical performance of the technology.

RadBall consists of a colander-like outer shell that houses a radiation-sensitive polymer sphere. It has no power requirements and can be positioned in tight or hard-to reach places. The outer shell works to collimate radiation sources and those areas of the polymer sphere that are exposed react, becoming increasingly less transparent, in proportion to the absorbed dose. The polymer sphere is imaged in an optical-CT scanner which produces a high resolution 3D map of optical attenuation coefficients. Subsequent analysis of the optical attenuation maps provides information on the spatial distribution and strength of the sources in a given area forming a 3D characterization of the area of interest.

This study completed at SRNL addresses key aspects of the testing of the RadBall technology. The first set of tests was performed at Savannah River Nuclear Solutions' Health Physics Instrument Calibration Laboratory (HPICL) using various gamma-ray sources and an x-ray machine with known radiological characteristics. The objective of these preliminary tests was to identify the optimal dose and collimator thickness. The second set of tests involved a highly contaminated hot cell. The objective of this part of the testing was to characterize a hot cell with unknown radiation sources.

The RadBall calibration experiments and hot cell deployment completed at SRNL were successful in that for each trial, the technology was able to locate the radiation sources. The NNL believe that the ability of RadBall to be remotely deployed with no electrical supplies into difficult to access areas of plant and locate and quantify radiation hazards is a unique radiation mapping service. The NNL consider there to be significant business potential associated with this innovative technology.

INTRODUCTION

The consequences of radiological operations at various U.S. Department of Energy (DOE) sites have resulted in substantially contaminated facilities (e.g., reactors, fuel and isotope processing facilities, laboratories, hot cells, gloveboxes, etc.). These facilities are usually associated with extremely high dose rates and, therefore, it is imperative to use remote technologies for characterization and decommissioning to keep worker exposures as low as reasonably achievable in these highly contaminated environments. Although technologies might exist in other industry applications that could be tested, modified, and deployed for characterization and decommissioning efforts throughout the DOE complex, development of new and innovative technologies is also needed. In addition, even though it might be possible to complete these tasks without remote/robotic systems, the benefits of remote systems to safety/ALARA and cost/schedule are expected to be substantial. A critical initial step in planning and implementing decontamination and decommissioning of contaminated facilities involves the development of an accurate assessment of the radiological, chemical, and structural conditions inside of the facilities. These conditions are often unknown for many of these facilities. Radiological and chemical contamination, as well as structural deterioration of such facilities presents risks to workers, which must be mitigated. To the extent that information can be collected to describe facility conditions using remote technologies, the conservatism associated with planning initial worker entry (and associated cost) can be reduced. For facilities confirmed to be high hazard, remote and robotic technologies for characterization, decontamination and decommissioning can further reduce the costs to mitigate worker risks.

Various national and international organizations (e.g., the U.S. DOE, Department of Defense, Department of Homeland Security, Nuclear Regulatory Commission, Environmental Protection Agency, and the International Atomic Energy Agency) deal with radioactive contamination on a regular basis. These organizations have expressed the need for better radiation detector systems to characterize and locate unidentified sources of radiation such as hot spots within glove boxes, hot cells, and other confined spaces where elevated radiation levels exist. These systems should provide 3D characterizations of the affected areas while having valuable properties that include low cost, robustness, and stability against falls, impacts, and extreme temperatures. In addition, the systems should be remotely deployable during the measurement/characterization process (no connecting power, communication cords or electronics) to ensure a high degree of deployability that may open up new possibilities for radiation measurement and mapping in areas of a facility, which were previously considered physically inaccessible with traditional electrical-based radiation detection systems. A suitable technology should also offer an inexpensive and safer means to perform initial radiological characterizations, in-process surveys, and final status surveys to enable effective decontamination while minimizing exposures to workers.

This study completed at Savannah River National Laboratory (SRNL) addresses key aspects of the testing of an innovative technology, RadBall; currently being developed by the National Nuclear Laboratory (NNL) in the United Kingdom. RadBall technology presents a significant opportunity to expedite initial characterization of radiologically contaminated facilities with respect to ALARA concerns, initial decontamination strategies, and costs associated with the decontamination efforts. RadBall will make radiation mapping safer and potentially more accurate and convenient than conventional detection devices, which are often much bigger and cumbersome due to their electrical components and accessories. A single RadBall can be positioned in a highly contaminated area, glove box, or hot cell and left alone to collect data instead of personnel spending valuable time carrying out manual scanning and surveying.

The device consists of a colander-like outer shell that houses a radiation-sensitive polymer sphere. The outer shell works to collimate radiation sources and those areas of the polymer sphere that are exposed react, becoming increasingly less transparent, in proportion to the absorbed dose. The polymer sphere is imaged in an optical-CT scanner which produces a high resolution 3D map of optical attenuation coefficients. The orientation of the opacity track provides the positional information regarding the source (achieved by using a reverse ray tracing technique). The activity of the detected source is assessed by quantifying the magnitude of the opacity change (which follows a linear relationship with respect to absorbed dose). There is the potential to characterize radiation sources by studying the depth of the opacity track (the measured opacity in the track over the depth of the track will follow a function that can be interpreted to estimate the characteristic energy or energies of the incident radiation source). The NNL have published information regarding RadBall development [1-3] and Duke University have published material on the characterization and optical–CT scanning of the radiation sensitive polymer, PRESAGE™ [4-7].

The first set of tests was performed at the Savannah River Site (SRS) Health Physics Instrument Calibration Laboratory (HPICL) using various gamma-ray sources and an x-ray machine with known radiological characteristics. The objective of these preliminary tests was to identify the optimal dose and collimator thickness of the RadBall. The second set of tests involved a highly contaminated operational hot cell. The objective of this part of the testing was to characterize a hot cell with unknown sources. The RadBall testing in the hot cell involved the characterization of the hot cell by using common methods such as teledetectors and smears to determine the dose rates and radionuclides present. Once this characterization was complete, RadBalls were deployed in the hot cell to obtain a comprehensive 3D characterization. Subsequently, the results from both characterization methods were compared and analyzed.

METHODS AND RESULTS

Savannah River Site Health Physics Instrument Calibration Laboratory

The HPICL at SRS contains nine Automated Irradiator Systems (See Figure 1). All of the irradiators were designed or refurbished by Hopewell Designs Incorporated to provide radiation beams of various types (beta particles, gamma rays, neutrons, and x-rays). The primary purpose of the equipment is to calibrate radiation detection instruments and test and verify personnel dosimeters. The sources and the exposures are therefore known with a high degree of certainty. The higher activity sources were ideal for the RadBall experiments since these sources provided shortened periods of exposure time. The highest ^{137}Cs and ^{60}Co sources were used for the majority of the experiments currently around 45.9 and 178 TBq (1,240 and 4,756 Ci), respectively.

Figure 1: Photograph of RadBall Positioned in Front of an Automated Irradiator System at HPICL.

Three experimental phases were completed at the HPICL which included the exposure of 45 RadBalls. Table I, Table II and Table III detail all of the experiments completed at the HPICL:

- Phase 1 experiments were primarily used to obtain information on the target dose for RadBall. Experiments were completed with a ^{137}Cs source with irradiations from 0.5 to 5 Gy and with a ^{60}Co source also with irradiations over the range of 0.5 to 5 Gy.
- Phase 2 experiments investigated the RadBall performance with different radiation sources and different collimator thicknesses.
- Phase 3 experiments investigated the ability of the RadBall technology to perform with high background levels of radiation. Un-collimated RadBall polymers were given a background radiation dose and then a second irradiation was performed with the collimator fitted.

The ^{241}Am source was used for one exposure; however, due to its low activity and therefore long exposure times, it was not used in any other test. With the exception of experiment 28 (^{241}Am exposed at a distance of 30 cm) all experiments were completed with the RadBall positioned 100 cm away from the radiation source. At 30 cm and 100 cm, the ^{241}Am source could not be considered a point source. An x-ray source was used which generated various photon energies with peaks at 166 keV, 120 keV, and 38 keV. The x-ray source was not ideal since it generated a distribution of photon energies; however, the peaks available were near the 60 keV gamma ray energy emitted from ^{241}Am. The x-ray machine offered a much higher rate of exposure than the ^{241}Am source and was therefore much more convenient in terms of exposure times.

Table I: Phase 1 Calibration Facility Experiments.

Exp.	Total Dose (Gy)	Radiation Source(s)	RadBall	Collimator Thickness (mm)
1	0.5	^{137}Cs	N-1-2	5.0
2	1.0	^{137}Cs	N-1-3	5.0
3	1.5	^{137}Cs	N-1-4	5.0
4	2.0	^{137}Cs	N-1-5	5.0
5	3.0	^{137}Cs	N-1-6	5.0
6	5.0	^{137}Cs	N-2-4	5.0
7	0.5	^{60}Co	N-2-1	5.0
8	1.0	^{60}Co	N-2-2	5.0
9	1.5	^{60}Co	N-2-3	5.0
10	2.0	^{60}Co	N-2-5	5.0
11	3.0	^{60}Co	N-2-6	5.0
12	5.0	^{60}Co	N-1-1	5.0
13	3.0	1.5 Gy ^{137}Cs + 1.5 Gy ^{60}Co (collinear)	N-3-2	5.0
14	6.0	3 Gy ^{60}Co (no collimator) + 3 Gy ^{60}Co	N-3-3	5.0
15	6.0	3 Gy 120 keV + 3 Gy 38keV x-ray (rotated 180°)	N-3-1	7.5

Table II: Phase 2 Calibration Facility Experiments.

Exp.	Total Dose (Gy)	Radiation Source(s)	RadBall	Collimator Thickness (mm)
16	2.0	1 Gy ^{60}Co (no collimator) + 1 Gy ^{60}Co	N-3-4	5.0
17	4.0	2 Gy ^{60}Co (no collimator) + 2 Gy ^{60}Co	N-3-5	5.0
18	8.0	4 Gy ^{60}Co (no collimator) + 4 Gy ^{60}Co	N-3-6	5.0
19	3.0	166 keV x-ray	N-5-5	5.0
20	3.0	2 Gy ^{137}Cs + 1 Gy ^{60}Co (collinear)	N-4-3	5.0
21	3.0	1 Gy ^{137}Cs + 2 Gy ^{60}Co (collinear)	N-5-6	5.0
22	4.0	3 Gy ^{137}Cs + 1 Gy ^{60}Co (collinear)	N-4-2	5.0
23	4.0	1 Gy ^{137}Cs + 3 Gy ^{60}Co (collinear)	N-4-1	5.0
24	3.0	^{60}Co	N-5-1	7.5
25	3.0	^{60}Co	N-5-3	10.0
26	3.0	^{137}Cs	N-5-2	7.5
27	3.0	^{137}Cs	N-5-4	10.0
28	0.5	^{241}Am	N-4-4	5.0
29	3.0	1.5 Gy 120 keV x-ray, rotated 90˚ & 1.5 Gy 38 keV	N-4-5	5.0

Table III: Phase 3 Calibration Facility Experiments.

Exp.	Total Dose (Gy)	Radiation Source(s)	RadBall	Collimator Thickness (mm)
30	3.0	1.5 Gy ^{137}Cs (no collimator) + 1.5 Gy ^{137}Cs (with collimator)	N-7-2	7.5
31	3.0	2.0 Gy ^{137}Cs (no collimator) + 1.0 Gy ^{137}Cs (with collimator)	N-8-2	7.5
32	3.0	2.5 Gy ^{137}Cs (no collimator) + 0.5 Gy ^{137}Cs (with collimator)	N-7-4	7.5
33	3.0	2.75 Gy ^{137}Cs (no collimator) + 0.25 Gy ^{137}Cs (with collimator)	N-8-5	7.5
34	3.0	2.85 Gy ^{137}Cs (no collimator) + 0.15 Gy ^{137}Cs (with collimator)	N-8-3	7.5
35	3.0	1.5 Gy ^{137}Cs (no collimator) + 1.5 Gy ^{137}Cs (with collimator)	N-7-1	10.0
36	3.0	2.0 Gy ^{137}Cs (no collimator) + 1.0 Gy ^{137}Cs (with collimator)	N-8-1	10.0
37	3.0	2.5 Gy ^{137}Cs (no collimator) + 0.5 Gy ^{137}Cs (with collimator)	N-10-3	10.0
38	3.0	2.75 Gy ^{60}Co (no collimator) + 0.25 Gy ^{137}Cs (with collimator)	N-9-1	10.0

39	3.0	2.85 Gy ^{137}Cs (no collimator) + 0.15 Gy ^{137}Cs (with collimator)	N-7-3	10.0
40	3.0	^{60}Co: Mimic a distributed source by moving the RadBall in a direction perpendicular to the line between the source and the RadBall initial position. I.e. irradiate using a ^{60}Co to deliver 0.5Gy. Then, move the RadBall by 0.5 cm and repeat a 0.5 Gy exposure until a total dose of 3.0 Gy is delivered.	N-9-2	7.5
41	3.0	^{60}Co: Repeat exp.40 moving the RadBall by 1.0 cm in each step.	N-9-3	7.5
42	3.0	^{60}Co: Mimic multiple sources that are close to each other by rotating the RadBall between each irradiation. I.e. irradiate using ^{60}Co to deliver 0.5 Gy. Then, rotate the RadBall by 5˚ and repeat exposure (0.5 Gy). Repeat this sequence until a total dose of 3.0 Gy is delivered.	N-8-6	7.5
43	3.0	^{60}Co: Repeat experiment 42 using an angle of rotation of 10˚.	N-8-4	7.5
44	6.0	^{60}Co: Irradiate RadBall with an initial dose of 1 Gy, then rotate the RadBall by 60˚ and give another 1 Gy dose. Repeat sequence until 6 irradiations have been completed and the RadBall has received a total dose of 6.0 Gy.	N-10-2	10.0
45	6.0	^{60}Co: Repeat exp. 44 with the RadBall tilted at a 45 degree angle.	N-10-1	10.0

After irradiation at the HPICL, the RadBall polymers were sent to Duke University Medical Center for optical CT scanning. The data results from the optical CT scan were subsequently analyzed with the image processing software, ImageJ.

A Selection of RadBall Irradiations from HPICL

Figure 2 shows two side view images (left) and a montage of horizontal slices moving through the RadBall top to bottom (right) produced in ImageJ from the optical CT scan data for RadBall N-2-4 (irradiated with a 5.0 Gy ^{137}Cs source from a distance of 100 cm with a collimation thickness of 5.0 mm). The top left image is a vertical slice taken from the middle of the RadBall. It shows the radiation tracks entering from the left of the RadBall at a slight angle above the horizontal. The bottom left image shows the radiation tracks penetrating into the polymer through the holes of the collimation device. The set of montage images shows radiation tracks appearing in the polymer as you move up through the stack of horizontal slices with the middle of the RadBall showing the largest number and highest intensity radiation tracks. This is consistent with aligning the radiation source to deliver the radiation dose to the middle of the RadBall.

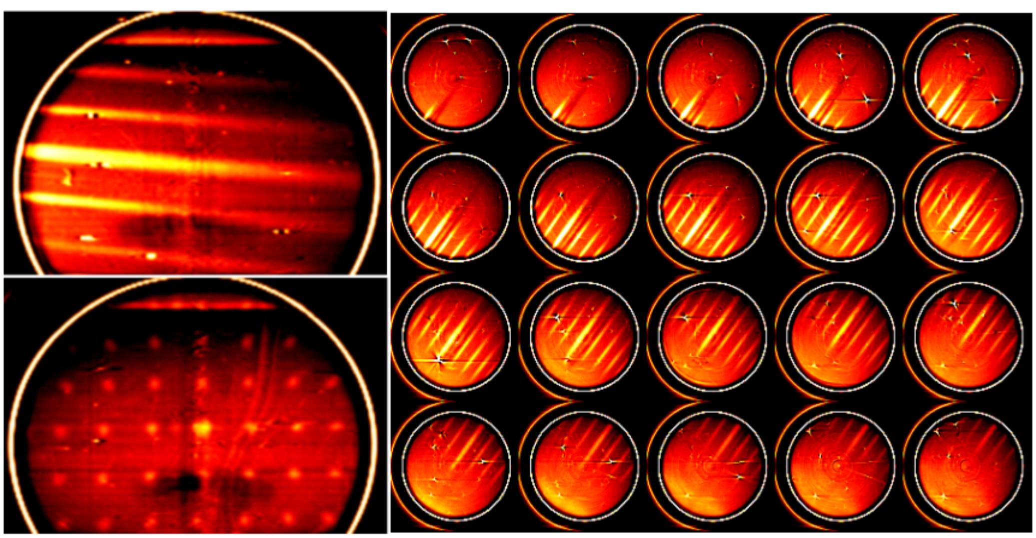


Figure 2: Example of Optical Scan Images of RadBall N-2-4.

Phase 1 experiments 1-12, produced results similar to that displayed in Figure 3 which shows images of a horizontal slice of a RadBall (N-2-4) with (a) pre and (b) post contrast enhancement applied (a feature within the ImageJ software which allows the contrast between the radiation tracks and the background to be enhanced). For both the ^{137}Cs and ^{60}Co radiation sources, the experiments demonstrated a linear response between the opacity change of the PRESAGE^{TM} polymer and the radiation dose delivered.

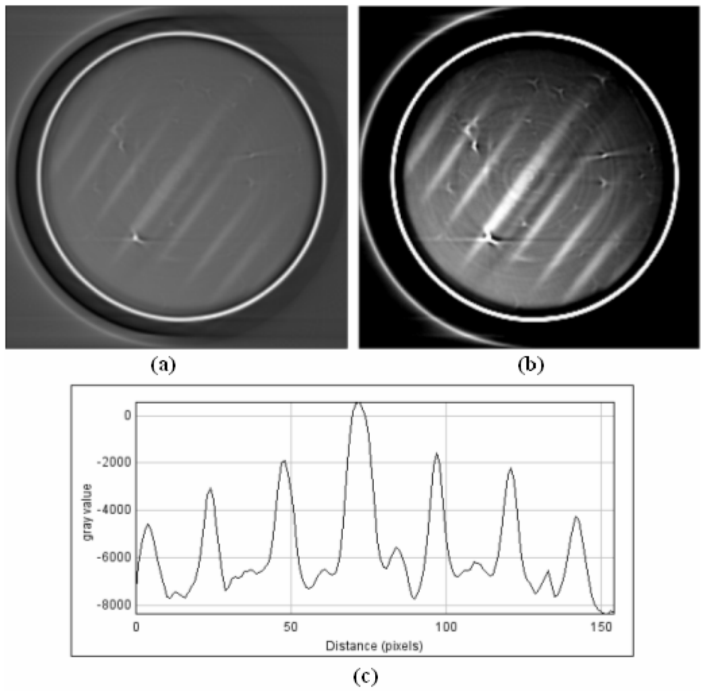
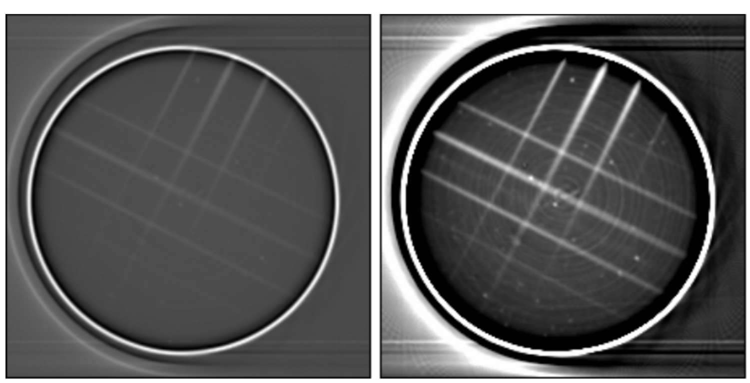


Figure 3: Images of (a) Pre and (b) Post Contrast Enhanced Slices of RadBall N-2-4 (c) Plot Profile of Tracks.

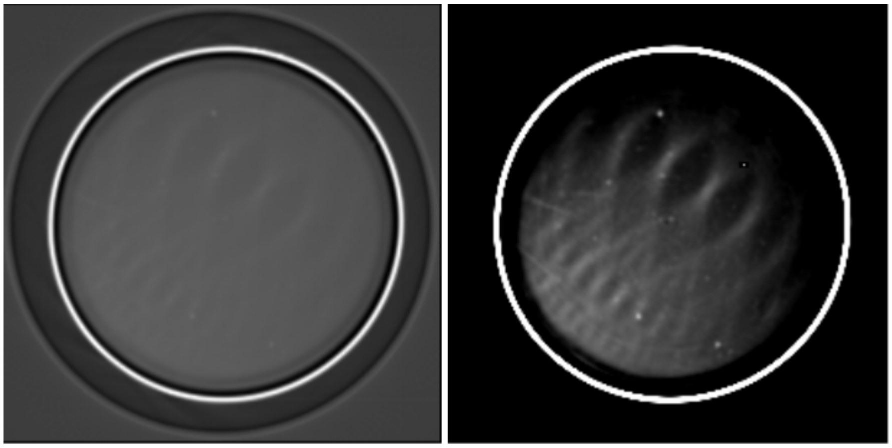
Figure 3 (c) is a plot profile taken from across the radiation tracks shown in Figure 3(b) of RadBall N-2-4 and highlights the ability to be able to pick out the radiation tracks from against areas of the un-irradiated polymer. Seven tracks are visible in the plot profile with a wider diameter radiation track in the middle of the RadBall. This is to be as expected as the middle collimation hole was slighter larger than the other holes on the collimation device. The diminishing intensity of the peaks to the left and right of the middle peak is due to the curvature of the collimator geometry. Figure 4 shows the scan images of RadBall N-4-5 irradiated with two sources (1.5 Gy 120 keV x-ray and 1.5 Gy 38 keV at 90˚ to the first irradiation). The scans show 4 radiation tracks entering from the top left and 3 radiation tracks entering from the top right which cross-over in the middle of the RadBall.



(a) **(b)**

Figure 4: Images of (a) Pre and (b) Post Contrast Enhanced Slices of RadBall N-4-5.

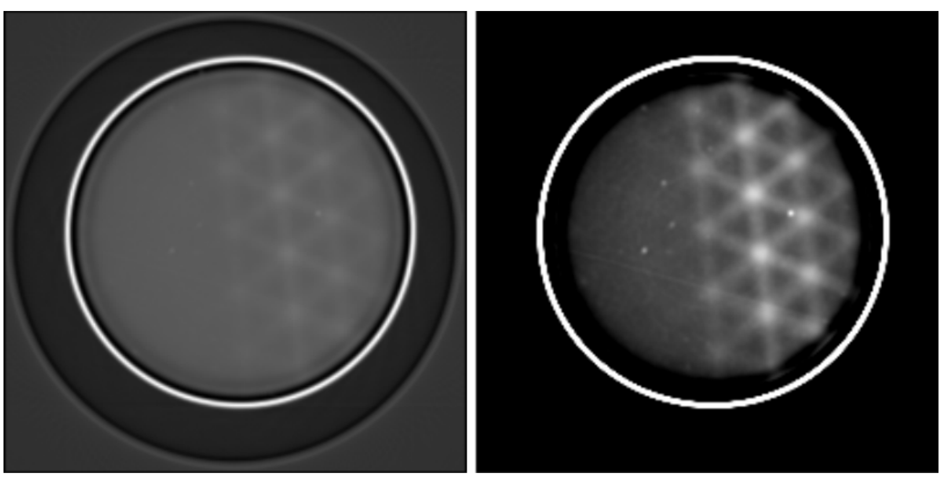
Figure 5 shows optical scan images for RadBall N-8-4. The aim of this experiment was to simulate multiple sources that are close to each other. The RadBall was delivered a ^{137}Cs dose of 0.5 Gy, rotated by 10 degrees and then delivered another ^{137}Cs dose of 0.5 Gy. This exercise was repeated until a total dose of 3.0 Gy was delivered. The scan images from RadBall N-8-4 highlight an interesting infringement pattern effect, where the radiation tracks are closer together at the bottom left of the image and become more dispersed and spread out towards the top right of the image. Brighter spots appear where radiation tracks are overlaid over one another.



(a) **(b)**

Figure 5: Images of (a) Pre and (b) Post Contrast Enhanced Slices of RadBall N-8-4.

Figure 6 shows optical scan images for RadBall N-10-2. In this experiment the RadBall was given an initial dose of 1 Gy, rotated by 60 degrees and another 1 Gy dose delivered. This exercise was repeated until six irradiations had been completed. The pattern appearing in the polymer is similar to isometric graph paper. Higher intensity bright spots appear where one or more radiation tracks have been overlaid increasing the radiation dose delivered to that area.



(a) **(b)**

Figure 6: Images of (a) Pre and (b) Post Contrast Enhanced Slices of RadBall N-10-2.

All 45 RadBall irradiations completed at the HPICL resulted in radiation tracks that were visible in the optical CT scans and have demonstrated the effective performance of the RadBall against the selected radiation sources and doses. Analysis of the RadBall optical CT scans from the HPICL experiments has indicated that for optimum contrast and thus ability to accurately locate radiation tracks in the PRESAGE^{TM} polymer, a target dose of between 3 – 5 Gy is required. At these target doses, the contrast of optical CT scans is improved by increasing the collimator thickness. Experiments completed with the 10 mm collimator provided the optimum contrast for data analysis. The ability of the RadBall technology to characterize the different radiation sources is currently being investigated.

Locating Radiation Sources

Using software developed in-house by the NNL (based on a reverse ray tracing technique), the ability of the RadBall technology to accurately locate radiation sources was tested on the data from the calibration experiments. In this example, Figure 7 shows the predicted locations of the HPICL radiation source from 9 radiation tracks that had developed in RadBall N-2-4. The software predicts a point source in 3D space, to demonstrate this 3D position on a 2D graph, three sets of data have been plotted to denote the position of the predicted radiation source in the XZ, XY and YZ spatial positions. For a RadBall to radiation source distance of 100 cm, the RadBall predicts the position of the radiation source to within 10 mm (within 1% accuracy).

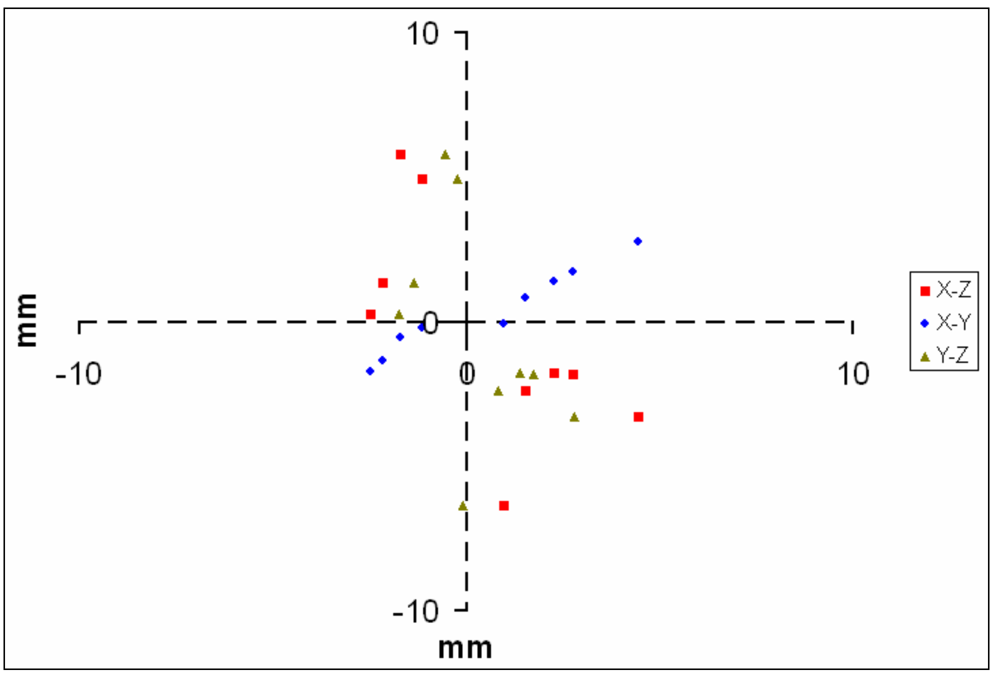


Figure 7: RadBall Predicted Radiation Source Locations at HPICL.

HOT CELL DEPLOYMENT

The Savannah River National Laboratory Shielded Cells Facility has been utilized to work with a wide variety of highly radioactive samples. These cells offered an area to test RadBall as over the years, their use has resulted in the build-up of contamination on the walls and floor. Another benefit of testing the RadBall is there is already infrastructure to move the RadBall around in the cell with the manipulator arms and crane. The shielded cell can also be viewed during exposure, which is beneficial for knowing where the RadBall is in the cell and how it is orientated. Figure 8 shows photographs of the Shielded Cells Facility and the Hot Cell in which RadBall was deployed.

(a) **(b)**

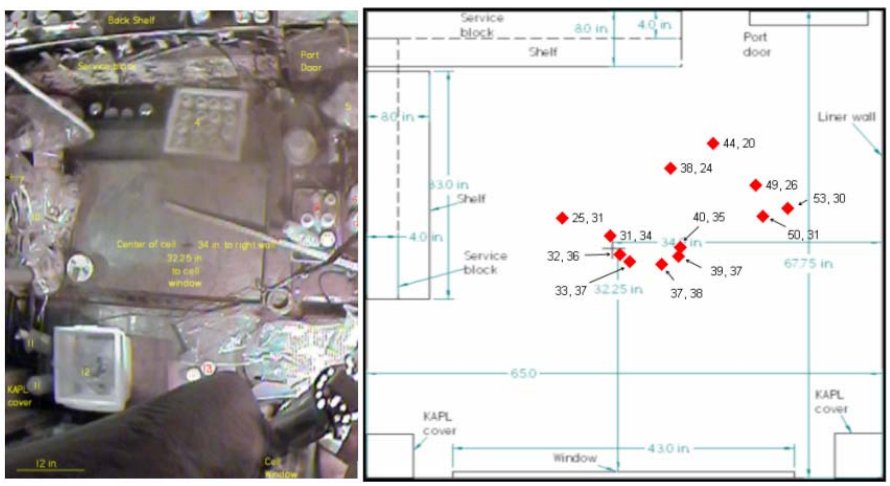
Figure 8: Photographs of (a) SRNL Shielded Cells Facility (b) RadBall Deployed in Hot Cell.

An electronic personal dosimeter (EPD) was placed in various shielded cells to gain an estimate of dose rates. The shielded cell with the highest EPD reading was chosen to minimize the amount of time RadBall would need to be exposed in the cell. Figure 9 is a 3D visualization of the chosen hot cell created in Autodesk Inventor and is used in conjunction with the radiation results from the deployed RadBall to effectively visualize the origins of the detected radiation.

Figure 9: 3D Visualization of the Hot Cell in the SRNL Shielded Cells Facility.

Swipes were taken in the selected hot cell and ^{60}Co, ^{137}Cs, ^{154}Eu, and ^{241}Am sources were found on the floor and walls. Other isotopes may be present in containers in cell. The EPD was used to estimate exposure rates at various locations in the selected shielded cell. The centre of the floor gave a reading of 0.18 Gy hr^{-1} (18 Rad hr^{-1}) on the EPD. The EPD read 0.02 Gy hr^{-1} (2.0 Rad hr^{-1}) at 145 cm and 0.039 Gy hr^{-1} (3.9 Rad hr^{-1}) at 91.4 cm above the floor. It was estimated that at 107 cm there would be 0.0326 Gy hr^{-1} (3.26 Rad hr^{-1}).

RadBall N-7-5 was deployed in the hot cell at a raised height of 107 cm above the floor and left for a 72 hour time period with a 10 mm collimator. The optical CT scans of N-7-5 showed 21 faint radiation tracks in the RadBall polymer. The co-ordinates of these tracks were imported into the NNL's in-house software along with the geometry of the hot cell. These combined data sets predicted the location of the radiation sources in the hot cell. The majority of the radiation was deemed to be originating from the floor. These predicted radiation location results are overlaid in Figure 10 on a CAD drawing of the floor and in Figure 11 on a floor view from the 3D visualization of the hot cell. RadBall has located 12 closely distributed radiation sources originating from the floor which are pointed towards the bottom of the equipment tray and the bottles located on the right hand side of the tray shown in Figure 10(a). This analysis is consistent with the RadBall pre-deployment EPD investigations which confirmed that the highest radiation doses were on the floor of the hot cell. Whilst not knowing the isotopes in the bottles to the right of the tray, it is reasonable to assume that the tray on the hot cell floor would have the highest radiological contamination in the hot cell from bottle spills etc. This contamination would be concentrated at the lowest point in the cell.



(a) **(b)**

Figure 10: (a) Photograph of Hot Cell Floor (b) CAD Drawing With Located Radiation Sources.

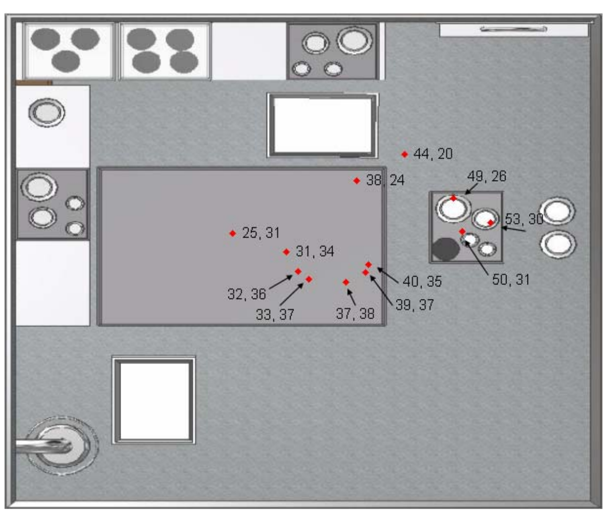


Figure 11: Hot Cell Floor with Located Radiation Sources (Visualization Background).

DISCUSSION AND CONCLUSIONS

The RadBall technology has responded well during the HPICL calibration facility experiments. Radiation tracks were visible in all of the 45 experiments and demonstrated that the RadBall technology is sensitive to ^{60}Co, ^{137}Cs and ^{241}Am sources over the radiation range of 0.5 to 6 Gy. Based on the ability to produce scan data with a suitable contrast between radiation tracks and the background of the RadBall polymer, the target dose for the RadBall is 3 – 5 Gy and the optimum collimation thickness is 10 mm.

The HPICL Calibration experiments have demonstrated that the RadBall has the ability to locate radiation point sources with an accuracy of 1% over a distance of 100 cm. Further work is ongoing to investigate whether the RadBall technology is able to characterize different radiation sources.

Upon completion of the calibration facility testing, the RadBall technology was deployed in a hot cell in the SRNL Shielded Cells Facility. RadBall located the strongest radiation doses originating from the floor of the hot cell and the location of these radiation sources has been displayed on a 3D visualization of the hot cell. This represents the first successful hot cell deployment of the RadBall and a further step in demonstrating the NNL's unique radiation mapping service with the ability to be remotely deployed with no electrical supplies into difficult to access areas of plant and locate and quantify radiation hazards.

FURTHER WORK

Future milestones involve the development of a robot for remote RadBall deployment into highly contaminated facilities, portable optical CT scanner development, and RadBall deployment at another DOE facility using the robot and portable scanner to promptly obtain visualizations of the contaminated hot cell or glove box. Further software and visualization development will also take place to provide an enhanced, texturized output image to better define the sources of radiation in the deployed environment (e.g. similar to map contours).

ACKNOWLEDGEMENTS

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REFERENCES

1 Stanley SJ, RadBall: A small deployable polymer based radiation mapping device for locating, quantifying and characterising contamination in a given cell/glovebox/room, *Nuclear Future*, 4(6), pp 302-308, 2008.

2 Doran SJ, Stanley SJ, Jenneson PM, Prott E, Adamovics J, RADBALLTM: a new field for 3D dosimetry, *DOSGEL: The 5th International Conference on Radiotherapy Gel Dosimetry*, University of Heraklion, Crete, 2008.

3 Stanley SJ, RadBall ready to roll, World Nuclear News (www.world-nuclear-news.org), June, 2008.

4 Guo P, Adamovics J and Oldham 2006 M Simple 3D validation experiments for PRESAGE™/optical-CT dosimetry *Institute of Physics Publishing Journal of Physics: Conference Series* **56**187–190

5 Guo P, Adamovics J and Oldham M 2006 Quality assurance in 3D dosimetry by optical-CT *Institute of Physics Publishing Journal of Physics: Conference Series* **56** 191–194

6 Guo P, Adamovics J and Oldham M 2006 Investigation of the dosimetric characteristics of PRESAGE™ Institute of Physics Publishing Journal of Physics: Conference Series **56** 207–210

7 Oldham M 2006 3D dosimetry by optical-CT scanning *Institute of Physics Publishing Journal of Physics: Conference Series* **56** 58–71