The Windscale Advanced Gas-cooled Reactor

Dismantling operations & Main results

Abstract

The Windscale Advanced Gas-cooled Reactor Decommissioning Project is one of the four "*first*" CEC pilot projects funded under the "*E.C. R&D Programme on Decommissioning of Nuclear Installations*", 1989-1993.

The tasks carried out under this programme have seen a gradual change in the working techniques employed, from "hands-on" to the training and preparation for fully remote working.

This gradual change being a result of the changing radiological environment within WAGR.

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1. Introduction

The Windscale Advanced Gas-cooled Reactor (WAGR) was built and operated by the United Kingdom Atomic Energy Authority.

WAGR was an industrial scale development model for the British AGR nuclear power stations.

The 100 MW_{th} reactor ceased operation in 1981 after 18 years of successful operation. A decision was made to decommission WAGR to *Stage III*, hence returning the site to green field status.

The decommissioning programme commenced with the achievement of the following specific aims in mind:

- 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 the 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.

The following "*summarises*" the work done to date at WAGR in the mentioned period; more has been done up to now but it is very difficult to get any information about.

Particular attention is then paid to the tasks which have been funded by the CEC R&D Programme on Decommissioning of Nuclear Installations 1989-1993, these tasks being:

- Removal of Top Biological Shield;
- Cutting and Handling Refuelling Standpipes;
- Dismantling the Reactor Pressure Vessel Top Dome;
- Inactive Trials of the Remote Dismantling Machine;
- Heat Exchanger Removal;
- Remote Dismantling of the Hot Box.

The following describes each of the technical operations carried out on the reactor, in an order that reflects that in which they were performed.

These descriptions are followed by a statement of lessons learned through managing the tasks.

Remote Dismantling Machine (RDM) testing and trials were not carried out over the reactor hence the section covering that topic was written in isolation from previous activities.

Heat Exchanger removal has undergone a review of strategy; the following compares the two strategies and defines the benefits gained from adopting the revised methodology.

2. Technical Operations

Decommissioning tasks commenced in 1982 with the removal of the fuel elements from the reactor core: this task was completed in 1983.

Once emptied of fuel, the fuel channels were used as a storage facility for treated reactor operational waste.

Large scale dismantling began in 1989 with the partial removal of the Reactor Refuelling Machine, weighing some 470 tonnes. The lower gantry section of the machine was left intact as this was to be used as a lifting frame and transporter for the subsequent removal of the Top Biological Shield (TBS).

3. Standpipe Cut I

Prior to the removal of the Top Biological Shield the first phase of refuelling standpipe cutting took place.

The WAGR pressure vessel is penetrated by 247 standpipes and a further 6 independent test loop tubes. The standpipes run from refuelling floor level, down through the pressure vessel top dome and into the Hot Box, as shown on Fig. 1.

The cutting and removal of the standpipes was planned to be carried out in five phases of work.

Initial cutting of the standpipes was performed using an abrasive wheel technique. The abrasive wheel technique was successful in cutting the tubes but proved too slow to be satisfactory.

As a parallel activity a plasma arc-cutting machine was developed to be deployed down the inside of the standpipes. The plasma arc technique proved to be more successful than mechanical cutting methods and was therefore adopted for use on subsequent phases of standpipe cutting.

The plasma arc cutter is shown in Fig. 2 and 3.

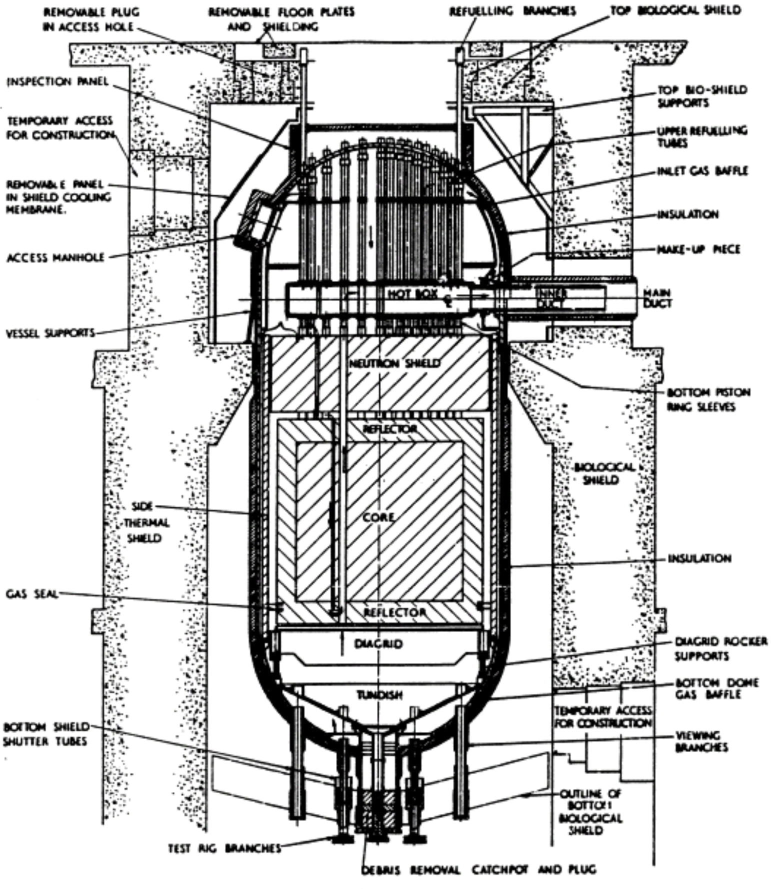

Figure 1. Reactor Vessel Internals

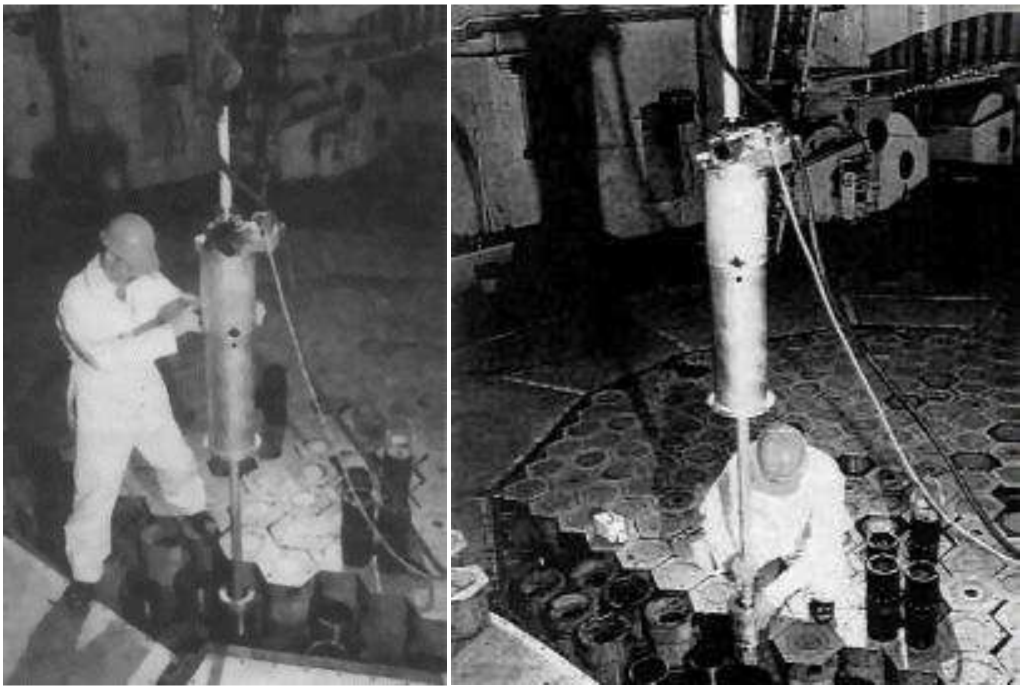

Figure 2 and 3. Plasma arc cutter while cutting a standpipe

4. Top Biological Shield (TBS)

The prime function of the TBS was to act as a gamma shield and the design of the reactor meant that it was not subjected to significant neutron activation or contamination during its life.

Monitoring after removal revealed surface contamination levels in the order of 5 to 10 Bq/cm^2.

However, the complexity of the structure prohibited comprehensive monitoring and dictated that all precautions must be taken to guard against any release of contamination during the cutting operation.

The TBS was constructed from a concrete filled, mild steel shell. It had a diameter of 5 m and weighed 60 te (tons-equivalent). The size and weight of the TBS prevented a straightforward disposal operation.

The refuelling machine gantry was used as a platform upon which four hydraulic jacks were mounted to lift the TBS clear of its seated position. Once lifted, the gantry was traversed along its rails until clear of the reactor where it placed the TBS in a ventilated temporary containment.

Due to the materials used in the construction of the TBS it was decided that thermic lancing be used as the cutting process as shown in Fig. 4 and 5.

Other techniques were considered, as reported previously. The cut sections were wrapped in PVC to prevent the spread of loose contamination prior to disposal via the building crane and reactor hall goods airlock.

Figure 4 and 5. Dismantling of the Top Biological Shield

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5. Standpipe Cuts 3 and 4

Following the removal of the TBS, standpipe cutting recommenced.

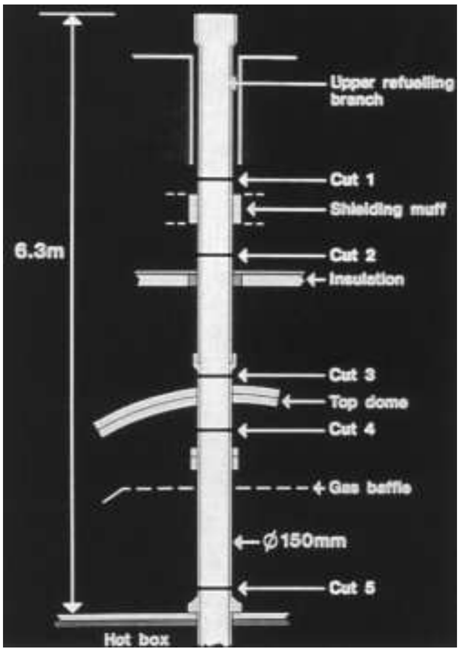

Figure 6. Location of standpipe cuts

The erection of a temporary scaffold platform across the reactor top dome provided adequate access to obviate the need for cutting the standpipes in position 2.

Cut 3 was carried out using the plasma are torch as was used previously on Cut 1.

Upon completion of Cut 3 a temporary load bearing floor was installed over the reactor vault at refuelling floor level in the recess previously occupied by the TBS.

The temporary floor was constructed such that access could be gained to the standpipes via any one of sixteen removable panels which revealed a 1 m^2 opening.

Cut 4 differed from the two previous cuts in that the cut pipe was not removed as part of the operation.

The aim of the operation was to cut each standpipe below the profile of the reactor pressure vessel top dome and thus isolate the top dome from the reactor internals. Each standpipe was inspected using video equipment following the cutting operation to confirm that the pipe had been completely severed.

The planned cutting positions are shown in Fig. ; Fig. 7 and 8 show a detailed view of the plasma arc cutting torch and the combined standpipe cutter/grab.

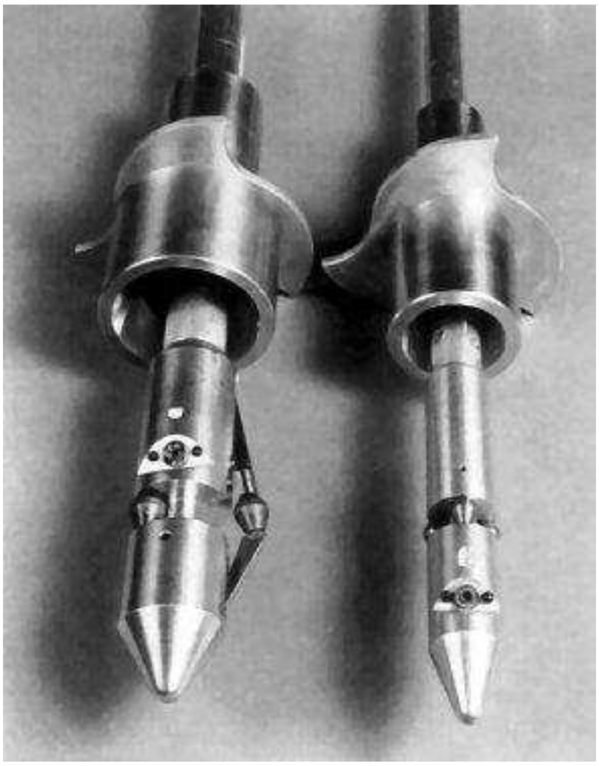

Figure 7. Detailed view of the plasma arc cutting torch showing the locating camera

Figure 8. Combined standpipe cutter/grab

6. Top Dome

The Top Dome was the upper hemispherical end of the steel reactor pressure vessel.

The original methodology for dismantling the top dome was to cut it in-situ into pieces less than 1 m^2 and to remove these through the temporary floor above.

An initial radiation uptake budget using estimated radiation values showed this method to be impractical. A revised methodology using a bulk posting technique reduced the estimated dose uptake to an acceptable figure.

A circumferential cut was made around the upper central portion of the top dome known as the crown section. Conventional industrial oxyacetylene equipment was used to make the cut. The torch was deployed on a remotely operated tracked vehicle.

The cut section was posted out with a flexible membrane attached between it and the reactor vault in order to maintain containment and hence reduce the spread of contamination, as shown on Fig. 9.

The cut section was placed in a ventilated temporary containment where it was size reduced for case of disposal. A similar operation was performed on the lower portion of the top dome, the plain dome section.

The methodology is discussed in more detail in a previous CEC paper (111) presented at the 3rd Seminar on Practical Decommissioning Experience with Nuclear Installations in the European Community.

Figure 9. Flexible membrane attached around the cut section

7. Standpipe Cut 5

The removal of the top dome left an array of refuelling standpipes exposed above the hot box.

The final phase of standpipe cutting removed these pipes, leaving reactor hot box. The final phase of standpipe cutting removed these pipes, leaving approximately 200 mm long stubs protruding through the hot box top plate.

The removal of the top dome had meant an increase of radiation levels on the temporary floor to 78 μSv.h^{-1}.

This increase necessitated a revised method of deploying the cutting equipment into the open ended standpipe. A Closed Circuit Television (CCTV) system was installed to enable the operator to approach the standpipes with the cutter suspended from the reactor hall crane, with minimal "hands on" guidance required to finally insert the cutter.

8. Stay Tubes

Stay tubes is the collective term used to describe a variety of tubes inside the hot box which gave added rigidity to the structure.

A small bore plasma arc cutter, developed under a complementary *" EC R&D project F12D0026-M "* was used to perform the cuts.

The cutter was suspended from a purpose built frame, which incorporated remotely controlled drives to produce the three axes (X Y Z deployment RIG) of movement required to position the tool in the tube.

The frame was positioned on the temporary floor, with the cutter accessing the reactor via any one of the 16 removable panels.

The following Fig. 10 and 11 show respectively the hot box and the 3-axes deployment RIG.

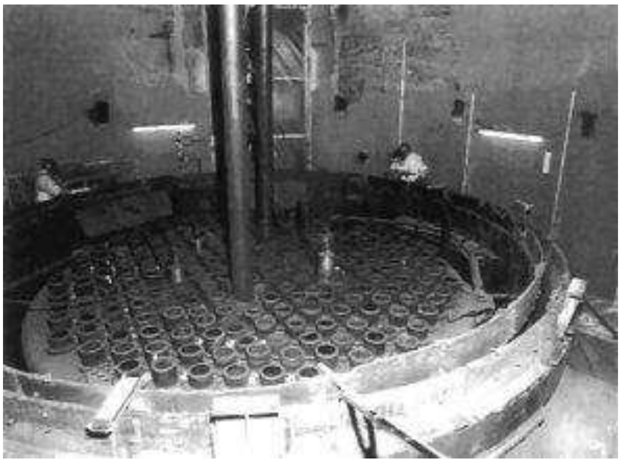

Figure 10. Hot Box after removal of Top Dome

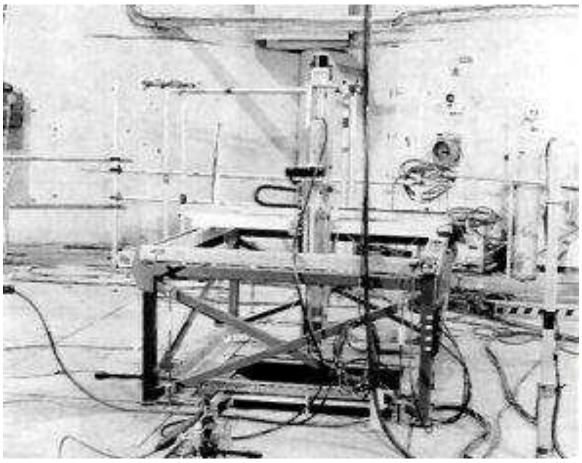

Figure 11. "X Y Z" deployment RIG

9. Results from Technical Operations

9.1. Dose Uptakes for Standpipe Cutting

Throughout the successive cutting and removal operations on the reactor, operators were working in and around increasing radiation levels.

This was a known hazard and was managed accordingly hence the gradual move away from manual deployment of equipment to a semi-remote technique.

Table 1 shows the average daily rates at which standpipes were removed for each of the *"four"* (2 is omitted) phases of cutting.

It can clearly be seen that as the method of cutting the pipes moved towards semi-remote operation the productivity rate decreased. However, this disadvantage is easily outweighed when compared to the saving on operator dose uptake in view of the rising dose rates.

Operation	Number of Pipes Cut	Total Dose (man*mSv)	Radiation levels (µSv/h)
Standpipe Cut n°1	12 cuts/working day	1.5	6-10
Standpipe Cut n°2	-	-	20
Standpipe Cut n°3	13 cuts/working day	7.4	20
Standpipe Cut n°4	9 cuts/working day	7.2	20
Standpipe Cut n°5	7 cuts/working day	7.3	78 increasing to 225

Table 1. Average Daily Cutting Rates and Dose Uptakes

From the table it can be seen that although the radiation dose rate increased by a factor of 7.5 between Cuts 4 and 5, there was no significant increase in the total dose per operation.

The value of 150 µSv/h shown for Cut 5 is the average for the task as the radiation level changed as material was removed.

9.2. Top Dome

Preliminary dose budgets performed for in-situ dismantling of the top dome highlighted the unacceptably high operator dose uptake for this methodology.

For this method the total dose uptake was estimated to be approximately 180 man*mSv for the WAGR dismantling team with a dose to all mechanical technicians and tradesmen (six in total) substantially exceeding the 15 mSv/year limit.

The revised methodology (bulk posting technique) had a dose budget of 21.2 man*mSv.

The actual total dose uptake for the operation was 18.99 man*mSv with a highest individual recorded dose of 2.34 mSv.

9.3. Stay Tubes

Initial dose estimates were based upon the radiation levels at refuelling floor level rising to 450 µSv/h following the removal of the refuelling standpipes.

This resulted in a dose budget of 54.88 man*mSv. Upon completion of the standpipe cutting, radiation levels had only risen to 225 µSv/h.

The revised dose budget was produced with an end result of 24.35 man*mSv.

This figure was still considered to be unacceptably high; a detailed study of the cutting schedule followed which revealed that the operation could be carried out in a shorter time than originally planned.

This meant that as dose uptake is proportional to the time spent in the radiation field, the dose estimate would reduce accordingly. The dose budget for the revised methodology was 14.85 man*mSv.

The actual dose uptake for the operation was 7.42 man*mSv.

10. Problems Encountered

Four of the six experimental loop tubes were cut using the plasma arc torch previously used in standpipe Cut 5 operations.

However, this equipment could not be used to access the two remaining small loop tubes due to size constraints.

In order to cut the remaining two small loop tubes, a plasma arc torch was mounted on a motorised carriage used previously to cut around the loops during top dome removal. The carriage was fitted to a circular track which ran around the outside of the loop tube. The torch was supported on three legs which were positioned to locate inside the adjacent cut standpipes.

Problems were encountered with this method as the location did not provide sufficient control in positioning the cutting torch relative to the workpiece (loop tube). Several attempts were made to rectify this problem without success.

Eventually due to programme demands and increasing operator dose uptake when measured against limited operational progress, this method was abandoned after making no successful operations and the two small loop tubes were cut manually using a disc grinding tool.

The radiation uptake by the "Operations Team" is shown compared with pre-operational estimates in Table 2.

The decision to change methods is clearly justified by the dose assessment and actual dose uptake.

Method	Number of Tubes Cut	Estimated Dose Uptake (µSv) Total	Estimated Dose Uptake (µSv) Highest Individual	Actual Dose Uptake (µSv) Total	Actual Dose Uptake (µSv) Highest Individual
Modified Standpipe Cutter	4	4 136	998	1 479	524
Tracked Cutter	0	2 052	426	2 983	705
Manual Grinding	2	3 727	650	1 087	523

Table 2. Radiation Uptake in Loop Tube Cutting

11. Waste Handling

The technical operations carried out under the CEC programme have produced large quantities of *"Low Level Waste"*.

The following is a summary of the waste(s) removed from WAGR as a result of carrying out these operations:

- *Top Biological Shield*: the combined weight of the TBS and the 12 outer shield blocks was 139.2 te which had an average activity of 0.2 kBq/cm.
- *Standpipe cutting* operations produced the following quantities of waste:
  - Cut 1 = 5.5 te,
  - Cut 3 = 18.5 te, and

- ◦ Cut 5 = 10.75 te.

  Total weight = 34.75 te

- *Top Dome Removal*: the crown section of the top dome weighed 27.7 te. The plain dome and associated internal gas baffle weighed 15.9 te.

  Total combined weight : 43.6 te.

12. Review of Technical 0perations

All operations on WAGR are preceded by the preparation and approval of a safety case.

As part of this safety case the expected dose uptake for the operation is calculated. This is done from actual radiation surveys of the areas to be worked in and estimated times of operations being done in these areas.

Following this exercise, a revision of methodology may be necessary in order to reduce the estimated dose uptake, to comply with the *"Alara principle"*.

This criteria has been the largest single factor in determining the methods in which operations have taken place in WAGR.

As a result of the repeated exercise of estimating the dose uptake prior to each operation, the calculated figure seldom differs greatly from the actual dose uptake (which is always recorded as work progresses).

The only exception to this was standpipe Cut 5 : this was largely due to the work being carried out in a radiation field which changed as the job progressed.

The estimated rate at which the radiation levels would increase gave rise to uncertainty and hence a large error. It is also very difficult to introduce a factor which accurately represents the rate at which operators becoming familiar with short duration tasks being performed repeatedly.

This factor introduces further error in the estimates.

13. WAGR Remove Dismantling Machine (RDM) - *Trials and Testing*

The decommissioning of the WAGR reactor required a remotely operated dismantling machine to cut and, in conjunction with a handling system, transfer the material through a purpose built waste route, into a Waste Packaging building.

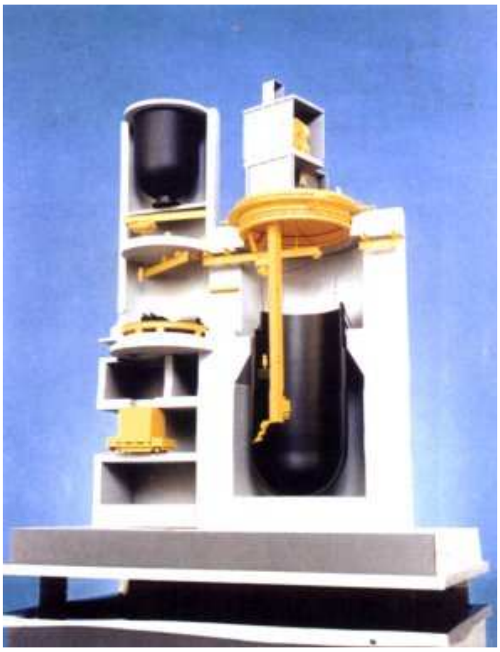

Figure 12. Remote Dismantling System

The RDM can be divided into two areas of equipment these being:

- *Dismantling Equipment*

  The dismantling equipment performs two main functions, which is to maintain the radiation shielding of the reactor vault, and dismantle the reactor vessel and its internals.

  Shielding is accomplished by a rotating shield floor positioned at refuelling floor level in the space previously occupied by the reactor TBS. Actual cutting of reactor components have been accomplished by a seven degrees of freedom articulating arm which will deploy cutting tools mainly in the form of oxy-propane cutting torches.

  The manipulator is attached to a platform that is supported and positioned by a segmented mast that passes through the rotating shield floor.

- *Waste Handling Equipment*

  To support and remove the dismantled parts of the reactor vessel and internals, a 3 te transfer hoist is used which is supported by and traversed on an independent slew beam positioned below the shield floor.

  In addition, the cable feed system enables the transfer hoist to traverse out of the rector vault into the adjacent sentencing cell, or into the maintenance cell directly opposite.

  Control of the plant is generally from control station number one (CSI) which is located in the *"adjacent non-active administration building B55"*. However, control of the hoist and waste handling equipment can be transferred to local control stations. Viewing of operations is achieved by CCTV systems.

  In addition to standard systems, the manipulator will view his operations on a 3 dimensional stereo viewing system. The RDM is described in greater detail in the paper presented at the *4th Seminar on Practical Experience with Nuclear Installations in the European Community* [2].

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14. RDM Testing and Operator Training

For testing and operator training the mast module was assembled in the Remote Dismantling *Machine Test Facility* (MTF).

The facility consists of a steel structure at refuelling floor level and holes cut through the floor levels below the facility allowed installation of the mast structure. The 3 te transfer hoist and a beam, of similar capacity, to that of the slew beam over the reactor, is also provided in the facility.

Three operators selected to undergo training were involved in the commissioning of the manipulator.

This served the purpose of providing an early introduction to the kit and also gave them an insight into the machine's control system. Operators were initially taught fundamental safety related operations with the manipulator and RDM and gradually moved onto more complex tasks as the safety related operations became a natural routine task.

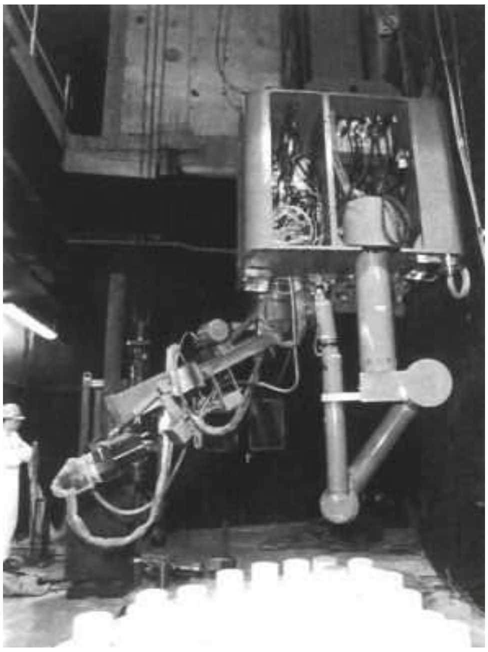

Figure 13. Remote Dismantling *Machine Test Facility* working on polystyrène mock-up

Similarly, initial operations were carried out using just the manipulator with compliant surfaces to limit the potential for damage to equipment. But as the operators became more competent with the equipment, gradually more tools were used.

This culminated with the manipulator being used to remotely deploy several different oxy-propane cutting torches to cut up steel fabricated mock-up reactor components in conjunction with the 3 te transfer hoist and various grabs.

The manipulator being deployed in the MTF is shown in Fig. 13.

15. Results of Testing and Training

The testing and training was planned to run for 24 weeks. However, due to problems with the installation of equipment to be used during this phase of work, the programme was completed after 36 weeks.

During this time areas of concern were noted on several pieces of equipment, these areas being:

1. Insufficient information being fed back to the operator at the main control desk CSI (*Control Station I*) regarding the status of the RDM.
2. Unreliability of features within the gas cutting control system.
3. Lack of positional information for the stereo camera deployment boom.

This led to problems being encountered when attempting to establish a parked position for the boom prior to platform withdrawal from within the reactor.

These areas, although giving rise to concern for future operational use, did not present insurmountable problems during the testing phase of work.

During the testing period, the advantages of a 3D stereo viewing system became apparent when used with the complex motions of the manipulator.

Tasks performed without the stereo viewing system took considerably longer to perform, if they could be completed at all.

Initial trials with the gas cutting system deployed by the manipulator, involved operators cutting plain mild steel plate approximately 75 mm thick. This was successfully completed with the cutting torch set at a stand-off distance from the work piece of 50 mm and traversed across the late at 3 or 4 mm/second.

Upon inspection of the cut pieces it was found that the quality of finish along the cut edge suggested that the torch was capable of cutting much thicker material. Later trials with the gas cutting system involved more complex components to be cut.

These typically represented the hot box top and bottom plates. The top and bottom plates are constructed from 7.5 mm thick mild steel with a 19 mm thick inner stainless steel insulation consisting of layers of dimpled foil.

In order to increase the heat input required to cut this material, a system was developed to inject iron particles into the flame. Under testing conditions this method proved very successful, with the composite materials being cut cleanly.

This was achieved with a material stand off distance of 80 mm and a traverse speed of 2 or 3 mm/second.

The use of a small select team of trainees has been advantageous during initial training on manipulator operations. An inexperienced operator requires constant supervision and tuition until he is familiar with basic functions.

Initial response from operators when introduced to the main control area, CSI, is one of apprehension. This is mainly due to no previous experience of control room operation on their part.

However, this feeling is quickly overcome once operators become involved in performing duties. Extensive use of full scale mock-ups had highlighted potential problems in advance and enabled solutions to be found.

Close interaction between the development and operations department at all stages of the strategy formulation and testing has proved beneficial in terms of training and identifying potential operational problems.

16. Heat Exchanger Dismantling

During 1991, an option study was carried out to determine the optimum method for the disposal of the four WAGR heat exchangers.

From the study the following methodology was deemed most suitable:

1. *Partial decontamination of internals*: this was a single pass water flush to remove loose contamination and hence reduce the spread of particulate.
2. *Size reduction*: localised shielding would be provided within the heat exchanger biological shield through which operators could deploy thermal cutting torches to cut up the vessels and their internals.
3. *Disposal*: cut sections of the exchanger would be placed in a standard ISO container and transported by road to Drigg, the UK Low Level Waste Disposal site.

Since the study was done a significant change of strategy has been adopted for heat exchanger removal.

This change came about as the result of a mid project review by the adding organisation where it was noted that conditions for acceptance to Drigg had changed. In Particular no surface dose criterion now applies.

During March and April 1993 an initial study was undertaken to evaluate the option of single piece removal for direct disposal to Drigg. The conclusion of that study was that there were no technical objections.

A technical summary of the strategy follows:

1. Preparatory work is required prior to lifting of heat exchangers from within B50 containment building. This includes:
    . Sealing all bio-shield penetrations and removing equipment from above heat exchangers A and C (B and D having being cleared prior to jacking up to make way for the reactor waste route in 1986).
    b. Install a temporary containment between the upper end of the bio-shield and the hole in B50 upper hemisphere through which the heat exchanger will be lifted.
2. Lifting of each of the four beat exchangers will be carried out by a boom crane positioned outside of B50. Once lifted clear of the B50 containment building, the boom crane will work in tandem with a second smaller crane to rotate the heat exchanger through 90° to the horizontal position for transport purposes.
3. Transport from B50 Windscale to Drigg disposal site will be via road. Initial discussions have taken place with the Cumbria highways and Transportation Department.

The benefits from the revised methodology can be seen in Table 3.

	Method 1	**Method 2**
Dose Uptake	1600 man*mSv	384 man*mSv
Duration	6 years	3 years
Cost ratio	3	1

Table 3. Heat Exchanger Disposal Methodology Comparison

17. Conclusion

The hands-on phase of decommissioning WAGR has shown two major lessons.

Firstly, that using radiation uptake as a criteria for selecting dismantling methods has had a positive effect in improving the dismantling techniques.

Secondly, the principle of removing large items or sub-assemblies from the high radiation field for further size reduction has advantages in terms of dose uptake and the variety of techniques which can be applied.

Non-active trials of the remote dismantling machine prove once again the need for adequate allowance for training and the value of thorough testing of complex equipment prior to installation in the active environment.

18. References

[1] *Preparation for Remote Dismantling and A Review of Dose Control*. E Taylor, P Sloan, J Tomklnson, C Stubbs. Presented at the 3rd Seminar on Practical Decommissioning Experience with Nuclear Installations in the European Community.

[2] *Optimising the Methodology for Cutting the Reactor Hot Box and Training in the Use of the Remote Dismantling Machine*. P Sloan, S J White. Presented at the 4th Seminar on Practical Decommissioning Experience with Nuclear Installations in the European Community.

19. Acknowledgement

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