The Windscale Advanced Gas Cooled Reactor (WAGR) Decommissioning Project
A Close Out Report for WAGR Decommissioning Campaigns 1 to 10 - 12474

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ABSTRACT

The reactor core of the Windscale Advanced Gas-Cooled Reactor (WAGR) has been dismantled as part of an ongoing decommissioning project. The WAGR operated until 1981 as a development reactor for the British Commercial Advanced Gas cooled Reactor (CAGR) power programme.

Decommissioning began in 1982 with the removal of fuel from the reactor core which was completed in 1983. Subsequently, a significant amount of engineering work was carried out, including removal of equipment external to the reactor and initial manual dismantling operations at the top of the reactor, in preparation for the removal of the reactor core itself. Modification of the facility structure and construction of the waste packaging plant served to provide a waste route for the reactor components.

The reactor core was dismantled on a ‘top-down’ basis in a series of ‘campaigns’ related to discrete reactor components. This report describes the facility, the modifications undertaken to facilitate its decommissioning and the strategies employed to recognise the successful decommissioning of the reactor.

BACKGROUND

The WAGR was the prototype industrial scale development model for the CAGR nuclear power stations, the UK's second generation of reactors. Constructed between 1957 and 1961 and operated successfully by the United Kingdom Atomic Energy Authority (UKAEA) until its shutdown in 1981, the reactor containment building (Figure 1) was an all welded hemispherical dome, 41m in diameter, providing a controlled area and pressure containment, to totally envelop the reactor and its associated biological shielding.

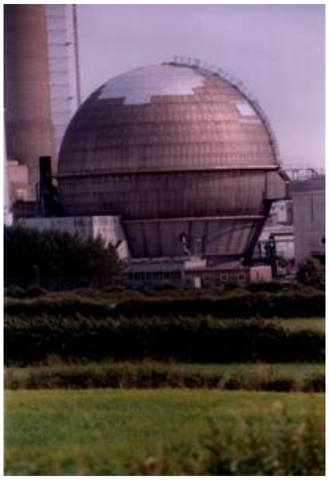


Figure 1 Reactor Containment Building

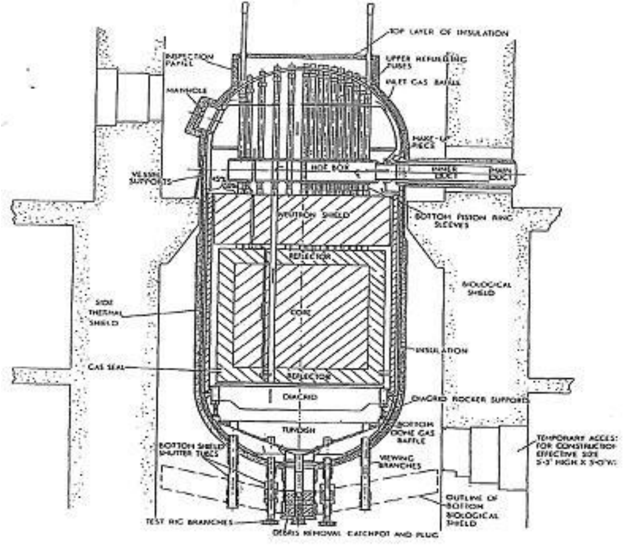


Figure 2 Reactor Schematic

The reactor (Figure 2) consisted of a steel pressure vessel 16.3m high and 6.5m diameter with domed ends. Internally there was a Graphite Core, surrounded by the plates of the Thermal Shield and surmounted by a Neutron Shield and hot gas collection manifold (Hot Box). There are 253 vertical channels extending up from the base of the core to the refuelling tubes at pile cap level, penetrating the Neutron Shield, Hot Box, the top dome and biological shield. The approximate weight of this structure was 820 tonne; a significant concrete bioshield surrounding the reactor.

In anticipation of the UK's likely nuclear decommissioning needs, the UKAEA initiated preliminary decommissioning studies for WAGR in 1975 and followed these in 1981 with the decision to decommission WAGR to Stage 3 (restoration of the area occupied by the facility to a condition of unrestricted re-usability).

In 1993 a project review was undertaken involving the major stakeholders. Studies indicated that there would be less cost to the government to put the facility into care and maintenance than continue with the decommissioning. To ensure continuation of the project, the nuclear power generators agreed to contribute towards the cost. The review concluded that there should be a greater emphasis on cost effective decommissioning rather than development of techniques and data gathering. The project completion was re-defined as the completion of core and pressure vessel decommissioning, with demolition of the bioshield and containment building deferred.

The aims of the decommissioning project were;

- To demonstrate the feasibility of dismantling a nuclear power generating reactor safely and at acceptable cost in terms of money and radiation exposure;

- To identify the engineering problems and to develop and adapt industrial techniques and equipment for their solution;
- To establish routes and appropriate authorisation procedures for disposal of the wastes arising;
- To acquire and record the information, data and expertise that would be of use in the design and subsequent decommissioning of nuclear power plants.

FACILITY MODIFICATION

Following fuel removal, initial preparatory works saw the removal by manual means of external ancillary reactor equipment and redundant services, the top biological shield, refuelling stand pipes, the pressure vessel top dome and the reactor refuelling machine, in preparation for the installation of the Remote Dismantling Machine (RDM) and construction of the associated waste route.

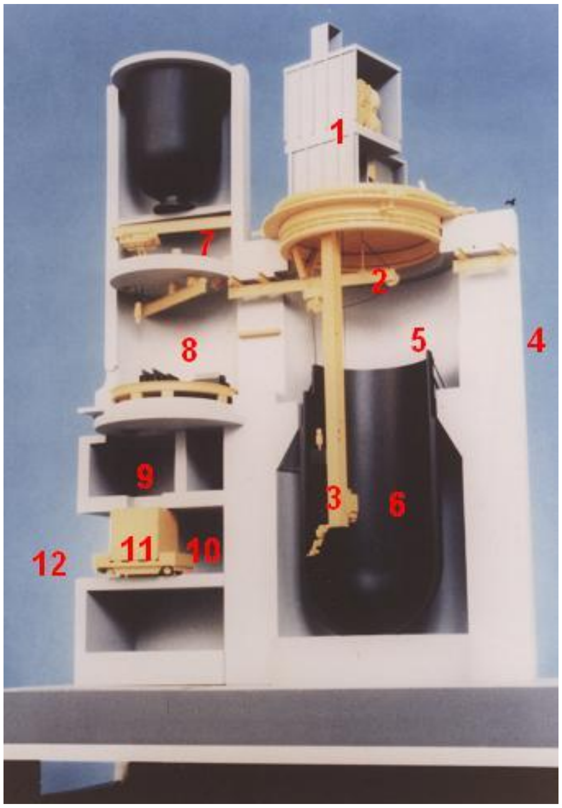
To allow dismantling of the ‘in-vault’ reactor components the extract ventilation systems were modified in order to prevent the release of airborne radioactive particulates from within the reactor pressure vessel and reactor vault into the outer containment or to the atmosphere. Two plants, the ‘Vessel’ and ‘Vault’ Ventilation Plants’ were installed and commissioned to meet the requirement of AECP 1054 the code of practice for the ‘Ventilation of Radioactive Areas’.

Each of the coaxial ducts from the Reactor Pressure Vessel to the four Heat Exchangers A, B, C and D were severed and sealed, the concrete containment structures at the top of all heat exchangers removed and disposed of and each was stripped of their insulation lagging. This modification allowed the heat exchangers B and D to be raised by 12.4m out of the bioshield to produce compartments for the Waste Route and for the maintenance of equipment to be used for Reactor Core Dismantling.

During 1995 the four heat exchangers were lifted out of the WAGR containment building through holes cut in the roof of the containment building and transported to the National Low Level Waste Repository (NLLWR) near Drigg in Cumbria, as single items of Low Level Waste (LLW). The heat exchangers were placed within the waste vault and each was internally grouted prior to being entombed in concrete within the vault.

RDM Installation

The RDM (Figure 3) was installed during 1993, on the pile cap in the area previously occupied by the Top Biological Shield, providing remote access to the internal components of the reactor.



Key:

1 RDM Upper Module
2 Slew Beam & 3te Hoist
3 Manipulator Platform & Mast
4 Maintenance Cell and to Lower Enclosure
5 Reactor Vault
6 Reactor Core & Pressure Vessel
7 8te Hoist
8 Sentencing Cell
9 Upper Loading Cell
10 Lower Loading Cell
11 WAGR Box
12 Grout & Concrete Filling Cell

Figure 3 RDM and Waste Route Layout

The RDM provided the means to deploy the tooling and equipment required to undertake the decommissioning of the WAGR, it incorporated a rotating shield floor at pile cap level, to maintain radiation shielding above the reactor, whilst providing the equipment necessary to allow the completion of reactor dismantling tasks.

An electrically driven slew beam, item two in Figure 3, was installed directly below the RDM, with a centrally mounted torsion beam providing the pivot point for the beam, enabling rotational movement through 360 degrees. An electrical hoist (Figure 4) of 3 tonne capacity (the 3te hoist) was installed onto the slew beam, its electrical services being transferred to it through a pulley and guide roll system within the RDM and through the centre of the torsion beam, facilitating hoist coverage over the full diameter of the reactor vessel.

An extendable mast, suspended within the RDM upper containment module projected downwards into the reactor vault, with rotation of the RDM moving the mast through 360 degrees within the reactor containment. A platform with manipulator was deployable along the mast, from the RDM lower containment module, to the working position at the bottom of the mast (Figure 5).

Positional data was provided for the RDM, its slew beam and the manipulator platform from resolver sensors, though this was purely to provide input to the RDM graphical mimic and not to facilitate any form of closed loop system control. Coordinates from the mimic display were often noted in order to enable the operator to return equipment to a specific position within the reactor.

Figure 4 Rotating Slew Beam with 3te Hoist

Figure 5 Mast Assembly with Manipulator Platform

Tooling Systems

The 3te hoist was engineered with the capability for the deployment of a range of cutting tools and grabs, designed for specific decommissioning tasks, the grab control system providing a configurable interface between operator control desk and the tool, to suit specific tooling power and control requirements.

Alignment of the slew beam to fixed beam sections from the reactor vault to the Maintenance or Sentencing Cells would enable transfer of the 3te hoist to these adjoining work areas during maintenance or waste sentencing activities.

The Schilling Gamma 2 ‘Tool Change Out’ (TCO) slave arm (Figure 6) is a remotely operated six degree of freedom servo hydraulic manipulator derived from a ‘commercially off the shelf’ system used throughout the oil and gas industry.

It was adapted by the manufacturer to suit the customer specific requirements, with a limited production run of five units being imported into the UK for use within the nuclear decommissioning environment. The slave arm was radiation hardened, by use of radiation-resistant materials for seals, bearings, and wire insulation in order to allow operation inside a highly radioactive environment; it was fitted with a remote tool change system, allowing the attachment of different tools, with capacity for both hydraulic and electrical services, for use in support of the decommissioning tasks.

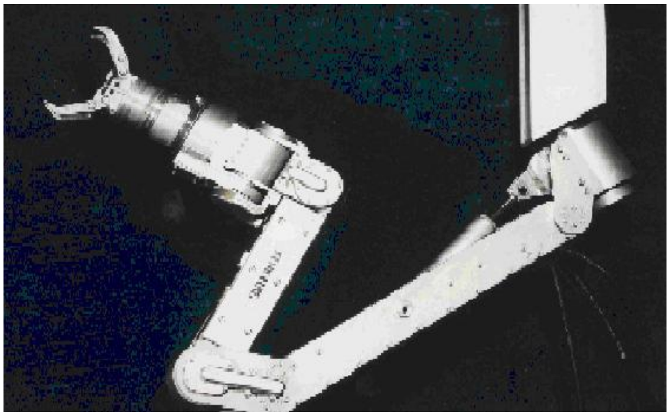


Figure 6 Schilling Gamma II TCO Manipulator

The Schilling manipulator was installed in preference to the ‘Taylor Hitec’ electric manipulator from the original design as this had been deemed unsupportable, being a ‘one off’ and little more than a prototype, with a limited payload capacity of 35 kilograms compared to 120 kilograms for the Schilling manipulator.

The manipulator was mounted inboard of the mast, operating preferentially towards the centre of the reactor vault and whilst support through the manufacturer, maintainability and payload were better than the redundant Taylor Hitec manipulator, at two metres long it was almost a metre shorter.

There were circumstances where the manipulator may be considered a sub-component of the deployment system, were it for example being used to deliver tool such as a reciprocating saw to the workface and others where it would be considered a tool in its own right if it was being used for pick and place tasks.

Operator control of the manipulator was through the UK Robotics Advanced Teleroperation Controller (ATC) with operator interface through a PC monitor running a 'Windows' graphical front end as a means of interfacing to joysticks and other input devices. The hardware is based on industrial computer technologies developed during the mid 1990’s to replace the proprietary Schilling master controller, in order to provide additional operator feedback and control.

Basic features of the ATC included resolved motion control in world, tool and tool-offset modes, though in operation this capability was never recognised, as the philosophy at WAGR was to drive the manipulator in single or multi joint mode, due in part to the limited working envelope that came about from the compromised manipulator mounting position in front of the mast assembly. The ATC also provided a capacity to record simple paths through a ‘teach and repeat’ process, useful for repetitive tasks such as latching tools but by the nature of the hydraulic manipulator repeatability at the tool tip was not accurate enough to enable automated tool docking.

Maintenance Cell

The Maintenance Cell was constructed within the boishield of heat Exchanger D, directly opposing that of the Sentencing Cell, with a shield door assembly separating it from the reactor vault, providing an area in which to maintain the 3te hoist. The import of tools and their manual connection to the 3te hoist was undertaken in the Lower Enclosure, a purpose built enclosure directly below the maintenance cell, with adequate ventilation and barriers to ensure that the contamination is contained within the enclosure and that safe access is maintained for the operators.

1.1.1 Operator Stations

For decommissioning activities there were three main operating areas, Control Station 1 (CS1) for the main in vault activities, CS2 for waste handling within the Sentencing Cell and CS3 for waste assaying within the Upper Loading Cell before onward movement through the waste packaging plant.

Viewing of remote operations was serviced by a Closed Circuit TV system, using a proprietary switching matrix device from the commercial security market, this allowed the connection and control of up to 48 cameras, many of which were fitted with pan and tilt and a supplementary light assembly, at operating areas throughout the facility.

Within the reactor vault four camera units were mounted on adjustable jib arms to the bioshield wall above Corbel level, with two other units fitted within the RDM shield floor, alongside high powered halogen lighting providing illumination to the vault area, with similar lighting arrangements to the rest of the facility. Each camera unit was remotely recoverable to allow for its maintenance or replacement and the head unit from any of the in vault camera units could be remotely deployed from a cable reeling drum, down into the vault as decommissioning progressed. Any camera could be selected and viewed from multiple monitors at any of the operator control stations with lead glass shielded viewing windows at CS2 and CS3 supporting camera views from those areas during local operations.

Waste Route

The Waste Route consists of three cells, Sentencing Cell, Upper Loading Cell and Lower Loading Cell (areas 8, 9 and 10 respectively from Figure 3), constructed within the bioshield of Heat Exchanger B.

The newly constructed Waste Packaging Building (Figure 7 and 8) built into the north-west side of the WAGR, provided the concrete filling cell and and associated operating areas within it and had overall dimensions of 27.5m length, 6m width and 12.75m height.

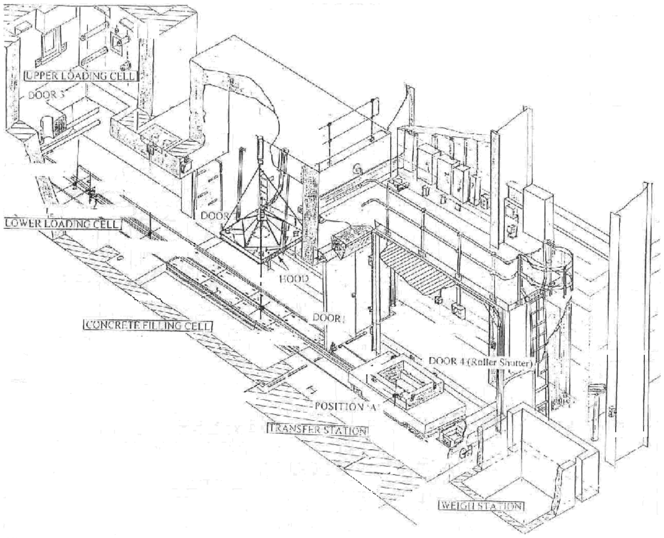


Figure 7 Waste Packaging Building Schematic

Figure 8 Waste Packaging Building – Transfer Station

The Waste Route was designed principally to handle Intermediate Level Waste (ILW) arising from dismantling operations within the reactor core and pressure vessel and so provided the required levels of shielding, although LLW was also to be handled via this route.

The Upper Loading Cell, for the assaying of waste, was constructed immediately beneath the Sentencing Cell with the Lower Loading Cell, where the waste was placed into the WAGR box, directly below that. The lower loading cell, which is at ground level relative to surrounding plant, extended radially out from below the heat exchanger bioshield, into the newly constructed Waste Packaging Building adjoining the main WAGR facility.

Once a piece of waste was removed from the reactor vault it was to be transferred into the sentencing cell, either for incorporation within a waste basket with other wastes or direct loading through the upper loading cell into the WAGR box within the Lower Loading Cell.

Once the WAGR box was loaded with the assayed waste it was transferred to the adjacent concrete filling cell on a rail mounted bogie. In-fill grout, mixed in a purpose built grout and concrete plant, is pumped into the box to take up all the void space. A reinforced concrete lid is cast on the box to complete the container and the bogie driven on into a transfer cell for clearance, concrete curing and export.

WAGR Waste Box

The container adopted at WAGR for the storage/disposal of LLW and ILW is a rectangular reinforced concrete box 2.4 x 2.2 x 2.2 m with top entry (Figures 9 and 10). The enclosing walls of the container provide both structural integrity and radiation shielding of the contents to IP-2 standards, whilst the dimensions were chosen to accommodate WAGR Thermal Shield plates and graphite blocks without cutting.

Two types of concrete are used to construct the boxes, dependant upon the shielding requirements of the contents. Normal density (2.4 $t.m^{-3}$) concrete is used for the majority of the waste whilst a high-density (3.9 $t.m^{-3}$) mix using magnetite aggregate, is used for the more highly active wastes.

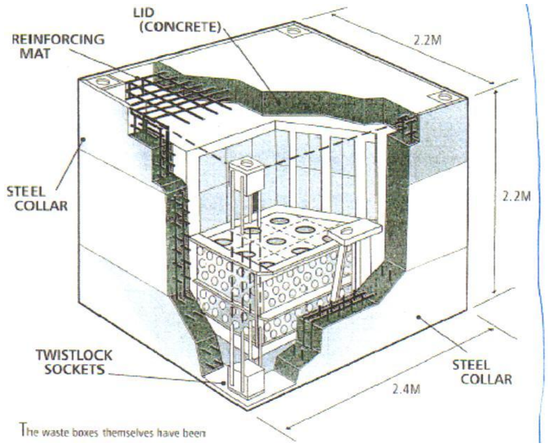


Figure 9 WAGR Waste Box

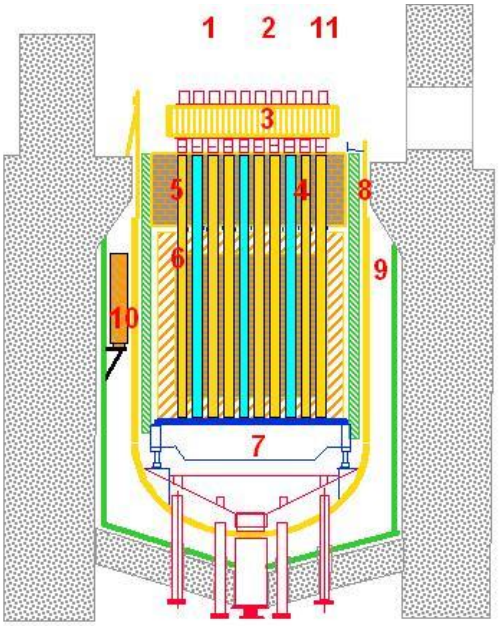
Figure 10 WAGR Waste Box Store

The design and development of the box and the consequent sizing of the Waste Packaging plant were completed prior to the formation of Nirex (now the Radioactive Waste Management Directorate (RWMD) of the NDA). To ensure that a future disposal route is available Nirex approval of the WAGR box was sought and a Letter of Comfort received.

The ILW waste packages are moved to a purpose built store situated a short distance from the encapsulation plant. This store has been designed to provide weather protection for stored ILW boxes, whilst the concrete walls of the facility provide radiological protection to personnel outside the building. A ventilation system is incorporated to protect the operators from the diesel exhaust of the 52te forklift truck used for box handling operations. Low-level waste boxes are monitored to confirm that they meet transport requirements, and transported to the NLLWR site as soon as practicable.

A paper presented to the WM Conference 2004 [Ref 1] discussed the long term management of package records relating to the ILW packages.

OVERVIEW OF WAGR DECOMMISSIONING



Campaign:

1	Preliminary Operations
2	Operational Waste
3	Hotbox
4	Loop Tubes
5	Neutron Shield
6	Graphite Core & Restraint
7	Lower Structures
8	Thermal Shield
9	Pressure Vessel & Insulation
10	Thermal Columns & Outer Ventilation Membrane
11	Final Clean-Up

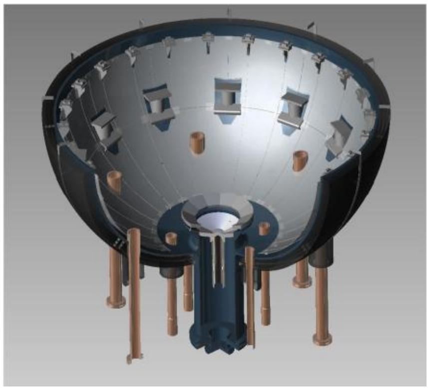
Figure 11 WAGR Campaign Schematic

Decommissioning of the WAGR was undertaken in a top down approach from above in a series of ‘campaigns’ (Figure 11), in order to allow the ongoing development of the tooling and methodologies for subsequent campaigns as decommissioning progressed.

This enabled the early commencement of decommissioning whilst later campaigns were still being developed and allowed for any applicable learning during decommissioning activities to be passed from one to the next.

The Neutron Shield decommissioning campaign and several others following it made use of 3D computer aided design modelling packages for the mechanical design of the tooling. These modelling packages were also utilised for the production of three dimensional modelled images of the reactor assembly (Figure 12) from the original manufacturing drawings to aid the design process.

Anticipated wasteforms were often modelled within the waste baskets (Figure 13) in order to support the design and process implementation through visual means, enabling early definition of the waste package strategy and waste box quantities.



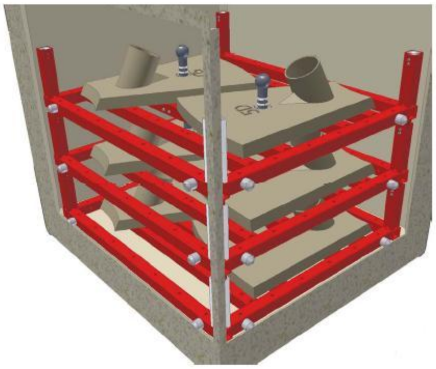


Figure 12 Modelled Reactor Components Figure 13 Modelled Waste Basket Packing

Tooling Deployment – WAGR Decommissioning Campaigns

Campaign 1 Preliminary Operations

The Preliminary Operations campaign was for the final preparation of the reactor area prior to the commencement of in vault remote operations, involving the manual removal of the coaxial ducts and final making cut outs to the pressure vessel aligned with sentencing cell and maintenance route to enable the import and export of equipment and waste through the facility. No remote works were undertaken as part of this campaign.

Campaign 2 Operational Waste

The Operational Waste campaign was concerned with the removal of redundant fuel stringer and reactor channel components, such as control rods, arrester mechanisms and neutron shield plugs, which had been stored within the fuel channels awaiting the availability of the waste route for their disposal.

These items had been removed as part of the defuelling operation, and the LLW fraction disposed of to the NLLWR. The parts of these items classified as ILW (>12 GBq t^{-1}) were size reduced, fitted with lifting pintels and returned to the fuel channels to await commencement of reactor decommissioning.

Removal of these items was undertaken using the 3 t hoist and a lifting grab designed to engage with the pintels, seven high-density boxes were used to contain the 770 items of waste, however some items were stuck in the fuel channels, and could not be removed during this campaign but were all removed as part of Campaign 7.

Campaign 3 Hotbox

The Hot Box was the gas manifold used to divert the hot coolant gas into the heat exchangers. It was a short flat-ended cylindrical vessel, fabricated from carbon steel approximately 5m diameter and 1m high, effectively in the shape of a large pillbox. The Hot Box was lined with insulating material, comprising multiple layers of alternate, dimpled/plain stainless steel foil (Refrasil), up to 19mm thick on the underside of the top plate, 38 mm on the bottom plate and 25mm around the side wall of the box. The Hot Box also contained 253 stainless steel fuel element guide tubes and 100 carbon steel stay tubes. In total it weighed 31 tonnes.

Industrial Plasma arc cutting was adopted to undertake the size reduction as it proved the most adaptable of the potential systems with a narrow kerf producing least particulate. The Hot Box was dismantled in a series of mini campaigns using 40 - 200 amp Plasma torches deployed both by remote rigs and used manually. Efficient plasma arc cutting relies on the cutting head being maintained at a constant offset from the subject. The deployment tool used to remove the Upper Refuelling Tubes (URT) attached to the top of the Hot Box was designed to stand on three legs over the tube with the torch suspended within. By vertical and radial movements the torch was intended to cut between the tube flange and the Hot Box top plate. In operation there was great difficulty maintaining the torch offset and cutting at the correct point, resulting in many failed cuts and damaged torches. 60 cuts were achieved in 2 months with an accrued dose of 8-man mSv. After due safety consideration, manned access was adopted to undo the bolts with power wrenches. The remaining 129 URT assemblies were removed in 4 days for a dose of 9 man mSv.

It was always intended to remove the sidewalls by using controlled manual intervention as the main radiation dose source was expected to be the Fuel Element Guide Tubes, which were to be removed prior to this stage. In practice this proved not to be the case, with significant dose emanating from the refrasil insulation. To allow manual intervention, the dismantling sequence was changed and the insulation was stripped from the bottom plate before removing the sidewalls. This was achieved remotely by cutting the insulation into sections using a rig-mounted plasma torch and a combination of remotely operated tools to place the pieces in an adjacent waste basket. Having reduced the radiation dose rate, the sidewall was removed manually, the operator gained benefit from the shielding by working outside the mild steel sidewall plate. The campaign took 13 months to complete.

Campaign 4 Loop Tubes

There are six Loop Tubes, identified as HP1, HP2, A, B, D, and E. These were the experimental fuel channels and were constructed from work-hardened stainless steel. As such, they were installed in the core for the lifetime of the reactor and had become highly activated, potentially giving a dose rate of 120 Sv/hr from the central sections.

To avoid spreading fragments of such active material around the reactor, size reduction using a hydraulic shear was adopted in preference to flame cutting or sawing. To minimise the risk of the tube becoming trapped in the shear blades, and to make the cutting process more efficient, the 14m high Loop Tubes were filled with high-density cement grout. Grout connectors had to be attached to the bottom of the six tubes in the area below the bottom bioshield known as the crypt. Because the area has localised dose rates to 1 mSv/hr a mock up was constructed and rehearsals undertaken to ensure that doses from the operation was 'As Low As Reasonably Practicable' (ALARP). Grout was mixed in a mobile plant, transferred into the containment building and pumped into the tubes. This operation was completed in less than a week. The three items of shearing equipment were designed for fully remote installation into the reactor vault: a 'fail safe tube clamp'; the 'loop tube lifting device'; and the shearing machine itself. Because of the risk of highly active shards being present on the shear, both it and the supporting frame were also encapsulated as LLW on completion.

The campaign was very successful, taking only three and a half months, with a significant proportion being grout-curing time. Although the equipment could be installed totally remotely, after the first installation, manned intervention was adopted to make the service line connections to the equipment. This activity accrued little additional dose but reduced time and ensured that no damage was caused to the plugs and sockets by using the manipulator.

Campaign 5 Neutron Shield

The Neutron Shield was manufactured from graphite, stainless steel and mild steel in two major parts. The Inner Neutron Shield (INS) contained the reactor upper fuel channel sections, and consisted of stainless steel guide tubes within graphite blocks all surrounded by the Outer Neutron Shield (ONS) that comprised solid blocks of graphite held together by tie rods and topped by thermal shield plates. The Neutron Shield contained nearly 2300 components and weighed over 90 tonnes.

Stage 1, the release of 96 thermal shield plates around the ONS, was originally intended to be a remote operation involving 1250 activities planned to take 38 shifts to complete. Because the area dose rates were lower than expected, generally between 100 and 200 μSvh^{-1}, controlled manual intervention was used to drill out the tie bars through the thermal shield plates completing the work in only 5 shifts.

Stage 2 consisted of reducing the length of the restrictor sleeves to ensure that two layers of graphite bricks could be packaged in each box. The prime contractor had procured an internal pipe-milling machine, suitably adapted for remote deployment, but the machine failed to deliver the promised production rates. Because of the low dose rates, manual intervention was adopted to cut the steel fuel channels using a modified 100 mm angle grinder. To minimise dose uptake, the machine was deployed remotely and operated manually to achieve production rates of over 6 cuts per hour. This simple grinder adaptation cost £4000 to manufacture compared to £100,000 for the original machine.

Stage 3 used the same manually operated grinder extended to cut the liner tubes within the top layer graphite. A ball grab was then used from the 3 tonne hoist to remove both block and liner and place them in waste basket box furniture, 60 blocks per box, there were 253 blocks per layer

Stage 4 involved the removal of the ONS plates released in Stage 1. A two point magnetic grab deployed beneath the 3 tonne hoist removed the plates and transferred them into waste baskets.

Stage 5 removed 3 mm thick boron steel plates from the ONS using a self-contained single pad vacuum grab. This was followed by the removal of two layers of ONS graphite blocks. These solid blocks had no lifting features, so a tool was developed to drill and tap a thread in three holes at the top of the graphite and bolt itself to the block. By using special drill bits this was achieved in one action.

Stage 6 was a repeat of Stage 3, however the dose rates had increased to an extent that the work had to be carried out remotely. This had been anticipated and in the intervening period, a second modified grinder had been developed to motorise the manual actions used in Stage 3. This machine, deployed on the 3 tonne hoist, was used to cut the liner tubes within the second layer graphite. The blocks were then removed as in Stage 3.

Stage 7 was a repeat of Stage 5, removing layers of ONS graphite blocks. As each layer was removed a self-contained hydraulic shear was deployed to crop the 96 tie bars close to the surface of the next layer.

In Stage 8, the ball grab was used to remove the bottom layer of graphite. At this point the RDM mounted Schilling manipulator fitted with a combined shear and gripper tool was deployed to sever a number of thermocouple wires that were attached to the stainless steel sockets that join the Neutron Shield to the core.

Stage 9 saw the removal of the final layers of the ONS as in stages 5 and 7. In Stage 10 the support plates were removed using the magnetic grab. Finally, in Stage 11 the manipulator was used to clean up the surface of the newly exposed core to be ready for the next campaign.

In summary, 90 tonnes of graphite and steel were removed and packaged in 32 WAGR boxes (22 LLW, 10 ILW from the lower sections where the stainless steel guide tubes or sockets had been more highly activated). The work was completed 6 months ahead of programme despite the difficulties encountered, which could be attributed to the experience gained during initial operations.

Campaign 6 Graphite Core and Restraint

The Graphite Core and Restraint system consisted of 200 tonnes of graphite blocks in 8 layers, each comprising 253 fuel channel blocks surrounded by a graphite reflector forming a flat cylinder approximately 5 m in diameter and 800 mm deep. The layers were each restrained by a tensioned steel beam slotted into grooves around the top circumference of the reflector. The WAGR Core was heavily instrumented and the graphite blocks were interlaced with many thermocouple wires and flux scanning tubes.

Many of the tools used in the removal of the Neutron Shield were used for the core removal including ball grabs, the graphite drilling tool and manipulator fitted with various tools. The most significant difference between the two campaigns was the cutting of the restraint beams. This was accomplished using a standard industrial reciprocating saw mounted in a remotely deployed frame and fitted with additional motor systems to advance the blade and clamp the tool in position. A full scale mock up of a quarter section of the core was constructed to test all the equipment. During testing it was established that components of the restraint beam, when close to breakthrough, were prone to move and trap the saw blade causing it to break. Remotely deployed clamps were designed to hold the components in place until the saw cut was completed.

Each beam was cut into twelve sections and at each cut three clamps were required. Initially these clamps proved difficult to fit, however with experience the task was refined and became a routine operation. This was illustrated by the rate of progress with the first 10 boxes completed in 13 weeks whilst the following 13 boxes only took 7 weeks.

Dose rates within the reactor vault increased by at least two orders of magnitude as the Graphite Core was removed. In areas previously accessible for tool changes, the dose rate increased to 30 – 40 mSv/hr whilst the dose rate at contact with the exposed core components became ~500 mSv/hr.

In consequence, the controlled man entries proposed for certain operations could not be permitted; replacing manual by remote operations reduced the dose from the predicted value by a factor in excess of ten.

Once the initial practical difficulties had been overcome, progress was rapid with production becoming limited by the encapsulation process rather than waste production. The removal of the core was completed in February 2003, having taken 9.5 months, just over half the planned 18 months duration.

Campaign 7 Thermal Shield

The Thermal Shield was a vertical cylinder of steel plates surrounding the core and comprised 168 plates in 14 courses of 12 plates in each course. Each plate was constructed from three 2” plates formed to a radius and bolted together. The edges were offset such that the stacked plates interlocked with adjacent plates both vertically and horizontally to form a stable structure, with a system of "fishplates" to complete the connections. The Thermal Shield was designed to be replaceable in service and each plate had designed lifting trunnions in place. The Thermal Shield structure supported bundles of thermocouple wires and flux scanning tubes.

Risk analysis identified two major risks to a simple lifting strategy: (i) would the plates be held together by corrosion or thermal distortion and (ii) would the existing lifting trunnions be reliable, so a range of tools was developed to overcome the anticipated problems. However, discussions with retired staff elicited that the plates had been assembled with graphite lubricant in the joints, and initial trials showed that little force was required to complete the separation. So not all the tools were fully developed or put to use on plant.

The campaign was completed with very little difficulty. Removal of fishplates in the narrow space between the Thermal Shield and the pressure vessel proved to be awkward but did not pose too great a problem. The 13 layers of Thermal Shield removed in campaign 7weighed 180t and were packaged into 5 LLW WAGR boxes and 15 ILW boxes, the campaign took 3 months, again saving 50% of the planned duration.

For safety clearance purposes (see Campaign 8 below) the upper sections of the Lower Structures were also removed as an extension to Campaign 7 (7a) since the methodology was broadly similar in each case, utilising disassembly by mechanical means, taking 5 weeks to complete and giving rise to the production of 7 ILW boxes.

Campaign 8 Lower Structures

The remaining components of the Lower Structures were the diagrid and the ring girder that combine to form the structure that supported the core and all the reactor internal components. The ring girder was a 5.84m diameter circular hollow box section beam 571 mm high and 273 mm wide supported on brackets fixed to the wall of the pressure vessel through a system of bearings. The diagrid, connected to the inside of the ring beam was a welded steel lattice structure of beams 57mm thick and either 300mm or 1000mm deep. The whole structure was surmounted by core support plates and associated components.

The methodology chosen for size reduction of these components was to use an industrial oxy-propane cutting torch, and in view of the potential for explosion, the Nuclear Installations Inspectorate (NII) of the Health and Safety Executive (HSE), called in the safety case for Campaign 8 for examination. To mitigate against potential delays from this review, all Campaign 8 operations not requiring oxy-propane cutting were removed from the scope and included in the addendum to campaign 7 (7a). In respect to oxy-propane cutting itself, a technical report was produced to support the safety case and outline the hazards and safeguards of the operation in terms of both industrial and nuclear issues.

The paper concluded that the engineered safeguards were more than adequate to prevent a propane explosion, and that the remaining small quantity of reactor graphite present in the form of dust and granular debris would not burn or explode, although the propane-oxygen monitoring system was enhanced.

A dialogue was opened with the NII Site Inspector and his assessor to explain the situation and obtaining an understanding of NII concerns in advance of providing them with the safety case itself.

It was clear that use of Oxy-Propane with Iron Powder Injection (OPIPI) would place a significant additional burden on the containment ventilation system (an additional 22kg of particulate) and a review was carried out to determine whether the existing system was fit for purpose, or whether it should be upgraded or replaced.

Use of wet scrubbers was ruled out, as there was no available waste treatment route, so UKAEA looked to improving pre-filtration. A system of momentum separators and cyclones and spark arrestors was selected rather than introducing additional filters.

The new ventilation system was procured at a cost of ~£1M. It utilised circular ductwork, reducing the potential for dust accumulation compared to the old box-section duct and higher-efficiency safe-change HEPA filters. The system was successfully tested at the manufacturers factory, and was installed and commissioned on site by September 2003

The cutting torch was designed for deployment on a tracking system, comprising a low voltage electrically driven ball screw actuator. Electrical and cutting gas supplies were provided to the tool from the RDM through an umbilical assembly which was connected to the tool umbilical through an Umbilical Connection Mechanism using the manipulator.

The Torch Tracking System was a 3te hoist deployed tool with positioning and motive power for traversing an oxy propane cutting torch along predetermined cut paths for segmenting the diagrid lattice structure and the ring girder. The torch incorporated an iron powder injection system, which when deployed raises the power from 0.25MW to 0.5MW, though this enhancement was only deployed on the hollow ring girder to ensure it was cut in a single pass.

Following thermal segmentation waste handling was undertaken using various mechanical and magnetic type grab, for the movement of wasteforms to baskets within the Sentencing Cell for onward processing, giving rise to 5 ILW and 3 LLW boxes in a campaign lasting 9 months.

Campaign 9 Pressure Vessel and Insulation

The reactor Pressure Vessel and Insulation (PV&I) was a composite structure that provided the reactor primary containment within a mild steel pressure shell, up to 76mm in thickness, covered with a thermal insulation packing comprised of a magnesia and asbestos based cladding matrix of 200mm thick, with an outer capping of thin gauge aluminium sheet.

With the top dome removed during preparatory works the remaining vessel structure was essentially a hemispherical ended pressure vessel, supported by 16 off angled vessel supports located around the outer periphery of the vessel and supported at the corbel. The lower hemisphere featured 12 off nozzle tubes and a central branch containing the debris removal system projecting through the vault floor into the reactor crypt void area.

The Horizontal and Vertical Cutters utilised the same OPIPI hot gas cutting techniques seen during Campaign 8 and were used for the size reduction of the PV&I matrix as a composite steel and insulation wasteform.

Two problems were immediately apparent; firstly the excessive blinding of the HEPA filters in the reactor ventilation system due to the inability of the system to handle sub micron particulate generated during the iron oxide cutting process and secondly the insulation not being attached to the PV to provide the expected composite waste form. Hot gas cutting operations were suspended whilst an optioneering exercise was undertaken to investigate other decommissioning options, which ultimately led to an early cessation of OPIPI cutting on the completion of PV barrel removal, with a revised tooling and methodology utilised a manipulator deployed hot gas cutting torch without iron powder injection to complete the removal of the Lower Hemisphere (LH).

Figure 14 Low Force Compaction

The revised methodology involved the segmentation of the LH steel in shallow bands around its circumference, using a hoist deployed ‘Kinshofer’ clam shell grab with its onboard hydraulic services, to ‘peel’ the wasteform leaving the insulation in place to be harvested to the waste basket later using the same grab. The steel wastes were encapsulated in grout within a sacrificial waste container in order to immobilise the asbestos contamination, before being placed into an ISO container for disposal as LLW.

The insulation was placed into 200 litre steel drums which were low force compacted (Figure 14) using a commercially available hydraulic compactor with a 240kN press force, modified to include a local ventilation take off. This operation resulted in a size reduction of up to three quarters in drum height, which were then manually transferred to an ISO container for disposal as LLW. Secondary ‘soft’ asbestos contaminated wastes, such as paper suits, rubber gloves and HEPA filters were processed in similar fashion prior to disposal.

Campaign 10 Thermal Column and Outer Ventilation Membrane

As part of the Thermal Columns and Outer Ventilation Membrane (TC & OVM) assembly there were two thermal column assemblies within the reactor containment (item 10 from Figure 11), 180 degrees opposed from one another and set between the bioshield wall and pressure vessel. Each was made up of 80 graphite blocks, measuring approximately 2000mm tall by 1600mm wide and 670mm deep overall, supported on a steel lattice framework projecting out from the bioshield wall.

The wall of the OVM provided a 3mm thick mild steel curtain over the whole surface of the bioshield wall below corbel level, with a standoff of approximately 150mm behind it which during reactor operation allowed the forced airflow flowing between them to cool the concrete. The floor membrane was similarly constructed using 6mm thick plate with the same standoff to allow the cooling airflow across the face of the concrete.

Decommissioning of the OVM utilised the manipulator hot gas cutting torch developed for Campaign 9 to size reduce the steel plates. As the face of the OVM wall and the outer floor plates were underneath the Corbel at a radius outside the reach of the manipulator this necessitated the repositioning of the manipulator to the rear and left of the manipulator platform. Mounting the manipulator adjacent to the mast brought with it the added advantage of being able to position the torch and undertake cutting operations using platform raise / lower as the mechanism to track the torch along its cut path, horizontal cuts were undertaken through a rotation of the RDM.

Figure 15 Counter Balanced Lift Arm Tool

The working envelope of the 3te hoist was also limited by the Corbel assembly; leading to the development of the Counter Balanced Lift Arm (CBLA) (Figure 15), which when suspended from the 3te hoist provided the offset lift capability from the 3te hoist beneath the Corbel.

Brackets securing the top plates of the TC assemblies were selectively severed using the manipulator deployed torch enabling the removal of individual or pairs of graphite blocks with the CBLA and clamshell bucket. OVM plates when severed were allowed to free fall onto the membrane floor below and were subsequently picked up using the CBLA and placed into the waste basket, prior to encapsulation and disposal via ISO container as LLW.

Campaign 11 Final Clean-up

At time of writing this report Campaign 11 tooling is still under development but is expected to include manipulator and 3te hoist deployed tooling with which to undertake a clean down of the areas within the reactor containment in preparation for the facility being placed into care and maintenance regime.

SUMMARY OF WAGR DECOMMISSIONING

Early decommissioning tasks at the top of the reactor were undertaken manually but the main of the decommissioning tasks were carried remotely, with deployment systems comprising of little more than crane like devices, intelligently interfaced into the existing structure.

The tooling deployed from the 3te hoist consisted either purely mechanical devices or those being electrically controlled from a ‘pushbutton’ panel positioned at the operator control stations, there was no degree of autonomy in the 3te hoist or any of the tools deployed from it. Whilst the ATC was able to provide some tele-robotic capabilities these were very limited and required a good degree of driver input which due to the operating philosophy at WAGR was not utilised.

The WAGR box proved a successful waste package, adaptable through the use of waste box furniture specific to the wasteforms generated throughout the various decommissioning campaigns. The use of low force compaction for insulation and soft wastes provided a simple, robust and cost effective solution as did the direct encapsulation of LLW steel components in the later stages of reactor decommissioning.

Progress through early campaigns was good, often bettering the baseline schedule, especially when undertaking the repetitive tasks seen during Neutron Shield and Graphite Core decommissioning, once the operators had become experienced with the equipment, though delays became more pronounced, mainly as a result of increased failures due to the age and maintainability of the RDM and associated equipment.

Extensive delays came about as a result of the unsupported insulation falling away from the pressure vessel during removal and the inability of the ventilation system to manage the sub micron particulate generated during IPOPI cutting operations, though the in house development of revised and new methodologies ultimately led to the successful completion of PV&I removal.

In a programme spanning over 12 years, the decommissioning of the reactor pressure vessel and core led to the production 110 ILW and 75 LLW WAGR boxes, with 20 LLW ISO freight containers of primary reactor wastes, resulting in an overall packaged volume of approximately 2500 cubic metres containing the estimated 460 cubic metres of the reactor structure.

REFERENCES

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