Harwell's Liquid Effluent Treatment Plant: past, present and future challenges in radiation protection

Gordon Gallacher [1] and Robert Thickett [2]

(1) Nuvia Ltd, Bld 351.28, Harwell, Oxfordshire, UK

(2) Research Sites Restoration Ltd, Bld 175, Harwell, Oxfordshire, UK

Abstract

Research and development were carried out at Harwell over many decades. As part of this, a Liquid Effluent Treatment Plant (LETP) was built to process and sentence waste effluent. Harwell and LETP are now subject to a decommissioning programme which involves (i) dealing with and sentencing historical waste and (ii) the demolition of facilities.

LETP currently handles a number of liquid wastes such as laboratory carboys and sludges held in tanks. The LETP's facilities include a Carboy Washing Facility (to process lower levels of carboy waste) and two Encapsulation Plants (to encapsulate low level and 'elevated' level wastes). As well as processing these historic wastes, a number of older delay tanks and pumphouses have recently been subject to Post Operational Clean Out operations and demolition.

A new Replacement Effluent Treatment Plant (RETP) is being built to replace LETP in dealing with liquid wastes generated during remaining work at Harwell. The RETP is being constructed in an old delay tank system which was first subjected to POCO operations to remove legacy waste and address contamination.

Radiation protection staff support all operations and radiochemical laboratories are essential in identifying waste fingerprints. The latter is particularly important as a wide range of radionuclides were used at Harwell during its sixty year history and record keeping in the early days of the nuclear industry did not meet today's high standards.

This paper describes past, present and future operations and challenges. It stresses the importance of the associated radiation protection principles and practices used at Harwell. For example, Risk Assessments, "HAZOPs", ALARP measures and Safe Systems of Work are developed and implemented. The plant holds a variety of instrumentation including hand held monitors and activity-in-air alarms. External and internal doses are measured using suitable techniques. Contingency planning and emergency response training are carried out.

Key words: liquid, sludge, waste, decommissioning.

1 Introductory overview

Harwell was chosen as the UK's centre for civil nuclear power research and development in the 1940s. The United Kingdom Atomic Energy Authority (UKAEA), owner and principle resident of the site, gained an international reputation for excellence while carrying out valuable scientific research and development during many years of operation.

As part of this work, a Liquid Effluent Treatment Plant (LETP) was commissioned to the north of the main site in 1948. This is a complex of buildings and large tankage facilities for the receipt, treatment and sentencing of radioactive liquid wastes. In over sixty years of continuous service, the plant has monitored and processed a variety of routine and non-routine liquid effluent arisings from the Harwell facilities.

Having provided a significant contribution to science in the UK, the ex-UKAEA and LETP facilities are now subject to a decommissioning programme. This involves a number of key topics.

- A Replacement Effluent Treatment Plant is being commissioned which will service the needs of the Harwell site for the duration of its active operations.
- The remaining historical radioactive wastes stored at LETP will be processed and sentenced appropriately.
- The facilities at LETP will be subject to a Post Operational Clean Out (POCO), decommissioned and then demolished.

This work is being funded by the UK's Nuclear Decommissioning Authority (NDA) and managed and driven by Research Sites Restoration Ltd (RSRL). RSRL provides a core team of Health Physicists / Radiation Protection Advisers who provide and manage radiological protection support and advice to staff and teams around Harwell (and at Winfrith in Dorset). Nuvia Ltd provides much of the Health Physics support for this work such as seconded Health Physicists, an Approved Dosimetry Service and surveying staff.

This paper provides an overview of past, present and future operations and challenges at LETP. It stresses the importance of the associated radiation protection principles and practices.

Figure 1 Aerial photo of LETP

2 General radiation protection principles

Radiological protection is a key principle in LETP. Where practicable, engineered solutions are preferred. Where this is not possible, work relies on a wide range of ALARP measures. All work must comply with the Nuclear Site Licence and the United Kingdom's Ionising Radiations Regulations 1999 (IRR99 [1]). A selection of issues are highlighted.

Justification, Risk Assessment and ALARP

All work at LETP has to be justified. The risks and hazards must be assessed and compared to the benefits gained from carrying out the work. Further to this, options are examined and work planned such that dose uptakes are As Low As Reasonably Practicable (ALARP).

Engineered facilities

Where practicable, it is better to provide an engineered solution rather than having, for example, staff processing waste while simply dressed in PPE. However, parts of the plant were built many years ago. The cost of re-designing and building new plant would be prohibitive. In addition, some of the tasks require a hands-on manipulation of equipment.

Work areas

Many areas within the complex are designated under IRR99 as either supervised or controlled and have Local Rules which describe the minimum requirements or conditions for entering the areas. These documents are provided in a poster format and are displayed in the areas.

Where contamination may pose a risk, areas are only accessed via carefully controlled barriers where staff don PPE and dosimetry. When exiting a contamination controlled area, barrier procedure involves monitoring of staff and equipment, removal of PPE and washing.

Dosimetry

Dosimetry is provided through Nuvia's Approved Dosimetry Service (ADS). Operational teams are provided with dosimetry that is specifically targeted to their work patterns.

External Dosimetry is assessed using TLD whole body dosemeters for gamma and beta dosimetry, and, if appropriate, a CR-39 dosemeter for neutron dosimetry. Extremity TLDs are issued when appropriate to assess dose to extremities.

Electronic Personnel Dosemeters (EPDs) are used to help manage the work and allow on-the-job dose assessment to be carried out. The EPDs are set to alarm if staff exceed task-specific dose restraints or are exposed to elevated dose-rates.

The primary internal dose assessment technique is the Personal Air Sampler (PAS). Where appropriate, staff also routinely provide urine and faecal bioassay samples and attend a whole body monitor. The frequency and programme are designed to address the hazards, risks and radioisotopes that staff may encounter during their work.

Radiological monitoring

Within the facilities, the general environment is carefully monitored by Health Physics Surveyors. Routine surveys are carried out following a pre-agreed survey schedule.

When carrying out active operations, surveyors accompany work groups and provide on-the-job monitoring support. Radiological hold points are set by, for example, assessing the potential re-suspension of any contamination and the subsequent potential dose to staff.

All radiological monitoring instruments are calibrated at least once per year (as required by IRR99). In addition, surveyors carry out daily checks using test sources to ensure that instruments are functioning correctly.

Alarming gamma-ray monitors are located at key positions. These are set to alarm at dose rates which would be considered unusual. In addition, a strict air sampling regime is in place where there is a potential for low level chronic releases. Alarming activity in air monitors are positioned at strategic locations to provide an alert to significant breakdowns in contamination containment or control.

RSRL also ensures that it meets it environmental responsibilities. A number of the buildings are vented through stacks with HEPA filters which remove the vast majority of particulates. Samplers are located in the stack systems which measure the amount of activity discharged. Liquid discharges are also carefully sampled to ensure that RSRL does not exceed its discharge authorisations.

3 Radiochemical Laboratories and Fingerprints

LETP has a selection of radiochemical laboratories which use UKAS accredited procedures to provide an analytical service for operations. This is particularly important as a wide range of radionuclides have been used at Harwell during its sixty year history and record keeping in the early days of the nuclear industry did not meet today's high standards.

The laboratories carry out conventional liquid analysis of environmental, low- and intermediate-level activity samples. In addition, they are able to undertake soil analysis and a wide range of chemical and radiochemical analysis. Typical representative samples would be taken from a facility to be processed (eg from a delay system or from a container of waste). These samples can be assessed using a number of techniques. These include:

- solvent extraction, followed by electro plating and counting in an alpha spectrometer;
- liquid scintillation counting;
- gross alpha and beta analysis (using a 10-Channel Low-Level Planchette Counter);
- gamma spectrometry (UKAS 17025 accredited for ^{60}Co and ^{137}Cs); and
- chemical analysis of lead, zinc, cadmium, iron (carried out using inductively coupled plasma mass spectroscopy or atomic absorption spectrometry) prior to the safe disposal of waste to landfill.

A typical finger print might consist of the following radioisotopes:

- beta/gamma emitters- Co^{60}, Sb^{125}, Cs^{134}, Cs^{137}, Eu^{154}, Eu^{155};
- beta emitters- Pu^{241}, Ni^{63}, Fe^{55}, H^{3}, Sr^{90}; and
- alpha emitters- Pu^{239}, Pu^{240}, Pu^{238}, U^{238}, U^{235}, U^{234}, U^{232}, Am^{241}, Cm^{244}, Cm^{242}, Ra^{226}.

Analysis can also be carried out on both pre-treatment and post-treatment effluent to determine the effectiveness of any processing, to assist with sentencing of waste and to ensure that environmental discharge authorisations are not exceeded.

Risk assessments: monitoring

This laboratory analysis helps in assessing hazards and producing a prior risk assessment. For example, if staff are carrying out on-the-job monitoring using conventional radiation protection instruments, they will not be able to detect low energy beta particles from ^{241}Pu. In addition, working conditions in this old plant may be grimy or damp, thus making it difficult to detect the presence of alpha emitters such as ^{239}Pu. Thus, staff may only detect the presence of beta particles from such isotopes as ^{90}Sr.

However, the prior risk assessment will have taken into account the fingerprint of the waste. If higher-energy betas are detected during on-the-job monitoring, then it is appreciated that alpha emitters and lower-energy beta emitters will also be present. Thus, hold points for the operation can be set by assuming that these "hidden" radioisotopes are present and using resuspension factors to assess the likely dose consequences.

4 LETP facilities: past, present and future

A selection of LETP's facilities and operations are described briefly.

Delay Tanks

Active buildings on the main Harwell site contain delay tanks in which active effluent is stored temporarily. Once a sufficient volume has been collected in a delay tank, the effluent is sampled to assess the activity and then (i) discharged via a pipe system to LETP or (ii) transported to LETP using a tanker. At the LETP, the waste is then processed and sentenced accordingly.

A large number of obsolete systems have been / are subject to Post Operational Clean Out (POCO) operations. This involves conducting radiological monitoring and sampling of residual wastes to assess the hazards. Plans are then made to remove pipework, tanks etc and to carry out clean up operations. This involves establishing and using a Safe System of Work (SSoW) including entry-exit procedures for staff, Local Rules, contamination hold-points and emergency instructions.

Following POCO work, the area is handed over to a general decommissioning team where plans for the demolition of the structures are implemented.

Low Level Treatment Plant (LLTP)

The LLTP consists of a number of facilities, pipes, filters and tanks which are used to circulate liquid waste and take samples for analysis. The analytical results are used to select a treatment process that will optimise the removal of radioactivity. Chemical treatment and floc separation are used to remove radioisotopes and to ensure the pH is within the discharge consent limits.

Treated effluent is subsequently filtered to remove residual entrained solids. The liquid can then be discharged directly to the environment via a pipeline.

Sludge Settling Tank (SST)

The SST allows sludge to settle out under gravity. The supernate and the sludges can then be processed separately.

Lost Paddle Cementation Facility (LPCF)

Processed Low Level Waste sludges (eg from the SST) can be encapsulated within the LPCF.

This facility is contained and is ventilated through HEPA filters. It uses waste drums which have non-retrievable "lost paddle stirrers" within them. Waste sludge is added to the drums and then dry cement is added to the sludge via a cement hopper. The paddles are turned remotely to set the cement and encapsulate the waste.

Encapsulated drums are stored until sufficient numbers (normally thirty-seven drums) have been collected to fill a Half Height ISO container. The waste is then sent (via the Harwell Solid Waste Plant) to the Low Level Waste faculty at Drigg.

Figure 2 Lost Paddle Cementation Facility (LPCF)

Carboy Emptying and Washing Facility (CEWF)

The CEWF is a contained and ventilated facility for washing carboys.

First, the carboys are drained and the contents transferred to a Medium Level Treatment Plant. The empty carboys are then placed inside the CEWF, where they are washed using a water jet which is fired into the inside of the inverted carboy. After washing, the carboy is withdrawn from the facility and undergoes Health Physics monitoring before being released for re-use or disposal.

Medium Level Treatment Plant (MLTP)

The MLTP is a purpose built, glass fibre vessel. Once filled with carboy liquors from the CEWF, the liquors are stirred, sampled and analysed within the laboratory facilities. The pH of the liquors is adjusted to produce an alkaline solution which is transferred to the SST (for conditioning with active sludges).

Whessoe Tanks

A number of chemical tanks (manufactured by Whessoe) were commissioned during the 1960s to the north of the LETP. These 70 m^3 capacity tanks are made of mild steel and lined with bonded rubber liner. The tanks are lidded and have been fitted with short exhaust stacks incorporating filters. The tanks are located in bunded areas. When operational the tanks were used for a number of activities. For example, some carboy liquors were precipitated and settled within the tanks. Sludges from this were pumped to the HLA (described below) in the early 1990s.

Figure 3 Whessoe Tanks

One tank still contains active low-level sludges which are currently being processed through the SST. All of the other tanks are now empty and plans are being finalised for the decommissioning of this facility.

- Health Physics surveys are being carried out around the supporting areas. For example, Nuvia's portable Groundhog / spectroscopy system has already been used to help provide data based on gamma-ray measurements.
- Sampling of the structures has been started. This includes the core drilling of tanks and the sampling of residual sludges. Samples are analysed in the laboratories and compared to historical information.

The above surveying and sampling operations allow the facilities to be characterised and plans to be implemented regarding the consignment of wastes.

- POCO, decontamination and tie-down operations will soon commence.
- Size reduction and the decommissioning of the main structures will be undertaken.

All surveying, sampling, decontamination and POCO / decommissioning operations are (and will be) supported by a Safe System of Work (SSoW) including entry-exit procedures, Local Rules, contamination hold-points and emergency instructions.

'High' Level Activity (HLA): storage tanks

The HLA storage tanks contain 'higher' level aqueous effluents and sludges (such as accountable nuclear material) which, when received, was too active for immediate treatment.

Groups of four HLA storage tanks (made of glass fibre reinforced plastic and stainless steel) are located within shielded brick/concrete (secondary containment) tanks covered with removable concrete slabs. The secondary tanks stand inside a concrete bund (tertiary containment).

Figure 4 'High' Level Activity (HLA) tank tops

Ventilation plants draw air into the HLA tank systems to help prevent the escape of contamination. Leak detection systems are also in place within the secondary containments. Following the processing of waste from a HLA tank, water may be added to stop residual contamination drying out and becoming airborne.

To initiate the processing of HLA wastes, mixers are used to stir the contents in each tank to produce a homogeneous mix. This mixing is important as a representative sample is then taken from the tank so that the fingerprint of the waste can be established. This is needed for the subsequent waste sentencing.

The mixing itself can present radiological protection challenges. For example, Tank 4.3 waste emitted higher levels of radiation than previously encountered. In addition, the tank contained debris (such as tape) which could block up both (i) the mixers during stirring operations and (ii) the equipment used in encapsulating the waste. Specially designed "baskets" were placed over the mixers to trap the debris. However, these had to be manually unblocked when debris became entangled in them. Thus, operations were planned carefully to ensure that staff dose was As Low As Reasonably Practicable (ALARP).

After completing the mixing and sampling, waste is pumped to a neighbouring Encapsulation Plant for immobilisation in cement.

HLA: Encapsulation Plant (EP)

This plant was actively commissioned in 2003 to encapsulate waste from the HLA tanks. The following provides a brief overview of the waste encapsulation process.

- A pre-determined volume of HLA tank waste is transferred to a feed vessel.
  A "lost paddle" 500 l drum is placed in position under the feed vessel.
- The 'sludge' waste is transferred under gravity into the drum.
  Cement is then fed into the drum and mixed with the waste.
- The encapsulated waste is left to cure for twenty four hours.
  To minimise the void in the drum, inactive grout may be pumped into the drum.
- A drum lid is fitted manually through an inspection hatch.
- Each drum is swabbed as it is rotated on a turntable. The swabs are monitored for loose contamination. If monitoring shows contamination levels are below permissible levels, the drum is allowed to move on. If permissible levels are exceeded, the drum is manually sprayed with a PVA/water mix to fix the contamination prior to export from the encapsulation facility.
- Drums are then transferred out of the encapsulation plant into a shielded interim store to complete the curing period (twenty-eight days).
- When sufficient drums have been collected and cured, they are transferred to the Harwell solid waste store for sentencing as either Intermediate Level Waste (ILW) or Low Level Waste (LLW).

The EP's safety features include containment, ventilation and shielding.

HLA: support facilities

A cement laboratory has been established in the building. This houses equipment (such as glove boxes) for (i) the handling and diluting of waste samples prior to analysis within the laboratories described above and (ii) conducting cement immobilisation trials on waste samples. Measurements are also conducted to determine heat release profiles, viscosity and density to demonstrate compliance with waste disposal conformance requirements.

In addition, the building contains two vented Modular Decommissioning Facilities (MDFs) where hands on work can be carried out with contaminated equipment.

HLA: decommissioning

Once all the waste has been processed, RSRL will undertake decommissioning of the HLA facilities.

- Residual waste "heels", which could not be removed following the methodology described above, are still present in the bases and corners of the primary storage tanks. Therefore, plans are being formulated to remove these residual heels. This will involve scraping the residues to one side and collecting the material using vacuum cleaners with long nozzles.
- Plans will be finalised for the removal and sentencing of HLA tank "furniture" (such as pipework and bracings).
- Plans will also be finalised for the size reduction and sentencing of the tanks themselves.

5 Emergency Response

Pre-work risk assessments allow appropriate measures to be implemented to avoid any incidents occurring. However, as part of its emergency response procedures, RSRL also implements measures to (i) limit the scope of any problem and (ii) deal with any emergency which may occur. The latter includes spills of radioactive waste, fires and injury to staff.

All facilities produce local emergency response plans.
For example, if a major contamination incident occurred then all staff would evacuate from the incident area ("Red Area") to a pre-identified intermediate safe area ("Amber Area"). Emergency response staff and Health Physics would then ensure safe evacuation from the "Amber Area" to a final safe area ("Green Area") via a zoned decontamination-barrier

arrangement. Gross decontamination would take place in the initial zone while final re-assurance monitoring would take place at the last stages.

In addition, following RSRL policy at Harwell, trained staff (such as a Local Incident Controller) would manage the response to, and recovery of, any emergency using established procedures and following the Command and Control philosophy.

RSRL carries out training and emergency exercises on a routine basis so that staff are fully trained to respond to any incidents. The training involves facility staff, Health Physics personnel and the Harwell Site Emergency Response Team.

As part of its nuclear licence commitments, RSRL carried out a major emergency demonstration exercise in 2008 at LETP. This was witnessed by members of the Nuclear Installations Inspectorate (now Office of Nuclear Regulation). The exercise simulated the dropping of a drum of radioactive waste in the LETP compound. Casualties were recovered, contamination was contained, and general command and control functions demonstrated.

6 General waste sentencing

To provide an example of how much waste is currently processed, during April 2010 to March 2011 ten half-height ISO containers of low-level solid waste (from operations and encapsulation) were despatched to Harwell's solid waste plant for onward disposal to the Low Level Waste Repository at Drigg. This involved a disposal of 25.7 GBq of alpha activity and 196.8 GBq of beta activity.

RSRL always endeavours to sentence waste to meet Best Available Techniques (BAT). For example, RSRL is currently looking at eliminating surface contaminated metal wastes being consigned to the Low Level Waste Repository at Drigg.

7 The future: Replacement Effluent Treatment Plant (RETP)

A new RETP is being commissioned to replace LETP and deal with liquid wastes generated during the remaining work on the main Harwell Site. This will be constructed in Harwell's solid waste plant where most of these active operations will take place.

<u>RETP design</u>

- Effluent from Harwell's solid waste plant will collect in a Disposable Settling Tank (DST).
- Supernate effluent shall be periodically drawn from each DST into its own evaporator. Residual settled solids shall remain within the DST.

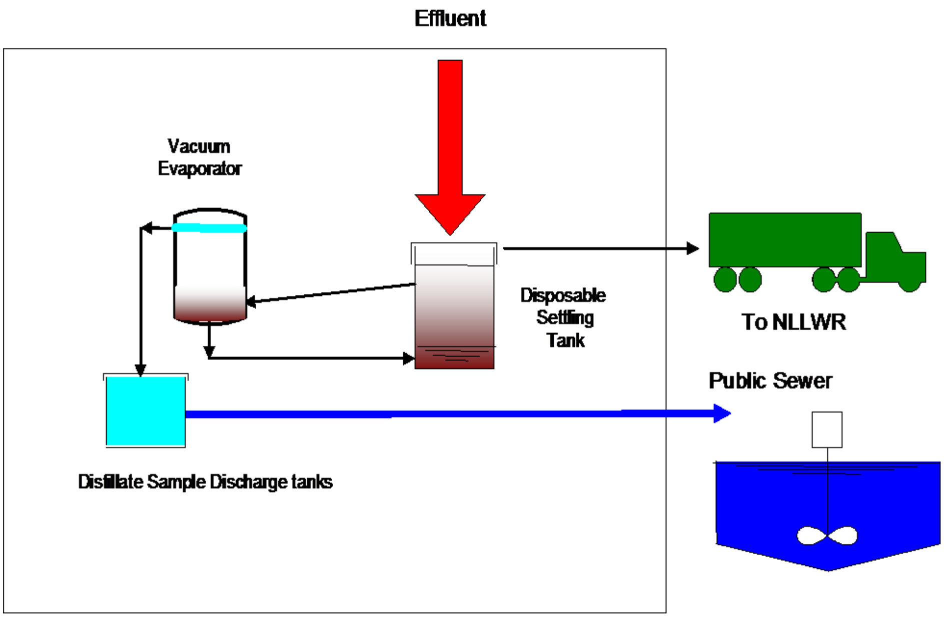

Figure 5 Overview of RETP

- The effluent shall be evaporated and condensed within an evaporator unit. The residues shall be returned to the DST.

- When sufficient levels of sludges have built-up within the DSTs, they shall be encapsulated with cement powder and subsequently consigned as low level waste.
- Condensate will be collected in a separate discharge tank for sampling and discharge (if acceptable) to the public sewer.

The RETP process shall minimise the active liquid discharge from Harwell and will allow the final closure of the LETP to be carried out.

RETP construction

The RETP will be constructed inside an obsolete delay tank located inside the solid waste facility. Prior to RETP construction, a major POCO operation was carried out to address the waste, contamination and contaminated equipment (eg tanks and pipework) found in this obsolete delay system. In planning this, a number of issues were addressed.

- HAZOPs, prior risk assessments and ALARP checklists were used to address hazards and risks, and to plan the work.
- Samples of residual waste were taken so that the fingerprint could be assessed.
- A Safe System of Work was established which incorporated Local Rules for the area and entry / exit procedures. As part of this, a zoned exit approach was developed where outer layers of PPE were removed in zones nearest the work faces and then further re-assurance monitoring was carried out as staff progressed through the zones.
- It was appreciated that a variety of techniques would be used in the clean up operations. These included the simple wiping of surfaces and the use of brick acid to remove outer layers of walling. As part of the prior risk assessment, calculations were carried out to assess the likely re-suspension of contamination and possible dose consequences to staff working in this area when the different techniques were used. A series of contamination hold points were set, and a matrix developed, which showed the upper limits when a particular technique could be used.
- A key stage in the process was to decide how far the area was to be cleaned. This involved comparing (i) the potential dose that would or could be accrued in carrying out POCO operations to (ii) the benefit achieved in making a cleaner working environment for the RETP facility. It was clear that all loose contamination had to be removed, but staff also had to consider how far surfaces with fixed contamination (eg brickwork) were cleaned.
- Finally, general Emergency Instructions were developed.

This POCO operation has now been carried out successfully following the principles described above. The delay system has now been cleared and cleaned, loose contamination removed and surfaces painted to help contain any residual fixed contamination in the building structure. Staff may now enter this area without the use of RPE.


Figure 6 View of delay tank before and after POCO

Work will soon commence on the construction of the RETP. With the former delay system having undergone successful POCO, much of this work can be carried out with minimal Health Physics support.

Authors

Gordon Gallacher started work in dosimetry at UKAEA Harwell in 1987. He now works as a Radiation Protection Adviser for Nuvia. As part of this, he has enjoyed secondments as a building health physicist to UKAEA and RSRL in both the Harwell solid waste plant (2001-2006) and LETP (2008-).

Robert Thickett started work at UKAEA (now RSRL) Harwell in 2001. He is the Senior Safety Adviser and Deputy ATO (Authority to Operate) Holder for the LETP.

Acknowledgements

The authors would like to thank the following RSRL staff for their support during the preparation of this paper: Andy Carey, Jeff Elliman, Steve Fisher, Alec Inns, Steve Jones, Stuart Pitman, Vaughan Rees, Gareth Thomas and Alan Thomas.

References

[1] Ionising Radiations Regulations 1999 and Approved Code of Practice
(ISBN 0 7176 1746 7)