# Remote Decommissioning of the Plutonium Experimental Extraction Facility, Sellafield – 17031

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## ABSTRACT

A redundant suite of gloveboxes formerly used for an experimental plutonium extraction process required decommissioning to avoid further degradation and a risk to other users of the Analytical Services building on Sellafield site. Following a full option selection process, remote techniques were chosen as the most appropriate (i.e. ALARP) decommissioning method. A nearby ventilation system from a previous project was re-engineered to ventilate the laboratory. Gloveboxes in neighbouring labs were cleared to create space to install a personnel access facility. The containment was reinforced where necessary to provide adequate protection from the remote machinery. Following a campaign of manual waste removal, including approximately 21 tonnes of lead chevron bricks released as exempt waste, a Brokk®[1] 90 remotely-operated vehicle (ROV) was deployed to perform remote size reduction of the glovebox suite. The resulting plutonium-contaminated material (PCM) was delivered to a Kraft Raptor manipulator for sorting and consignment to an on-site store in 200-litre drums. Despite indications from pre-decommissioning surveys of the presence of ILW in the shielded section, none was found.

Following the successful removal of the glovebox suite, and the emergence during the project of additional redundant gloveboxes within the Analytical Services building, the Remediation team has taken the opportunity to retain the decommissioning infrastructure as a remote glovebox breakdown facility.

## INTRODUCTION

### Facility Description

The Analytical Services building is one of the oldest on the Sellafield site, dating in part from the early 1950s. The building was constructed to house laboratories to perform analytical operations in support of the Windscale pile reactors, and later used for research and development relating to fuel reprocessing as well as other experimental work. A number of the laboratories are still active and support site operations; others are in care and maintenance and a number are undergoing, or have undergone, decommissioning.

The plutonium experimental extraction facility operated from 1974 until 1978, and was an expansion of an earlier pilot plant. The process was designed to separate Pu-238 from irradiated Np-237 fuel rods, for ultimate use in thermal batteries. The process was successful and the lab was shut down so a larger-scale process could be constructed. Following this all recoverable radioactive material was removed.

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[1] Brokk® is a registered trademark of Brokk AB in the United States and/or other countries.

The facility consisted of a suite of gloveboxes, both shielded and unshielded, in a linear arrangement. At the receipt end of the process was a gamma gate in the building external wall through which the neptunium rods were fed. In the shielded gloveboxes (Figure 1), operated via ball and tongs, the rods were cut by lathe into sections and dissolved in nitric acid before the solution was passed through a series of ion exchange columns, which were backwashed to extract the plutonium. After this the material was passed into the unshielded section (Figure 2) via transfer tunnels, where it underwent further processing and examination.

All the gloveboxes were constructed of Darvic, a calendared polyvinyl chloride (PVC) material which is no longer manufactured. This material is known to embrittle and darken with age, and also to degrade with exposure to acids, ultraviolet rays and ionizing radiation. The shielded gloveboxes were Darvic underneath with a shield wall constructed of lead ‘chevron’ bricks surrounding the gloveboxes.

Also included in the facility were two lead-shielded bulges, situated on the plinth in an adjacent lab, which had been used to dispense items into the main laboratory. At some point the dispensary hatches had been covered, surveys indicating that they had been bricked up and plastered over.

Figure 1 - Shielded section

Figure 2 - Unshielded glovebox

As with many experimental processes on the site, once research was complete the facilities were left in extended care and maintenance. Over time equipment such as glovebox pressure gauges deteriorated and thus could no longer be relied upon. Additionally many records relating to the process and the equipment could not readily be located. Clouding of the Darvic material made inspection of the glovebox contents more difficult.

The project’s stated endpoint was the removal of all active plant and equipment, i.e. the glovebox suite plus all inventory, all services, and any ancillary equipment. Three waste streams would be generated:

- Small amounts of exempt waste or LLW cleared manually from the laboratory prior to glovebox containment being broken
- PCM would form the majority of the waste; all glovebox shells and internals, plus stands and ancillary equipment
- Due to the nature of the process, the presence of ILW (in the form of fuel swarf, pennies or rods) in the shielded section could not be ruled out. This was supported by radiation surveys showing elevated levels in the cutting cell glovebox. Additionally, experience from a previous similar project suggested that large amounts of ILW could have been left in the facility at the close of operations.

A laboratory decommissioning project would ordinarily end with the lab being remediated to free breathing levels, with any contamination mapped and fixed, prior to handover to the facility owner pending final decommissioning of the building.

### Overall Scheme

It was considered that both the size of the facility and its construction (floor, ceiling and most walls being reinforced concrete) lent itself well to remote decommissioning. By contrast, many other labs in the Analytical Services building are congested and only separated from adjacent facilities by partition walls. The opportunity existed to retain the remote infrastructure as a breakdown cell once the extraction facility glovebox line had been removed.

At the time the project started, another remote decommissioning project within the same building was drawing to a close [1]. Whilst the facility this dealt with was very different – a series of highly active shielded cells – the project had given the team a large amount of experience in remote decommissioning tools and techniques. A number of operators had become very skilled at operating and maintaining ROVs in a cramped environment often with poor visibility and high radiation levels. It was intended to use this experience to inform the design of the new project, as well as to retain the skilled operators to drive the new machinery.

The envisioned process involved the installation of a personnel access facility, PCM and ILW waste routes, additional ventilation, and an ROV. After a ‘soft strip’ conducted manually in low contamination conditions (i.e. prior to breaking containment), the ROV would size reduce the glovebox suite and move the resulting waste to the relevant waste export station for disposal via the appropriate route. A gamma monitor handled by the machine would assist in waste sentencing, although ILW was only thought to be present in one section of one glovebox.

Characterisation indicated that although the gloveboxes were grossly contaminated internally, fissile inventory levels within the unshielded glovebox suite were very low (<1g). However a gamma scan of the shielded end, making a series of assumptions about the attenuation provided by the lead shielding, seemed to indicate that ILW would be present in the cutting cell. This would be in the form of cutting debris and swarf, or possibly complete fuel ‘pennies’ which had been dropped inside the glovebox. Due to the configuration of the glovebox it was not possible to conduct internal camera surveys; visibility was extremely limited due to the small windows and degradation of the Darvic glovebox inside the shielding. During the previous project to decommission the highly active cells, little ILW had been expected but a great deal had been found, which greatly lengthened the decommissioning process.

## DISCUSSION

### Techniques Used

A Brokk® 90 ROV was chosen to perform size-reduction of the glovebox suite. A Brokk® 180 had been used successfully on the previous project, but was too large and powerful to fit the project's requirements, and was reaching the end of its useful life. A quick-hitch was specified along with a number of interchangeable tools: a BCS10 circular saw, a Darda HCS7 shear, and a C02H-25 clamshell bucket. Trials had previously been conducted with the circular saw to determine its performance when cutting aged Darvic. The other tools had all been used successfully before.

Due to the layout of the lab, the standard cable reeling drum was adapted to traverse around 1.5 metres to and fro across the wall, in addition to its usual function of paying out cable. This ensured that when the Brokk® was working down one side or other of the glovebox suite, the cable would not be dragged across the gloveboxes. This system was simply constructed from vertical channel sections compressing against the floor and ceiling, with a horizontal catenary rail carrying the cable drum.

No specific maintenance area was defined for the Brokk®, due to the low external dose rates within the lab, but it was considered that a breakdown in an awkward space could still cause operators problems, for example if the machine was near a mass of sharps. Therefore the Brokk® was specified with an emergency backup system allowing it to drive at least the length of the lab following a total loss of power.

The second remote aspect to the project was more novel; rather than have an operator place waste into a 200-litre drum manually via a posting port, the project elected to have the waste sorted and placed into drums using a manipulator. This eliminated the need for the operator to handle sharps, a particular risk when trying to compact waste in the drum. It also eliminated the need for man entries into the cell, except for any breakdown maintenance and minor housekeeping tasks too delicate for the Brokk®.

For the waste sorting and posting task a Kraft Raptor manipulator was chosen due to the relatively low payload, but high dexterity, required. Its compact size and flexible mounting system also lent itself well to the layout of the waste posting facility. A roller conveyor, loaded by the Brokk®, would deliver waste to a bulge containing the manipulator, and operators standing in the free-breathing area would place the waste remotely into 200-litre drums for export.

The containment box in which the manipulator operated was constructed of stainless steel and made sufficiently robust to withstand impact from the manipulator. Although the Raptor incorporated a zoning function which was effective at preventing the arm impacting the containment box, this could not account for objects in the jaws coming into contact with the box. Additionally previous experience indicated that over-use of software zoning made the machine less useable.

Calculations were produced demonstrating that the containment box, and particularly the windows (12mm (½”) Lexan®[2]), were able to withstand impact from the manipulator. In order to add further confidence, a spare window was procured and impact tested at works trials. Despite elastic deformation in the region of 20mm (0.8”) in the centre, the window did not break.

Waste would be delivered to the manipulator via roller conveyor. It was concluded from trials that different waste containers were appropriate for different scenarios: where careful waste sorting and placement was required a flat tray design would allow for easy access, but for mass consignment of waste a construction-type plastic tub would allow the most efficient operation.

## Project Operation

A prior opportunity existed to remove the lead shielding bricks early (i.e. prior to breaking containment) rather than waiting for them to be contaminated, which would force their disposal as PCM. This would give significant benefits, as drum weight limits and the high density of the bricks mean that drums end up being exported almost empty by volume.

Bricks were removed manually by operators one-by-one with health physics in attendance to monitor radiation levels. When dose reached a certain level it was agreed that removal would cease (see Figure 3).

This approach allowed approximately 21 tonnes (approx. 23 tons) of lead bricks to be removed as exempt waste rather than becoming contaminated and requiring disposal as PCM, giving a substantial lifetime cost saving. The material has been retained by the site for future use.

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[2] Lexan® is a registered trademark of Sabic Global Technologies B.V. in the United States and/or other countries.

Figure 3 - Shielded section following partial lead removal

Following this process, and the removal of other soft waste as LLW, the laboratory was ready for the installation of decommissioning equipment. Installation of the majority of the ILW route was deferred due to this route not being needed until the very end of the glovebox suite, if at all.

Usual practice in decommissioning is that size reduction and disposal of the first glovebox constitutes active commissioning, and this convention was followed here. Following a review of active commissioning, permission was given for the project to progress into the operational phase.

A combination of circular saw and Darda shear was preferred by the operators for size reducing the Darvic. Operators first used the saw to create an opening in the glovebox, then changed to the shear and used the end paddles to break pieces of Darvic off until size reduction was complete (see Figures 4 & 5).

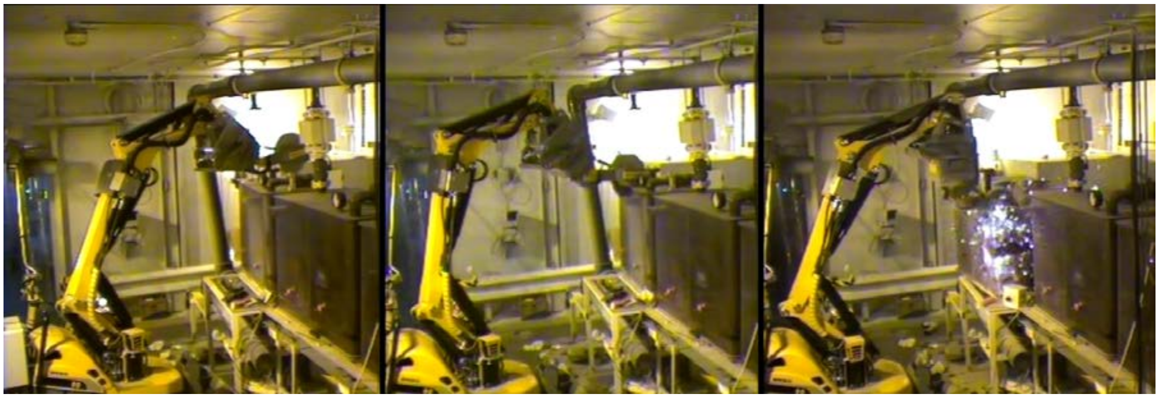

Figure 4 - Brokk® beginning size reduction of glovebox suite (CCTV stills)

Figure 5 - Darda HCS7 shear being used to break up Darvic (CCTV still)

Stands and other metal items were size reduced using the cropping function of the shear. Waste was sorted and handled using the clamshell bucket (Figure 6) and the shear paddles.

Figure 6 - Waste handling using C025H-25 clamshell bucket (CCTV stills)

Relatively small objects could be handled by the paddles at the end of the shear, despite the lack of force feedback and the remoteness of the operator. During a previous project operators were able to turn a latch approximately 25mm (1”) long using a combination of multiple camera angles and examination of the shadows around the object to build up a quasi-3D image. Similar techniques were used here to enable the handing of various small items of debris (see Figure 7).

Figure 7 - Small item held in HCS7 shear paddles (CCTV still)

As the gloveboxes were size reduced, quantities of debris nonetheless inevitably built up on the cell floor. Many pieces were handled by the clamshell bucket and shear paddles as above. Very small items and general debris could be swept up using whatever material was available, and pushed around the cell using the ‘dozer blade’ on the front of the Brokk®. Previous experience had led the team to specify these (rather than the standard outriggers) for exactly this purpose. Allowing too great a quantity of debris to build up on the cell floor can cause mobility problems for the Brokk® as it can become ‘beached’.

As would be the case during a manual decommissioning project, waste was segregated and stored within the laboratory to give the optimum packing fraction when posted out into drums. An area of the lab was used as a buffer store for size reduced Darvic so that it could be mixed with other waste prior to export. This was due to downstream restrictions on the percentage of Darvic in each PCM drum.

Commercially available plastic tubs were used for collection and storage of waste. Trials with the manipulator had shown that these were easy to handle and able to withstand the forces exerted by the jaws. They could also easily be picked up using the shear on the Brokk®. Metal-type containers tended to be too rigid and deformed plastically when handled by the Brokk®.

Between five and six tubs’ worth of waste was placed into a drum at any one time by the Kraft manipulator. The plastic tubs were used until they ripped, at which point they were added to the drum as waste. Tubs containing large quantities of fine debris were added to the drum whole (as opposed to tipping the waste in and re-using the tub) to prevent the posting area becoming cluttered.

A number of tools were fabricated to aid waste posting operations: a compaction tool consisting of a disc on the end of a rod, a hook for reaching items on the conveyor, and a brush for housekeeping within the containment box. All tools had a ½” T-handle to engage with the manipulator jaws.

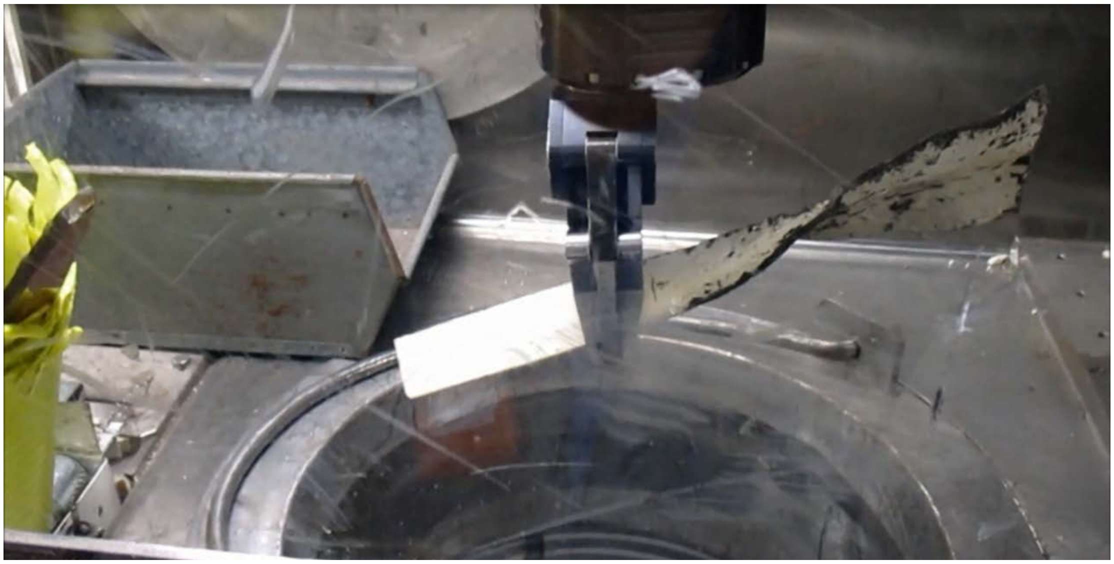

Figure 8 - Manipulator consigning cropped metal waste to PCM drum (video still)

Ordinarily PCM drums would be topped off with a layer of soft waste, to prevent sharps puncturing the bag once the lid is fitted. Due to the lack of soft waste being generated in the laboratory (because of the relative lack of air-fed suit entries and associated contaminated suits), an alternative system had to be introduced. Polystyrene discs approximately 150mm thick were imported in batches and used to top off the drums. Whilst this approach artificially increases the volume of waste generated, it is necessary to maintain safe downstream waste handling operations. It must also be compared against the much larger volume of soft waste that would be produced during manual operations.

A limited number of housekeeping man-entries were made into the cell; these were usually combined with entries being made to repair the Brokk® (see ‘reliability’ section below). In addition a campaign of cleanup was undertaken in between finishing decommissioning of the unshielded section and commencing the shielded section. This was primarily to maintain proper waste segregation in case ILW was found. In the event, surveys undertaken at this point did not indicate the presence of ILW within the shielded section. It is thought that the high readings picked up by historic surveys were due to gross contamination in the cutting cell.

Figure 9 - General view of cell mid-decommissioning (CCTV still)

Decommissioning of the shielded section was conducted in largely the same manner as the unshielded section, since the gloveboxes were Darvic underneath the shielding. The last glovebox, the cutting cell, presented the greatest challenge to the equipment as it contained a lathe supported by a steel framework (Figure 10). The frame was removed from the Darvic glovebox shell, before the metalwork was cropped with the shear.

Figure 10 - Removal of internals from cutting cell glovebox (CCTV stills)

The lathe bed was the largest item cropped by the shear (Figure 11).

Figure 11 - Lathe being cropped by Darda HCS7 shear (CCTV stills)

This completed the removal of the glovebox suite. There remained two lead cell bulges in the wall of the cell, protruding into the neighbouring laboratory. These had been over-clad at the beginning of the project to allow them to be decommissioned from the rear. Following a campaign of cleanup, the penetrations into these cells were re-opened (having been previously bricked up) and enlarged slightly to improve access. The two lead cells each consisted of four walls of lead chevron bricks – two walls, a front, and a roof supported by a metal plate. The contents, which had been previously unknown due to the total lack of access, zero visibility and heavy shielding, turned out to be minimal, consisting of only a few empty pieces of laboratory glassware.

The lead bricks were removed manually by operators for disposal as LLW; as they had been sealed in the cells for the duration of the decommissioning work, contamination was minimal.

The final stage of cell clearance was to size reduce the large metal plates that had supported the upper part of the shielded section. These plates could be exported as LLW due to their density and ease of decontamination, but required extensive size reduction to allow them to fit out of the cell. The plates were cut into sections, first remotely using the circular saw on the Brokk® and then manually into smaller sections, before being moved onto pallets for export.

## CONCLUSIONS

### System Maintenance & Reliability

All equipment placed into the cell was chosen for its minimal maintenance requirements; indeed no scheduled maintenance was due on any in-cell item over the course of the project. Intervention was limited to repairing any breakdowns. It is the authors' opinion that the simplicity and fit-for-purpose nature of the equipment was a significant factor in the success of the project.

The project used an ‘operator-maintainer’ strategy, i.e. those operating the machines were also responsible for maintaining them in working order. This incentivizes the operators to use the machines in the most sustainable manner. This strategy had been used to great effect on a previous remote decommissioning project and was carried over here.

Experience from previous projects involving Brokks® in a similar environment suggested that hydraulic hoses were the most likely item to fail, and thus the project devised a short lead time method of procuring these. Experience also suggested that the shear blades would eventually blunt, but the relatively short duration of this project meant that this did not happen.

During the course of the decommissioning work, the shear blades appeared to splay slightly, although this did not affect their function. It is believed this was due to the behaviour of Darvic material when undergoing shearing.

Two hydraulic hose failures were encountered, both of which were repaired the same day by operators in air-fed suits. In addition, three loose hydraulic fittings were encountered, which were again rectified by operators in air-fed suits using hand tools.

The only other failure encountered was during the cutting of the large support plates that formed part of the shielded section. These 25mm (1”) thick mild steel plates were being size reduced using the BCS10 circular saw. The saw performed effectively but cutting was slow due to the depth of the material. A new blade type was fitted to determine if cutting speed could be improved, at which point the saw developed an out-of-balance vibration. It is believe that the centre nut worked loose allowing the saw blade to bend.

Over the lifetime of the project it was not anticipated that the Kraft Raptor manipulator would require any routine maintenance. However, in case of breakdown and to allow general access into the containment, gloveports were provided in the containment. These were covered by an interlocked guard to prevent access whilst the manipulator was operating. They were ordinarily blanked, requiring a glove to be fitted if access was necessary. Inactive trials undertaken at the manufacturer’s facility had included several operators being trained in all aspects of maintaining the arm. Its modular nature also meant that parts could be swapped out rather than rebuilt, if desired.

At some point during operations one of the bolts in the jaws came loose and this was not noticed by the operators. This resulted in the bolt bending slightly. As a precaution the jaws were swapped for a heavy-duty set, which were used successfully for the remainder of the project.

## Project Timeline & Outcome

The optioneering stage of the project commenced in 2009, when the use of remote technology was first selected. Preliminary design activities were completed in late 2010. There followed a period of trial work to select the manipulator. Following project sanction and safety case activities, detailed design commenced in 2011.

Further trials to fine-tune the position of the manipulator and to select waste export trays were held in mid-2011. During this period, civil modifications (primarily widening of doorways) were undertaken to allow the import of plant and equipment into the cell.

Ordering of long-lead items such as the Brokk® and Kraft manipulator took place in early 2012. Final trials, as well as maintenance and operator training, took place in mid-2012. The project then finished procurement activities and installed the plant and equipment, commencing in early 2013.

At the same time, work was undertaken in a neighbouring laboratory to remove redundant gloveboxes in order to clear space for the personnel access facility.

Following a stage of financial, safety and regulatory approvals during 2013, inactive commissioning of some systems commenced in 2014 while manufacture and testing of other systems was concluding.

Size reduction commenced in December 2014. The unshielded gloveboxes were size reduced and exported by the end of May 2015. This included a scheduled pause after the first glovebox while the active commissioning phase was reviewed and approval sought to progress to the next stage.

Following the removal of the unshielded gloveboxes, the project then paused to undertake visual and radiation surveys of the remaining (shielded) gloveboxes. These surveys were delayed by a fault with the building ventilation, which prevented access into the cell. Following the surveys, size reduction of the shielded section commenced in late June 2015 and was complete by August. All waste was posted out by the end of October 2015.

The two lead-shielded bulges situated on the plinth in the neighbouring laboratory were then decommissioned. Both the lead bricks and the contents, which were minimal, were removed manually by operators in air-fed suits. This operation was complete and the resulting waste posted out by the end of December 2015.

A series of large, 25mm (1”) thick plates which supported the shielded section were then size reduced to allow their export as mixed metals LLW. This operation was completed in mid-2016.

The remainder of the lead bricks, which had been stacked in a corner of the lab and overwrapped to avoid contamination, were then monitored to determine their waste route. Contamination levels were low enough to allow their export as LLW. This operation is ongoing at the time of writing. It is being conducted remotely, the bricks being placed into drums for transfer to the Studsvik®[3] LLW metals recycling plant in Sweden.

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[3] Studsvik® is a registered trademark of Studsvik AB in the United States and/or other countries.

At this point all waste will have been removed from the laboratory and under normal circumstances a campaign of decontamination would be undertaken to allow its return to free-breathing status. However at the inception of the project it had been envisaged that the cell could be retained to process other redundant gloveboxes contained within the building. During the project's lifespan, work was undertaken to clarify the quantity and nature of this additional inventory, which proved to be significant.

These factors led the project team to elect to retain the cell as a breakdown facility. Some limited decontamination is to be undertaken, and preparations are being made to import 8 further highly contaminated gloveboxes from a nearby lab into the cell for size reduction and disposal as PCM. These preparations are in the early stages and transfers are likely to commence in early to mid-2018.

In the intervening period the cell will be left in a quiescent state, with the remote machinery being periodically exercised to avoid seizure.

### Project Statistics

Gloveboxes decommissioned: 9, plus 2 lead cell bulges
Machine hours: Brokk® 460, Kraft Raptor 80 approx (269 drums @ 20mins each)
Number of 200-litre PCM drums produced: 269 (includes bagged soft waste present before decommissioning commenced; excludes lead for Studsvik® recycling)
Quantity of exempt lead removed: 21.3 tonnes
Quantity of LLW lead to be removed: 22 tonnes approx

## REFERENCES

1. Gamberini, D.A. (1996) *Decommissioning of the B205 Fuel Reprocessing Pilot Plant Using Machine Assistance.* European Commission Nuclear Science & Technology Series. Report number EUR16975.

## ACKNOWLEDGEMENTS

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