DECOMMISSIONING OF WINDSCALE PILE 1

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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. Since 1986 the United Kingdom Atomic Energy Authority (UKAEA), the owners of the Pile, have been undertaking a series of projects to progressively clean up the facility and prepare for the main decommissioning task, the removal of the core. In a new approach rather than specify a detailed work programme the UKAEA adopted a cardinal point tender process which was combined with interactive relationships with the selected bidders to ensure viable proposals, which would satisfy safety requirements, were submitted.

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 during the bidding phase has been continued which has confirmed and refined the proposal for a top entry with four manipulators dismantling the core from the top under an argon atmosphere. The removal components will be treated in a waste processing facility and placed in $3m^3$ or 4m boxes for long term interim storage.

To date the design has been completed, the main safety cases have been prepared and the access modifications to allow manipulator deployment and waste transfer are in progress.

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.

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.

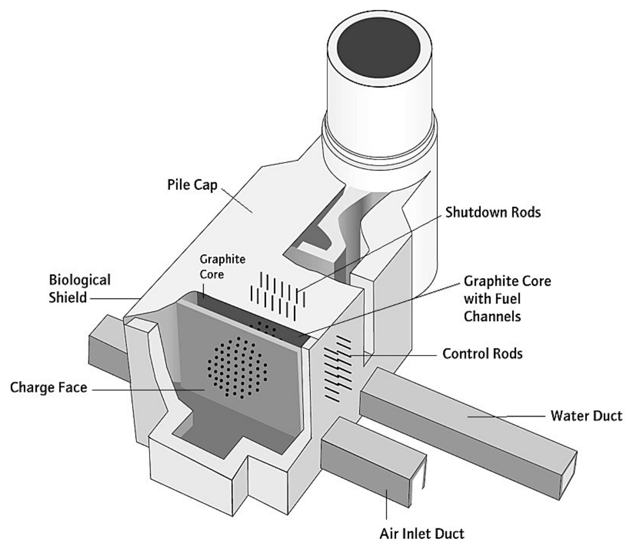

Fig. 1. Slide show isometric view of pile and chimney

REMEDIAL WORK AND INVESTIGATIONS

Following the sealing of Pile 1 in 1958 it was placed under long term care and maintenance with periodic camera survey to ensure there was no serious degradation. In the mid 1980s, with better technology available, a programme of more in depth investigations were initiated aimed at gaining a better understanding of the condition of the core and assessing options for the longer term. A programme of improvements was commenced which included recovery of fuel and debris still in the charge and discharge voids, better sealing of the inlet and outlet ducts, dedicated and filtered forced extract ventilation, refurbishment of the charge hoist and improved core condition environmental monitoring. The water duct behind the Pile was cleared of debris (this included fuel and isotope cartridges, sludge and miscellaneous items), drained and washed down. In depth video surveys of all channels was undertaken with finally intrusive surveys to take samples of core graphite. The surveys showed condition from almost as built with fuel in good condition to areas where fuel was badly damaged and melted. There was limited evidence of damage to the graphite moderator, though in one point above the fire area there is apparently a burning through of the graphite between a shut down rod channel and a fuel channel suggesting a chimney effect.

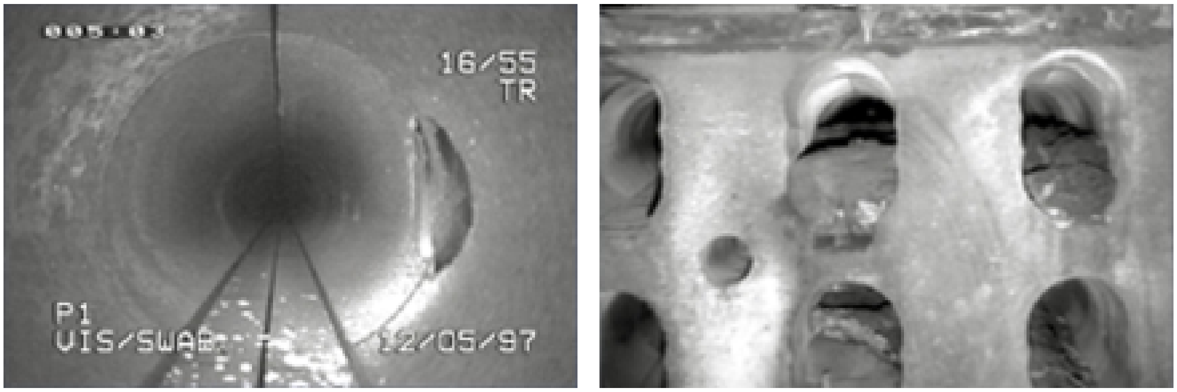

Fig. 2. Video clip stills of fuel channel with burn through and damaged fuel areas

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. Nitrogen had the advantage of lower cost but is unable to extinguish a hydride fire should one start. Nitrogen is also of very similar density to air and any air in leakage would mix easily. Argon, though more expensive, will extinguish a hydride fire and its greater density tends to drive any in leaking air to the top of the core, it is the preferred option.

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 measurements of reactivity, 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 $70^{o}C$ sample data demonstrates that temperatures $>100^{0}C$ would be required. The proposed dismantling methodology will avoid the use of tooling which could generate such temperatures in the graphite.

Access

The main options were remote vehicles and manipulators for the main core removal operations. Manipulators were chosen as they minimise the physical loading on the core structure. The main alternatives then considered were top or side entry and the number and location of manipulators. Top entry was selected as it eased the deployment and no move of entry position was required during the life of the project. A four manipulator approach was selected as it allowed more workfaces to be available reducing disruption due to difficulties in one workface. The manipulators will be of the standard BNFL Commander type which will be used on a number of other projects on the adjacent BNFL Sellafield site. The manipulators will be deployed on masts located in the charge and discharge voids thus reducing the risk of disturbing the core during initial deployment. The masts are fixed and the manipulator is supported on a folding arm carriage which provides horizontal deployment. For tool changing and maintenance the carriage is taken through the bioshield to a maintenance facility constructed above the reactor. IGRIP modelling techniques have been utilised to ensure adequate access to all parts of the core can be achieved.

Outline of Process

The core components will be removed by the manipulators and placed in adjacent skips which when full will be lowered into bogies installed in both the charge and discharge voids. A cross link access will connect the two and the skips will be moved along the route of the air inlet duct to a new waste processing facility and store constructed on the site of one of the original Pile cooling air blower houses. In the process cell the waste will be sorted, identified, assayed and treated prior to packing in waste boxes. The main waste streams are undamaged graphite, undamaged fuel, isotope cartridges, damaged fuel and fire affected graphite. Undamaged graphite will be placed in 4m NIREX boxes, consideration is being given to the need to anneal the graphite and depends on the final repository scenario. Undamaged fuel will be placed in $3m^3$ boxes and stored pending further treatment, it is categorised as high level waste despite its low burn up. Damaged fuel will be subject to a passivation process to neutralise the effect of hydride. Following treatment, which is undertaken in an argon atmosphere, the packing and grouting of waste will be in air. Following packing the boxes will be moved into the store section which is designed to provide interim storage for at least 50 years.

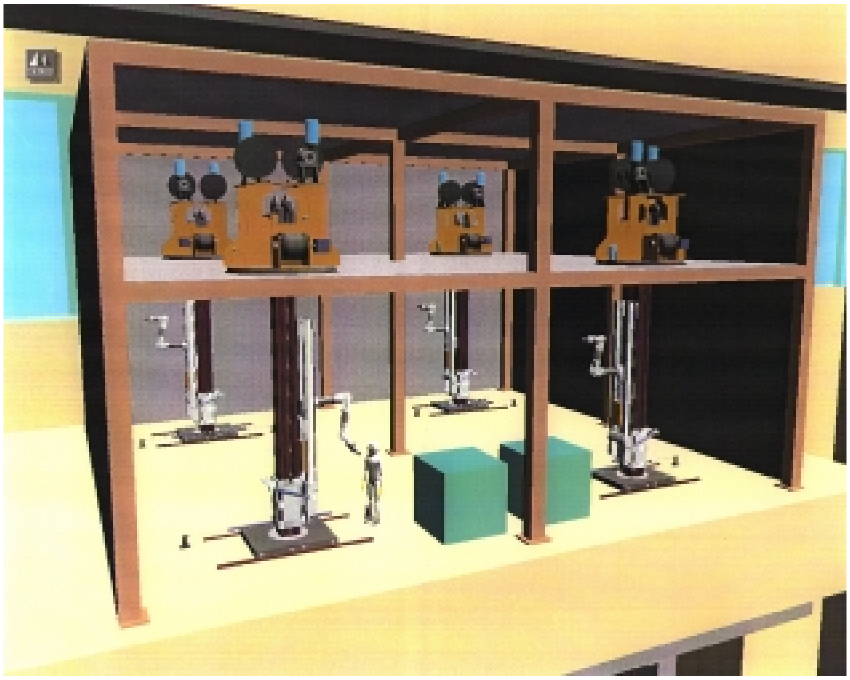

Fig. 3. Video still of four manipulator arrangement and manipulator filling skip

PREPARATORY WORK

Preparatory Work
Prior to decommissioning a large amount of preparatory work needs to be undertaken. This can be considered under three areas, manipulator access, sealing and waste transfer.

Manipulator Access
To allow deployment it is necessary to form four penetrations each of approx. 2m x 1m. The size is dictated by the size of the thermal shield plates as these must be removed. The shield plates are approximately 100mm thick, are supported on a steel framework and have a lifting beam underneath. The lifting beam was unexpected, it is not on drawings and is assumed to have been left from the construction phase. The concrete will be removed by coring, percussive techniques are not acceptable due to potential vibration to the core, eventually exposing the cast in shuttering. The shuttering, the insulation layer and the shield plate will be lifted out. The removal technique is such as to ensure there is no risk of dropping any significant item. Extensive camera surveys have been undertaken to confirm the arrangement and condition of the plates.

Sealing
To achieve the necessary low oxygen levels, protect the workforce and avoid unnecessary high argon usage, effective sealing of the bioshield is required. There are several hundred penetrations through the bioshield and charge face and additionally the actual bioshield concrete pouring techniques resulted in some leak paths. An extensive process of locating and sealing all known penetrations together with erection of new argon dams in the air outlet will be undertaken. Secondary barriers will be erected in key locations and the whole bioshield and Charge Face will be subject to a sealing membrane.

Waste Transfer
The waste will be placed in skips adjacent to the manipulators and lowered onto bogies in the air and water ducts. The air and water ducts will be linked with a new transfer corridor which also provides interim storage for inert core steel and aluminium components. The existing air duct will be modified and extended to connect to the waste processing facility. The transfer tunnel also provides a buffer store for removed material to allow some decoupling of the waste process cell from the core removal.

WASTE PROCESSING AND STORAGE

A dedicated waste processing facility will be constructed adjacent to the core building on an area created when UKAEA demolished one of the cooling air blower houses. The skips of waste will be emptied, sorted, assayed and treated as necessary. The waste output will be in $3m^3$ steel unshielded and 4m steel/concrete self shielding boxes with some low level waste exported in 200 litre drums. The principle streams and outline treatment process is:

- Undamaged Fuel. Confirm stability and place ungrouted in $3m^3$ boxes in suitable racks.

- Undamaged Graphite. Anneal if necessary and place in 4m boxes packed for minimum voidage.

- Isotope Cartridges. Identify, overpack if necessary and grout in $3m^3$ boxes.

- Fire Damaged Material. Assay, passivate if necessary and pack in $3m^3$ boxes grouted.

All boxes will be stored in a purpose built fully retrievable facility. The store is of concrete construction with overhead crane and designed for a minimum of 50 years. Assessment of improvements to extend the design life by a further 50 years have been undertaken.

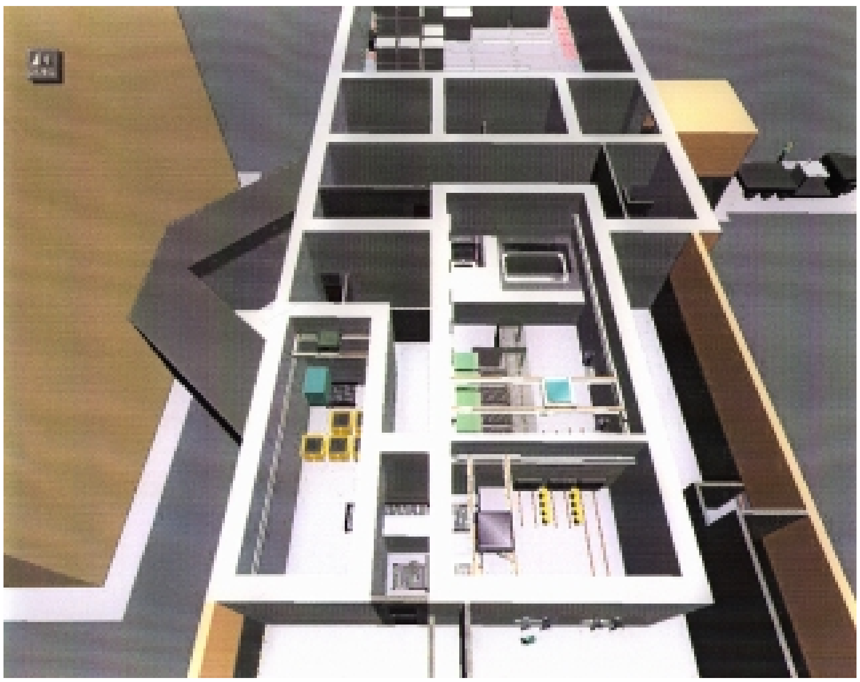

Fig. 4. View of process cell and store

FUTURE ACTIVITIES AND PROGRAMME

The current work is directed at preparing for the main dismantling phase. In addition to the construction activities described above it will be necessary to create room for manipulator deployment in the void between the charge face and the core by removing bridging tubes(introduced after the fire to feed thermocouple wires for core monitoring) and the cascade vanes which directed the cooling air up to the core. On the discharge face it is necessary to remove loose fuel and the burst slug scanning gear (large stainless steel assemblies which were moved behind the core to sample the cooling air from the channels). Use is to be made of a Brokk remotely controlled electo/hydraulic vehicle.

The dismantling of the core is due to commence in about 2002 and because of the cost of argon is scheduled to take about two and a half years with round the clock working, Finally there will be a clearing of debris from the core void, decontamination of the waste process cell and hand back to UKAEA.

SAFETY

A number of potential hazards have been described together with the engineering approach to minimise both their likelihood and any consequence. Whilst the Consortium is responsible for the production of the safety cases the overall accountability as site license holder resides with the UKAEA. Safety cases are considered by the UKAEA safety committees prior to submission, if necessary, to the UK regulator the Nuclear Installations Inspectorate (NII). The process followed is that UKAEA review the proposed designs and take part in the Hazard and Operability (HAZOP) studies. The safety case is then prepared and incorporates a process of interactive peer review with an independent reviewer appointed by UKAEA. The presentation of the safety cases is then undertaken by a joint UKAEA/Consortium team.

The control of the Pile buildings also remains the responsibility of the UKAEA and the Consortium must at all times work to the UKAEA safety management requirements.

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 project also provides contractual challenges to allow the UKAEA to quantify and limit its anticipated costs. The successful conclusion of the project will effectively remove any residual risk from the deteriorating core.

REFERENCE

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

ACKNOWLEDGEMENT

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