# REMEDIATION OF A RADIOACTIVELY AND CHEMICALLY CONTAMINATED SITE AT HARWELL

## BACKGROUND

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| Site | Site covering 7.2 ha known as the Southern Storage Area, near UKAEA Harwell, Oxfordshire. |
| Problem | Previous use of site for munitions storage, as well as processing, storage and disposal of radioactive and chemical wastes generated on the main Harwell site. |
| Management objectives | Remediation of site to meet requirements of planning condition on adjacent area of land owned by UKAEA enabling UKAEA to sell that land for residential development. |
| Remedial Objectives | Excavation and disposal of contaminated materials exceeding predefined risk-based clean-up levels (RBCLs). |
| Key project requirements | Achievement of RBCLs as a minimum end point, in order to achieve standard acceptable to Section 106 agreement of planning application for neighbouring housing development. |

## TECHNOLOGY

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| Process description | Excavation and removal of various contaminated materials, using a waste segregation strategy. Methodology involved monitoring for radioactive and chemical contamination in field, gamma and gross $\alpha\beta$ analysis and high-resolution gamma spectroscopy of bulk samples. |
| Mechanism | Physical removal and segregation of contaminated materials |
| Cost | Confidential |
| Duration | Various site investigations and remedial works since 1987<br>Final remedial works 2001/2002 |
| Lessons | ● Stakeholder involvement proved to be very successful and the positive relationship established early with local stakeholders was called upon more than once to maintain project momentum.<br>● The use of in field LLW minimisation assay methods and in particular the batch gamma spectrometer was successful.<br>● The risk based clean up approach provided a mechanism for transparency and defensibility of the clean up.<br>● Surprises are often three-dimensional in land remediation and waste volume estimates are subject to great uncertainty. |

## Background

The Southern Storage Area (SSA) comprises an area of land covering some 7.2 ha, situated approximately 1 km south of the UKAEA Harwell, Oxfordshire. The SSA shared a boundary fence with Chilton Primary School. There are also nearby residences and a farm.

The SSA was used by the RAF until 1945 as an ammunition store. From 1946 the site was used for a variety of waste storage and handling operations and for the "permanent" landfill burial of mixed chemical, beryllium and low-level radioactive waste (LLW). Typical operations included flask storage, decontamination and sea dump drum packing.

Physically the site consisted of open ground, small huts, concrete trackways and many large earth mounds surrounding the original bomb storage bays. A preliminary clean-up of the site was carried out during 1988–1990, to eliminate the need for the site to be licensed under the Nuclear Installations Act (as was required for the main Harwell site). However, this remediation was not sufficient to allow unrestricted access to the site, which therefore remained secure.

The objectives of the remediation were:

- Physical – To clean up the land to a condition suitable for unrestricted public access. Put simply to remediate the site such that it would be safe for children to play on. This implied a risk target and the determination of concentrations of contaminants that would be acceptable to leave on the site after clean up.
- Psychological – The SSA was a sensitive site with some local controversy. It was considered necessary not only to make the site suitable for public access but also to be seen to have done so in a transparent and acceptable manner. A second objective was therefore the removal of doubt.

The project came about as a necessary part of UKAEA's mission to restore the environment. In the 1990s an opportunity arose to link the remediation to the development of a neighbouring area for housing. A combination of the need to regularise the authorisation status of the site, the commercial opportunity and UKAEA's ongoing mission resulted in a project for complete clean-up starting in 1999.

## Selection of the remediation strategy

The characterisation of the site began with a review of historical records for the site, relating to munitions processing and material storage/disposal operations. Although records of the SSA lacked detail they provided an overall scope and were used to plan the safety design of the characterisation phase. Interviews with ex-staff proved useful.

Following a review of available historical information, a phased characterisation of the site was undertaken, including initial walkover surveys and trial pit investigations, followed by more detailed characterisation using a range of methods such as soil gas surveys, soil sampling, core sampling, trial pit sampling, probe surveys, groundwater monitoring and geophysical methods.

In order to determine the best practicable environmental option (BPEO) for contamination present at the site, a formal environmental assessment process was undertaken in collaboration with the National Radiological Protection Board. The BPEO was defined by the Royal Commission on Environmental Pollution in 1988 as "the option that provides the most benefits or least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term". Options were generated prior to consultation with regulators, local authorities and the public. A large number of options for end condition and remediation technology were created using workshop methods covering the range of:

- do nothing
- capping the wastes
- complete removal.

Using information from the site characterisation and best practice models, pollution linkages were developed for the site. Two linkages emerged as important;

- human health impact (inhalation, ingestion, contact, radiation exposure...) and;
- groundwater impact.

A regulatory/local authority forum was used to provide participation in the scoring and assessment of options for relevant official bodies. The scoring approach used was consulted and the results discussed in this forum. In parallel a programme of public communication was used to test opinion on the preferred option.

The BPEO emerged to be complete removal of all wastes from the site. Risk assessment was applied to create a series of risk-based clean-up levels (RBCLs) for the chemicals and radionuclides of potential concern. These were designed to achieve a risk target of $1 \times 10^{-6}$ per year. This was equated to 20 micro sieverts per annum dose to the public after remediation in addition to local background. (For comparison a typical background exposure for the UK is 2200 micro sieverts from natural sources). Table 1 gives a summary of the RBCLs and clean-up targets for radionuclides generated by this process.

**Table 1** *Summary of RBCLs and clean-up targets for radionuclides generated by BPEO*

| **Radionuclide** | **RBCL (Bq/g)** | **Background 95th percentile value (Bq/g)** | **Clean Up Target (Bq/g)** |
|---|---|---|---|
| Pb-210 | 0.59 | 0.1* | 0.7 |
| Ra-226 | 0.04 | 0.045 | 0.09 |
| Ra-228 | 0.06 | 0.05* | 0.11 |
| Cs-137 | 0.1 | 0.017 | 0.12 |
| Co-60 | 0.02 | 0.03* | 0.05 |
| Am-241 | 0.33 | 0.015* | 0.35 |
| U-234 | 2.5 | 0.018 | 2.52 |
| U-235 | 0.56 | 0.03* | 0.59 |
| U-238 | 1.4 | 0.016 | 1.42 |
| Pu-238 | 0.25 | 0.002* | 0.25 |
| Pu-239 + 240 | 0.44 | 0.003 | 0.4 |
| Pu-241 | 13 | 0.04* | 0.4 |
| Th-228 | 0.04 | 0.022 | 0.06 |
| Th-230 | 0.63 | 0.024 | 0.65 |
| Th-232 | 0.25 | 0.023 | 0.27 |
| Sr-90 | 6.4 | 0.01* | 0.4 |

**Notes**
* Analytical limit of detection

When the informal consultations were complete the environmental assessment was published in detail and in summary. The published version was subject to external independent peer review by consultants working under contract to the local authority. The peer review and response was built into a final version of the assessment and also publicly distributed.

The final environmental assessment was submitted in support of conditions relating to the Town and Country Planning Application for the neighbouring housing development and formally consulted.

## Implementation and validation of the remediation strategy

After the BPEO had been accepted further stakeholder communication took place, the business case was finalised and contract specifications were prepared that carried forward the promises made to date. Contractors were selected competitively with safety and environmental competencies as a top priority.

In parallel with the environmental assessment process the UKAEA safety management system was implemented and a series of safety cases produced. The principal contractor drew up a detailed remediation plan and this became the definitive statement of how the works were to be completed.

The contractors selected for the work were RWE NUKEM and VHE Construction Ltd. After the contractors had completed off site design and documentation a detailed topographic survey of the site was undertaken, in addition to baseline surveys of noise and ecology. Background radioactivity and chemical surveys were also undertaken. The contractor set up and commissioned the safety controls and other support systems required for the works. Commissioning included rehearsal of emergency plans with the local services. The works were then completed over a two-year period. Validation of the works was carried out at the end of each phase and at the end of the overall project. After demobilisation of the contractor the site was landscaped and topsoiled. The contractor produced a post-remediation report, a health and safety file and a land quality statement.

Throughout the works UKAEA maintained close supervision and controlled the implementation through a series of process systems and staged approvals. For example, every waste shipment leaving the site was controlled by the contractor and additionally signed off by UKAEA. UKAEA maintained a full-time site team of supervisors and employed further support contractors to carry out independent audit, surveying, monitoring and validation.

### Clean-up method – general areas

The general land areas of the SSA were of low hazard. Typical contamination was < 10 Bq/g of Cs-137 in patches up to a few square metres. Chemical and radioactive contamination was predominantly at the surface but could also occur randomly throughout the depth of made ground. The approach adopted was to dig over every part of the SSA down to base geology in layers 300 mm deep. Before digging in an area the next layer was surveyed and sampled using a full range of methods. Any "hotspots" were removed from the layer using targeted digging and then the entire layer was bulk dug and placed elsewhere on the SSA for later reuse as clean fill.

Waste was put into 1 $m^3$ woven bulk bags and over wrapped. The wastes were then sent to a dedicated waste assay facility on the SSA. Some very low hazard wastes and scrap were bulk dug and held in stockpiles for later shipment offsite in bulk waste containers.

All drains, roads, buildings, foundations and other structures were surveyed and removed as waste or processed for reuse. All bagged wastes were overpacked in reusable containers for shipment to landfill. The over-wrapped bulk bags were disposed of intact to a landfill cell and immediately capped.

### Clean-up method – burial pits

One of the principal risks to workers and the public arose from the presence of significant quantities of beryllium and beryllium oxides in the burial pits. Beryllium is a light strong metal used in the nuclear industry because of its material and neutron performance properties. Some of the forms of oxide as a respirable dust can be very toxic to sensitive individuals and beryllium has a very low maximum exposure limit (MEL).

All of the pits were dug inside a ventilated enclosure designed to ensure inward leakage. Exhaust ventilation air was filtered through high efficiency filters, monitored and discharged via stacks. The enclosure was contained within an outer weather shelter. Workers used a hierarchy of protective measures including damping down, careful digging, monitoring, hygiene precautions, health surveillance and finally personal and respiratory protective equipment.

Waste was segregated at the workface and put into 1 $m^3$ polypropylene woven bulk bags. A representative sample for analysis was taken during filling. The bags were posted out of the enclosure into an overwrap and taken to a dedicated waste assay facility. Large wastes were compacted at the workface and put into bags or wrapped individually and exported from the enclosure.

The pits were dug either side-on or from the top-down and were overdug to remove any materials that had migrated from the sides or base. In general chemicals and radionuclides had moved < 1 m into the surrounding geology (the main exception being the known chlorinated hydrocarbon groundwater pollution arising from the chemical pits). After removal of all materials above the clean up targets the pit surfaces were sampled and validated. The remediated pit holes were backfilled with low-permeability clay and geotextile layers at the request of the Environment Agency.

### Waste management

All bagged wastes were processed through a waste assay facility on the SSA. A representative sample from each bag was taken during filling and the wastes were monitored during filling, according to the Radioactive Substance Act and its Exemption Orders. Samples or combinations of samples were analysed for metals, organic chemicals (gas chromatography – mass spectrometry), volatile organic compounds, and poly-chlorinated biphenyls (PCBs) and screened total alpha-beta activity.

The use of total alpha-beta radioactivity screening provided a sensitive indication of potential radioactivity but was unreliable as an indication of absolute level when radioactivity above background was present. Bags suspected of being LLW were rotated on a turntable in front of a calibrated high-resolution gamma spectrometry system designed to police the limits necessary to consign the waste correctly under the RSA and exemption orders. Further details of this process are provided in Box 1. The combination of these measurements was used to decide the appropriate waste route. Fingerprinting was not utilised formally because of the heterogeneity of the wastes, but it was possible to group waste types using experience gained as the work proceeded. The decision methodology utilised was agreed with the Environment Agency prior to use. Duplicate quality assurance samples were taken for 5 per cent of the total.

## Verification monitoring

Thoughout the remedial works a verification programme was undertaken to confirm compliance with the remediation objectives. The programme involved continuous sampling and monitoring, culminating in a final survey. The programme was designed to demonstrate the following:

- soil reused on site met the remediation targets;
- the final surface (and the base of pits prior to infilling) met the required remediation targets
- soil at the final surface before topsoiling the site met the remediation targets
- any soil left on site containing material that exceeded the RBCL still met the risk target. This was demonstrated by refining the risk analysis reported in the environmental assessment by using actual monitoring and other site-specific information.

In total approximately 10 000 samples were taken for all sampling criteria, including waste categorisation, with almost 19 000 separate analyses performed.

**Box 1** *Use of high-resolution gamma spectroscopy at the SSA*

Two Canberra ISOCS systems were used to quantify the activity of material during the Southern Storage Area remediation exercise. Each of these consisted of a high-resolution gamma-ray detector, with processing electronics, linked to a computer system. The material to be analysed was contained in 1 $m^3$ bags, which were placed on a turntable and rotated in front of the stationary detector – this was to improve the overall sampling of the material in the bag.

These measurements yield high-resolution spectra – the peaks in which correspond to gamma-ray generating decay processes from radioactive nuclides. In particular these gamma-rays can be from artificial (man made) isotopes, such as $^{137}Cs$ or $^{60}Co$, or from naturally occurring radionuclides such as uranium and thorium.

RWE NUKEM calibrated the system such that the measurements enabled actual activity figures – Bq/g concentrations – to be determined. The results from these were then automatically compared with regulatory limits in a database and the material sentenced accordingly.

The actual measurement process took 15 minutes for each sample bag, plus a further five minutes for the transfer of bags on and off the rotating table. Measurement times could vary for other applications depending upon the radionuclide range of interest. At SSA the mix of artificial and natural radionuclides made the analysis fairly complex, but at other sites contaminated with a few radionuclides, such as radium contaminated sites, the measurement time would be much faster.

The two systems operated for a total time of one year and performed well. Several minor problems with the cooling systems for the detectors were encountered, but these were quickly solved. The system was robust, the methodology sound and the solution acceptable to both the customer and the regulator. It would be relatively easy to adapt this technique to other waste sentencing applications.

## Technology performance

### Technical

The SSA land remediation is a leading example of the clean-up of a radioactively and chemically contaminated site. The clean-up targets were achieved and the land is now suitable for unrestricted public access. The verification process revealed that only 57 results out of a population of more than 13 000 measurements exceeded the RBCLs for reasons other than limitations of the measurement device (ie the limikt of detection exceeded the RBCL) or natural background levels. Thus, more that 99.5 per cent of the measurements were directly compliant. For the remainder a revised risk estimate was derived using the refined site-specific risk assessment methodology.

The key achievements of the remedial works include the following:

- 14 000 $m^3$ of wastes that exceeded a clean-up target were disposed off site mainly to licensed landfill (a small quantity went to high-temperature incineration)
- 230 $m^3$ of low-level radioactive wastes disposed of to the BNFL Drigg repository
- 4500 $m^3$ of scrap and unsuitable inert materials removed from the site to landfill or for recycling
- 250 000 $m^3$ of soils sorted through in total
- 11 landfill pits and 7 ha of land totally remediated to base geology
- land returned as suitable for unrestricted public access
- land re-profiled and designed for use as an amenity area
- no significant dose or other exposure to workers
- no off-site release distinguishable from background.

### Financial

A significant issue arose because some of the old degraded oils in the burial areas contained PCBs at low concentrations. In many cases this complicated or prevented use of landfill waste routes and led to increased costs. This had not been identified by the characterisation to a sufficient degree. The project was completed prior to the introduction of the Landfill Regulations 2002. These regulations significantly complicate finding cost effective routes for hazardous chemical wastes.

### Workability

The project took place over two winter periods and operations continued throughout. Over one winter the outer weather shelters suffered wind damage in severe storm conditions. This did not give rise to any environmental concerns but did cause delay. The project experienced a period where rain levels exceeded “1 in 10 year” levels and this caused some delay.

UKAEA always expected to find some munitions left behind from the Second World War, and munitions surveys were built into the remediation design. The extent of munitions finds was beyond expectations, however, and gave rise to cost and delay. Some 1200 live practice bombs, 13 000 small arms munitions, 30 landmines and many other odd items were discovered. Three munitions burial pits were found and munitions were otherwise scattered randomly across the site.

Several large German bomb casings were uncovered (500 kg and 750 kg). The first of these to be discovered led the Harwell site emergency standby arrangements to be enacted and to the evacuation of the school, garden centre and nearby residences. The event lasted for a few hours until RAF Bomb Disposal was able to confirm that the device had been previously defused.

### Stakeholder interests

The sensitivity of the SSA and the project objective to build confidence in the clean-up led to stakeholder involvement being a key enabling part of the project. A formal system was adopted which involved:

- systematic development of a project policy (openness, transparency, truthfulness, effectiveness, timeliness....)
- development of goals (no surprises, confidence generating...)
- the identification of relevant stakeholders
- the selection of communication, consultation and participation methods
- the training of project staff
- monitoring and review of success through local attitude survey.

Many techniques were used in parallel. Particular attention was given to the local community and the school. Some of the techniques used were:

- local liaison committee briefings
- talks to the parish council
- public meetings
- a regulators forum
- local media
- project-specific newsletters
- site visits
- one-to-one dialogue

### Technology risk management

Formal risk management tools were used to support the business case for the remediation and to focus risk management actions. Key risks were distributed between the contractor and UKAEA, allocated to that party in the best position to manage the risk. Some risk events occurred that were either entirely unexpected or that exceeded upper expectations.

Overall conventional waste volumes were 50 per cent higher than expected from the estimates produced using the characterisation information. Put simply, the characterisation missed a number of waste patches that fell between sampling points. This is an unfortunate reality of land remediation projects where the waste is buried too deeply for surface surveying and is widely distributed. Land remediation is necessarily carried out in “three dimensions” and consequentially waste volumes can increase quickly on the discovery of unknown areas.

Counterbalancing the above risk, the project achieved a 100 per cent reduction in LLW waste volumes compared to predictions. The use of careful segregation at source and assay based on sensible averaging volumes proved practicable and cost effective.

Some areas of the general land were found to contain fibrous asbestos wastes. This was easily dealt with using specialist sub-contractors and required mini-containment operations in some cases. Cement-based asbestos materials were ubiquitous in parts of the site and required hand picking.