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THE REMEDIATION OF RADIOACTIVE CONTAMINATION AT THE LONDON 2012 OLYMPIC PARK

Fellingham, L. R.[1], Wright, J.[1], Sliney, M.[2], Adsley, I.[1] and Beddow, H.[1]
[1] Nuvia Limited, Harwell-Oxford, Didcot, OX11 0RL, United Kingdom
[2] Magnox Limited, Harwell-Oxford, Didcot, OX11 0RA, United Kingdom
Lori.Fellingham@nuvia.co.uk

Abstract

The London 2012 Olympic, now Queen Elizabeth, Park is in an area of the Lower Lea Valley in Stratford, East London. It was once home to a diverse range of industries, such as chemical and fertilizer manufacturing, engineering works, metals processing, etc. Parts of the site were also formerly used as domestic and industrial waste landfills. Several of these industrial activities both on- and off-site used raw materials, which contained naturally occurring radionuclides. As a consequence the site had areas with extensive contamination, including from radioactive materials. This paper describes the remediation of the site from that contamination. It describes the identification, removal, assaying, management and disposal of the resulting radioactive wastes. A major issue was the extremely short timescale available to undertake all of these activities, given the need to construct and test the new facilities before commencement of the Olympics. This necessitated the development of approaches and equipment to identify and particularly to assay and sentence such material quickly with the minimum of double handling, etc.

The contamination was in discrete areas and in parts several metres deep. Some included full natural uranium (U238) and thorium (Th232) chains, others truncated radium (Ra226) and truncated Pa231 chains. The gamma signatures of the naturally occurring radioactive material (NORM), supported with sampling and analysis, were used with areal surveying to identify areas with elevated levels of radioactivity. The contaminated spoil was removed and transported to central bunded, storage locations. There the spoil was assayed and segregated by category by gamma spectrometry. Combinations of bag, truck and calibrated bucket monitoring systems were used.

Approximately 7600 tonnes of radioactively contaminated spoil were identified. The bulk was very low level waste (VLLW). It was disposed of in a dedicated disposal cell, which was constructed on site in the southern abutment to a road and pedestrian bridge. A small proportion, comprising primarily of individual artefacts, was low-level waste (LLW). This was disposed off-site to the UK national LLWR.

1. Introduction

The London 2012 Olympic, now Queen Elizabeth Park is in the Lower Lea Valley in an area of East London, which was once heavily industrialised. It was also for a time the location of the research reactor of London's Queen Mary College University. Parts of the Park were home to a diverse range of contaminative industries from the arrival of the railway in Stratford in 1839 through to 2007. By 1896 the area was becoming developed with industries, such as chemical works, engineering works, oil and candle works, colour works, etc. Later phosphate-based fertiliser manufacture, metals processing, enamelling, colour and chemical manufacture occurred on the site. Later parts of the site were also used as landfills. These included the former “West Ham Tip”. Finally, the areas were built over again with industrial units housing another range of light industry, housing, etc. Several of the past industrial activities both on- and off-site used ores and materials, which contained NORM. As a result of chemical processing, smelting, etc, the radionuclides concentrations were enhanced above their natural levels. In many but not all of this processing the enhanced radionuclide concentrations appeared in waste products. In other cases the primary products were radioactive, e.g. clocks, watches, instruments, etc, with luminous dials, tiles glazed with uranium-rich pigments, old gas lighting mantles with thoria coatings, etc. Ultimately these products were discarded to become waste. Thus the sites became contaminated by radioactive wastes, either at the point of production or in the landfills in use at the time.

The site is shown below. It occupies an area ~2.5 km^2. For remediation and construction purposes the entire Olympic Park area was divided into North and South Parks approximately along the line of a suburban railway. The North Park was to become the home of the Velodrome, Hockey, Handball, BMX, Fencing, Paralympic Tennis, etc, facilities. The South Park was to house the main Olympic Stadium, the Swimming Pool and Basket Ball Arena, as well as the Olympic Village. The two parks were subdivided into discrete areas, i.e. Construction Zones, for the development of the site. Finally the entire site was overlain with a 10 m square reference grid.

2. The Enabling Works

Prior to any construction a major programme of enabling works was undertaken. This involved firstly removing all of the existing buildings and structures on the site, including below ground structures. Then all of the soil, etc, on site was checked for contamination, removed, where necessary, remediated as far as practical and then returned to site or disposed of as waste, if necessary. The contamination included from chemical, radioactive and hazard substances.

The timetable for the Olympic Games required that the site be cleared and redeveloped with the new Games facilities available within a 4 year period. This required identification and remediation of the site from chemical and radioactive contamination as part of the Enabling Works. Those works involved the excavation and treatment of $>2 \times 10^6$ m^3 of soil.

The time constraints required enhanced approaches to characterisation and particularly to waste assaying and sentencing. In addition, a key objective of the redevelopment of the site was to recycle and reuse as much material from the site’s former form as possible with a target of >90%. This required effective waste segregation and minimisation.

Initial general contamination investigations were undertaken by the main engineering design services provider. A DQO-type process was used. The work involved the construction of >3000 boreholes across the Park. Many were sampled at multiple levels. The associated analyses were for chemical, biological and hazardous contaminants. They provided a clear picture of the state of that contamination across the Park. They also provided the basis for the remediation plan.

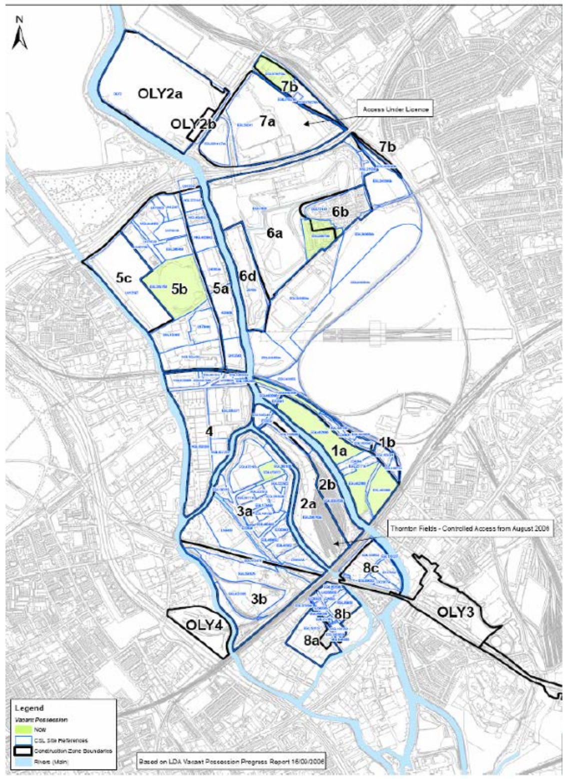

Figure 1 Overall Layout of the Olympic Park with North and South Parks and Construction Zones

To achieve the re-use, etc, target of >90% required that ~80% of the contaminated soil on the site had to be cleaned up. The spoil was firstly screened using a conveyor-based system to remove any solid artefacts before passing it to one of two "soil hospitals", where it was brought for further testing, processing, treating, etc, before reuse. These "soil hospitals" were supported by 5 separate soil washing plants around the site.

Prior reviews of historical records had identified some areas, where the potential for radioactive contamination existed. However, initially radiological contamination was not perceived to be a significant issue and the core samples were not monitored for radioactivity. Early in the general site clearance process elevated levels of radioactivity were detected in the North Park. The initial response was to attach some radiation detectors to the installed conveyor sorter, as the radioactive contamination emitted gamma radiation. This could be monitored to low levels with sensitive monitoring instrumentation and by sampling and analysis.

Further detections required a more comprehensive approach to the conveyor sorter. It was redesigned with an alarmed CsI detection system, which was capable of detecting any artefacts or volumes of contaminated soil at levels above 2 times background. The system is shown below.

The next step was to enhance the radiological contamination detection scheme. Systematic gridded surveying was not initially feasible in many areas due to the scale and rate of the earthmoving operations. Hence teams of Health Physics' surveyors worked closely with the construction teams to monitor areas around the construction operations, spoil heaps, etc, wherever safe.

Figure 2 Monitoring Area of the Sorter Conveyor

To gauge the extent of contamination across the Park all of the original characterisation core samples were re-examined by monitoring with hand-held radiation detectors to identify any showing significantly above background βγ signatures. These samples were then analysed on-site using a portable high resolution gamma spectrometer (Canberra ISOCS system with HPGe detector). These revealed areas of radioactive contamination and area specific radionuclide signatures.

The radioactive contamination derived from a number of discrete processes. Some included the full natural uranium (U238) series, some derived from the truncated natural chain, based upon radium (Ra226), some derived from a truncated uranium U235 chain, based upon Pa231, and some included the full natural thorium (Th232) chain.

Selected samples of these wastes were sent off-site for independent laboratory analyses. Maximum concentrations measured were:

- 40 Bq/g for ^{226}Ra;
- 15 Bq/g for ^{232}Th;
- 16 Bq/g for ^{231}Pa;
- 72 Bq/g for ^{238}U.

Areas, where cores indicated contamination, were given extra focus with assigned Health Physics monitoring. Identification of contamination was based on screening spoil at 2 x background. Anything above this level was subjected to closer monitoring. Levels for the latter were based on modelling detector responses against projected in-ground radionuclide concentrations and types of source distribution(1,4,5).

Plans below identify the areas of radioactive contamination found in the North and South Parks, respectively. The contamination areas are highlighted in blue. The green areas in the North Park indicate the locations used for the temporary waste storage at various times. The red area shown in the South Park is the location of the final waste disposal area on site for Exempt/VLLW.

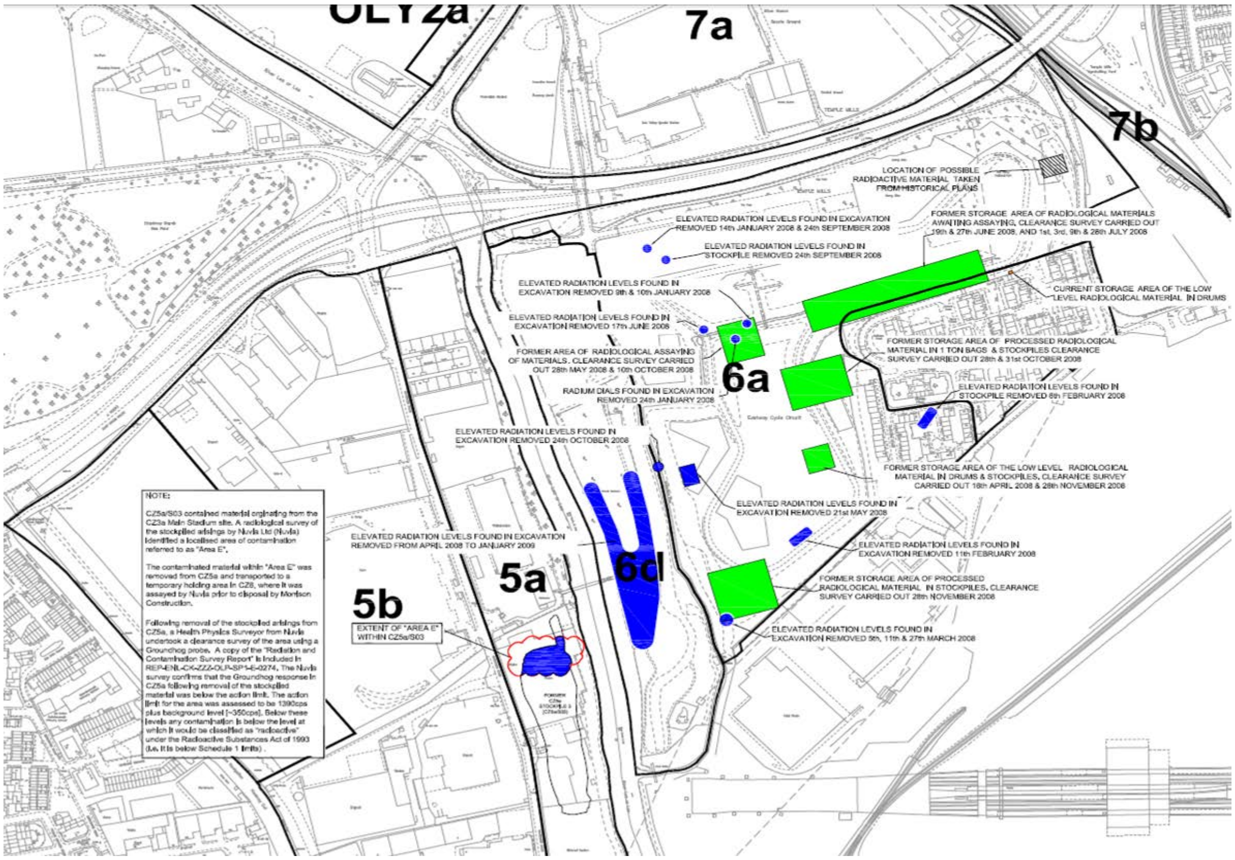

Figure 3 The North Park and Contamination Locations

As the works progressed, any detected contamination above the clearance levels(1) was excavated and transported to area specific stockpiles in a dedicated, bunded holding area in the North Park. Remediation of the areas was carried out in accordance with agreed Method Statements. Contamination was found in discrete areas and in some areas to depths of several metres. During the course of the works, the location of the holding area and all of the stockpiles had to be moved several times to allow further enabling works and construction in those areas.

3. Completion of the Olympic Stadium

Prior to the handover of main stadium island area from the Enabling Works team a surface radiation survey was carried out of most of the area. Some parts could not be surveyed. These were primarily the embankment ("podium") and some areas immediately outside the "bowl" area.

During work undertaken in constructing the stadium, the potential remained for revealing radioactively contaminated spoil, particularly in areas that could not be surveyed previously and in areas where significant excavations (deeper than the 2 m capping layer) were undertaken. Radiological monitoring was therefore undertaken throughout the construction works to identify any elevated levels of radioactivity in these areas and ensure no workers on the site were exposed to unknown elevated levels of radioactivity.

All suspect radioactive waste excavated during these works was stored and transported under a strict Duty of Care regime. The majority of the suspect radioactive waste, which was segregated and removed from the Stadium site, was transported to the North Park holding areas. There it was also assayed using sensitive gamma monitoring equipment before being reused or disposed of through authorised routes. A small amount of radiologically Exempt waste, which was generated towards the end of the overall programme was disposed of off-site to an appropriately licensed disposal facility.

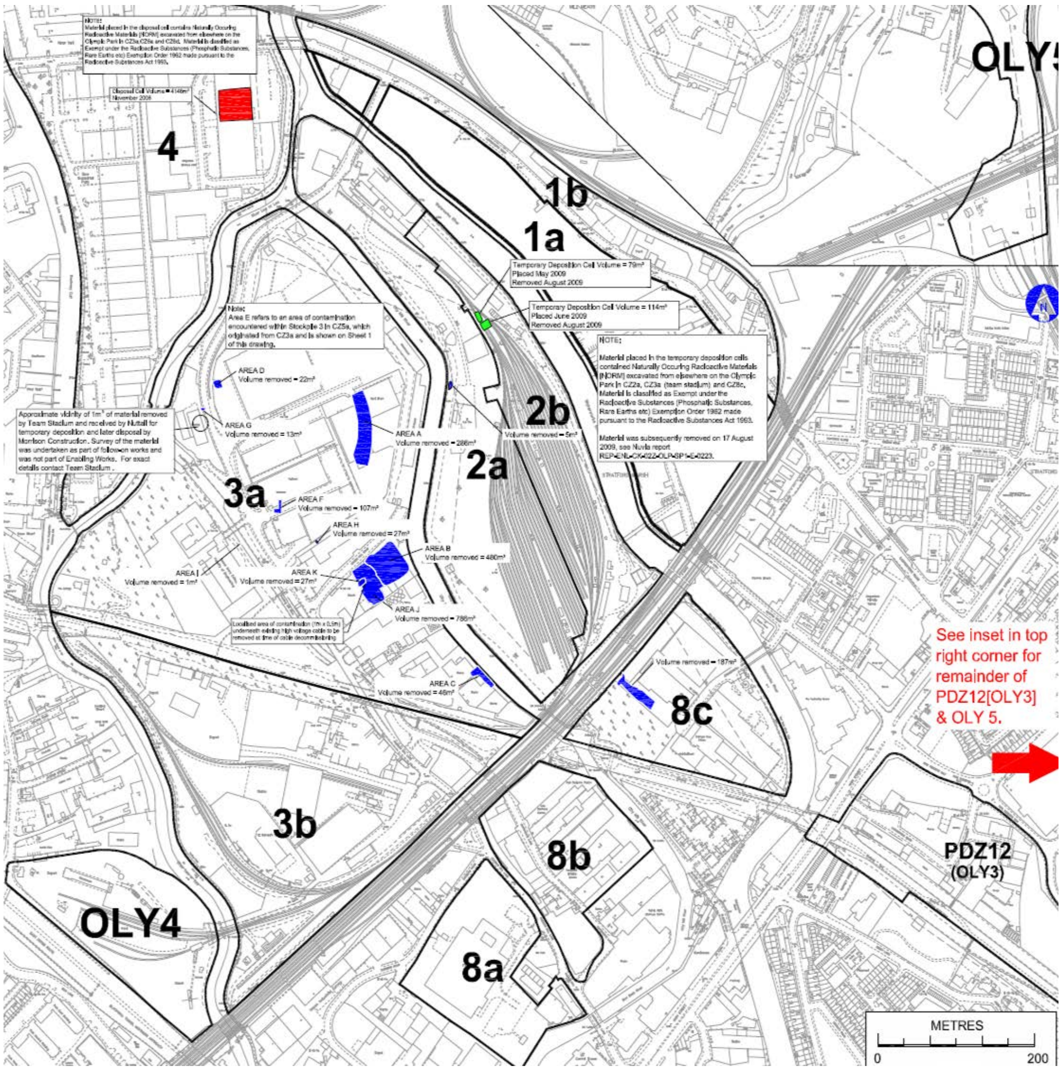

Figure 4 The South Park and Contamination Locations

Following completion of the main Olympic Stadium a 100% survey of the Stadium and its Island was completed. Some of the results are shown on the following areal gamma radiation dose rate plot. The survey included all of the grounds surrounding the Stadium, every surface within the stadium, including the spectator areas, athletics track, field sports areas, offices, changing rooms, etc. It demonstrated a complete absence of any residual contamination. The most significant gamma signatures derived from the imported concrete used in the stadium structure and granite kerbstones and facings.

4. Waste Assaying

In the holding area the stockpiled waste was initially checked by loading into 1 Te fabric builder's bags. These were placed on a rotating turntable and assayed using a Canberra ISOCS-based, portable high resolution gamma spectrometer system.

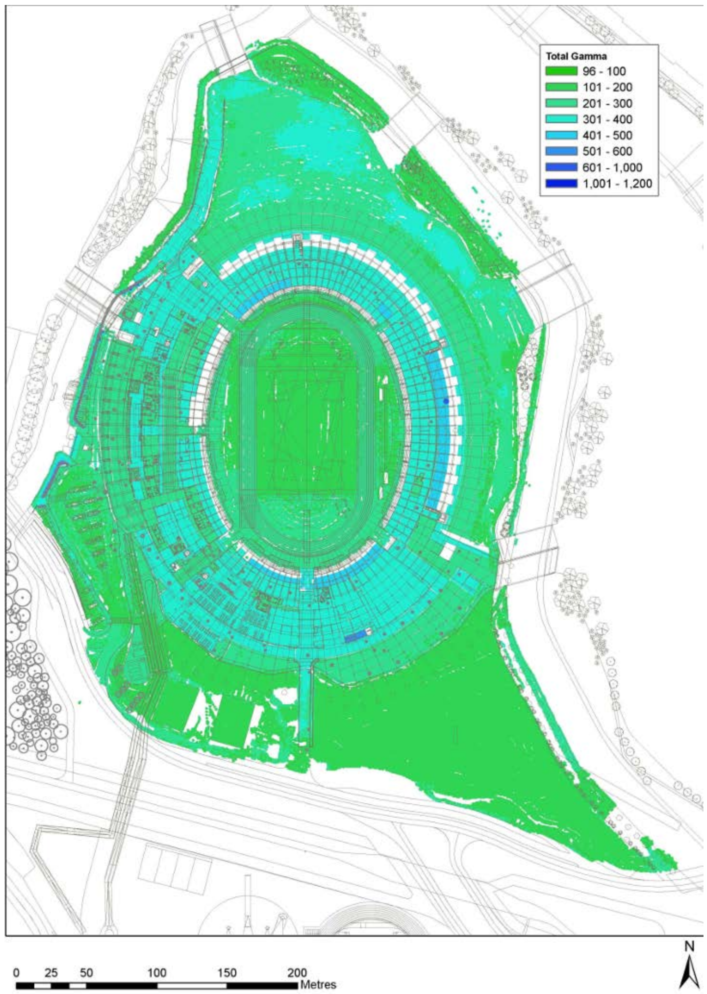

Figure 5 Gamma Dose rate Distribution Survey of the completed Olympic Stadium and Island

To achieve the desired detection limits this process took ~ 5-10 minutes per bag. When allowance was made for the need to handle the bags and to calibrate the system periodically, the daily throughput was in the range of 30-40 bags or tons.

When the waste volumes were initially small, this approach, augmented with additional systems, appeared feasible. However, as more areas of contamination were discovered and waste volumes rose significantly, it became apparent that a much faster waste assaying/sentencing approach was needed. The bag-based gamma assaying was retained for the generation of gamma fingerprints for the material in the stockpiles from the different areas and for quality checking the bucket monitoring system results.

The first approach was to monitor each individual excavator bucket full of spoil using a hand-held, NaI-based, gamma scintillation probe. The probe measured the total gamma output from the bucket. The analysis treated the bucket volume as effectively a semi-infinite source. Hence a total gamma dose rate could be related directly to the total specific activity of the spoil using the gamma fingerprints determined with the bag assaying system.

This approach worked successfully, but had two major drawbacks. Firstly, it required the HP technician to be very close to the excavator and excavation face with all associated major health and safety risks. The second was the uncertain quality control on the process. As a consequence a purpose built, assaying/ sentencing system (GEM) was developed. This is shown below.

The Gamma Excavation Monitor (GEM) system used a 3” NaI scintillation detector built into a rugged holder and frame. It was fitted with a large display panel on one end with a set of 4 lights. These were clearly visible to either the excavator driver or banksman. One light indicated that the unit was counting the bucket contents. A green light on count completion indicated that the material was “clean”. An amber light indicated that the contents were Very Low Level Waste (VLLW). A red light indicated Low-Level Waste (LLW).

Figure 6 The Gamma Excavation Monitor System

The system was calibrated using the Monte Carlo radiation transport code, MCNP, with standard sizes of buckets and loading levels. It was checked against the high resolution gamma spectrometric results for a bag standard. All results were logged to provide a QA record. This system was able to process up to 400 buckets per day, with a typical excavation bucket holding ~1.0-1.1 Te of spoil. It enabled the stockpiled waste to be quickly assayed and sentenced into the appropriate waste categories. The cleared spoil was loaded immediately into trucks for recycling on site, whilst the VLLW and LLW were held in distinct stockpiles for later disposal.

In the course of the work on the initial construction of the main stadium traces of asbestos were found in an area of the podium. The waste from this area was sent off-site to a special waste disposal site at Teesport.

This waste was checked first to confirm that it was clear of radiological contamination. In this case a different monitoring approach was used. The waste was damped and loaded directly into an 8 x 4 dumper truck and sheeted. The truck had a load capacity of ~20 Te. It was then driven into a monitoring frame. There its contents were assayed by determining an average gamma dose rate from measurements made at locations on 1 m spacings along the centreline of the sides and end of the truck tray.

The other contaminated spoil was removed safely and transported to the central bunded storage locations within the North Park. The locations of these storage locations were shown highlighted in green in the plan of the North Park earlier. In this area the spoil was assayed by gamma spectrometry, using bag and calibrated bucket monitoring systems. In the North Park the assayed wastes were stockpiled to await appropriate disposal.

In the waste assaying operations a total of 871 bags of waste, weighing 719 tonnes, were assayed on the rotating turntable with a high resolution gamma spectrometer. The results were used to generate radionuclide fingerprints for different area stockpiles for the bucket and truck assaying systems. They were also used to generate the radionuclide fingerprints for later radiological risk assessments.

Of the 871 bags some 766 were assayed to contain waste, which was classified as Exempt under applicable UK Radioactive Substances legislation, i.e. the Phosphatics Substances and Rare Earths Exemption Order(1) under the Radioactive Substances Act of 1993 (RSA 93). The remaining 105 bags contained waste, which was above the limit for that exemption order. This was in the low-level waste (LLW) category, albeit at the very bottom level of that category.

Table 2 below summarises the analyses of the bagged wastes in terms of their total and mean specific activities of individual gamma-emitting radionuclides, as measured by high resolution gamma spectrometry during the bag assaying

	Total Activity, Bq	Mean Specific Activity, Bq/g
^{208}Tl	1.80E7	2.74E-2
^{214}Bi	3.24E8	4.92E-1
^{219}Rn	7.14E7	1.09E-1
^{223}Ra	7.19E7	1.09E-1
^{234m}Pa	1.47E8	2.23E-1
^{234}Th	1.58E8	2.41E-1

The bucket monitoring involved assaying 5954 buckets with 6712.5 te of spoil, i.e. in ~1.1 te lots. Of these only 6 buckets were assessed to have LLW. A further 158 te of spoil were monitored in bags using the bucket monitor to give a total amount of spoil bucket monitored as 6871 te. Thus the total mass of radioactively contaminated spoil to be disposed of was ~7600 te.

5. Waste Disposal

After discussions with the Environment Agency it was agreed that all of the “exempt” contaminated spoil could be treated as from a single population for averaging purposes. This enabled all of this radioactive spoil to be disposed of as exempt material. The approach adopted was then to construct a dedicated disposal cell on-site. The design of the cell was in accordance with UK Environment Agencies guidelines(2). It is shown in the following two figures.

The cell was built as part of the base of the southern abutment to a pedestrian and road bridge, L03B, to the north of the main stadium. The disposal cell is in the form of a truncated pyramid. It is ~40 m square at its base and 20 m square at its top with a height of ~4.5 m. The base of the cell was formed from a disposal of Japanese Knotweed (JKW) contaminated spoil, which was also radioactively exempt material. The JKW spoil was placed first in the base of the cell and then contained by a covering black JKW barrier membrane. The remainder of the waste was then placed on top.

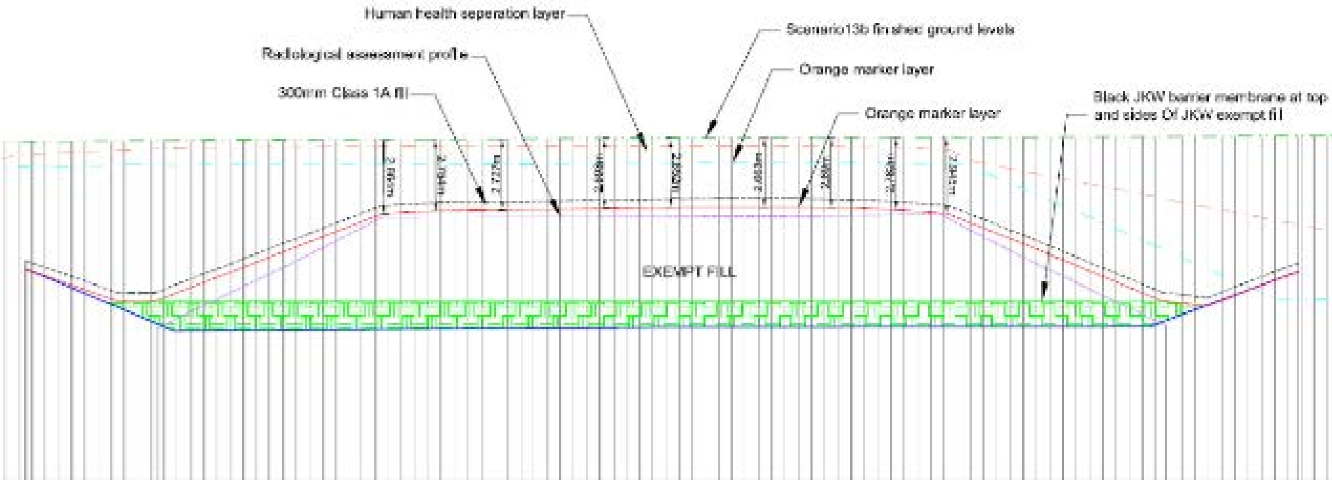

Figure 7 Vertical Plan Section through the Disposal Cell

The waste cell was covered on its sides and top with an orange geotextile marker layer. It was capped with another layer of radiologically clean general fill. Within the fill layer there is a further orange geotextile marker layer, which was located ~1.6 m above the former. It covers all of the cell's projected area. The minimum thickness of the clean cover over the top surface of the waste cell is 2.54 m with an average of 2.73 m. The clean cover included pavement with a bitumen top surface, which restricts waters infiltration.

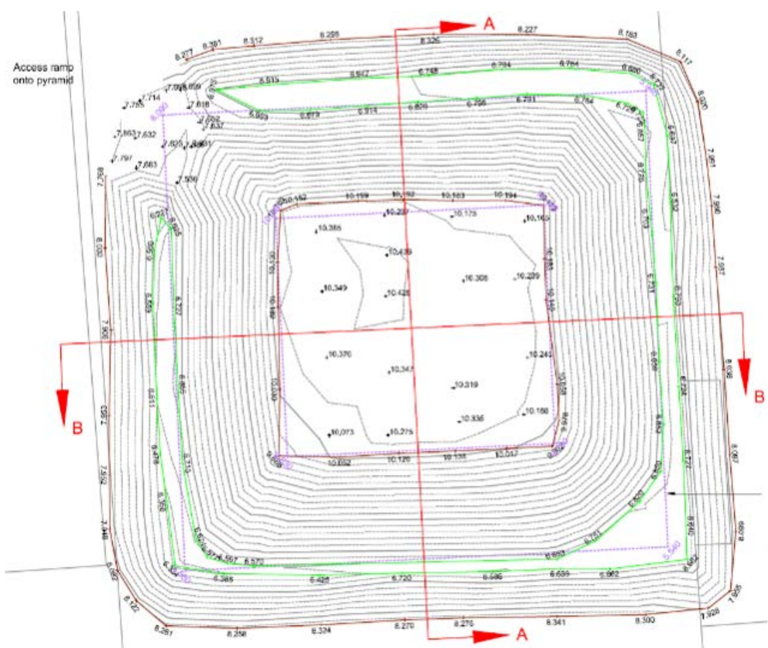

Figure 8 Plan of the Waste Disposal Cell

The finished, stone-faced abutment is shown in the photograph below.

6. Risk Assessments

Given the size and nature of the site and the works undertaken, it was not possible to demonstrate that no residual radioactive contamination may remain buried somewhere in the site. As a consequence a series of pollution linkage and radiological risk assessments were prepared of the risks to users/visitors from any potential residual contamination in different areas. These assessments were undertaken using the ReClaim code(5). In making the assessments account was taken of the benefits, which result from the various clean fill covers.

Figure 9 The completed Bridge Abutment with Disposal Cell

Conservative estimates were derived of the potential radiation exposures to users, including maintenance workers and site visitors, of areas of the Stadium site potentially containing soil contaminated with radioactivity. As no known areas of accessible contamination remained, the assessment used the maximum levels of radioactive contamination found anywhere at the Olympic Park at any time during the Olympics' works. The contamination was also assumed to be uniformly distributed across the entire area. In practice any contamination found was limited in volume and sparsely distributed. The estimates were prepared assuming the minimum clean soil cover thickness of 0.6 m. These assumptions likely overestimated the real risks by at least 2 and likely 3 or more orders of magnitude.

The results showed that the potential dose uptake and concomitant level of radiological risk for all of the potential site users were extremely very low, i.e. $<<1 \times 10^{-6}$/a. The residual risks are compliant with national and international limits and guidelines.

The assessments presumed no excavation or penetration of the ground below the marker layer. They also assumed continued use of the stadium site for sports and recreation use with necessary maintenance activities. No uncontrolled excavation or penetration of ground was to be allowed. The potential for ground contamination remains on site below the Earthworks Formation Level.

A separate, more comprehensive, radiological risk assessment was undertaken to determine the impacts of the waste in the disposal cell. It addressed potential exposures to humans living, working and/or playing on the site, now and in the future. It identified four groups of potential contamination receptors. These were: general site workers, maintenance workers, visitors to the Park and potential future residents on and near to the disposal site (adult, child and infants).

The modelling work had four main components:

i) Source analysis. This addressed the rates at which the contaminating radioactivity is released into the environment. It included the geometry of the contaminated zone, the concentrations of the radionuclides present, the rates of in-growth and decay of the radionuclides present and their rates of removal by physical processes, such as surface erosion and leaching;
ii) Environmental transport analysis. This considered the environmental pathways by which the radionuclides could migrate from the source areas. It determined the rates of radionuclide migration along these pathways and hence the relative significance of each;
iii) Dose/exposure analysis. This used dose conversion factors to estimate received radiation doses from exposures to the ionising radiation; and
iv) Scenario analysis. This considered the parameters, which control the rates of radionuclide release into the environment and the duration and extent of human exposure at any given location. They were determined by the patterns of human activity.

The modelling treated the contaminated zone as effectively a vertical cylinder of land with the contaminated soil/material as one layer. The underlying unsaturated and saturated geology was approximated by a series of discrete, homogeneous layers of defined thicknesses. Variations in the shape of the contaminated site were accommodated using shape factors and drawing out the shape. The radionuclide distributions were treated as approximately uniform throughout the contaminated region, so a single cylinder was used as the source geometry. This assumption was conservative.

The model considered the evolution with time of doses from each individual pathway. The potential exposure pathways for the different receptor groups are listed in the table below.

Exposure Pathway	**Residents**	**Maintenance workers**	**Visitors**	**Site workers**
External radiation	√		√	√
Contaminated dust ingestion	√	√	√	√
Contaminated soil and dust ingestion	√	√	√	√
Contaminated crops grown on-site ingestion	√			
Ingestion of meat from animals (fowl) reared on-site	√			
Dermal contact with soil and dust	√	√	√	√
Inhalation of radon gas	√	√	√	√

The assessment was undertaken using the RESRAD (V.6.5)(3) code, developed by Argonne National Laboratory (ANL). It has been extensively used to assess contaminated sites in the USA and overseas for many years. It offered greater flexibility than codes, such as RCLEA(4) and ReCLAIM(5), which were primarily developed to determine the current risks posed by levels of contamination on sites. RCLEA and ReCLAIM were used for this purpose at Olympic Park, in determining acceptable levels of residual contamination, which might be left on or near the surface after remediation works. RESRAD enabled account to be taken of the time evolution of the site. This enabled predictions to be made on future doses resulting from the migration of radionuclides from the site. This was particularly important in the disposal case, as the half-lives of many of the radionuclides of concern are in the range of 10^2-10^7 years.

The results showed that the radioactive wastes in the disposal cell present a negligible risk to roadway maintenance staff, general site workers or visitors to Olympic Park today or likely in the next 1000 years. All potential exposures will be very much below the lower threshold level of 2 x 10^{-2}mSv/a (10^{-6}/a risk of death or serious harm) for optimisation.

Should the disposal cell area in the future be used for housing, the same conclusion will generally apply. Bar a restriction on radon exposures, doses to the occupants from all other sources would always be below the lower threshold level for optimisation of 2 x 10^{-2}mSv/a. Even without any restrictions for radon, the exposure to the resident would only be ~0.9 mSv/a over the first 100 years. The dose from radon could then rise to 2 mSv/a by year 1000. Radon control measures would be advised. They would be sufficient to ensure that total doses were always much below the public dose limit.

7. Conclusions

All significant areas of known contamination, which were identified using sensitive surface gamma surveys were removed and disposed of in the on-site disposal site, where possible, or alternatively off-site. Surveys undertaken following the removal of this material showed that the remaining material has acceptably low residual contamination and is below the appropriate UK national and EU thresholds.

In two cases very small quantities of material were left in-situ, i.e. at depth >3 m, in surveyed and recorded locations. The associated residual risks were estimated to be very low.

Surveys were undertaken in accessible areas and generally at the surface. There remains the possibility, therefore, that material might remain on-site either buried at significant depth or located in the limited inaccessible areas. As such, the appropriate precautions still need to be undertaken in the event of any future excavations.

The assessment of the radiological safety of the disposal of the wastes on site in the disposal cell demonstrated that the cell was fully fit for the purpose of disposing of the NORM waste arising from the redevelopment works at Olympic Park. It not only meets all relevant dose criteria, but the cell has been optimised, such that calculated prospective doses are substantially lower than the thresholds for optimisation.

8. References

1. Phosphatics Substances, Rare Earths, etc, Exemption Order. SI 2648, 1962.
2. Environment Agency, SEPA AND DoENI. Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation, London, 1996.
3. Yu, C., Zielen, A.J., Cheng, J.-J., Lepoire, D.J., Gnanapragasam, E., Kamboj, S., Arnish, J., Wallo III, A., Williams, W.A. and Peterson, H. User’s Manual for RESRAD Version 6. Report ANL/EAD-4. Argonne National Laboratory, USDOE, July 2001.
4. Penfold, J., Robinson, P., Walke, R. and Watson, C. RCLEA: The Radioactively Contaminated Land Exposure Assessment Methodology. Technical Report. QRS-1279A-III2, Version 1.0 (Draft Final). December 2005.
5. Nexia Solutions. ReCLAIM v2.0 User Guide. NDA00714.1/06/10/02.