REMOTE DISMANTLING METHODOLOGY FOR THE DECOMMISSIONING OF WINDSCALE PILE I

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ABSTRACT

Windscale Pile 1 operated for the production of military material until shut down following a fire in October 1957. At the time of the fire as much material as possible was removed but an estimated inventory of 15 tonnes of fuel and 2000 isotope cartridges remained. The Pile was sealed and placed under long term surveillance. UKAEA issued tenders for the Phase 2 decommissioning of the Pile involving the removal, treatment, packaging and placing into store of all the core components. A consortium of BNFL, NUKEM Nuklear and Rolls Royce Nuclear Engineering Services, was selected to undertake the core removal and treatment. The optioneering and safety assessment work undertaken selected dismantling within an inert atmosphere with the removed components treated in a waste processing facility and placed in $3m^3$ or 4m boxes for long term interim storage. As more information about the actual construction and condition of the core has become available further detailed analysis of every task has been carried out, supported in many cases by physical trials, which has allowed the selection of the most efficient tooling with consequent impact on deployment methodology.

This paper will illustrate the complexity of the construction, the method used to arrive at the dismantling tooling and the results of some of the inactive trials.

INTRODUCTION

The Windscale Production Piles, located on the Windscale site in the North West of England, were constructed during the late 1940s and early 1950s for the production of plutonium and isotopes in support of the British Nuclear Weapons programme. Information on the effects of irradiation on graphite was limited and whilst allowance was made for Wigner growth in the design of the core there was little understanding of the longer term issues. In the event the Piles were operated at a temperature range which led to rapid generation of Wigner energy in the graphite. The first indication that there was a problem came in unexpected temperature excursions whilst on power and a subsequent investigation concluded that it was the result of a Wigner energy release. A process of annealing of the core was introduced whereby nuclear heating was applied under reduced cooling raising the temperature above the normal operating range. When a rapid temperature rise indicating a Wigner release was detected the heating was shut down and the cooling increased. The annealing process became progressively more difficult and during the anneal in October 1957 a second burst of nuclear heating was applied followed by significant temperature rises in parts of the core and eventually the fire. Various methods of suppressing the fire were tried culminating in the use of water. (A full description of the history and events in 1957 can be found in Ref 1). Following the fire efforts were made to recover the maximum quantity of material from the core and other parts of the Pile, the control and shut down rods were fully inserted and the mechanisms removed, the air inlet ducts and the outlet chimney were sealed and a concrete screed was laid on the top biological shield. It is assessed that about 15 tonnes of fuel and up to 2000 isotope cartridges remain in the core mainly in the fire affected zone. The construction of the Pile is surprisingly complex and provides many challenges for remote dismantling. It has been necessary to carry out a detailed assessment of every operation to ensure that an efficient dismantling methodology is adopted.

DESCRIPTION OF PILE

The core is effectively a graphite cylinder 15m diameter and 8m long with its axis horizontal. The moderator is some 1900 tonnes of graphite containing 3444 fuel and 909 isotope channels. Fuel load was 180 tonnes (72000 cartridges) with a thermal rating of 180 MW and a maximum uranium temperature of 395^{0}C. Control was effected by vertical shut down rods and horizontal control rods. The fuel and isotope channels ran horizontally and fuel was fed from the charge hoist through the charge face into the channels. Used fuel was expelled from the discharge face where it fell into the water filled duct and into skips for transport. The pile was cooled by air fed from two blower houses through air ducts to the charge face. Exhaust air was taken by ducts to the chimney with filters at the top. The biological shield is typically 2.5m thick concrete lined with thermal shield plates and insulation. It is not a pressure vessel, the pile operated above ambient pressure only to the extent of flow resistance to the cooling air.

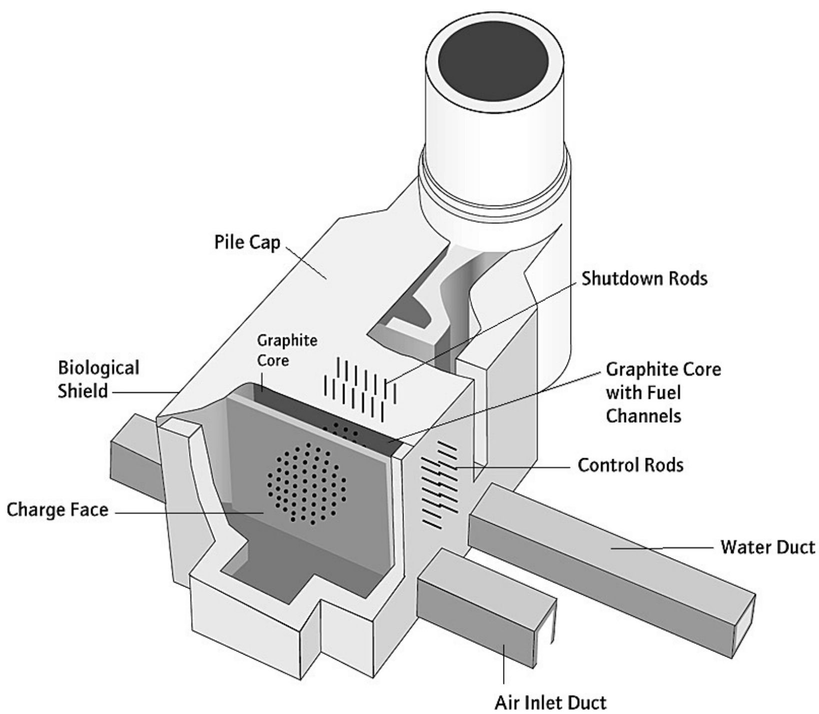

Fig. 1. Slide show isometric view of pile and chimney

To provide allowance for the expected Wigner growth gaps were allowed between the graphite blocks which were held apart by slats and tiles. To ensure that the graphite core remained stable the blocks were held in place by an arrangement of restraint girders and ties which were predominantly steel on the hotter discharge face and aluminium on the cooler inlet face. Compression was applied to the side of the core by a series of core restraint springs which held in tension until construction was complete and then released. There is no method of easily removing the tension in these springs. The top layer of blocks were additionally secured by a layer of cast iron blocks placed over them and there is only a gap of a few inches between these and the upper bioshield thermal shield plates. The core is penetrated by control and shut down rods and a number of flux measuring and experimental tubes. Burst fuel cartridges were detected by a series of larger sniffer tubes on the discharge face with internal division and which could be moved to identify the affected fuel channel. These BSSGs are substantial items one of which is dislodged from its slider mechanism. As the core is a cylinder within a square section bioshield baffle plates were installed in the corners to ensure cooling air did no bypass the core.

As a result of the fire both fuel and the elements of the graphite core were damaged. Although recovery was attempted approximately 15 tonnes of fuel and many isotope cartridges are estimated to remain in the core with several protruding from the discharge face or lodged on the BSSGs. Preliminary work carried out by UKAEA has removed the fuel which was present in the charge and discharge voids and has also drained and cleaned the water duct.

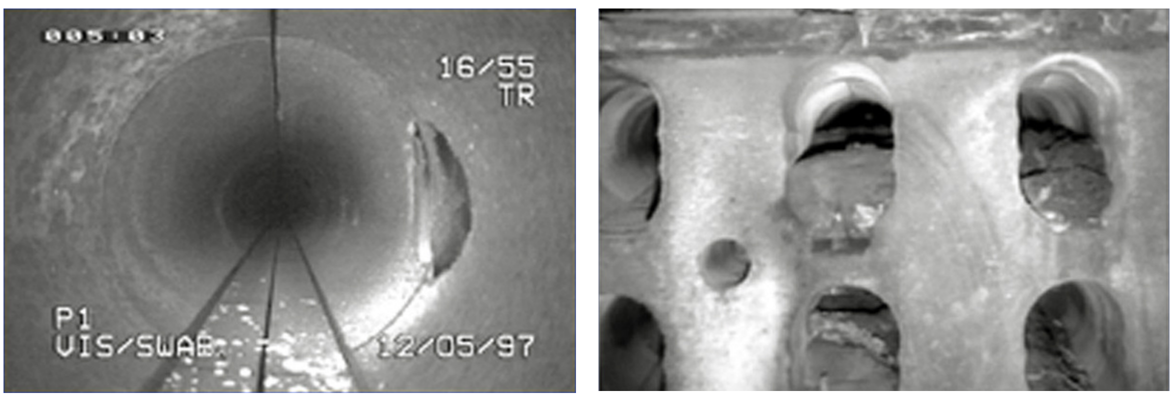

Fig. 2. Video clip stills of fuel channels showing burn through and Wigner gaps and damaged fuel areas

OPTIONS

In parallel with the investigation and improvement work the UKAEA had undertaken a number of option studies. The options considered ranged from do nothing to full decommissioning including demolition. The conclusion was that the potential risk posed by the core in its metastable state should be eliminated by its removal and treatment. It was also noted that there was no advantage to be gained from demolition of the bioshield at this stage.

Main Risks

The principle risks associated with the core dismantling were assessed to be

- Fire due to exposure of possibly hydrided uranium combined with the unknown condition of other material. It is postulated that it is possible that following the fire exposed uranium could be trapped in an oxygen deficient atmosphere which when combined with moisture remaining from the fire fighting could lead to the presence of hydride.

- Criticality as it is pessimistically assessed there is still sufficient fissile material to allow criticality and the condition of the fire affected zone is still largely unknown.

- Wigner release. There are still significant quantities of Wigner energy present and early sample results indicate the distribution throughout the core appears somewhat random, suggesting consistently poor results from the Wigner release campaigns.

It was considered that the realisation of any of these risks would be unacceptable as it would demonstrate a lack of control. The technical solution would need to ensure that the risk was as far as possible eliminated.

Options Considered

Fire. The main risk is posed from the exposure of possibly hydrided uranium leading to spontaneous combustion. The main alternatives considered were

- Fill the core with water. This had been used successfully on Fort St Vrain but for Pile 1 it was considered inappropriate primarily due to providing sealing for the necessary hydraulic head given that Pile 1, unlike Fort St Vrain, was never designed as a pressure vessel. Additionally there could be a large quantity of liquid effluent to be treated.

- Partial inerting where the area being dismantled would be subject to inert gas deluge. Whilst this would address the risk of fire at the workface the main perceived drawback was lack of protection should an area away from the workplace be disturbed by, for example, a collapse of part of the core. It could also be difficult to confirm and maintain the conditions at the workface as the local gas injection could entrain air.

- Full inerting where the core is subject to ventilation using only inert gas to ensure that oxygen concentration in areas where possible hydride would exist, the lower two thirds of the core, would always be below 2%. As with the water filling there is a need to provide sealing but the pressures involved are much lower allowing the use of spray applied rubberised material.

- The choice of inerting gases was narrowed down to nitrogen and argon. Options for combining both are being considered with Nitrogen the main gas but argon as a fire fighting back up.

Criticality.

The main issue is the unknown degree of sub-criticality of the current core. The core design was unusual in that, although the control rods covered the whole core, the shut down rods only penetrate to about mid-way. It is proposed to carry out reactivity measurements to assess the degree of sub-criticality, following which a decision can be made on the need to introduce additional neutron absorption. Methods to achieve this include the use of boron rods or beads.

Wigner.
The possibility of freezing or cooling the core was considered as the potential for Wigner release would be significantly reduced. The analysis concluded that the ventilation flow rate to maintain the lower temperature would be excessive. Additionally, although early models predicted that a Wigner release could be initiated at temperatures as low as 70°C, analysis of the recently taken samples demonstrates that temperatures >100°C would be required. The proposed dismantling methodology will avoid the use of tooling which could generate such temperatures in the graphite.

DEVELOPMENT OF DISMANTLING METHODOLOGY

An initial approach to dismantle the pile was developed at the bid stage. As the scheme progressed through design, it became clear that a review was necessary to ensure that the project objectives continued to be met by using the optimum methodology to dismantle the reactor. In particular the duration of dismantling has a direct impact on the usage of inerting gas.

Project Objective

The project objective was defined at the outset, *"to leave Pile One in a suitable condition for long term care and maintenance".*

To achieve this the project will need to:

- Remove all graphite, fuel, isotopes, control rods, shutdown rods and miscellaneous debris from the bioshield.
- Treat, process and package items in a form suitable for ultimate disposal.
- Carry out decontamination and remedial work to meet the requirements of the care and maintenance safety case.

At this stage the concept was:

- The use of remote handling equipment located at four points in the bioshield, to carry out the major core dismantling tasks
- To carry out the major dismantling tasks in an inert atmosphere to ensure that no fuel fires occur
- Export of waste using existing structures, where possible, to a waste handling facility located in a new ILW waste store.

A dismantling methodology review was undertaken to allow the following to be achieved:

- Definition of all dismantling activities that are required to complete each task and how each activity fits into the overall approach for dismantling Pile 1.

- Definition of an optimum sequence of activities for the dismantling programme.

- Definition of a sequence of activities that will describe how each task is to be completed.

- Definition of the requirements for remote handling equipment, and selection of remote equipment.

- Allow the development of targeted trials to test the methodology and equipment and to allow method statements to be produced for dismantling.

- Provide a clear and auditable decision making route to the optimum overall methodology.

It was important to maintain an overview of the overall requirements to dismantle the plant, rather than considering specifics in isolation, this ensures an optimised solution for the project.

A structured approach to the review process was adopted, this technique has been successfully used on other decommissioning projects at Sellafield. A series of workshops ware held to develop the overall methodology for the dismantling of the Pile. The workshops considered the project objectives and constraints, and defined an initial list of dismantling tasks. For each task an overall approach was developed along with a series of recommendations to be considered. These recommendations concerned interfaces, such as the waste transfer, others work required on mock-ups or further design/development work. The approach to each task was based on assumptions regarding the condition of the structure and the deployment system.
In considering tasks, detailed information, (drawings, construction photographs, video survey footage) concerning the construction and current condition of the pile was reviewed. The list of tasks developed formed the top level of a Work Breakdown Structure (WBS). The WBS can be further developed to provide cost estimates and durations for the development and dismantling phases.

The methodology review group was made up of members of all disciplines of the design team, members of the piles operations team, the safety case authors, decommissioning staff with remote handling experience, and representatives of the team who will construct the mock up rig.

Dismantling Activities
The project objective provided the driving force for the dismantling activities.
These were defined as:

- Installation of remote handling equipment in the bioshield.

- Use of specially developed tooling to dismantle the plant and recover the waste.

- Recovery of ILW and LLW from the plant, transfer of waste to the Waste Packaging Facility (WPF).

Dismantling Objectives
These activities, reviewed with the project objectives allowed the dismantling objectives to be defined. These were a list of requirements, which must be optimised in order to successfully complete the project. and include aspects such as :

- To ensure that all dismantling activities can be carried out safely within the requirements of the safety case (this objective must be achieved in full at all times).
- Minimise the volume of waste removed from the plant.
- Minimise the number of tooling systems and tool changes during dismantling.
- Minimise maintenance and maximise reliability of equipment.

Constraints
The major project constraints were defined at the outset. Examples of the major project constraints are:

- Dismantling can only take place in an inert atmosphere, which requires that the bioshield is as far as possible leak tight, and all penetrations used for decommissioning equipment are argon tight. Gas locks will be required for equipment that is to be withdrawn.
- Access to items within the bioshield is restricted, the available working space in both charge and discharge voids is narrow in comparison to the areas that must be covered by the dismantling equipment. The number of penetrations that can be made through the bioshield is limited by the availability of free space on the outside, it's structural integrity and the safety requirement to minimise the risk associated with potential argon leaks.
- There is currently no lighting or viewing installed in the bioshield. The number of penetrations that can be created for cameras lights and electrical connections is limited for the reasons above. The majority of viewing systems will have to be deployed remotely and installed where possible rather where ideal.

Task Grouping
As the team worked through the project on a task by task basis, individual constraints were also identified for individual tasks. For each task the start and end point were identified and generic issues such as access, viewing, lighting, tool changes required, waste requirements etc. were considered. The current status of design and the philosophy for tackling each item were also taken into account. Assumptions were noted at this stage. At the outset, the tasks were prioritised on the basis of the impact of the methodology adopted on the design process, and the requirement to establish mock up trials and tooling development work. The first four tasks to be considered were:

- Burst Slug Scanning Gear Removal.
- Quadrant Restraint Girders.

- Upper Quadrant Core Dismantling.
- Fire Affected Zone.

Each workshop threw out issues to be addressed. These were risk issues, project management issues, study issues, significant design issues, tooling issues, and mock up issues.

Conclusion

As the workshops progressed it became clear that the makeup of the core was considerably more complex than had first been envisaged. If the four mast concept was to be developed the access to the core was into narrow voids that required debris removal on one side of the reactor before the mast saddle could be deployed. This or example illustrated the loops that the design team found themselves in, where to remove the debris the saddle had to be deployed, but to deploy the saddle the debris had to be removed. Other problems arose when considering the layout of equipment on the pile cap, where the physical limitations of the size and strength of the structure became apparent.

The original philosophy for removing items from within the bioshield had been that there would be campaigns of items, such as graphite blocks, metalwork etc. Due to the makeup of the core this is not possible as access is restricted during the removal of the upper quadrants, so mixed waste will be generated. Access was a generic constraint, which recurred at virtually every task. There were outstanding issues where, without mock up trials, access was in doubt for items such as the quadrant restraint girders, where even if the manipulator system could reach, it was uncertain what tooling could be deployed in the space available.

The core is held together through a lattice of graphite slats, tiles blocks, and metalwork held in compression by springs. It will not simply come apart once the first block has come out, so robust decommissioning equipment will be required. Many of the tasks require blocks to be broken, or heavy tooling to be deployed to shear or cut through metalwork, the control rods for example are 60mm in diameter, and assumed to be stainless steel surrounding boronated steel. These are 8m long and there are 24 of them to be size reduced into 1m lengths to fit in the waste skips. The deployment system would need to be adequately robust to take the reactive forces that would be put through it for what could be considerable durations. Maintainability and operability of the equipment is also a key issue.

There are around 50 top-level dismantling tasks, many of which require several tool changes to allow them to be carried out. For example to remove the metal stringers on the discharge side it may be necessary to break graphite blocks to create access for tooling, cut the stringer using a shear or saw, remove the cut piece of stringer to the waste skip, clear up the broken graphite. The tool change system must be robust enough to change tools routinely with restricted viewing.

At the end of the methodology review there were still several outstanding issues that had not been resolved. The risks posed to the project by these issues were considered significant enough to consider an alternative option. Work is currently ongoing on this option to allow the decision to be made to commit expenditure to take it to detail level.

THE WAY FORWARD

To deploy tooling of the strength and reliability required to achieve the necessary short dismantling periods it is proposed to use remotely operated electro/hydraulic vehicles from the BROKK family. Trials are now being carried out to demonstrate the concept and refine specific tooling and a full scale mock up representing one quarter of the core has been constructed. The deployment of the BROKKs will be on platforms operating in the charge and discharge voids and moved by winches mounted on the pile cap.

Fig. 3: View of one Burst Slug Scanning Gear.

The tooling necessary for the majority of dismantling operations has now been identified and is being proved in concept and being developed for operations. The range of tooling is shown in Table 1

Tooling Table No 1

Tool	**Function**	**Tasks Required For**
Cutting Equipment		
Shear - large	Shearing large items in the water duct. Deployed by ROV in water duct.	BSSG size reduction. Horizontal stringer size reduction Control rod size reduction Plate Girder
Shear - small	Shearing small items (up to 50mm diameter). Deployed by manipulator	Bridging tubes Spears Scaffold poles Plate Girder Miscellaneous debris Foil hole liners
Reciprocating saw (a version with an integral clamp may be required).	General purpose cutting	Horizontal stringer size reduction Charge face metalwork size reduction Shutdown rod size reduction Control rod size reduction 'N' Frame size reduction Foil hole liners
Band saw	General purpose size reduction	Horizontal stringer size reduction
Chisel	General purpose breaking Removal of bolt heads	Breaking graphite block Separating blocks/ components Gaining access to components Dismantling of FAZ Metal work dismantling
Spreader	Separating, releasing items	Separating BSSG from guide brackets Separating graphite blocks Prying baffle plates away from supports Prying charge pans away from graphite blocks Dismantling of FAZ
Burster	Similar to spreader, but also designed to fit into isotope holes and fuel channels to burst graphite blocks	Graphite blocks Dismantling of FAZ

Tool	Function	Tasks Required For
Splitter	Similar to burster, but designed to split graphite blocks	Graphite block Dismantling of FAZ
Core drill	To remove difficult items, stitch drilling	Graphite blocks Dismantling of FAZ
Ceramic/glass cutter	To cut ceramics/glasses that might be found in the FAZ	Dismantling of FAZ
Thermocouple wire cutter	Cutting thermocouple wire	Thermocouple wire could be encountered at any point during core dismantling
Drill	Stitch drilling Attachment of lifting features	Graphite block removal Dismantling of FAZ General core dismantling
Clamps and Grabs		
Spring clamp	To retain the upper quadrant girder springs. May require a facility to compress springs, or to release springs after the spring is freed from the core	Upper quadrant girder dismantling/release of pre-load on core
Suction grab	To pick-up solid graphite blocks	Upper core dismantling
Magnetic grab	To pick up cast iron blocks	Upper core dismantling
Pin for lifting graphite block by the isotope channels	To 'pick and place' graphite blocks	Graphite block removal
"Fork" tool for lifting graphite blocks with fuel channels	To 'pick and place' graphite blocks	Graphite block removal
Clamps for the shutdown and control rods	Clamp to hold shutdown rods in place	Shutdown rod handling and removal
Grab for picking up broken pieces of graphite	To pick up pieces of broken graphite and general debris	Graphite block removal General core dismantling
Scoop/Clamshell bucket	To pick up pieces of broken graphite and general debris	General core dismantling

CONCLUSION

The Windscale Pile 1 project presents a range of technical and safety challenges which are addressed using primarily readily available and proven technology. The thorough task by task review allows both the most efficient tooling and the consequent deployment system to be identified. The project is complex and attention to detail is vital to achieve the objectives.

REFERENCE

1 Windscale 1957; Anatomy of a Nuclear Accident (Lorna Arnold, Macmillan Press Ltd).

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