

Studies, Transport and Treatment Concept for Boilers from Berkeley NPP, England – 13599

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ABSTRACT

In November 2011 Studsvik was awarded a contract to transport five decommissioned boilers from the Berkeley Nuclear Licensed Site in the UK to the Studsvik Nuclear Site in Sweden for metal treatment and recycling. A key objective of the project was to remove the boilers from the site by 31st March 2012 and this was successfully achieved with all boilers off site by 22nd March and delivered to Studsvik on 6th April. Four boilers have been processed and the fifth is planned for completion by end of December 2012. The project had many challenges including a very tight timescale and has been successfully delivered to cost and ahead of the baseline programme. This paper describes the project and the experience gained from treatment of the first four boilers. It is the first UK project to send large components overseas for recycling and provides new insight into the processing of Magnox gas-circuit components.

BACKGROUND

Berkeley was one of the first generation of nuclear reactors in the UK and had two natural uranium-fuelled Magnox Reactors, see figure 1 for the Magnox reactor principle.

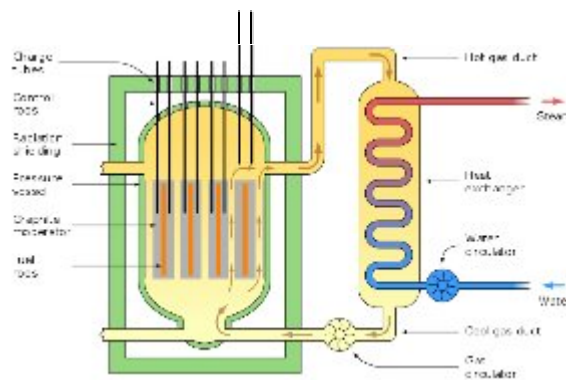


Fig. 1 Schematic of Magnox Reactor showing Reactor and Boiler

Berkeley came into service in 1962 and continued operation until Reactor 2 was shutdown in October 1988 followed by Reactor 1 in March 1989.

Each reactor had eight boilers (heat exchangers) located in housing structures external to the reactor building and connected by gas ducts above ground (inlet duct) and below ground (outlet duct).

Berkeley was the first commercial nuclear power station in the United Kingdom to undergo decommissioning and so far this has included the removal of all fuel from the site in 1992, and the demolition of structures such as the turbine hall in 1995 and cooling ponds in 2001. The current stage of decommissioning is to prepare the site for long term care and maintenance.

Each boiler comprises a 28.6 mm thick, mild steel pressure vessel, 5.33 metres in diameter and 21.34 meters in length with domed ends. Each vessel was held by a support skirt assembly.

Inside the pressure vessel is a square section duct that runs the full length of the boiler pressure vessel. This square section duct connected to the upper and lower gas ducts via inlet cone and outlet cone assemblies. This square section duct houses the boiler tube banks located horizontally.

Between the square section duct and boiler pressure vessel is an interspace that enabled access to the vessel and the tube banks. This was achieved by means of hinged doors on the internal duct and access penetrations on the outside of the pressure vessel. Vertical access ladders and hinged trap doors enabled personnel to climb the length of the pressure vessel.

As part of the decommissioning programme, all boilers were de-lagged and disconnected from the inlet and outlet gas ducts. The upper gas ducts were removed and size-reduced, and blanking plates were fitted to the gas duct apertures at the top and bottom of the boiler pressure vessel. The waterside headers and recirculation penetrations were cut and blanked on the outside of the boiler pressure vessel.

In 1997, the boilers were lifted from their support skirts and transferred to a horizontal position around each reactor building, see figure 2. Each boiler was located on two support saddles and positioned in pairs.



Fig. 2 Photographs showing boiler lowering and final example of one storage location

The total weight of each boiler is approximately 311 Mg(tonnes). This was recorded from the crane weighing device used during lowering from the vertical position. The estimated make-up of the boiler weight is as follows:

• Pressure Vessel	91 Mg (tonnes)
• Support beams and associated steelwork	30 Mg (tonnes)
• Tube Boxes	33 Mg (tonnes)
• HP Superheater tubes	16 Mg (tonnes)
• LP Superheater tubes	13 Mg (tonnes)
• Evaporator & Economiser tubes	100 Mg (tonnes)
Total	283 Mg(tonnes)

The remainder of the 311 Mg (tonnes) comprises ladders, other pipework and various other items. Following lowering operations one of the boilers (number 10) was size-reduced in a purpose-built temporary containment structure and the steel sections were decontaminated.

All of the fifteen remaining boilers have remained in place and have been subject to on-going maintenance and inspection.

Re-circulating carbon dioxide gas was used to transfer heat from the reactors to the boilers via the upper gas ducts. The gas cascaded down through the boilers and was returned to the reactor via the lower gas ducts. As a result, the internal surfaces of the boilers; boiler tubes, steelwork, vessel internals, have been exposed to hot radioactive gas carrying particulate and are therefore contaminated. As tritium was present in the re-circulating gas during operation, diffusion into the steelwork is known to have taken place.

The steelwork is not irradiated and the radionuclide fingerprint identifies that the main radionuclides are Tritium, Carbon-14 and Cobalt-60. Total activity for all fifteen boilers was estimated to be 532 GBq i.e. average 35.5 GBq per boiler.

Total weight of the boilers is estimated to be 4670 Mg (tonnes) giving a total specific activity of 114 MBq/ Mg(tonnes) and would therefore be classified as LLRW/LLW under the UK system of radioactive waste classification.

Measurements taken within the pressure vessel during 1997 identified the following radiological information:

- Dose rate - 50 μ Sv Beta/Gamma; 20 μ Sv Gamma.
- Contamination - 500 CPS Beta by RM6 / BP4 probe.
- No significant alpha contamination.

No evidence of contamination had been found within the water side of the boiler or in the steam pipework and the internals of the boiler tubes were thought to be free from surface contamination.

Radiological Characterisation

To allow Magnox to produce decommissioning strategies there was a programme of characterisation work carried out on the boilers and other Magnox boilers from the late 1980's

onwards. In 1987 gamma spectrometry measurements and swabs were taken primarily from Berkeley boiler 7 with additional measurements from four other boilers. The gamma spectrometry readings from within the boilers identified Co-60 as the dominant gamma emitting nuclide. Counting using high-resolution gamma spectrometry and subsequent analysis of the swab samples was carried out to determine the low energy gamma, and non-gamma emitting nuclides as ratios to the Co-60. A small number of radionuclides were inferred from the decay chains of those nuclides already identified through sampling and analysis. It was noted in the analysis report that the tritium inventory may be underestimated, as tritium is known to diffuse into the boiler steel itself, as well as being present as loose contamination. In light of this in the mid 1990's, as part of the dismantling and decontamination of boiler 10, steel samples were taken, and actual levels of tritium within the steel were determined using liquid scintillation counting methods. Interestingly it was noted in one report that whilst the boiler shell represents approximately one third of the total mass of the boiler, the internal surface of the shell accounts for only 3% of the total radioactive inventory based on the assumption that all internal shell surfaces are contaminated to the same extent. Through the collation of the sample and analysis information, the fingerprint and expected inventory of a boiler was generated by Magnox.

Following the dismantling of boiler 10, Magnox carried out continuous health physics monitoring of the boilers. In support of the procurement for the supplier to remove, transport and treat the boilers, it was necessary to produce a Waste Characterisation Form detailing the physical, chemical and radiological inventory of the boilers. In conjunction with the Magnox Support Office, Berkeley Site collated all the available information, including retrieving archived information relating to disposals from the dismantled boiler. The extensive characterisation work carried out by Magnox, over nearly 20 years was detailed in 6 reports held by Berkeley Site. This information was summarised and the radiological inventory was decay-corrected to bring it up to date.

INTRODUCTION TO THE PROJECT

The Berkeley Boilers project was initiated by Magnox plc. during 2011 and started as a Magnox Graduate project. The second year graduates were asked to look at options for the removal, transport and treatment of the boilers. As part of this project, the Low Level Waste Repository (LLWR) was engaged to provide advice on what options existed in the supply chain.

The graduates initially suggested that cutting the boilers into three ~100 Mg (tonnes) sections for transport off site for treatment was the preferred option; however as a result of the engagement with the supply chain through LLWR, the option of transporting the boilers whole was identified. This for many reasons was deemed to be more favourable, not least as it minimised the risk associated with on-site working, and construction of bespoke cutting containments. In order to underpin the credibility of transporting the boilers whole, transport studies were commissioned through LLWR's Waste Services Contract.

Transport and Treatment Options Study

Studsvik was one of two companies selected to carry out a feasibility study and selected a specialist heavy transport company Abnormal Load Engineering (ALE) to support them.

Studsvik and ALE evaluated a variety of options for lifting and transporting the boilers to Sweden. As part of this evaluation, stakeholders including regulators, local authorities and local ports councils were contacted to ensure that any selected option was credible.

In line with UK Highways Agency requirements, a key consideration was to minimize road transport and this was possible by transporting to the nearest port of Sharpness. However, this port has access constraints due to a lock gate arrangement which restricts the size of vessel that can be used. One of the underlying principles adopted by Studsvik and ALE was to minimize lifting boiler operations therefore a strategy to utilize roll-on-roll-off vessels was adopted. Such vessels capable of accessing Sharpness were limited to carrying two boilers therefore in order to optimize transport to Sweden, it was decided that pairs of boilers would be transported from Sharpness along the Severn Estuary to the larger port at Avonmouth where they could be transferred to a larger sea going vessel. This enabled five boilers to be shipped to the Studsvik facility in one voyage. A roll-on-roll-off vessel previously used by Studsvik for similar European projects was selected and a special purpose barge previously used by ALE was selected for the inland waterway leg of the journey.

Best Available Technique (BAT)

A Best Practicable Environmental Options (BPEO) study, into the options for the boilers was first conducted in 2001. At this time there was no offsite treatment route that was deemed viable to allow the boilers to be transported from the site and treated. Previous onsite experience, in 1995, when one of the boilers was size-reduced and treated in-situ had limited success, and it was not seen as a viable, cost effective option for the remaining 15 boilers. The outcome of this BPEO was that on-site storage until Final Site Clearance was the preferred option.

When the graduates started to investigate the possible options, it became clear that the 2001 BPEO was out of date and there had been significant changes to the industry and supply chain capability, many of these fairly recently. The main changes were around the national policy; 2007 UK Government Policy for Solid LLW, 2010 National LLW Strategy, 2006 Strategic BPEO for Metallic LLW (revisited in 2011). In support of the changes a number of routes had opened up through the LLWR's Waste Services Contract, which removes the requirement for individual sites to establish their own commercial routes, by providing competitively competed frameworks for accessing services such as Metallic Waste Treatment, and Incineration Services.

The graduate team produced an options paper, which demonstrated that there were a number of credible options available. Following engagement with LLWR and the suppliers on the Metallic Waste Treatment Framework, under the Waste Service Contract, it was identified that the boilers could be removed and transported off site for treatment. In order to underpin this option the transport study was conducted which detailed the transport route and any enabling works that would be required to make the option viable. The beauty of this solution was that the changes identified were minimal in scope and cost and could be undertaken quickly.

Magnox used the transport studies as the basis of a re-assessment of the original 2001 BPEO for the boilers. A panel of experts were convened to assess what the BAT should be, utilising Magnox's approved procedures. A screening process was carried out initially to identify alternative waste management options that could be applied; this allowed the waste management

end-point to be moved i.e. LLW to “out of scope” (equivalent to “free-release”); or a significant volume waste reduction. With the screening process and reasoned argument assessment, various options were considered including size reduction on site, disposal of the whole boilers to a dedicated facility, or off site treatment. It was concluded that the BAT was recycling of the boilers, transported whole and treated off site.

A competitive tendering exercise was carried out by Magnox via the LLWR Metals treatment Framework and Studsvik was awarded an initial contract for the transport and treatment of five boilers.

PROJECT DETAILS

Upon selection Studsvik began to work collaboratively with Magnox, LLWR and their heavy transport specialist ALE to develop the project programme and joint project risk register. The project officially commenced on 4th November 2011 and essentially comprised four stages;

1. Design and Characterisation
2. Site Enabling Works
3. Lifting & Transportation
4. Treatment

The contract to deliver five boilers to the Studsvik metal treatment facility in Sweden was let on a very tight timeline and a series of key stakeholder deliverables needed to be met in order to obtain approval to ship. A project team was formed from all parties involved in the project; Magnox Ltd, LLWR, Studsvik and ALE. The project benefited from having very clear goals, and strong support from all parties to achieve these goals. There were two key elements that helped the project meet the tight schedule. One was the use of an interactive documentation review process. This process required the key project documents be issued for review, after this initial review a face to face meeting was convened with all the reviewers present, all comments were discussed, agreed or discarded during a meeting, with the document ready for formal issue before leaving the room, this significantly reduced the documentation approval cycle and limited the amount of re-work needed as changes were discussed and made interactively. The other key element was a very strong communication process, all parties were actively involved in the decision making processes. This was achieved through the use of an active and dynamic communications process that included: weekly progress meeting, weekly programme management, the use a contract management portal and Microsoft “Live Meeting” software.

Design and Characterisation

A number of interrelated activities were carried out in parallel to achieve the project milestones.

Existing design information was reviewed and this was further informed through Non-Destructive Examination (NDE) of boilers and saddles by visual, ultrasonic and Magnetic Particle Inspection (MPI).

Assessment of the boiler structure under all transport loadings was undertaken by Finite Element Analysis, see figure 3, in line with the requirements of applicable regulations [1, 2, 3].

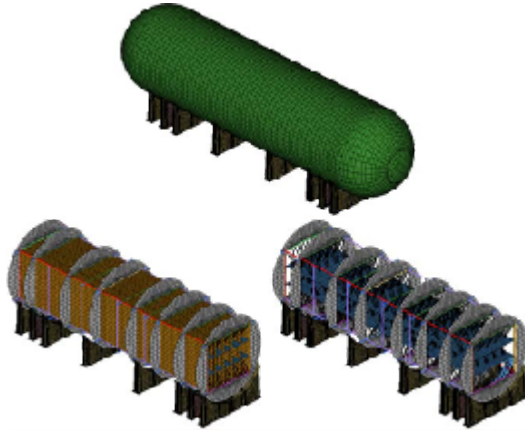


Fig. 3 Screen shots from the FEA Model

The assessment also considered the support saddle design and an optimum number of saddles was identified to ensure load security during all modes of on-site and off-site movement.

Radiological surveys were carried out to confirm dose rate and external contamination levels. Due to the specifics of the Berkeley Boilers any beta measurements recorded also contained a contribution from gamma radiation being emitted from inside the Boilers therefore a specific monitoring technique was established in order to determine the fixed beta contamination on the external surface of the Boilers.

As such a beta reading was taken as normal with the probe unshielded and at approximately 2mm from the surface of the Boiler. This reading represented the fixed beta contamination and the effect of the gamma radiation from the internal surfaces. This measurement was then repeated with the probe in the same location, but with a 1 mm thick piece of steel shielding the probe. The shield removed all contributions from the surface beta contamination, but had little effect on the reading due to internal gamma radiation. The differences between those two readings were then therefore representative of the external fixed beta contamination. The results were recorded and calculated to infer the Becquerels per cm² (Bq/cm²) and were compared against the transport limit of 0.4 Bq/cm² for alpha contamination and 4 Bq/cm² for beta/gamma contamination for external surfaces [1, 2]. The data collected confirmed that there was no external fixed contamination.

During the radiological surveys each of the boilers were also swabbed to determine if any loose contamination was detectable on the external surface of the boilers. A total of 345 swabs each taken over a surface area of 300cm² were removed from each of the five boilers and were assessed to see if there was any loose contamination detectable. None of the swabs measured above a

background level and therefore there was no evidence of loose contamination on the external surface of the boilers. This was as expected for the items stored externally for 14 years.

Beta/Gamma surface dose rate measurements were collected in order to confirm workers and public doses and for use in confirming compliance with the transport regulations [1, 2]. The dose measurements collected were also used to undertake further confirmatory assessments of the radioactive content of the boilers. Computer modelling was undertaken to assess the potential radioactivity based on the dose rates measured at 1m and in contact with the boilers. This modelling was performed using MicroShield software.

Dose rate measurements were taken at 1 meter distance from the boiler using an Exploranium GR135, sodium iodide detector. Table 1 summarises the dose rates measured for each of the boilers.

Table 1- Highest and Average Dose Rates Measured at one meter

Boiler Number	Highest Dose (µSv/h)	Average Dose (µSv/h)
9	1.5	0.9
11	2.2	1.3
12	3.1	2.0
13	1.9	1.3
14	1.7	1.0

Some small sections of the boilers recorded elevated contact dose rate measurements. These were very small collimated emissions which significantly reduced at a short distance. The dose rates measured ranged from 8µSv/h to 31.5 µSv/h.

On completion of the dose rate surveys of the five boilers a number of activity assessments were carried out using propriety software (MicroShield) to model the Co-60 emissions from the boilers. The models were developed to provide further confirmation to the accuracy of the Magnox radioactivity assessment.

These models were based on two different scenarios.

- Scenario One modelled the emissions associated with internal surface contamination.
- Scenario Two modelled the emissions associated with contamination spread homogenously throughout the internal volume of the Boilers.

Models were also undertaken to account for the activity associated with the “hot spot” emissions, identified above.

Table 2 shows the total activities calculated from the MicroShield modelling.

Table 2 – Comparison of Total Activity Data (per boiler)

	Total Activity Per Boiler (GBq)
Magnox Activity Assessment	35.5
Based on Internal Surface Contamination Models	45.9
Based on Internal Homogenous Volume Contamination Models	72.2

The results showed very good agreement between the modelling data and the Magnox data provided for the boilers.

An essential output from the work carried out was the preparation of a Transport Categorisation Report. This document collectively reported all engineering and radiological works and provided a Safety Case type document for the categorisation of the boilers as an SCO-I package.

Throughout the work regulators from the UK and Sweden were consulted and all necessary approvals were obtained. This included obtaining Transfrontier Shipment approval for transport between UK and Sweden, and Highways Agency Special Approval for abnormal load transport by road in the UK. A number of other stakeholders were engaged to ensure that all local and international requirements were met.

As there were a number of discrete transport movements utilising different organisations individual Radiological Protection Programmes were produced together with an overarching Command and Control strategy to ensure clarity of roles and responsibilities for Radiation Protection during transport.

Site Enabling Works

A number of on-site activities were carried out to prepare the boilers and support saddles for transport. This included removal of miscellaneous steelwork and thermocouple attachments plus modification to the existing support saddles to enable the load to be secured.

Civil works were undertaken to prepare the ground on-site and adjacent to the site in order to enable movement and temporary storage of the large loads. In some areas this included plate bearing tests and subsequent modifications to ensure ground stability.

During this stage of the work the Office for Nuclear Regulation (ONR) Radioactive Materials Transport Team (RMTT) organised independent radiological surveys that confirmed Studsvik and Magnox survey data.

Lifting and Transportation

A number of potential techniques for lifting the boilers had been considered by ALE and Studsvik. An important consideration was loading of underground structures. The final movement of the boilers from site to the barge carried out by a Self-Propelled Trailer (SPT), as shown in figure 4.



Fig.4 Photograph showing boiler loaded onto SPT

Four of the boilers were moved to temporary storage areas on the site and the fifth boiler was transferred directly to a road trailer for off-site transport to Sharpness. Three separate road transports were carried out over a seven day period, the first involving one boiler with each of the other transports involving two boilers, see figure 5.



Fig. 5 Photographs showing road transport arrangement

On arrival at Sharpness the boilers were transferred to a special purpose barge for shipment to the larger port at Avonmouth.



Fig. 6 Boilers loaded onto barge at Sharpness

On arrival at Avonmouth the boilers were offloaded and transferred to a dedicated storage area. Additional temporary security arrangements were implemented by Studsvik and ALE for the in-transit storage period prior to loading to the sea going vessel. Careful coordination of transport activities was essential to maintain the 14-day in-transit period specified by UK regulators.



Fig. 7 In-transit storage of boilers

All of the boilers were removed from the Berkeley site by 22nd March 2012 nine days ahead of the project milestone and the boilers arrived at the Studsvik site in Sweden on 6th April 2012.

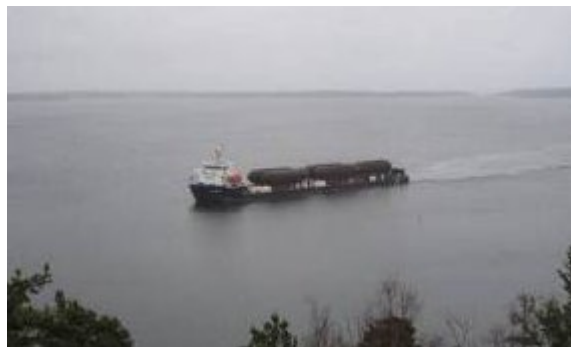


Fig. 8 Boilers arriving at Studsvik harbour

Prior radiological risk assessments had been produced for all stages of the transport and these were monitored through daily issue of Electronic Personal Dosimeters managed by Studsvik health physics personnel who accompanied the boilers through each stage of their journey. Maximum individual dose recorded for any transport operation was 22 μ Sv which was consistent with background radiation over the period. Collective dose for all transport related activities was 292 μ Sv which was significantly lower than the predicted 5458 μ Sv.

Treatment

On arrival at the Studsvik site in Sweden, all boilers were subject to radiological surveys and four boilers were transferred to an internal storage facility and one boiler was transferred directly to the Treatment facility.

Treatment of the first boiler started in April 2012 and an initial controlled breakthrough of the boiler shell was carried out to identify radiological conditions and enable collection of any residual materials.

During the segmentation of the first boiler it was important to learn where and how the different parts of the boiler were located and to segment it appropriately for the subsequent steps in the process of surface decontamination and thereafter melting. In order to achieve clearance of the material (ingots) after melting it was necessary to decontaminate the material before melting. All material was therefore decontaminated by blasting with steel shots before melting.

During melting of the material, representative samples are taken from the molten metal. These samples are then sent to the Studsvik radiometry laboratory for measurement and evaluation. Based on the results from the laboratory it can then be decided whether radiological clearance the ingots is possible.

Based on that procedure, including both decontamination and melting, over 96% of the incoming weight of each boiler can be released from regulatory control after treatment. The remaining 3-4% is secondary waste in the form of cutting residue, dust from the ventilation systems, blasting residue and slag from melting process.

Each boiler represents approximately 650 m³ and 311 Mg (tonnes) upon arrival at Studsvik for waste treatment. Studsvik will return <12 m³ of secondary waste to LLWR from each treated boiler for disposal. In terms of weight the secondary waste is <20 Mg (tonnes) from each boiler treated.

Through optimisation and high packing density of the secondary waste, the number of 200 litre drums created were less than that estimated during the feasibility study stage. This means that the number of HHISO has been reduced from a predicted 3 to 1.5 of packaged of secondary waste from each boiler.

All secondary waste will be returned from Sweden to LLWR for disposal at the UK LLW Repository. Studsvik will retain ownership of the radiologically cleared ingots in Sweden, which are supplied for remelting for the production of new steel products.

Radiological issues and dose rates during waste treatment

Dose Rates measured during treatment of boiler 11:

- Average 3.0µSv per hour inside the boiler shell
- Average 10µSv per hour within the tube banks
- Hot spots within the tube banks of up to 30µSv per hour

The collective dose from the treatment of this boiler resulted in 7.57 man mSv. Figure 9 shows the collective dose during the treatment period of boiler 11 which, was the first boiler treated.

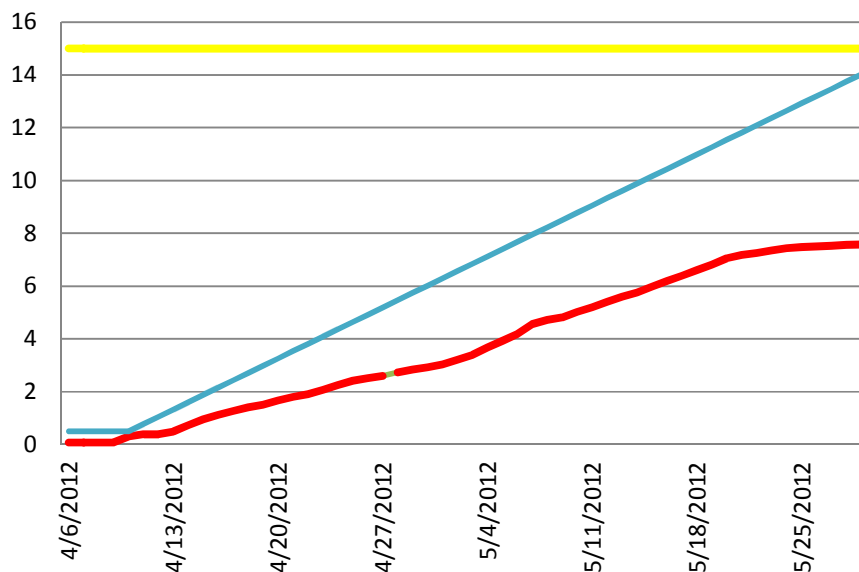


Fig.9 The collective dose for treatment of boiler no. 11 (mmSv). The yellow line is the aim for the collective dose, the blue line is the expected prognosis and the red line the actual dose.

During the treatment of the boilers there have been no issues relating to the working environment based on dose rates or contamination from the boilers. All work has been performed in accordance with standard facility procedures for the treatment of radioactive metal at Studsvik, Sweden.

Conclusions

- The Berkeley boilers project has demonstrated that large components from a Magnox gas circuit can be safely transported; size-reduced and effectively decontaminated enabling valuable metal to be recycled. To date recycling of up to 96% of steel has been achieved.
- All the secondary waste generated by the project to date is suitable for disposal at the LLW Repository.
- No secondary waste has been classified as ILW, although initial characterisation showed this to be a project risk, based on the C-14 content.
- The estimated volume of secondary waste was decreased even further, i.e. 1.5 HHISO per boiler instead of the calculated 3 HHISO
- The volume saved is 638m³ per boiler

- The project also showed a lower than estimated dose to personnel.
- The Berkeley boilers project has been the first of its kind in the UK and was successfully executed within a very short timescale. This was achieved through close teamwork between all parties; client, stakeholders, regulators, contractors and early /continuous engagement with all stakeholders.
- This project demonstrates that large items can be moved whole for treatment, which significantly reduces project timescales. Previously in the UK, shipment of large radioactive items was seen as difficult and unachievable. This project shows that large items can be moved whole, safely and delivery is quicker than if conducted on site. The project also demonstrates that having a focused team, working in alignment with clear goals, can deliver complex projects in tight timescales, safely and to budget.

REFERENCES

1. IAEA Regulations for the Safe Transport of Radioactive Material 2009 TS-R-1 Edition
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3. International Maritime Dangerous Goods Code, 2010 Edition, International Maritime Organisation