The Role of Gamma-ray Imaging in Performing Radiological Characterisation at the Magnox Storage Ponds at the Bradwell Decommissioning Site – 13628

Karl Hughes and Tracey Shaw
Babcock International, B14.1, Sellafield, Cumbria, CA20 1PG, UK

ABSTRACT

A gamma-ray imaging device has been used to perform radiological characterisation work at the spent fuel ponds complex at the site of the Bradwell Magnox Power Station, which is currently undergoing accelerated decommissioning. The objective of using a gamma-ray imaging system was to independently verify previous radiological survey work and to evaluate the adequacy of the random distribution of the destructive core sampling which had been performed. In performing this work the gamma-ray imager clearly identified the exact locations of the sources of radiation that gave rise to the elevated gamma dose rates measured by conventional health physics surveys of the area. In addition, the gamma-ray imager was able to characterise each hotspot as being either dominated by Cs-137 or by Co-60. The gamma imaging survey was undertaken with a RadScan gamma imaging system deployed on the walkways which run along the lengths of the ponds; this enabled the whole imaging survey to be performed with minimal dose uptake, demonstrating the ALARP principle within decommissioning.

INTRODUCTION

Since the mid 1990s gamma-ray imaging devices have become widely used within the nuclear industry, particularly within facilities undergoing decommissioning. These instruments provide images that indicate to plant owners and operators the distribution of gamma bearing contamination within a facility. This information is provided as a digital camera image overlaid with a colour contour map depicting radiation intensity. By using a gamma-ray imager this information can be made available from locations where man access is limited, either because of high gamma dose rates, or due to poor physical access. Gamma-ray imaging has been used extensively across the Sellafield reprocessing facility and at various other nuclear facilities worldwide, both in operational plants as well as those undergoing decommissioning.

The ponds characterisation work described in this paper was carried out using the RadScan gamma-ray imager supplied by Babcock International. This instrument is based on a small, tungsten-collimated sodium iodide (NaI(Tl)) based gamma spectrometer fitted to a pan and tilt unit. This imager can automatically scan a tightly collimated field-of-view over any scene of interest to produce colour overlays, an example of which is shown in Figure 1. This figure shows a Co-60 hotspot associated with the internal surface of one of the boilers at the Bradwell Magnox Power Station, which is currently undergoing accelerated decommissioning. The elevated radiation levels coming from this section of the boiler are likely to arise as a result of plate out of activity on the internal surface, which is most likely to be associated with an area of imperfection of its inner surface.

During a survey, the system acquires and stores both spectral and positional information which enables quantitative assay information to be produced in addition to the qualitative colour overlays.

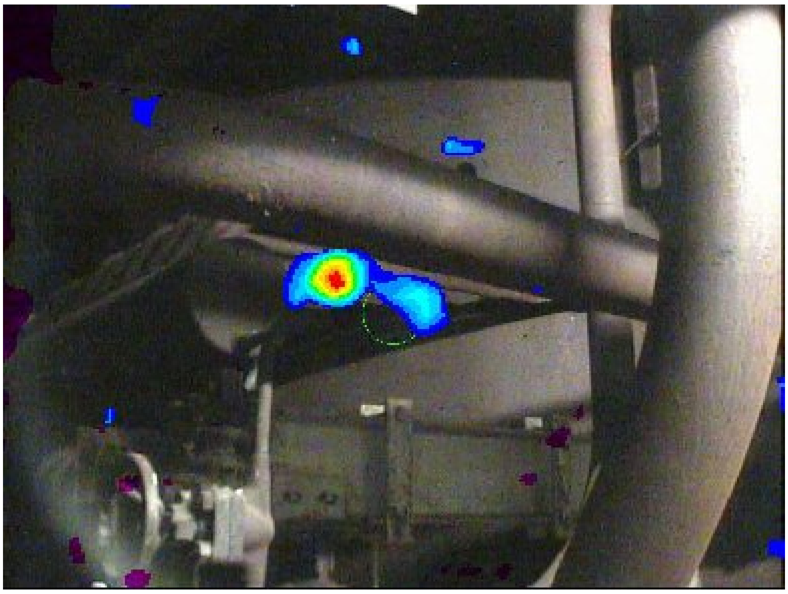

Fig. 1. An example image from the RadScan® gamma-ray imaging device.

The ponds complex at the Bradwell Magnox Power Station comprises two main ponds (north and south). The ponds were used for the temporary storage of the spent nuclear fuel from the site's Magnox reactors prior to being shipped to Sellafield for reprocessing. The ponds complex also has a centre bay, two end bays and two tunnels, the latter of which linked the reactors to the end bays. The ponds have been emptied of their fuel and, with the exception of the centre bay, are now dry. The residual levels of activity in the main ponds give rise to gamma dose rates that are around the 0.1 to 2 mSv/hr level at waist height in the pond. Each of the two main ponds are 6.7 metres wide, 6 metres deep and 30 metres long. The RadScan gamma-ray imager was deployed on the walkways that run alongside the ponds, where the gamma dose rates are typically around 10 μSv/hr. From a series of four locations on the walkways, per pond, it was possible to remotely survey the entire surface area of each pond, including all of its floors and walls. Gamma-ray imaging devices have never previously been used to map the entire surface area of contaminated pond structures.

Health Physics Survey of the Ponds

Conventional health physics gamma dose rate surveys of the two main ponds had been performed prior to undertaking the RadScan survey. The gamma surveys were undertaken manually, by sending a man into the pond with a hand-held probe. An array of 5 by 26 measurements of the gamma dose rate at 50 cm above the pond floor were taken of each pond using an uncollimated probe. This equates, approximately, to one measurement being undertaken every 1.25 metres in both the length and width of the pond. Example results from a survey of the Main North Pond is shown in Figure 2 which shows the 5 readings taken across the pond (labelled A to E) and the 26 measurements taken along the pond (one reading for each of the ‘lanes’, numbered 29 to 4). The gamma dose rates in this pond vary from 130 to 1,800 μSv/hr.

	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	
A	205	130	180	330	180	180	175	175	270	270	310	385	310	330	380	400	400	400	370	320	270	310	290	270	230	160	A
B	220	210	310	220	175	175	180	240	330	270	270	380	280	270	280	280	300	290	260	360	250	250	300	300	170	170	B
C	640	500	360	350	230	230	215	210	230	280	380	1500	740	350	280	270	280	275	260	270	250	300	750	260	250	270	C
D	1800	500	570	400	260	240	280	260	290	215	410	850	460	370	300	280	275	270	260	275	265	300	375	300	320	490	D
E	450	350	520	480	600	590	640	610	700	610	600	570	850	860	670	650	680	610	720	810	710	600	450	600	680	1300	E

Fig. 2. The results of a gamma dose survey of the Main North Pond. All readings are in μSv/hr, measured at 50 cm above the floor of the pond. Measurements are labelled A to E across the pond, and from 4 to 29 along the pond (corresponding to a bay number).

There are limitations associated with the gamma dose map shown in Figure 2. As the readings are taken with an uncollimated probe there is no directionality, as a result there is no way of knowing the origins of each of the measured dose rates. For example, there is no way of knowing whether the elevated dose rates seen in Row E of Figure 2 come from the floor or the adjacent wall of the pond, or from the interface between the two. There is also additional uncertainty introduced around measurement D29 as this measurement is adjacent to the opening from the pond to the centre bay, which is known to contain significantly elevated levels of radiation compared to the main pond. Acquiring additional measurements to further refine and understand the dose map has a high dose burden associated with it, and is not guaranteed to result in a complete understanding of the distribution of the activity present in the pond.

Further limitations of the health physics surveys include the lack of spectroscopy and the uncertainty associated with the positioning of the dose probe.

RESULTS OF THE GAMMA IMAGING SURVEY OF THE MAIN PONDS

A photograph of the RadScan gamma-ray imaging unit is shown in Figure 3, showing the inspection head which was deployed into the ponds area. The system is controlled from a workstation, connected to the measurement head by an 80 metre umbilical cable, which was located in an adjacent area of lower dose and contamination. RadScan was first deployed into the Main North Pond, and then subsequently into the Main South Pond. To optimise the view to the walls and floors of the pond, RadScan was deployed on both sides of the pond, and at various positions along the length of the pond.

Fig. 3. A photograph of the RadScan gamma-ray imaging system.

An example gamma-ray image acquired using RadScan from the walkways of the North Main Pond is shown in Figure 4 from which a number of key features can be drawn. Figure 4 presents data from the full gamma spectrum and so shows all significant gamma emitting radionuclides that are present. The most significant areas of contamination are seen running along the east wall of the pond; these correlate to the extended area of elevated dose of Row E on Figure 2. Closer inspection of this area of contamination, as shown in Figure 5, which is displaying counts from Cs-137 only, identifies that the contamination is associated with the lower part of the pond walls rather than the floor. A destructive core sampling point, the black dot at the centre of the 4 by 4 array of squares, can be seen in Figure 5, just below the centre right of the frame. It can be seen that the core sampling point lies at the edge of the contamination. Figure 4 also shows a line of contamination running along the top of the pond along the “wind water” line. RadScan was deployed behind handrails, an example of which can be seen at the top of the image.

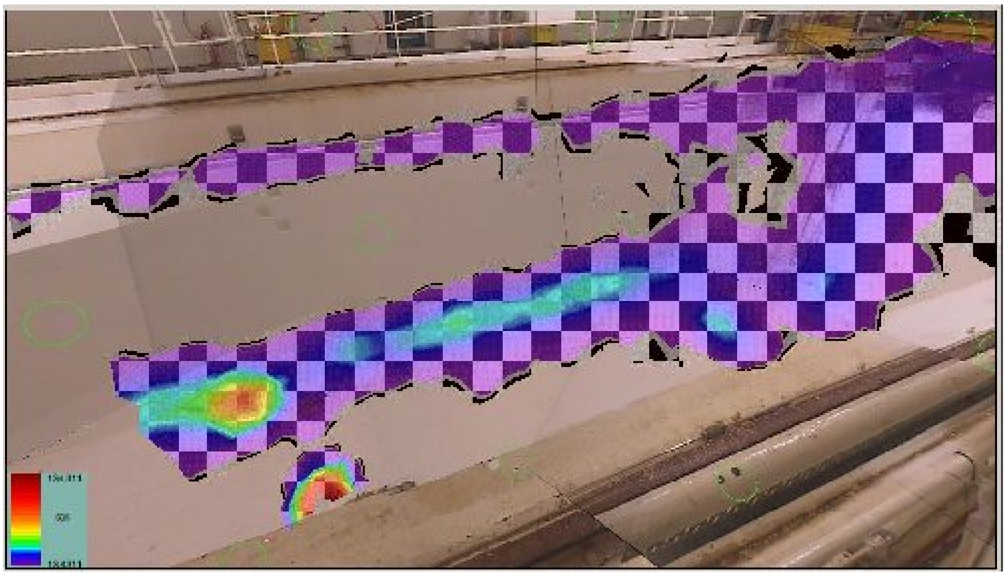

Fig. 4. An overlay showing some of the hotspots in the North Main Pond.

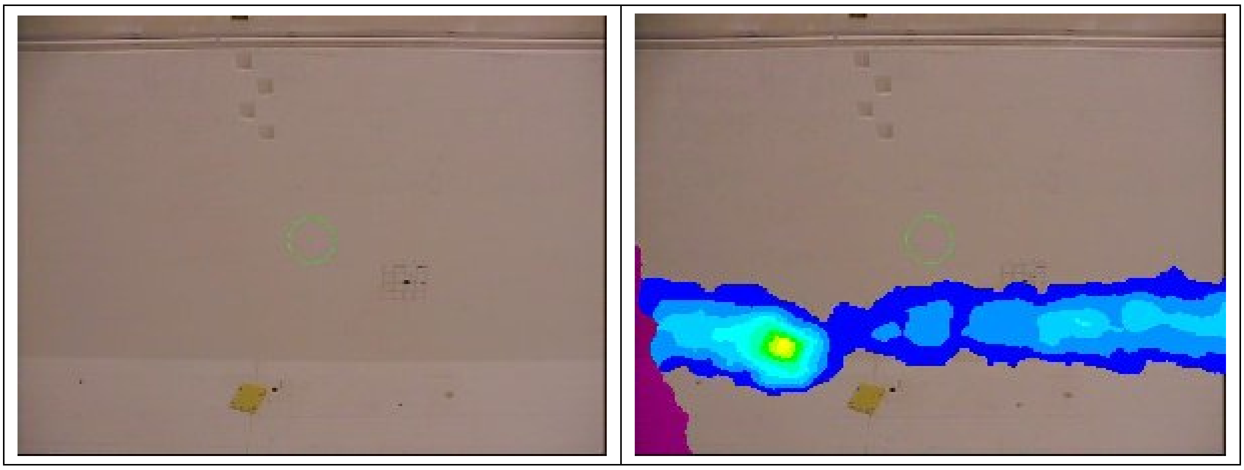

Fig. 5. Detail of the contamination in the North Main Pond. Its associated clean video frame and colour scale are also shown (this image shows Cs-137 contamination only).

Inspection of the gamma-ray spectra associated with the identified hotspots showed that all of the activity identified was Cs-137 with the exception of the single discrete hotspot closest to the RadScan in Figure 4, which was Co-60. This hotspot is shown in more detail in Figure 6 where it can be seen that the activity is very closely associated with a construction joint that runs across the pond. The location of this hotspot corresponds to the elevated gamma dose rate measured at position C18 in Figure 2. The transparent purple in this overlay identifies the edge of the scan which was undertaken. An assessment of the activity contained within this hotspot was made, based upon the measured scan data and an efficiency calibration of the RadScan unit. The Co-60 activity present in this single hotspot was determined to be 490 ± 30 MBq, based upon the assumption that the activity is unshielded. The total Cs-137 activity associated with the line of contamination running along the bottom of the pond wall was assessed to be 8 ± 2 GBq, again based on the assumption that the activity is unshielded.

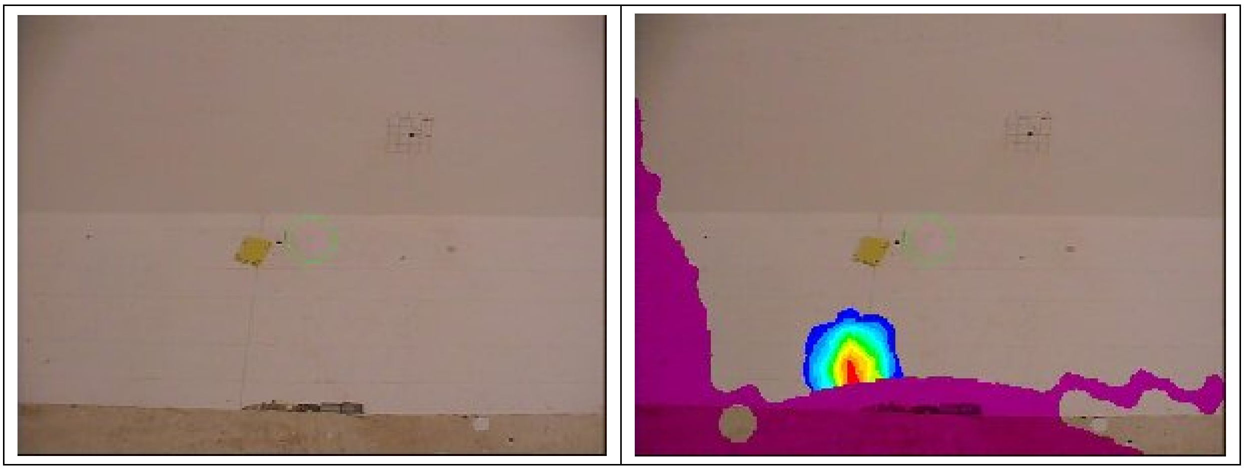

Fig. 6. Detail of the Co-60 hotspot in the North Main Pond. Its associated clean video frame and colour scale are also shown (this image shows Co-60 contamination only).

Figures 4, 5 and 6 show only a sample of the gamma-ray images that were acquired from the North Main Pond. The full series of overlays present a complete map of all of the significant contributors to the dose rate present in the pond.

Use of gamma-ray imaging has provided a marked enhancement in the characterisation of the contamination associated with the pond's surfaces. Previously ambiguous areas of elevated gamma dose rates have been replaced by definite knowledge of the actual locations of specific and quantified hotspots.

Comparison of the results from the North Main Pond with the South Main Pond

A similar series of automatic scans were performed on the South Main Pond to that performed on the North Main Pond. The results of one of the automatic scans undertaken from the western walkway is shown in Figure 7. This image highlights, as expected, that there are elevated levels of radiation associated with the Central Bay, which is running off the left hand side of the image. There was no evidence for any Cs-137 contamination running along the wind water line in the South Main Pond. The most intense source of radiation identified in the South Main Pond, shown as the area of red in Figure 7, had both Cs-137 and Co-60 associated with it, in roughly equal proportions. Closer inspection of the hotspot, as shown in Figure 8, identified that the Co-60 was more prevalent at the east (further) side of the hotspot, whilst Cs-137 was more dominant at the west extreme of the hotspot. Another destructive core sampling point can be seen towards the top of Figure 8 (also visible in Figure 7). It is clear, upon inspection of the gamma-ray images, that this sample point is not sampling an area of elevated contamination levels.

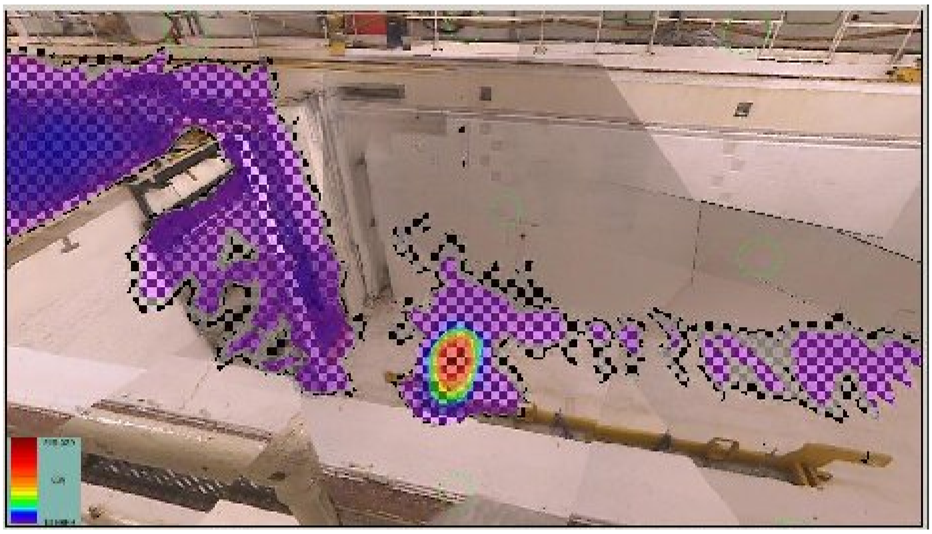

Fig. 7. An overlay of the South Main Pond shown looking towards the Central Bay.

Fig. 8. Detail of the most intense hotspot in the South Main Pond shown for Co-60 (left image) and Cs-137 (right image).

The scans of the two ponds identified a number of similarities and differences between the distributions of contamination between the two ponds. In both cases the majority of the activity was dominated by Cs-137 with occasional, discrete Co-60 hotspots being present. Only on one of the ponds was there any contamination associated with the wind-water line. The surveys also highlighted that contamination was associated with specific construction joints that run across the width of the pond. There was no evidence, in either of the ponds, for the presence of contamination being associated with rails that run the entire length of each pond (these were the rails upon which the spent fuel flasks were positioned when the ponds were operational).

Technical Benefits of Performing a Gamma Imaging Survey to Complement the Gamma Dose Rate Survey

Undertaking the gamma imaging survey at Bradwell has yielded an array of technical benefits above and beyond having performed just the conventional 2-dimensional gamma dose map of above the floors of the ponds. These benefits are highlighted below.

Gamma-ray imaging provided a collimated, directional response. The low resolution gamma-ray spectrometer is located in a tungsten shield which provided a tightly collimated field-of-view. This collimated response ensured that the resultant data was easy to interpret with regard to identifying the exact origins of dose rate, or locations of contamination. By contrast the gamma dose survey was sensitive to radiation from all angles of incidence, so even when a high reading was recorded the direction from which the high reading arose was not known. By moving a dose meter it is possible to 'hunt' for the source of radiation, but this process is difficult or impossible when there are multiple sources or complex source distributions. In environments akin to the ponds, this would also be a very dose intensive operation as all searching is performed manually. RadScan was used with its standard 4° collimator. At a typical range of 8 metres from the walkway to pond this offered a spatial resolution of about 0.5 m. This compares to the dose survey data being collected at about every 1.25 m. Through a simple change of the RadScan collimator, a spatial resolution of either 0.4 m or 0.25 m could have been achieved had this been necessary in order to further pinpoint the origins of the dose.

The combination of being remote and directional allowed all of the ponds' surfaces, both the walls and the floors, to be measured from the walkways. It would have been possible to have performed the RadScan survey from the floor of a pond had there not have been suitable walkways running along their length, although there would have been a higher personnel dose update associated with this option. The actual dose uptake associated with performing the gamma imaging survey was kept low by performing the survey from the ponds' walkways. RadScan performs its scanning automatically and only requires personnel to be present when setting up a scan. Each pond was measured through a series of 4 automatic scans performed over a total 48 hours of measurements.

The on-board spectrometry allowed the dominant radionuclides of each identified hotspot to be determined. For the survey work undertaken it was identified that the majority of the contamination was Cs-137, however additionally there were discrete hotspots that were identified to have only Co-60 and one that was found to have Cs-137 and Co-60 in roughly equal proportions. The gamma-imaging survey was performed after the destructive core samples had been taken, however, in future consideration could be given to using the results of the imaging to identify the best locations at which to drill core samples. This would enable cores to be taken at points specifically that represented areas of highest contamination, lowest contamination, or of a specific radionuclide mix.

The ability to correlate the results of the gamma-ray imaging survey with both the gamma dose survey and the fingerprints obtained from destructive analysis of core samples taken from the ponds provided additional assurance that characterisation of the pond was complete and well understood. The RadScan survey was also able to provide an indicative quantitative activity present in the ponds, both on a hotspot by hotspot basis, and as an estimate for the whole of each pond. The ability to perform quantitative assessments arises from the combination of having gamma-spectrometry and having a laser based rangefinder which measures the distance to the activity being measured. A laboratory based calibration of the system hence allowed the measured count rates to be interpreted in terms of activity.

CONCLUSIONS

The survey work identified a series of hotspots in the ponds. These varied from very localised and intense areas of intense Co-60 radiation, to areas of Cs-137 contamination that were correlated to construction joints in the pond, to activity associated with the wind-water line. The RadScan survey was used to complement and perform an independent verification of a health physics gamma-dose rate survey.

Gamma-ray imaging has clearly identified the exact locations of the sources of radiation that give rise to the gamma dose rates mapped. The collimated detector in RadScan means that the contamination map produced is not affected by the presence of other intense sources of radiation (which was the case close to the centre bay where dose rates far exceed those in the main ponds). The data from measurements can be used to effectively plan any future clean up work, as it identifies those areas of pond where there will be the greatest dose reduction relative to the clean-up effort expended. The survey results have also been used to demonstrate the adequacy of the random locations of the destructive core samples that have been taken from the ponds. For future destructive sampling work consideration is to be given to acquiring gamma-ray images prior to selecting core locations. Performing this additional characterisation work upfront would enable the locations of core sample points to be optimised with respect to the full range of levels of contamination present in an environment. As RadScan is a remote controlled and automatic instrument this detailed characterisation of the ponds was performed with relatively little dose uptake; a demonstration of the ALARP principle within decommissioning.