Unclassified **NEA/RWM/R(2011)2**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

20-Sep-2011

English - Or. English

NUCLEAR ENERGY AGENCY

NEA/RWM/R(2011)2
Unclassified

Radioactive Waste Management Committee

REMOTE HANDLING TECHNIQUES IN DECOMMISSIONING

A report of the NEA Co-operative Programme on Decommissioning (CPD) project

The corresponding RWMC report is also available on the OECD Nuclear Energy Agency webpage and as a printed publication.

JT03307284

English - Or. English

Foreword

The NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of a limited number of organisations actively executing on planning the decommissioning of nuclear facilities. The objective of the CPD is to acquire information from operational experience in decommissioning nuclear installations that is useful for future projects.

Although part of the information exchanged within CPD is confidential in nature and is restricted to programme participants, experience of general interest gained under the programme's auspices is released for broader use. Such information is brought to the attention of all NEA members through regular reports to the NEA Radioactive Waste Management Committee (RWMC), as well as through published studies.

This report describes generic results obtained by a CPD Task Group analysing the needs for remote technologies. The existing technologies able to meet these needs, the lessons learned and showing where improvements or further developments should be made in this domain.

The Working Party on Decommissioning and Dismantling (WPDD) of the RWMC would like to thank CPD for sharing the experiences from its important work.

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1. Introduction

In the context of nuclear facility decommissioning, the dismantling and the decontamination techniques represent an important task. In order to meet dismantling requirements, different cutting, separation and handling techniques can be used. For the selection of a dismantling or decontamination technique suitable for particular applications, many limiting conditions need to be taken into account, as an ideal universally applicable cutting tool or decontamination process may not be available. It may in fact be expedient to use a dismantling/decontamination technique which is not specifically tailored to that application in order to avoid additional high developmental investment and operating costs or to enhance safety and radiation protection. Remote technologies can be used during decommissioning in areas that are inaccessible or are unsafe for occupancy.

All of the technologies require an interaction to accomplish a task, even if only to turn the equipment on and off. While in almost all situations, hands-on operation by the worker is acceptable, in certain conditions it is not. For example, when a work area contains a hazardous environment, such as a high radiation field or a chemically contaminated atmosphere, human presence should be limited to maintain safe operating conditions. For a manually operated system, limiting human presence means limiting operating time and thus productivity. Therefore, it is often desirable to provide equipment that can be operated from outside the hazardous environment to overcome these limits. This is the primary reason for using remotely operated equipment. Some other reasons include re-utilization of facility resources, improved safety environment, cost reduction, and accessibility to hard to reach work areas. In decommissioning projects where remote equipment must enter hazardous environments, it is important to remember that the equipment should be kept simple or be proven under a variety of similar circumstances. This is done to ensure the success of the equipment's intervention, to prevent loss of time and effort, and to minimize exposure to hazardous environments caused by retrieving a failed piece of remotely operated equipment.

1.1 Enhanced safety

Remote equipment that can tolerate high radiation fields while effectively performing required tasks is beneficial in reducing both exposure and cost. For example, nuclear facilities require repair or maintenance of primary equipment such as steam generators. Because the areas are highly radioactive, workers who enter these fields can receive their legal dose limit in only a few minutes of work on the equipment, which means more workers to complete each task and an increase in overall dose burden. Remotely operated technology can minimize manual intervention time in these areas, thus enhancing safety and productivity.

1.2 Cost reduction

The use of remotely operated equipment can also result in cost reductions. The first example for cost reduction is the same as the reduction of personnel exposures. To perform a manual task in a high radiation field, many workers are required to avoid excessive doses. There are therefore additional expenses associated with the large numbers of workers employed for the high radiation task. In other words, since the remote equipment operating in the high radiation field replaces many human workers, the employment costs for those human workers are saved. Another aspect of remote operation for cost reduction is accessibility. Remotely operated detection devices can be inserted into piping and areas in the nuclear facility that are too small for human entry. The survey of the pipes can show that they are not contaminated and can remain in the facility after decommissioning. This reduces the cost for removal of potentially contaminated materials as well as reducing the volume of suspect material requiring disposal in an appropriately -designed facility.

1.3 Productivity improvement

Because of the cumbersome nature of some protective clothing, worker efficiency can be greatly reduced. In addition, workers may need to participate in multiple rehearsals to train for a task before it is performed. Thus, the overheads to accomplish a task in an area with a hazard such as a high radiation field are very large. When remotely operated equipment can be used to accomplish the task, fewer workers are required. Even though the operator of a remote system will require training to be able to perform a given task effectively, the overall work hour requirement is lower, which increases productivity.

1.4 Utilisation of facility resources

A facility to be decommissioned often already contains remote equipment. Such equipment can be used in the decommissioning effort. For instance, remotely operated resources such as master slaves or electromechanical manipulators may be used to aid the dismantling of the areas in which they are installed. Remotely operated cranes, fuel handling machines and other equipment can be used during this phase as they were used during operation. Such possibilities should be extensively studied, as using existing equipment will reduce the overall cost of the decommissioning project.

1.5 Accessibility

Remote equipment can provide access to work locations that operators cannot physically enter. For example, it is virtually impossible for a human to survey small diameter pipes to validate them for free release, to remove a contaminated component from its perch several metres above a hot cell floor, or to remove abandoned materials from the bottom of a quarry overlain by several metres of water.

1.6 Disadvantages for remote operation

A major disadvantage of remote operation is the fact that the operator is often located a significant distance from the work being performed, and cannot provide an immediate response to the task or problems. Visual contact may be non-existent and the operator has to rely on visual aids such as cameras. Also a worker will probably need rehearsals with mock-ups of the work area, as opposed to manual operation which in most cases does not require training and rehearsals to prepare for the task (except in severely hazardous situations).

2. Remote dismantling systems

2.1 Introduction

Most currently available technologies and processes could be successfully converted for remote operation. The conversion activity must take into account each system function performed by manual operation, and provide a suitable operator interface with visual and electronic feedback from the remote work site to the operator's location. Other factors to be considered when preparing remote activities include tool setup and change out, operating clearance for remote equipment, terrain conditions for mobile equipment, and material handling operations. In some cases, basic manual tools can be modified to suit the remote system. For example, modification may include changing the grip to something an effector can grasp, using remote alignment and pinning methods and using self standing bails. Successful remote operation requires the operator to see the area in which the work is being performed and manipulate the equipment well enough to accomplish the required tasks.

Remote technologies can be categorized into several areas such as detection, segmenting, decontamination, handling, sampling and handled remote equipment. These are described below.

2.1.1 Detection equipment

Detection equipment such as cameras or measuring equipment can be used for surveys and data gathering activities, or can be combined with other remote equipment for real time operator monitoring. It is important to note that as well as real time monitoring, remote detection equipment can perform the important function of gathering data for subsequent analysis, data that may not be readily gathered by human observation.

2.1.2 Cameras, lights and sound

Most remote operations rely on real time visual feedback to an operator. This information is the main link between the operator and the remote operation being performed. Use of cameras, lights and sound are essential to the success of a remote operation. A typical camera, lighting and sound system could be added to the robot or the telemanipulator. Cameras, lighting and sound capture systems could also be mounted on positioners that permit several degrees of freedom. Signals are transmitted to a receiver and visually displayed on large monitors for the operator's use. With the use of a stereo camera system, data can be fed to stereo monitors, providing the operator with limited depth perception. A stereo camera system can also permit mapping of the panned area or creation of a computer model that can be used in self guided robots or virtual reality system displays. For other remote operations, such as gathering visual data about stacked radioactive drums in a storage warehouse, a self guided robot can be equipped with recording equipment as well as cameras and lights. In this situation, no real time visual data are needed, as after the robot returns from its pre programmed mission the tapes are removed and examined in an off line mode.

2.1.3 Other detectors

Other detection equipment may be required for specialized tasks such as using a radiation detector to determine the most highly radioactive material in an area so it can be removed first, or using an infrared detection system to monitor areas where heat sensitive materials or equipment are required for decommissioning activities. Many of the characterization techniques can be used in a remote application. These applications may include measuring alpha, beta, gamma or neutron radiation, checking floors for volatile organics and mercury, using infrared cameras to detect heat, using microphones and radios to detect sound, or taking temperature and humidity measurements.

2.1.4 Segmenting equipment

Almost all of the segmenting equipment (cutting tools) can be applied to remote use, and many tools have been converted for remote operation, including circular saws, nibblers, arc saws, plasma arc cutters, reciprocating saws, laser cutters, friction saws, grinders and rotary hammers. Converting some equipment to remote application is easy. For example, plasma arc cutters already have remotely operated cutting heads, so extending these to a hostile environment is simple. Other cutting tools are designed specifically for manual operation, so special fixtures, equipment or custom designed tools are required for remote operation. Heavy equipment, which is usually used for material handling, is now being converted for remote operation. Some remotely operated heavy equipment is exclusively used for segmenting. An example includes remotely operated backhoes with a ram implement attachment, used for breaking concrete. Other remote equipment that falls into this category includes nut running tools and impact wrenches. These are standard tools that have been used with remote systems and can be applied to decommissioning activities.

2.1.5 Decontamination equipment

Some decontamination techniques are suitable for remote operation, including processes such as scabbling, vacuuming, steam cleaning and spraying. However, some techniques may be more difficult to adapt to remote use. For example a remotely positioned vacuum bell, an in situ cleaning device normally used to apply electro polishing electrolyte or other surface cleaning chemicals, may have to be coupled to a bridge mounted, teleoperated manipulator if the task is to decontaminate cladding in a hot cell. Although the adaptation is made more difficult by situational complexities, it is still feasible. As the tasks required become increasingly complex, the functions to be combined become more numerous, inputs to the remote system increase, and remote operations become more difficult and sometime impossible.

2.1.6 Material handling equipment

Lifting, packaging and removing materials generated in the decommissioning effort are among the most important parts of the operation. Most facilities have a materials handling system in situ and if it is still functional at the time of decommissioning, operating costs and potential procurement delays can be reduced. It will also minimize the frustration at the end of the project when it is time to survey clean subcontractor equipment. Where facility-based materials handling equipment is not available or usable, equipment should be carefully selected to minimize recontamination of clean areas. Materials that are generated during decommissioning can be lifted using grapples, clamshells, or specially designed tools mounted on a remote manipulator. In general, the lifting capacity of a remote manipulator is limited. Another limiting factor includes the physical clearance available in the material handling corridor. Existing operating systems that can aid handling operations include automatic guided vehicles, palletizing robots, cranes, hoists, elevators and conveyors.

2.1.7 Sampling equipment

Mobile robots can be designed for air, water, oil and debris sampling. Some robots also have drilling capabilities so that they can bore through concrete walls and extract samples from within a structure. This technology has been best applied in disaster management when the situation renders process knowledge useless and alters structural configurations by scattering debris and blocking normal passageways.

2.1.8 Handled equipment

Handled remote equipment usually takes advantage of the distance rule in limiting radiation doses to operators. This class of equipment is utilized when dose rate limits for operators would be exceeded in contact situations, but where dose rates are manageable. Examples include long reach extensions to power wrenches and long reach hand triggered grapples. Using a long reach power wrench, an operator can, for example, reach down into a vault and loosen bolts associated with a dismantling task. A long reach hand triggered grapple might be used to remove hot elements from a mist eliminator or to retrieve equipment that has fallen into an inaccessible location.

Different dismantling and decontamination techniques and processes are presented, which have already been successfully used in decommissioning applications. On the basis of process and operating conditions, a pre-selection of suitable techniques can be carried out. But a final selection for a specific dismantling requirement always results from the consideration of local conditions and national regulations.

2.2 Cutting tools

2.2.1 Mechanical

Technique	Materials	Environment	Remote operation feasibility	State of development
Shears	All metals	Air/UW	++	Industrial
Power nibblers	MS, SS	Air/UW	+	Industrial
Saws	All metals	Air/UW	++	Industrial
Milling cutters	All metals	Air/UW	++	Industrial
Orbital cutters	All metals	Air/UW	+	Industrial
Abrasive cutting	All metals	Air/UW	+	Industrial

UW: underwater, MS: mild steel, SS: stainless steel
++: excellent, +: good, o: average, -: poor

2.2.2 Thermal and similar

Technique	Materials	Environment	Remote operation feasibility	State of development
Plasma arc	All metals	Air/UW	++	Industrial
Flame cutting	MS	Air/UW	+	Industrial
Powder injection	All metals	Air	o	Industrial
Thermal lance	All metals	Air/UW	-	Industrial
Abrasive water jet	All metals	Air/UW	o	Almost industrial

UW: underwater, MS: mild steel
++: excellent, +: good, o: average, -: poor

2.2.3 Electrical

Technique	Materials	Environment	Remote operation feasibility	State of development
EDM	All metals	Air/UW	o	Industrial
MDM	All metals	Air/UW	o	Industrial
Consumable electrode	MS	Air/UW	+	In development
CAMC	All metals	Air/UW	+	In development
Arc saw	All metals	Air/UW	o	In development

EDM: electric discharge machining, MDM: Metal disintegration machining, CAMC: Contact Arc Metal Cutting, UW: underwater, MS: mild steel
++: excellent, +: good, o: average, -: poor

2.2.4 New and emerging cutting tools

Technique	Materials	Environment	Remote operation feasibility	State of development
Laser	All metals	Air / UW	o	In development
Liquefied gas	All materials	Air	o	In development
Explosive cutting	All materials	Air / UW	o	In development

UW: underwater
++: excellent, +: good, o: average, -: poor

2.3 Arms

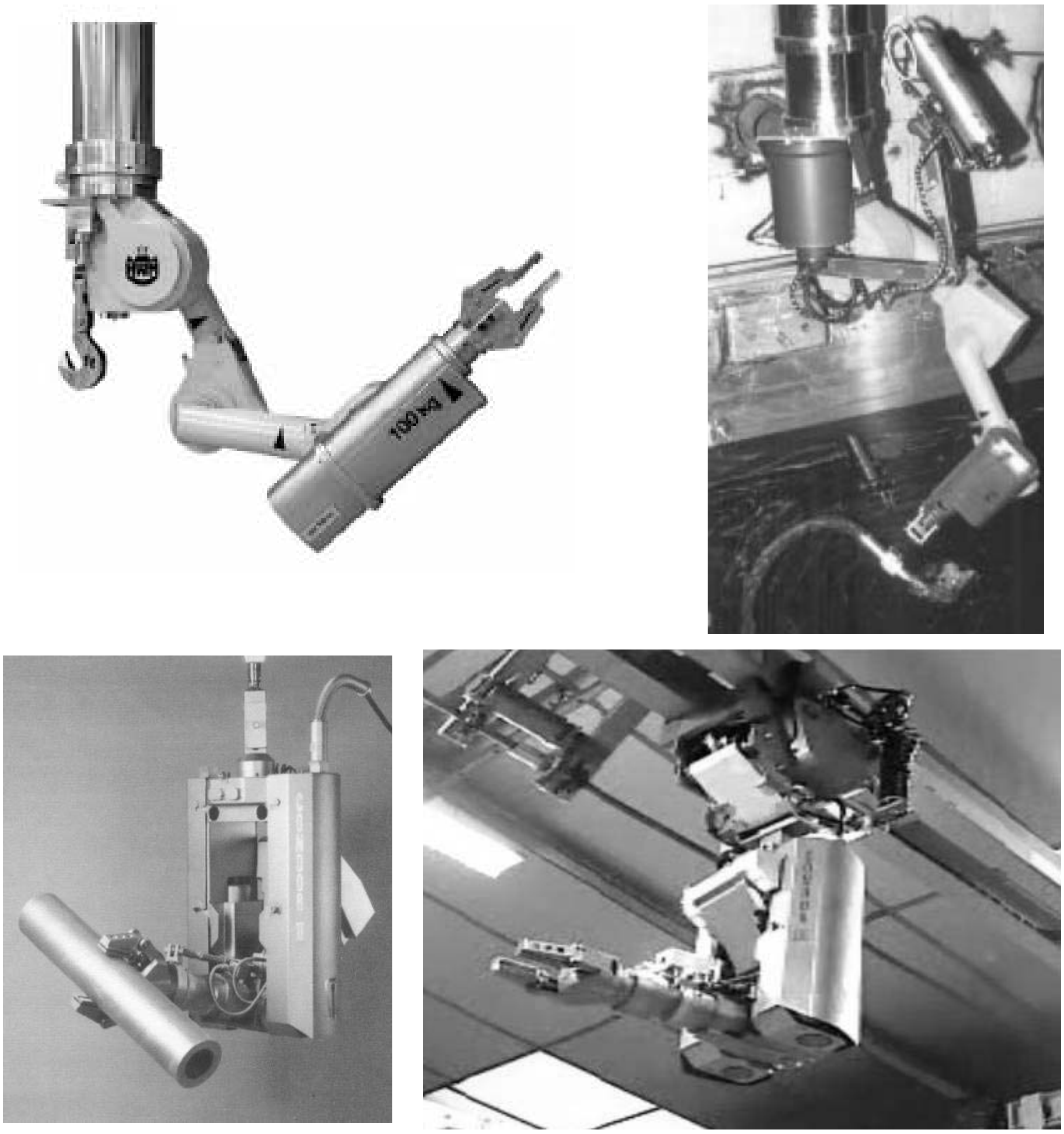
2.3.1 Electrical manipulators

In this section, different electrical manipulators will be presented. These manipulators can be classified in 3 families, depending on their payload capacity, their number of axes and their dexterity:

- the power manipulators;
- the simple telemanipulators;
- the master slave telemanipulators.

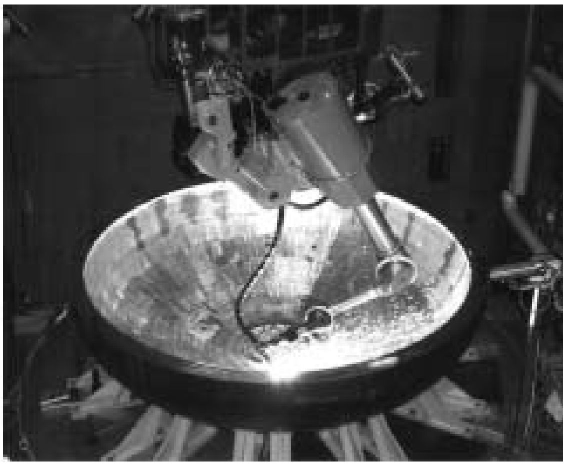
The first class of manipulators is the power manipulators shown in Figure 1. These manipulators have between 2 and 4 axes, a payload capacity of 50 kg to 500 kg, a length of 1 to 3 metres, and they are usually mounted on a crane (telescopic or not) to access to the working area. Their simple design, with high mechanical gear ratio, very few (or no) sensors, and no sophisticated control technology, make them more suitable for heavy duty low dexterity tasks. They are usually resistant to the environment, including high level radiation (typically more than 10 kGy). They may be expensive, compared to other solutions, because their production remains limited in numbers of units per year. Long term maintenance may be a problem and is dependent on the availability of spare parts and the know-how provided by the manufacturer.

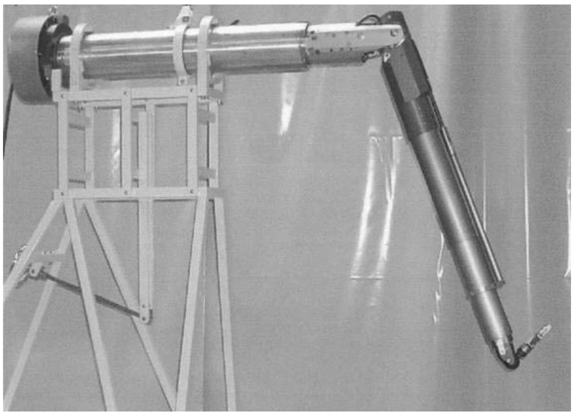
Figure 1: Power manipulators



The second class is the simple telemanipulators shown in Figure 2. In this class, the manipulators have 6 degrees of freedom, a standard payload capacity of 20 kg to 250 kg for a range of 1 to 4 metres working in any position within a hemispheric volume centred on its base. They may be introduced into a cell through a horizontal or a vertical penetration hole, and may be embedded on a carrier to give access to a remote working area. The modular design of these arms makes them easy to adapt to the application. The control system provides basic operating functions using a portable joystick interface to move the manipulator. Their more sophisticated design and control technology make them suitable for tasks requiring medium dexterity. They are resistant to the environment, including high level radiation (typically more than 10 kGy), and may be protected against contamination by booting. Some of them are not expensive, compared to other solutions. Long term maintenance may still be a problem, depending on the number of telemanipulators sold per year.

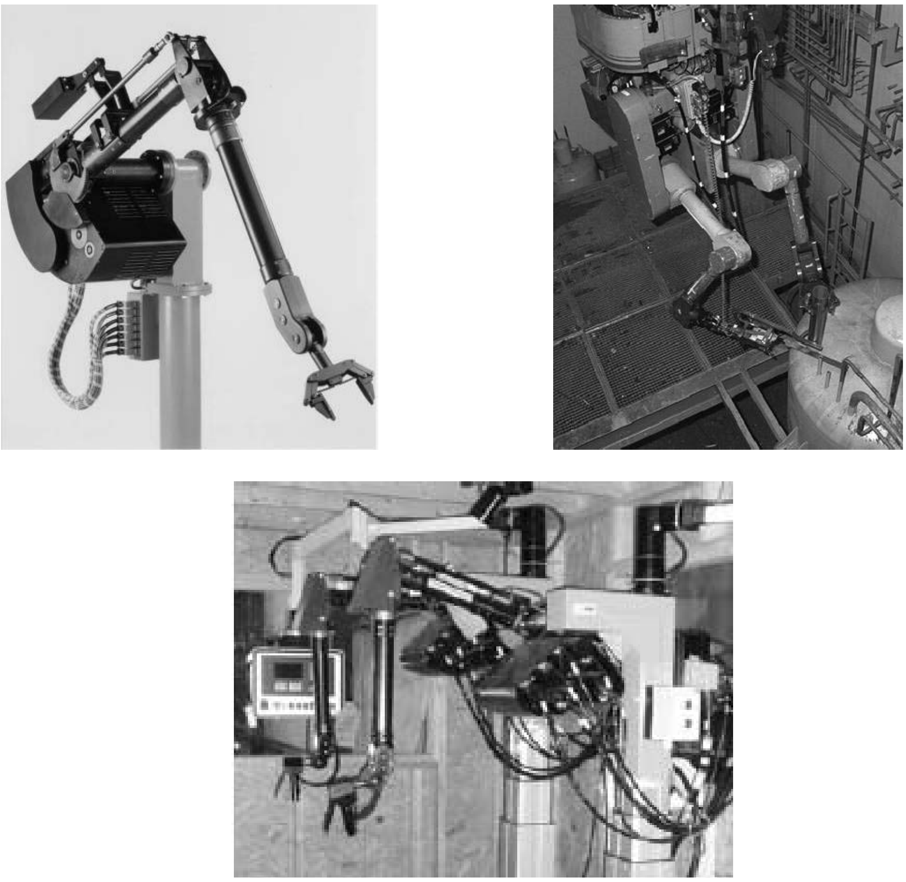
Figure 2: Simple telemanipulators





The third class is the master slave telemanipulators shown in Figure 3. In this class, the manipulators have 6 or 7 degrees of freedom, a standard payload capacity of 20 kg to 60 kg for a range of 1 to 3 metres. They are usually embedded on a carrier to give access to a remote working area. The control system provides operating functions using force feedback master-slave technology, enabling these telemanipulators to carry out tasks requiring much higher dexterity and productivity than simple telemanipulators. They are resistant to the environment, including high level radiation (typically more than 10 kGy), and may be protected against contamination by booting. The cost may be higher than simple telemanipulators due to the increased number of functionalities.

Figure 3: Master slave telemanipulator



2.3.2 Hydraulic manipulators

In this section, 2 families of hydraulic manipulators will be presented, classified depending on their payload capacity, their number of axes and their dexterity:

- the simple manipulators
- the master slave telemanipulators

The first class is the simple manipulators shown in Figure 4.

Figure 4: Hydraulic telemanipulators

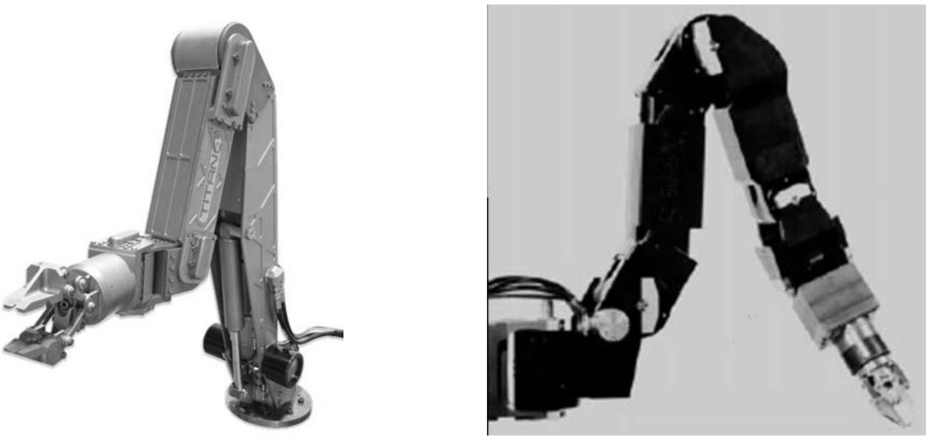
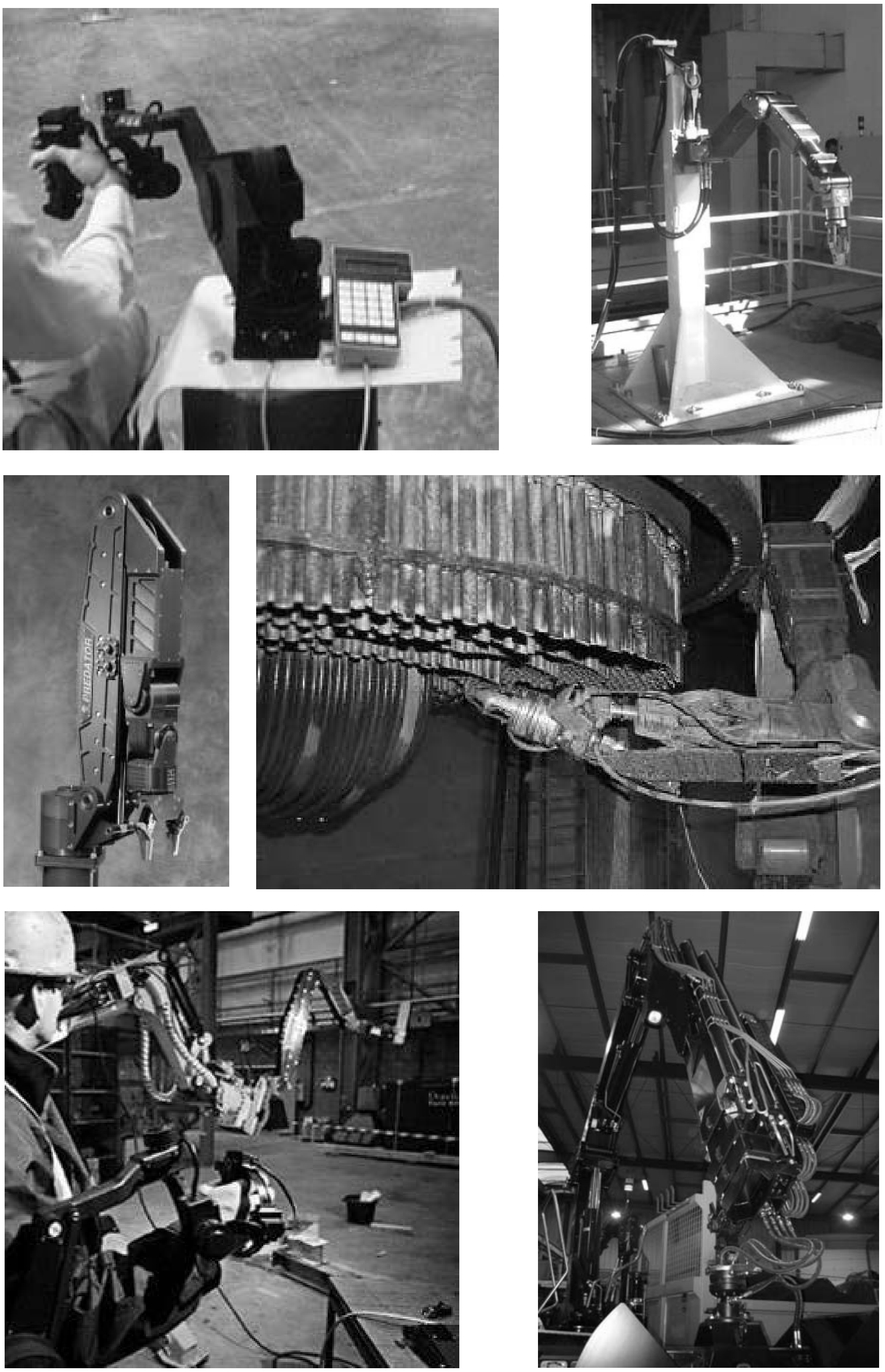


Figure 5: Hydraulic master slave telemanipulators



2.3.3 New developments and evolution of master slave technologies

Figure 6: Electrical master slave industrial robot

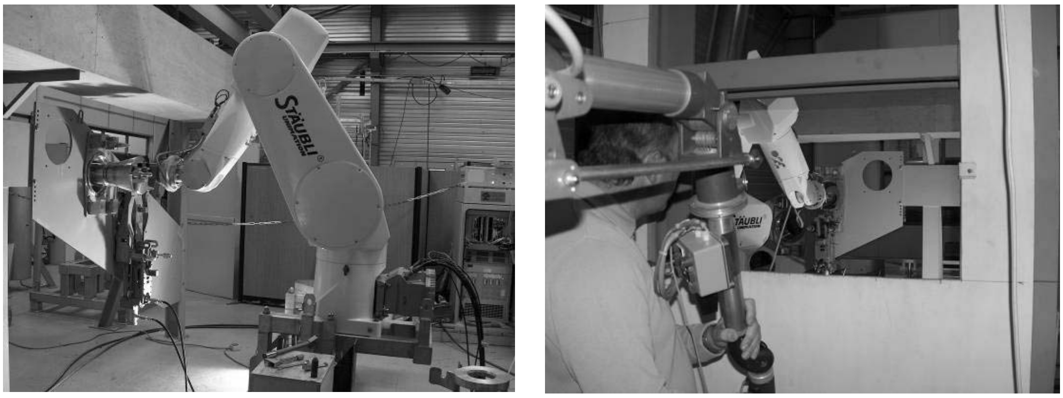


Figure 7: Re-engineering of an existing master-slave manipulator with electrical power and remote control

Motor box replacing the conventional master arm and its counterweights

Slave arm inside the hot cell in "celling configuration"

2.4 Carriers

2.4.1 Characteristics required for a carrier

Several initial characteristics allow the definition of a carrier's operation.

2.4.1.1 Task (inspection, sampling, cleaning up, dismantling)

The type of task decides the kind of carrier required. Thus, missions of inspection or of sampling can require lighter tool carriers and tools than for tasks involving dismantling or handling.

2.4.1.2 Load

Depending on the type of task, the tools and their tool carriers are decided on before the type of carrier itself. These tools and tool carriers generate the loads (forces, momentum, etc) and so influence the choice of carrier.

2.4.1.3 Intervention environment

The nature of the environment also impacts the choice of a carrier suitable for the required level of technologies (in air, under water, etc.) This can also need additional equipment to meet specifications linked to an explosion risk, chemical state, etc …

2.4.1.5 Stability

The environment obviously determines whether a carrier with proven stability is necessary. However, it is not the intrinsic stability of the carrier alone, but of the carrier within its future environment which need to be assessed. Thus, a carrier with a tool carrier at the limit of its extension will not be taken into account if the location does not allow it.

2.4.1.5 Access

Different access possibilities can exist:

- From above
- Lateral (from the side)
- From beneath (mainly under water.)

2.4.1.6 Irradiation resistance

Irradiation resistance is a condition which will guide the choice of one carrier over another. However, the dismantling phase when the carrier is to be used needs to be taken into account in order to establish a truly realistic level of protection.

2.4.1.7 Decontamination

Dismantling generally requires the progressive removal of barriers, which necessarily means intervening in partially contaminated zones. Two options can be considered:

- A basic carrier, with a low cost and small footprint, for occasional operations.
- A complex, high-cost carrier for repetitive operations over long periods.

In the case of a basic carrier, it is usually easier and cheaper to consider it as disposable waste after its use.

In the case of a carrier with more complex technology, a decontamination zone needs to be set up.

2.4.2 Bridge + lifting unit

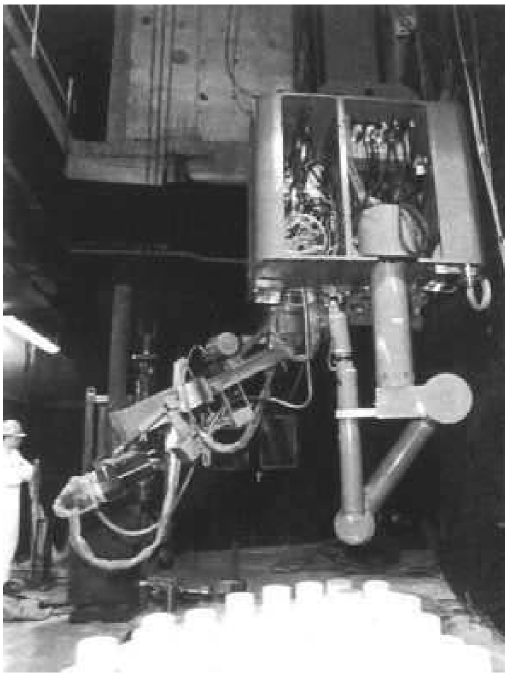
2.4.2.1 Straight lifting unit (Telescopic system)

The telescopic carrier nests into a set of tubes or equivalents, sliding in relation to the others.

PIADE carrier (ELAN IIB)

ATENA carrier (AT1)

Remote Dismantling Machine (RDM) – (WAGR)



U storage carrier (CEA Marcoule)

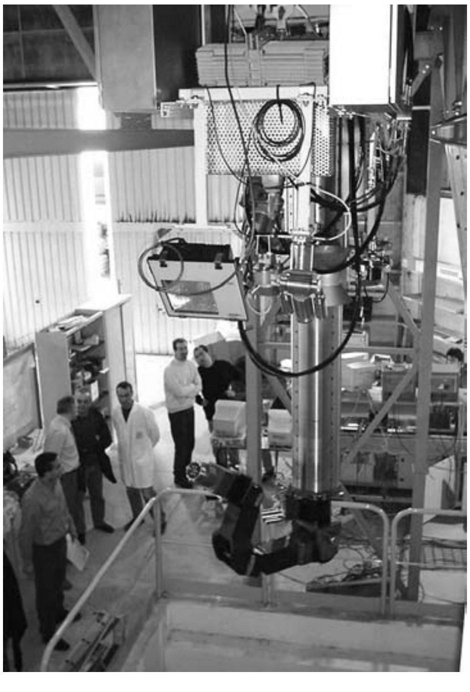
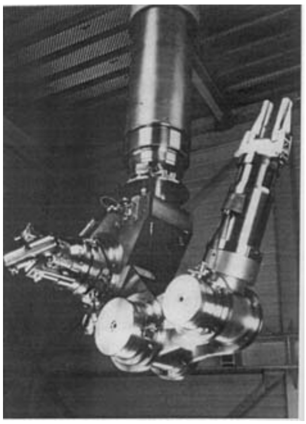


Figure 8: Telescopic carrier TMTC developed by Cybernetix (Load 500 kg and 6m reach)



Application of a telescopic system used in classical industry (after adaptation) could be considered.

This concerns telescopic systems based on those used for telescopic lifters. These robust systems allow a deployment over a length of up to 25 m.

Several concepts exist:

- Several positions set with a telescopic system, with the first segment of the telescope remaining outside the cell and so protected from contamination. This requires quite heavy handling operations, with decontamination work on the telescope.
- Association with a bridge, but which no longer allows removal of the first segment from a cell.

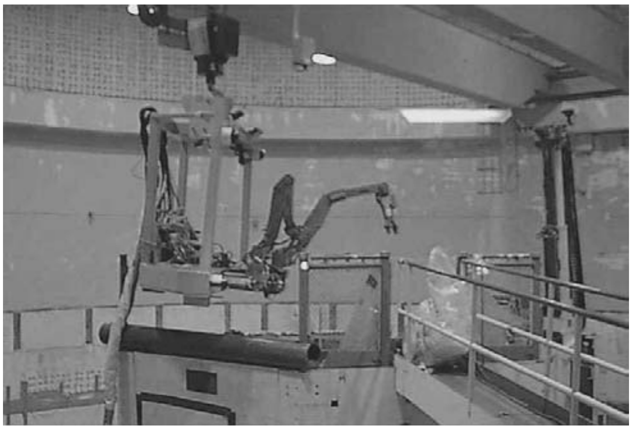
In all cases, particular attention must be paid to possible cable breakage, which is the main risk associated with a telescopic system.

2.4.2.2 Suspended lifting unit

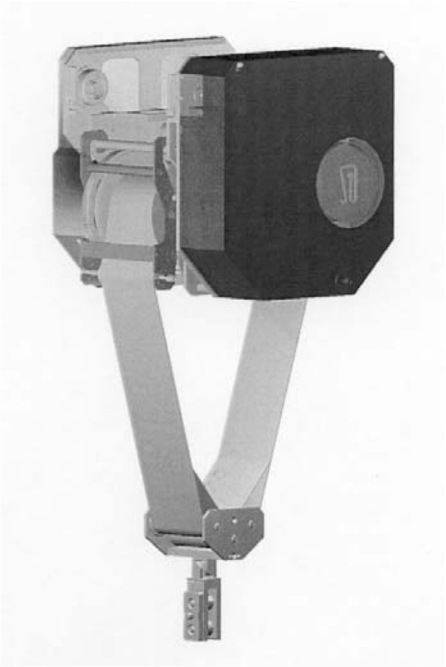
A suspended system is able to connect to a system hung by a cable or equivalent under a travelling crane bridge or a gibbet.

Figure 9: suspended carrier.

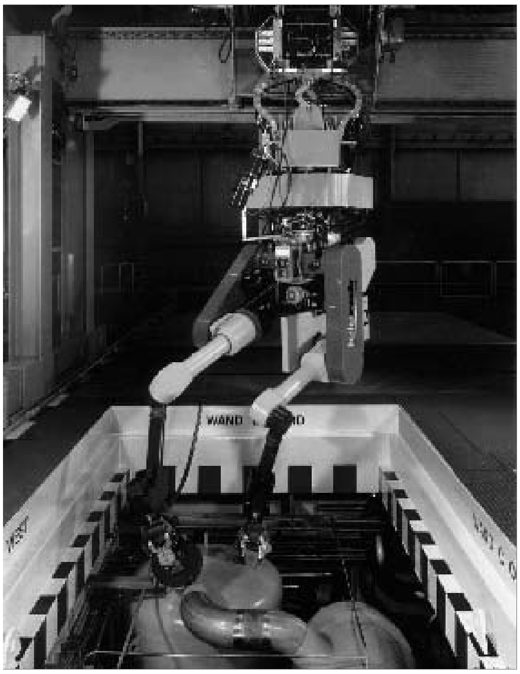
Dual Arm Work Platform at CP-5



Auto-stable Hoist – SIT



System with chain - WAK/Arm type



2.4.3 Mobile carrier

Despite their size, the mobile carriers are high power demolition machines. They can be 6 to 8 times more efficient than manual demolition, can go through narrow openings and can work in very restricted spaces. They can therefore be perfect for interior works. BROKK and HUSQVARNA have developed a number of machines on wheels or tracks for public works demolition worksites.

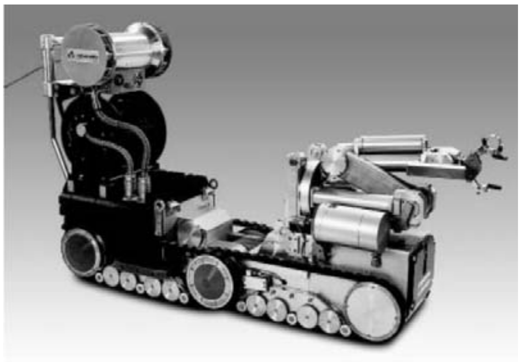
For lighter applications like operation viewing, radiological characterisation, cleaning up or decontamination, a number of solutions have been developed by INTRA in collaboration with CYBERNETIX, REMOTEC, GIAT Industries or ECA.

Figure 10 :Earthly carrier

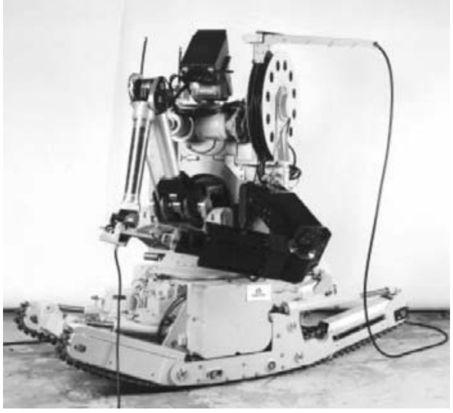
BROKK 90

HUSQVARNA DXR 310

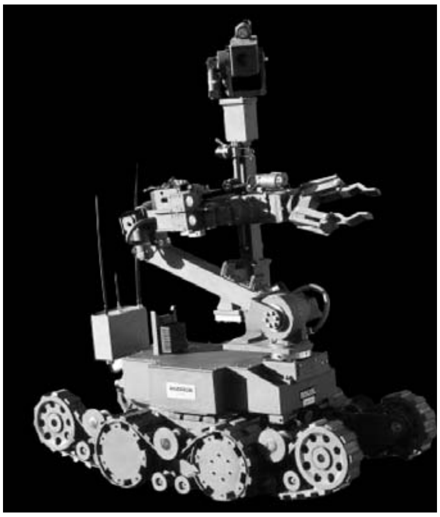
EROS



MENHIR (CYBERNETIX)



REMOTEC Engine



Lifting table

Telescopic elevator (AICHI)

Telescopic elevator (MANITOU)

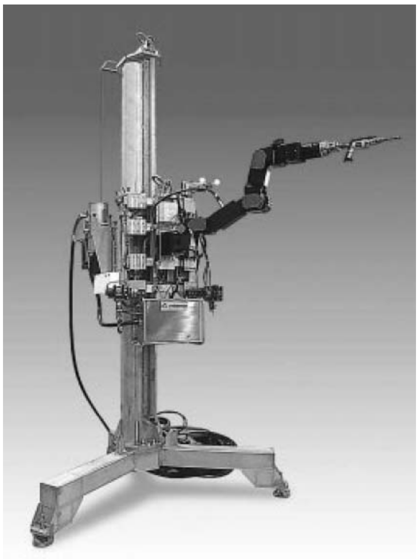
2.4.4 Vertical supports

These can be defined several ways:

- Circular gibbet: This combines a revolving motion with a horizontal translation movement, allowing coverage of a cylindrical volume.
- Longitudinal support: This associates two translation movements (1 longitudinal and 1 vertical) comparable to a bridge allowing parallel vertical coverage.
- Vertical mast: This uses one vertical movement. The other movements are carried out by the arm.

Figure 11: Vertical supports

Vertical mast (TOTEM by CYBERNETIX)



Circular gibbet

Longitudinal support

2.4.5 Immersed carrier

The carriers designed to work underwater have made considerable progress in terms of miniaturisation, pressure resistance, and leak tightness.

Figure 12: Immersed carriers

VISIT II from ECA/HYTEC

H1000 from HYTEC

3. Lessons learnt from dismantling projects

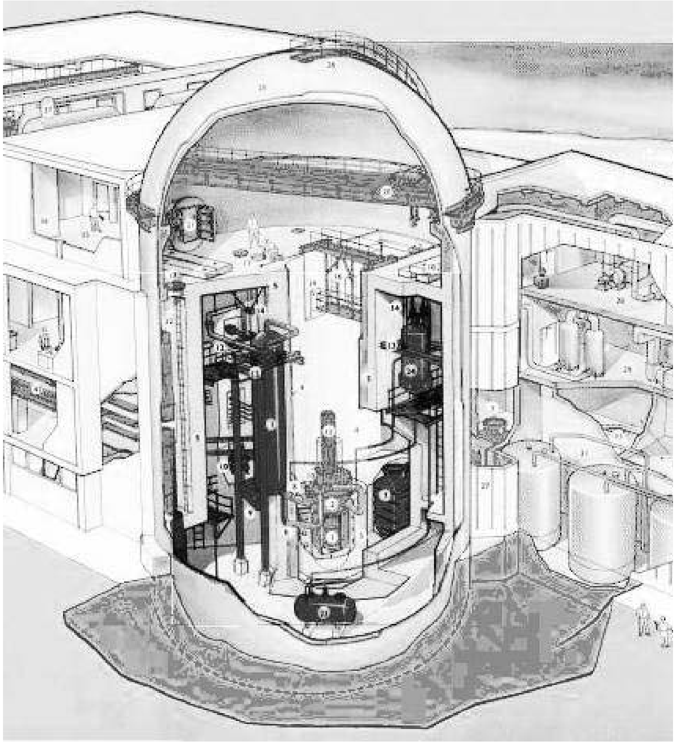
3.1 Belgian reactor 3 (BR3)

3.1.1 Facility description

The BR3 plant at Mol in Belgium was the first PWR (Pressurized Water Reactor) plant outside the USA (United States of America), and was built at the end of the fifties. It is from the same generation of reactors as those in Trino Vercellese (Italy) and Zorita (Spain). The reactor had a small net power output (10 MWe) but comprised all the loops and features of a commercial size PWR plant. In 1964, after 2 cycles, the original Westinghouse internals were exchanged (except for the thermal shield) with different internals for a project called "Vulcain". The Westinghouse internals were stored in a shielded chamber situated in a corner of the refuelling pool. Although the intention had been to reload the original internals when the Vulcain experiment was completed, this was never done, and the Vulcain internals remained in the reactor until the final shutdown.

The reactor was started in 1962 and shut down in 1987 after 25 years of continuous operation. In 1989, the plant was selected as a pilot decommissioning project by the European Commission within the 3rd Programme of Research and Technical Development.

Figure 13: Cut view of the BR3 reactor building



3.1.2 Progress and achievements

The main progress and achievements have been:

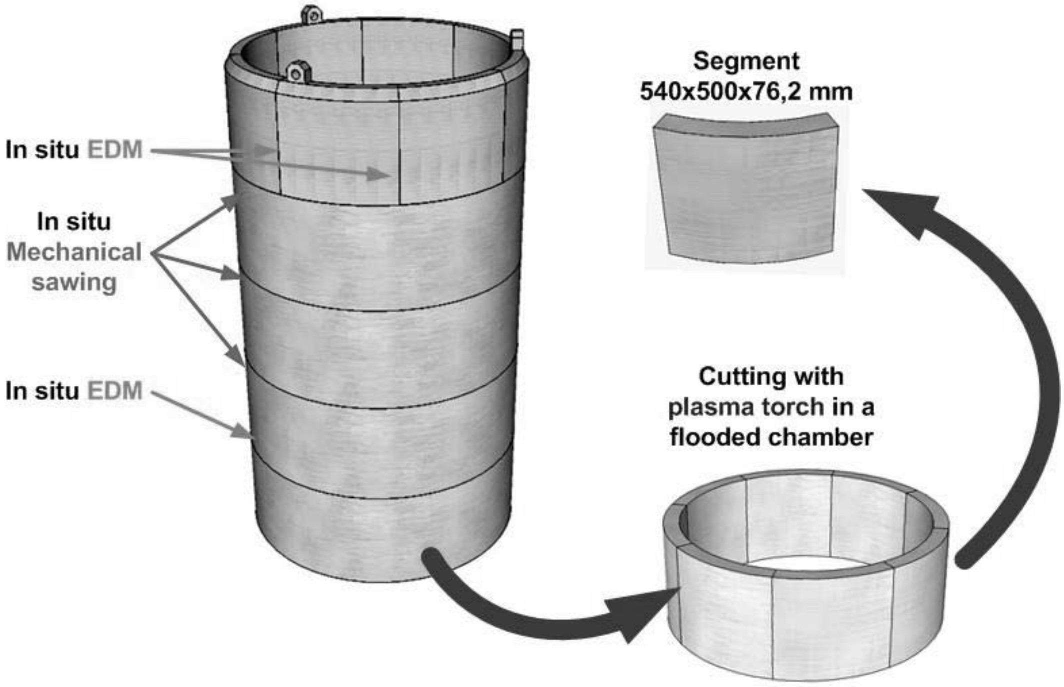
1987	Reactor shut down
1989	Selected as a pilot decommissioning project by the European Commission
1991	Full system decontamination of the primary loop
1993 – 1995	Cutting of the first high activity part: the thermal shield
	Remote dismantling of both sets of highly active reactor internals
1999	One-piece removal of the Reactor Pressure Vessel (RPV)
	The MEDOC® decontamination facility brought into service
	MEDOC® (Metal Decontamination by Oxidation with Cerium)
2000	Cutting up of RPV shell and packaging in 400 litre waste drums
2000–2001	*In situ* decontamination of the steam generator
2002	Dismantling of contaminated loops and equipment
	Dismantling the secondary non-contaminated circuits and components
	Dismantling of main primary coolant loop
	In situ decontamination of the pressurizer
	Transfer of fuel assemblies to the dry storage facility in Castor BR3® containers
	Dismantling and decontamination of concrete in the basement
2004	Dismantling and cutting of the large components, the remaining RPV head and bottom, the pressurizer and the steam generator with remotely controlled HPWJC (High Pressure Water Jet Cutting)
2006	Replacement of the principal ventilation system followed by the dismantling of the old ventilation system, the stack included
2008	Dismantling of the Neutron Shield Tank (NST) using remotely controlled HPWJC
	Dismantling and decontamination of concrete in the Waste & Ventilation building
2011	Decontamination and dismantling of the reactor pool
2013	Dismantling and decontamination of concrete in the reactor and auxiliary buildings
2014	Dismantling and evacuation of activated concrete in the reactor building
2020	Final project completion

Decontamination of the primary loop proved to be very efficient, with dose rates in the vicinity of the loop reduced by an average factor of 10, enabling operators to work 10 times longer for the same dose uptake or commitment. The decontamination process also resulted in a change of waste category for some of the internal components i.e. ILW (Intermediate Level Waste) to LLW (Low Level Waste) and some HLW (High Level Waste) to ILW.

3.1.3 Dismantling operations

Three different cutting techniques were examined for dismantling the highly radioactive reactor internals: plasma arc torch cutting, electric discharge machining (EDM) and mechanical cutting using a milling cutter.

Figure 14: Different cutting techniques on the thermal shield



The results obtained led to the selection of underwater mechanical cutting as the preferred technique. The main advantages of mechanical cutting can be summarised as:

- well known technique, used in workshops and only requiring adaptation to work under water;
- secondary waste (chips or swarf) easily trapped;
- low amount of waste if the tool and the kerf are thin;
- no emission of smoke, gas or dissolved ions;
- overall operation duration comparable to other cutting processes.

Two main mechanical cutting techniques were selected: the circular saw and the band saw in association with a turntable. The goal was to cut the highly active internals into segments compatible with the final disposal waste package (400 l waste drum). All cutting operations were carried out underwater in the refuelling pool.

Both techniques were shown to be reliable, usable and efficient. The circular saw produced more volume of secondary waste (metal swarfs) due to a greater kerf width. The required volume of metal (swarfs) to be removed was three times higher than with the band saw. The average overall cutting speed was 1.25 times higher with the band saw. During the project both types of cutting tools were used in a complementary way, but where possible (depending on the height, the shape and the existing access on both sides of the piece), use of the band saw was maximised.

It was originally planned to collect the swarf during the cut by means of a suction frame surrounding the saw blade. Swarf was also collected in a funnel with a collecting basket placed under and inside the work piece. On completion of the horizontal cutting of the Vulcain internals, due to frequent blocking of the suction system, the swarf collection was stopped during the cut, but was pushed into the funnel by a water jet after each cut. The remaining swarf located on the turntable was then sucked off at the end of each cutting campaign using a straight suction hose. The total calculated weight of swarf generated for the whole cutting campaign was 133 kg, of which 104 kg were collected by the two methods described above. The remaining 29 kg were located at the bottom of the pool and in the reactor pressure vessel, and were removed by suction afterwards.

Figure 15 : Circular saw

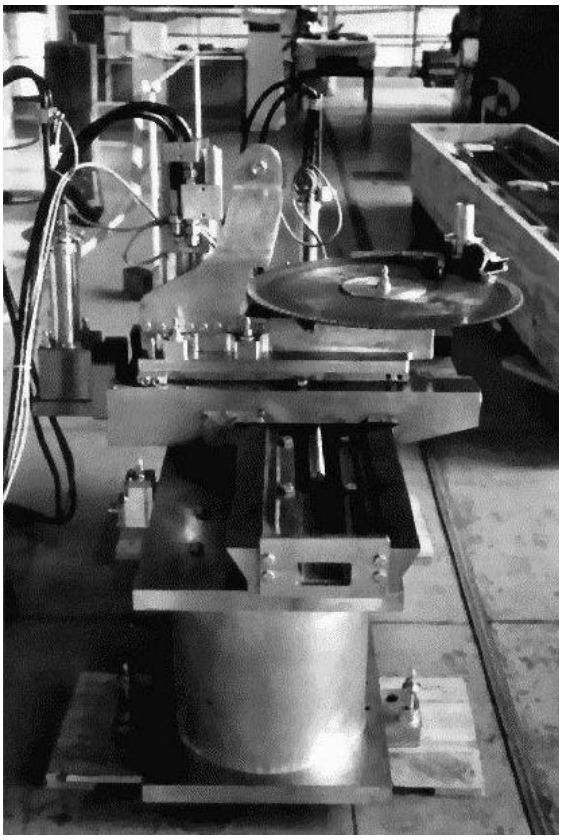
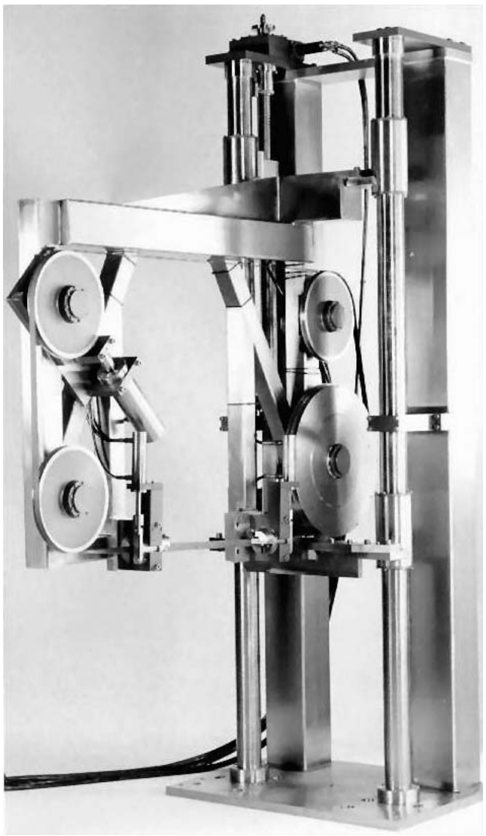


Figure 16 : Band saw



Although the dismantling of the reactor internals was mainly achieved using the cutting techniques described above, several auxiliary techniques were also used to carry out some specific tasks. These tasks included preparing the internals before cutting, and disconnecting, to complete a cut begun with a main technique or a back-up technique. These auxiliary techniques included: hydraulic shears, core drilling, unbolter, reciprocating saws and electro discharge machining (EDM). Although the use of EDM is not recommended as a cutting technique for dismantling thick reactor internals, its flexibility can be advantageous for some "surgical operations". However, any surgical EDM work needs a lot of development and tests to be carried out before implementation, as the positioning system of the EDM-head has to be very precise.

Figure 17: Hydraulic shears

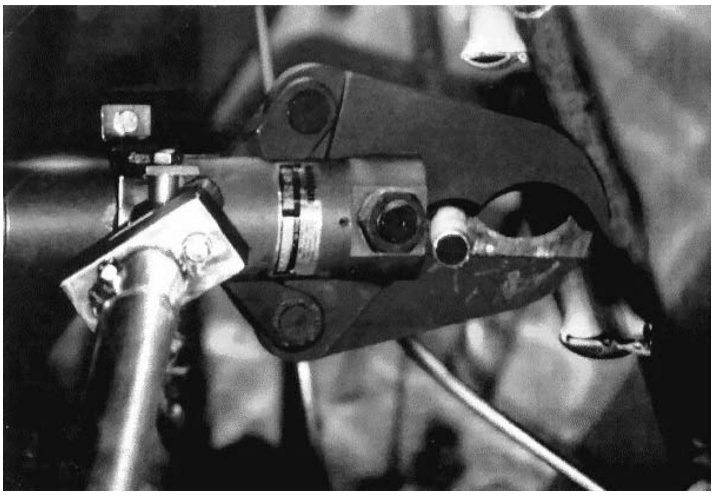


Figure 18: Core drilling

Figure 19: Electro Discharge Machining

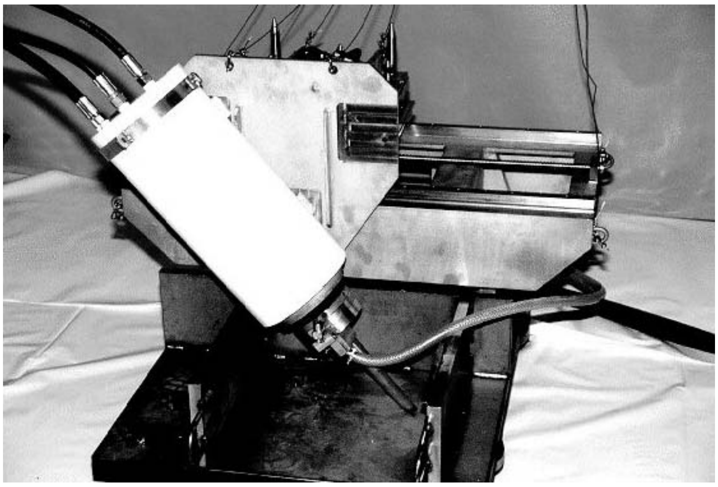
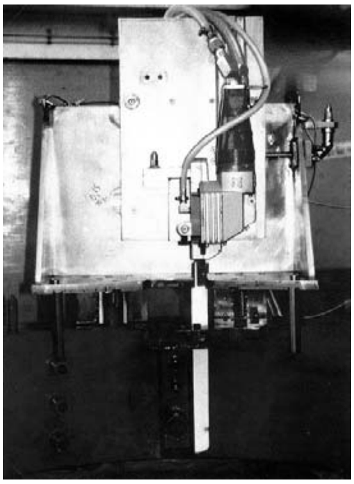


Figure 20: Reciprocating saw



3.1.4 Dismantling the Reactor Pressure Vessel

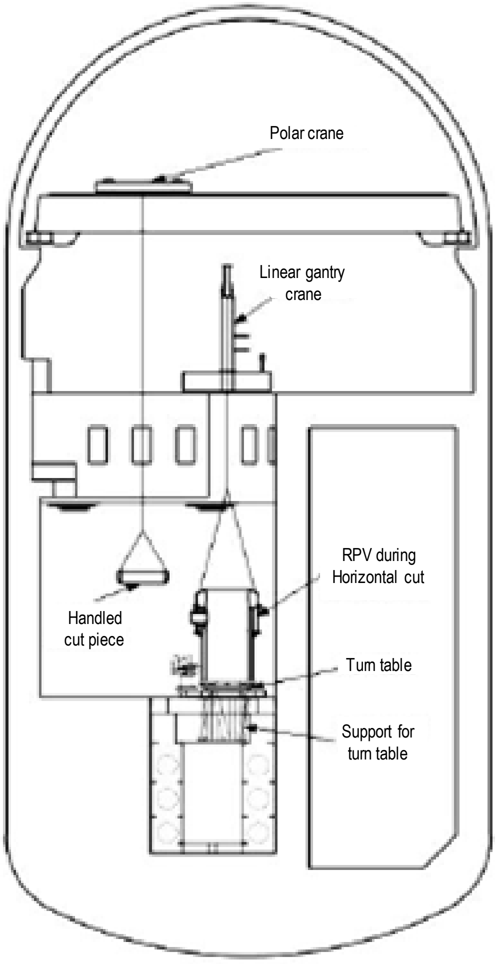
The next phase of the work was the dismantling of the Reactor Pressure Vessel (RPV). The RPV was a 28 tonne carbon steel forged piece clad with stainless steel.

The strategy selected for RPV dismantling was:

- Decoupling of the RPV from the primary loop
- Re-installing of the refuelling pool integrity
- Removal of the RPV in one piece from its cavity into the refuelling pool
- Cutting into rings and then segmentation of the RPV into pieces ready for packing

The figure below shows the refuelling pool and the strategy used for the RPV dismantling.

Figure 21 : Dismantling of RPV inside the reactor pool



The cut rings were handled using a set of three automatic clamping devices suspended from the polar crane. These tools were adapted from industry to be activated remotely. For the manipulation of segments, a specific tool was designed in order to move and place them in the storage racks.

In addition to collecting the metal swarfs produced with the cutting, there was also the need to remove and collect the thermal insulation (including particulates of glass fibre insulation which otherwise reduced visibility in the pool) that surrounded the RPV. Several techniques were employed to collect the problematic insulation, including the main pool filtration system, an additional external filtration system with resins, collection net, plunger pump and a commercial pool cleaning robot.

3.1.5 Water jet cutting as a dismantling tool

The decommissioning project for the BR3 pressurized water reactor was also important as a test bench for different dismantling tools and decontamination techniques. After the dismantling of the reactor pressure vessel and its internals, using different mechanical and thermal cutting tools, a new tool, water jet cutting, was used for the dismantling of some large contaminated components inside the reactor building.

The equipment was supplied by the consortium CYBERNETIX – AQUARESE.

3.1.5.1 The cutting tool comprises:

- a JET EDGE-55/75 high pressure pump
- a JET EDGE cutting tool, slightly modified in order to be compatible with the robot as a tool carrier
- an abrasive delivery system (SAM) from AQUARESE to feed the abrasives at a controllable flow rate to the cutting tool

Figure 22: Cutting tool

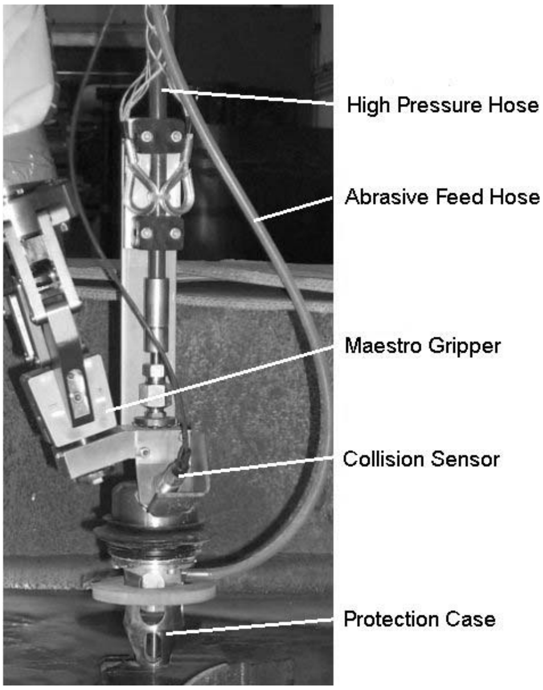
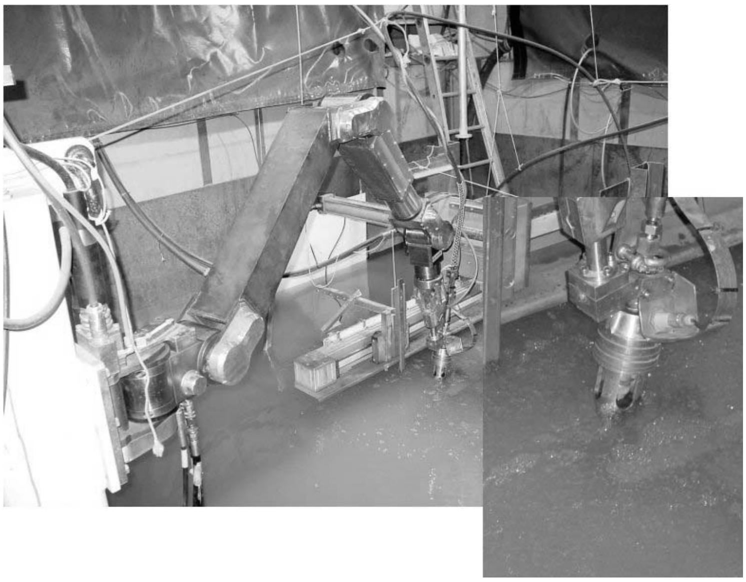


Figure 23: Equipment during cold tests



The standard cutting tool was modified and 3 points improved:

1. An interface plate in the form of a cross, in order to take the tool with the gripper.
2. A protection case was mounted around the focusing tube to avoid damage to the tube in case of a collision.
3. A collision sensor was added with a double function:
    - **Safety function**: in case of a collision with an unexpected part, the sensor signal alerts the system and stops the equipment immediately.
    - **Learning function**: a special function in the robotic operating system is capable of storing the actual position of the tool which is in contact with a component. With those 'learned' points, the program can reproduce the cutting trajectory afterwards.

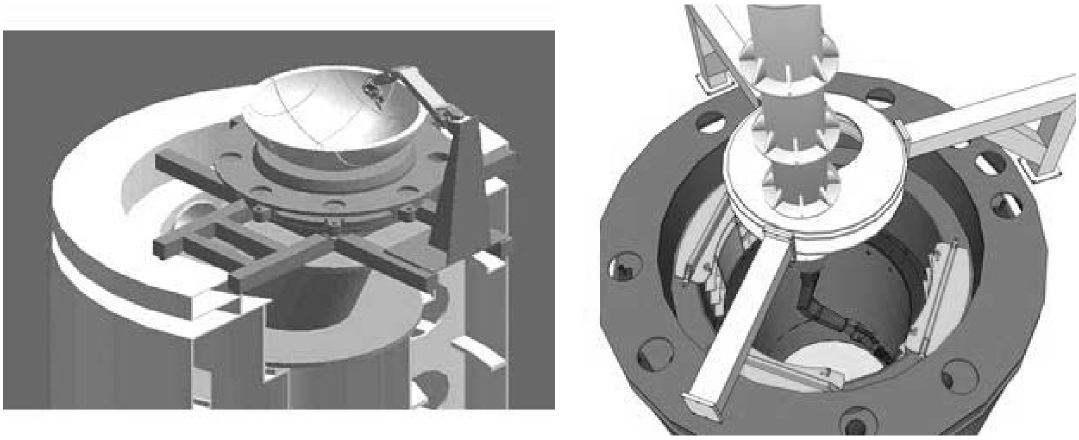
The following tool parameters were used:

Retained orifice diameter which corresponds to a water flow rate of 4.5 L/min at nominal pressure of 3792 bar	0.41 mm
Focusing tube diameter	1.2 mm
Cutting pressure measured at the tool	3600 bar
Nominal abrasive flow rate	450 gr/min
Particle size of abrasive (Australian Garnet)	50 Mesh

3.1.5.2 The deployment system

The manipulator used was a MAESTRO arm (CYBERNETIX) with 2 different supports. The arm could be used in 2 different configurations depending on the components to be dismantled.

Figure 24: Maestro on turntable configuration (left) & NST configuration (right)



The arm is made of titanium with six stainless steel articulations and equipped with a gripper. Joints 'a1', 'a2', 'a3' and 'a5' are hinge type and joints 'a4' and 'a6' allow an axial rotation. Joints 'a1' up to 'a4' were modified with multispeed resolvers.

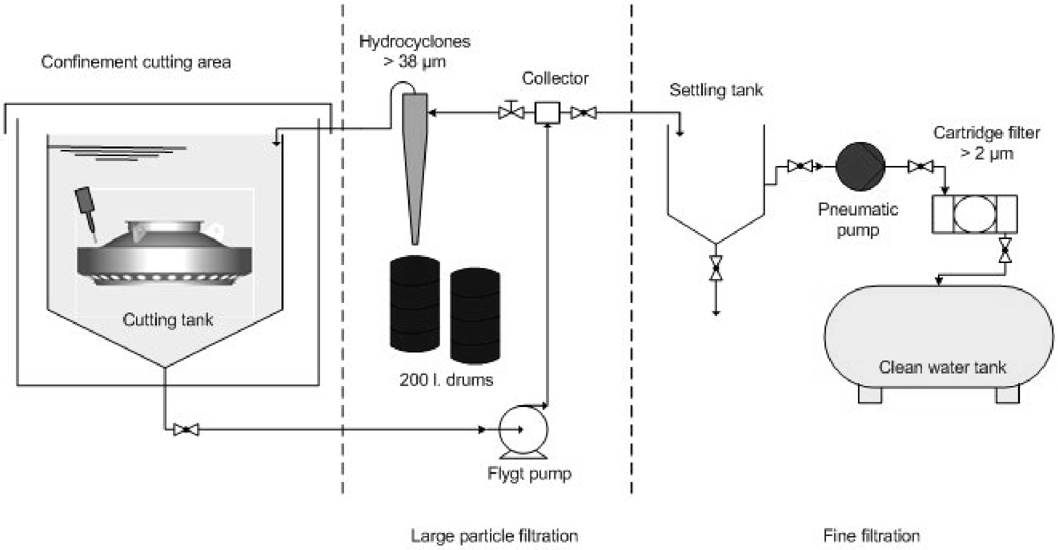
The manipulator’s design accepts working in a hostile environment (under irradiation and submerged). Most of the control hardware, like electronic boards, is mounted in a separate control cabinet that is installed outside the high radiation field. Other, less sensitive, parts and connectors are placed in hollow spaces inside the arm, kept under a slight air overpressure to avoid any entrance of water. The robot is completely watertight. Due to its polished surface, it can easily be decontaminated.

The manipulator is controlled by means of a keyboard and mouse or joysticks.

Concerning the MAESTRO arm, it was initially foreseen to use water glycol (UNIL Firex 46) as hydraulic fluid. It was a must when the equipment was ordered (presence of fuel and the use of ion exchangers to clean the fuel pool). Later on, the fluid was changed to normal hydraulic oil.

In order to "clean" the water after cutting operations, a 3 stage filtration system was built consisting of the following parts: settling tanks, hydrocyclones, electric and pneumatic pumps and cartridge filters.

Figure 25: Simplified view of the filtration system



3.1.5.3 *Equipment acceptance tests*

The acceptance tests consisted of a verification of the actual performances. The proposed geometries for the cutting tests were pieces or small mock ups like blocks with different thicknesses, a section of a primary tube, a section of the mounting ring. The tests were not a great success. Therefore they were restricted to cutting simple geometries: steel bars of 25, 60, 125 and 160 mm thickness. The cutting tests on these pieces allowed establishment of a cutting performance table in function of the thickness.

Afterwards cutting tests on more representative pieces were performed:

- Drilling test in plain steel
- Cutting a 160 mm steel block under water to prepare for the RPV head
- Cutting a mock up of the NST mounting ring
- Cutting a section of the primary tube.

3.1.5.4 *Problems during the acceptance tests*

The first cutting tests in Marseille were not very successful. The arm didn't respect the learned trajectories during cutting. Therefore the tool was removed and replaced by a pencil to look at the problem more closely.

With the pencil, the arm had to follow a predefined trajectory (a rectangle) on paper. Serious deviations were observed that sometimes occurred very suddenly, between the theoretical and the reproduced trajectory (about 10 mm). One of the main causes of this problem was the unstable support of electrical cables and resolvers in the articulations.

Other phenomenon observed were vibrations in a perpendicular plane to the cutting direction. The vibrations affected the efficiency of the jet resulting in a larger cut and reduced cutting speeds. Many interventions for adjustments to the different robot parameters were needed in order to optimize the robot's use of the water jet cutting technique.

After transferring the equipment to Mol, the acceptance tests continued with the support of a CYBERNeTIX team, who carried out the 'fine tuning' of the control parameters.

Another problem discovered was variations in speed during the cutting process. Water jet cutting requires a smooth movement and unexpected accelerations and decelerations could be too brutal for this cutting technique, meaning uncut areas and a reduction of the average cutting speed as a consequence. To fix this problem, a software modification was needed.

During a major overhaul of the robot another electrical problem appeared. During the immersion tests, done with COMEX, it seems that some (salty) water entered one of the main electrical connectors on the arm. Many pins inside the connector were corroded and were the cause of occasional short circuits.

At the same time CYBERNeTIX took the opportunity to make some other modifications:

- Replacement of the water glycol by normal mineral hydraulic fluid, as it wasn't a necessary requirement anymore (fuel was evacuated from BR3 to the dry storage facility).
- The mode of controlling the servo valves was modified in order to improve the behavior at slow speeds.
- Replacement the single speed resolvers on axes 'a4' and 'a5' by multi speed resolvers in order to improve the stability of the arm.

All these modifications led to the equipment still in use today with acceptable results.

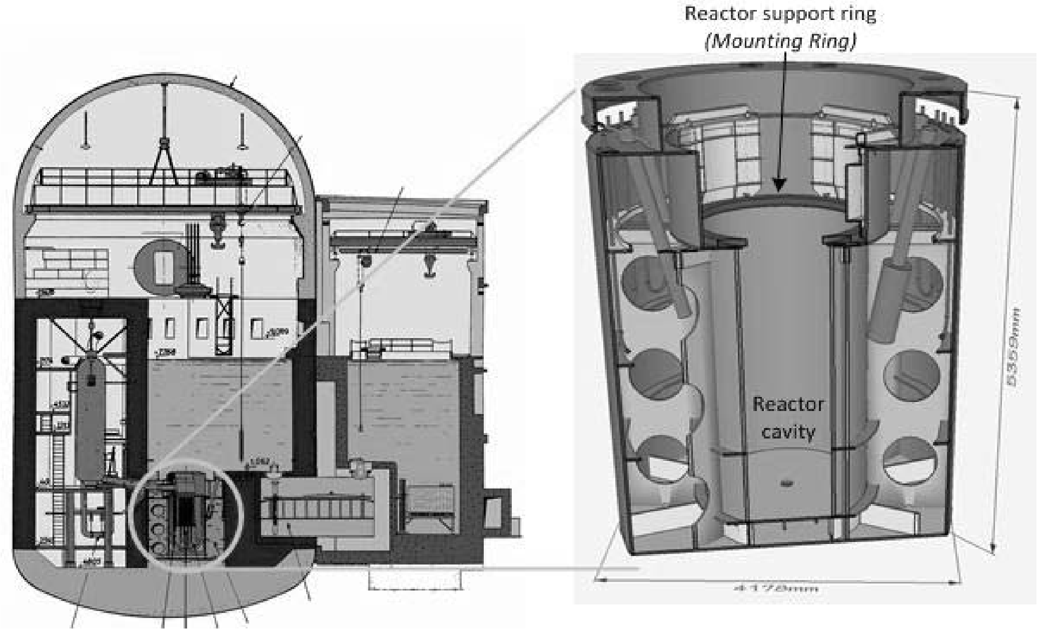
3.1.6 Dismantling large components inside the reactor building

During the preliminary study for the dismantling of the Reactor Pressure Vessel (RPV), some research was also carried out for the dismantling of the so-called Neutron Shield Tank around the RPV.

Very quickly, it was clear that cutting this piece could not be carried out using the existing mechanical cutting techniques employed for the RPV and all of the internals. The choice was made of an abrasive water jet cutting system. Although abrasives produce a lot of secondary waste, the total cost for such secondary waste is less than 20% of the waste cost in comparison with plasma cutting (evaluation 1997).

Due to the high activity of this piece, it was obvious that this work had to be performed under water for radiological reasons and that the cutting tool should be remotely controlled. Therefore a robot or manipulator was indispensable.

Figure 26: Location and section view of the NST



In order to best use the investment and not only to cut about 200 m of the NST, the project was widened to include other large components in the reactor building. The equipment is also used to dismantle the remaining parts of the reactor pressure vessel (head and bottom), the steam generator (vertical U-bend steam generator) and the pressurizer.

The actual cutting of the large components is done inside the reactor building. The reactor pool is used as a cutting workshop. The different components are transferred into the pool, except for the NST which is a part of the pool bottom.

3.1.6.1 RPV head and bottom

The cutting equipment was installed on the operating deck, which is the floor around the reactor pool. The cutting tool was mounted on a fixed support and was fed via the turntable. The maximum thicknesses were 170 mm for the head and 64 mm for the bottom. Cutting of these components was performed in two steps. In the first step, two circumferential cuts were made in each component. For the second step, the equipment was installed on the floor of the pool. The cut was done inside the VST with the aid of the arm. One ring from the hemispherical bottom was segmented. The average cutting speed was about 20 mm/min.

Because 400-l drums are the standard waste packaging in Belgium, all the rings were cut into the right dimensions to fit these drums. This was done using the RRA (Rolls Royce) band saw.

After thorough decontamination using the MEDOC® process, the pressurizer and the steam generator were segmented using high pressure water jet with abrasive, the tool being carried and moved by the MAESTRO arm.

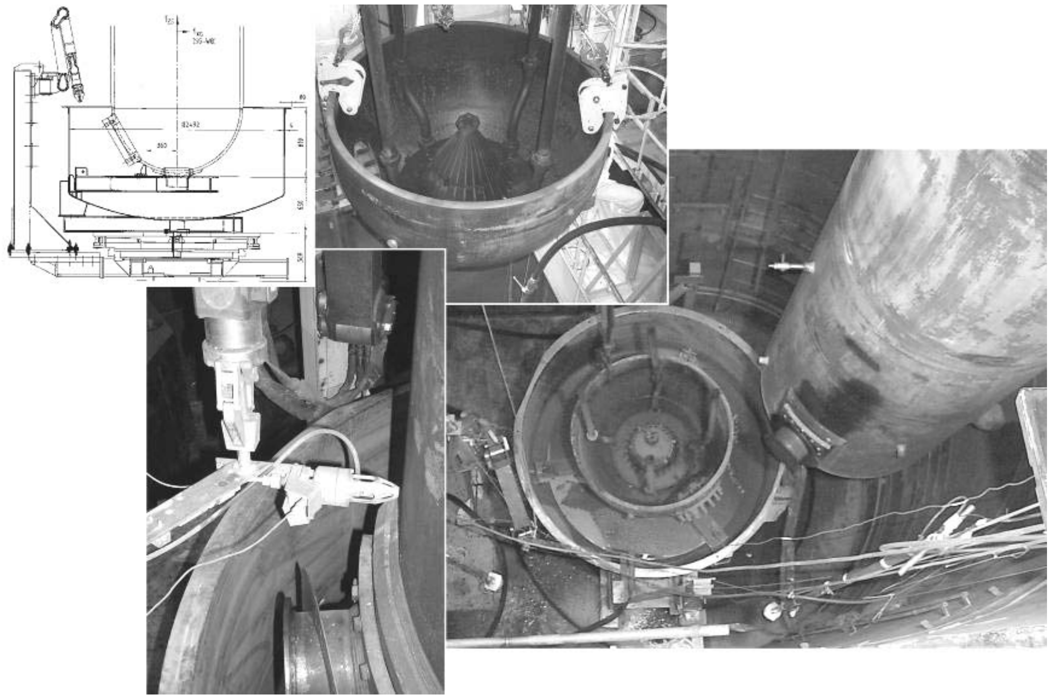
3.1.6.2 Pressurizer

The thickness of the pressurizer wall was 92 mm. It was cut into 7 rings. The cutting feed (about 16 mm/min) was via the turntable and the arm served as a static tool support. A circumferential trajectory in the bottom part of the pressurizer was programmed to remove the surge line nozzle. The speed on this 157 mm thick part was 5 mm/min.

3.1.6.3 Steam generator

The steam generator (a vertical U-bend heat exchanger), was placed upside down in the reactor pool. The outside shell was cut with the HPWJC tool in a static position. The feed (65 mm/min) was via the turntable. A small rotation of the tool was needed to penetrate the cylindrical wall to start the cut.

Figure 27: Dismantling of the steam generator



The segmentation of the U–bend part of the tube bundle was also done with the HPWJC cutting tool in a fixed position. In a single pass about 6 or 7 tube rows were cut simultaneously. A total of 6 complete rotations were therefore necessary to separate the tube bundle. This operation was extremely time–consuming. Therefore, in order to minimize time, the other tube bundle cuts were performed using a diamond wire.

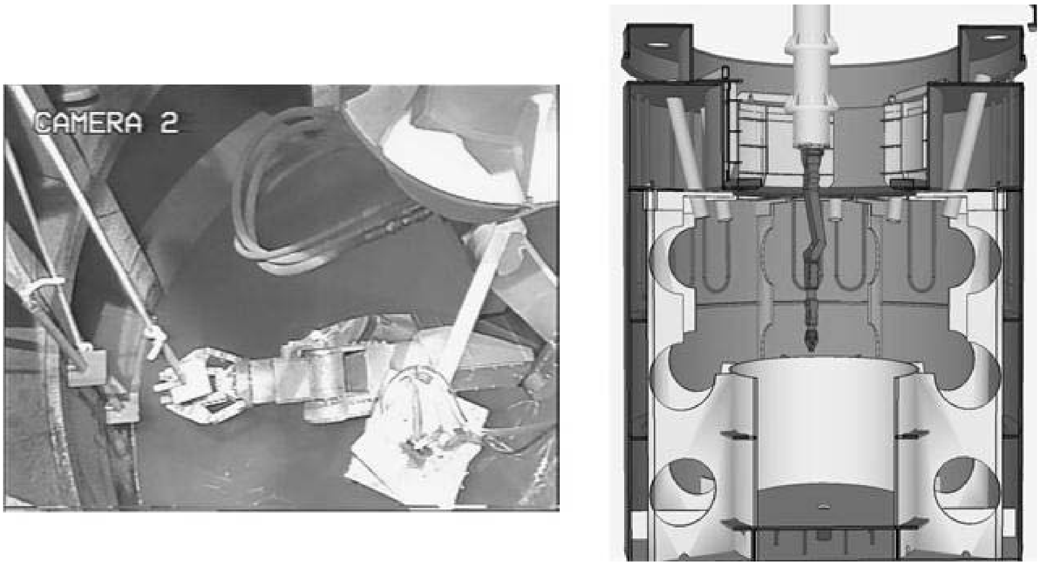
3.1.6.4 Neutron Shield Tank (NST)

The NST was a double-sided, welded, cylindrical structure anchored in the concrete and welded to the bottom lining of the reactor pool. It was largely made of 20 mm thick carbon steel, filled with water and included reinforcing ridges, cooling coils and instrumentation tubes.

This highly activated component had a double function: supporting the weight of the reactor pressure vessel and avoiding activation and dehydratation of the surrounding concrete due to neutron leakage from the reactor core.

The dismantling of this complex component required the full potential of the robotic arm. The arm was mounted at the bottom of a long mast supported by a tripod. The cut planes were in the three directions. All the coordinates determining the points of a trajectory were calculated and checked by a simulation to verify that there would be no collision between the tool and the piece or between the arm and the environment.

Figure 28: Real view inside the NST during dismantling (left); Drawing with all the MAVA parts removed except the mounting ring (right)



3.1.7 Lessons learned

The main experience gained on the BR3 project has shown:

- The benefit of full system decontamination in reducing operator doses, and lowering some waste categorisation. This operation should be carried out as soon as possible after shutdown if existing plant equipment such as the primary pumps, heat exchangers, valves, instrumentation, etc. is to be used during decommissioning. This is not only important for aging, maintenance and repair considerations, but also if the existing knowledge of operators in running that equipment is to be utilised.
- The importance of using full-scale mock-ups to trial the remote dismantling of highly radioactive components. The main advantages are:
  - avoidance of having to solve equipment "teething problems" in the controlled zone and on contaminated pieces;
  - optimisation of the cutting parameters to produce as little waste as possible and to work as fast as possible for a specific cutting tool and task;
  - testing of the various parts of the dismantling procedure, including the handling of cut components, dismantling equipment and maintenance and tool exchange;
  - operator training on the actual dismantling equipment in an environment similar to the real one, thus leading to shorter operational time and improved understanding of the functioning of the dismantling machines. This also improves the operators' radiation protection.
- The benefit of using proven industrial cutting techniques for the dismantling of highly radioactive components. This avoids the R&D (Research & Development) or "teething problems" of new technologies and enables better estimation of the amount of waste generated and the actual time to set up and to operate the equipment.

- The use of robotics was more demanding than expected:
    - the combination of the process with the deployment system proved to be very complicated. The very low speed and the high stability and rigidity required from the cutting process were very difficult to attain with a hydraulically driven telerobotic arm.
    - much attention should be given to the “man-machine” interface. BR3 never tested a master arm in combination with a "virtual" model. Probably this could facilitate some interventions
    - working with only indirect viewing by cameras is indispensable (hostile environment) but difficult if the working area is rather limited. The cameras used should be small, have a good resolution and be flexible. The biggest problems encountered were bad positioning, bad light and shadows from the environment.
- That research and development of new techniques, processes and procedures should be made in research centres and trialled in realistic environments to minimise problems when carrying out the actual dismantling on site.
- The benefit of using under water cutting for the remote dismantling of highly radioactive components. The use of water as radiation shielding is a very effective way of working. The water provides several advantages which are important for the dismantling operation:
    - a good shielding capacity: e.g. for typical components from LWR (Light-Water Reactor) reactors, about 2 metres of water depth are enough for shielding;
    - full visibility for the operators: as a lot of operations are one-off operations, and as one cannot avoid some surprises in dismantling, direct viewing (i.e. not through a television system) is a definitive advantage;
    - a trapping medium for aerosols and dust produced by various cutting processes. It can also decrease the (toxic and dangerous) gas production from thermal cutting processes
    - with adequate filtering and purification, it can even limit the production of effluents and waste from the operations.
- The underwater operations carried out on different work pieces (and for instance on the two sets of internals, having undergone different decay storage periods) have shown that the different specific activity of the components had no significant influence on the dose uptake of the operator. This can play an important role in the selection of a decommissioning strategy.
- The importance of setting up the waste routes for contaminated materials. The volume of materials to be sorted, handled and consigned is a huge undertaking in decommissioning logistics. The dismantling of a power plant or nuclear facility produces a very large amount of material (waste, contaminated materials, effluent) which has to be managed efficiently to avoid any bottlenecks in the process.
- The benefit of good planning for the installation of handling equipment (e.g. decontamination area, size reduction workshop, sorting area, measurement and characterization areas, truck loading area, etc), so that future dismantling work does not interfere with existing material transfer routes.

- That concrete dismantling or decontamination is a very dirty job which if not managed properly (containment, ventilation, and filtration), can spread radioactive contamination. Precautions against contamination spread (whether a wet or dry system is used) are an important factor in concrete dismantling and decontamination.
- Using an easy-to-use ALARA (As Low As Reasonably Achievable) planning tool for optimizing the radiation protection in complex operations. Classical software or calculation tools are often too laborious to use for one-off operations or for comparing different possible scenarios. The application of user friendly 3D (Three Dimensional) ALARA planning tools, which are currently emerging on the market, is proving to be of great benefit. For the preparation of some circuit dismantling, BR3 used the in-house developed VISIPLAN® 3D ALARA tool.

3.1.8 Bibliography

European website on Decommissioning of Nuclear Installations – Decontamination processes and waste management at BR3.

European website on Decommissioning of Nuclear Installations – The BR3 dismantling operations and related techniques.

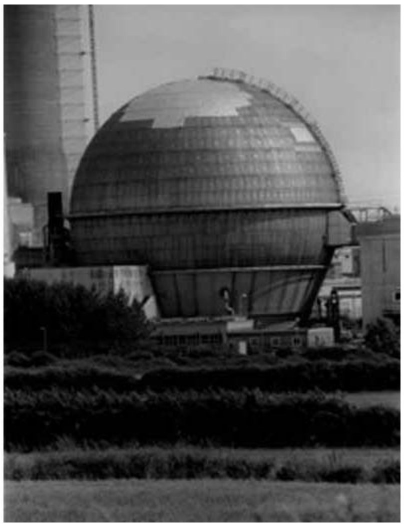
Innovative Remote Dismantling Techniques – Final Technical Report – February 2005.

3.2 Windscale advanced has-cooled reactor (WAGR)

3.2.1 Description

The Windscale Advanced Gas-cooled Reactor (WAGR), situated at Windscale in England, was constructed between 1957 and 1961 to provide design and operational experience for the UK's (United Kingdom) first generation gas cooled reactors. WAGR was a carbon dioxide cooled, graphite moderated reactor using uranium dioxide fuel in stainless steel cans. It operated for eighteen years at an electrical output of 33 MW(e). The reactor was shut down in 1981 after achieving all of its intended research and development objectives.

Figure 29: WAGR

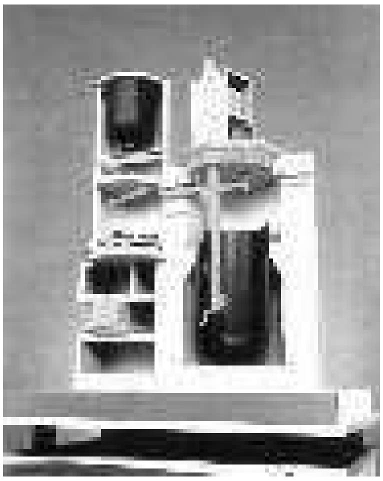


Given the anticipated variation in doses, the decommissioning plan encompassed a combination of remote, semi-remote and manual operations. The principle stages foreseen to undertake the remote work included:

- a remotely operated remote dismantling machine (RDM) to deploy tools to dismantle the high dose components
- a waste route through which to move the components, sort them, assay and grout
- an interim storage facility for the grouted containers (boxes).

The RDM consisted of two handling systems deployed beneath a turntable mounted at the reactor operating floor level. The first system was an extendable mast from which a remotely controlled manipulator was suspended. The second system consisted of a series of suspended crane rails that enabled a 3 tonne hoist to travel across the reactor vault into the adjacent cells. A two storey building mounted above the turntable provided access for tool changing and maintenance.

Figure 30: RDM



The waste route was constructed through two of the heat exchanger bioshields, to take advantage of their shielding. To achieve this, the heat exchangers were raised by 12 metres to make space available. Diamond drilling techniques were used to create the openings into the reactor vault which provided access for the 3 tonne hoist system integrated with the RDM. The dismantled components were moved laterally from the reactor to the sentencing cell where they were placed in box elements (racks or baskets). The waste was assayed and loaded into waste containers (WAGR boxes) for encapsulation in cementitious grout. LLW boxes were transported to the LLW repository for disposal while ILW boxes were stored in the nearby WAGR ILW box store awaiting transfer to a national repository.

3.3.2 Progress and achievements

The key WAGR project dates are:

1962	Reactor first produced power.
1981	Reactor shut down.
1983	Fuel discharged.
1989	Construction of waste packaging plant.

1990 – 1992	Top biological shield and pressure vessel top removed and replaced with a removable shield.
1993	Remote dismantling machine (RDM) installed above core.
1993	Construction of ILW store.
1994	Lifting out of four heat exchangers and disposal in LLW facility.
1999 – 2006	Dismantling and removal of core components (campaigns 1-10).
2007	Reactor removal complete.

The reactor core components are currently being decommissioned in a series of 10 campaigns as shown below.

Dismantling methodologies and tools were developed specifically for each campaign. Full size mock-ups were used to test the tools, train the operators and assess the duration of operations. In some cases, despite successful trials, the tools did not perform as expected during operation. In these situations, simple tooling and manual intervention was required.

To date, campaigns one through seven have been successfully completed using a mix of remote and hands-on operations. Campaign 8 has commenced and the diagrid has been removed. At the time of writing, removal of the ring girder is 30% complete. All resultant wastes have been appropriately packaged for disposal (LLW) or storage (ILW).

Campaign 1: Preliminary operations – controlled manual activity to prepare the top of the 'hot box' for remote operations

Campaign 2: Removal of operational waste from the fuel channels.

Campaign 3: Dismantling of the 'hot box'.

Campaign 4: Removal of the loop tubes

Campaign 5: Dismantling of the neutron shield

Campaign 6: Removal of the graphite core and steel restraint structure

Campaign 7: Dismantling of the thermal shield

Campaign 8: Size reduction and removal of the lower structures (diagrid and ring girder)

Campaign 9: Size reduction and removal of the pressure vessel and insulation including the tundish

Campaign 10: Size reduction and removal of the outer ventilation membrane and experimental thermal columns and final clean out of the reactor bioshield.

After preliminary operations to prepare the top of the reactor, campaign two comprised the removal of operational waste from the fuel channels. These wastes were reactor components, e.g. control rods and neutron shield plugs, which had been cut up and stored in the fuel channels at the end of the reactor's operational life.

Campaign three comprised the removal of the hot box – a massive and complex structure used to receive and channel the gas coolant into four heat exchangers. Size reduction of the hot box was carried out using industrial plasma arc cutting torches deployed both by remote rig and manually. Great difficulty was experienced when cutting the upper refuelling tubes that were attached to the top of the hot box using a remote rig, due to the difficulty in maintaining a constant torch offset and cutting at the correct point. This resulted in many failed cuts and damaged torches, with only

60 cuts being achieved in two months and an accrued worker dose of 8 man-mSv. After due safety assessment, manned access was adopted to undo the tube refuelling bolts with power wrenches. The remaining 129 tubes were removed in four days with an accrued worker dose of 9 man-mSv.

Further difficulties in campaign three also arose from an unexpectedly high dose emitted by the hot box insulation material (Refrasil). This meant that the planned dismantling sequence needed to be changed to first remove this material by remotely cutting the insulation into sections using a rig mounted plasma torch. Once this radiation source was removed, hand held plasma cutting could then be used to cut up the hot box side-walls.

Figure 31: Plasma arc cutter while cutting a standpipe

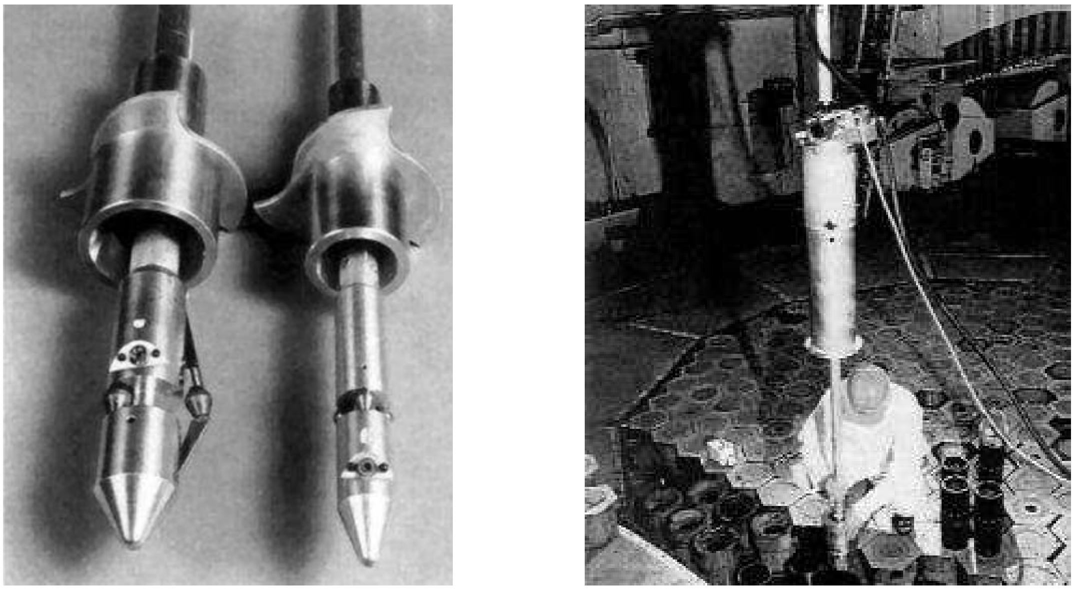


Figure 32: Dismantling of the Top Biological Shield

Campaign four comprised the removal of six loop tubes that had been used to carry out fuel experiments. The loop tubes were some of the most radioactive components in the plant, having been exposed to prolonged irradiation in the centre of the core, which meant all operations had to be carried out fully remotely. The methodology adopted was to cut the tubes into 1.1 metre lengths using a hydraulic shear. To minimise the risk of the tube becoming trapped in the shear blades and to make the cutting process more efficient, the tubes were first filled with grout. Cold shearing was selected because it produces far less dust or vapour than would have resulted if sawing, grinding or hot cutting techniques had been used. The campaign was very successful, taking only 3.5 months to complete.

Campaign five comprised the cutting and removal of the neutron shield. Maximum use of manual intervention was made where possible, resulting in faster dismantling whilst still maintaining operator dose well within the budget dose. Again difficulties were encountered with the deployment of some remote tooling. The slow cutting speed of an internal pipe milling machine, identified for cutting upper fuel channel sections, was found to have a tendency to rotate the tubes – something that had not been anticipated during tooling development. However, a modified angle grinder was found to be a suitable alternative that could be used for both manual and remote deployment by hoist, and provided a much cheaper solution. In summary, 90 tonnes of graphite and steel associated with the neutron shield were removed and packaged as waste. Despite the difficulties encountered, the campaign was completed 6 months ahead of schedule. The total dose uptake was 17 man-mSv compared to a budget of 43 man-mSv.

Campaign six, to remove the 210 tonnes of graphite from the core and associated restraint structure, used many of the tools deployed in campaign five. The most significant difference between the campaigns was the cutting of the tensioned steel restraint bands, which locked the layers of graphite blocks together. This was accomplished using a standard industrial quality reciprocating saw mounted in a remotely deployed frame. A full size mock-up of a quarter section of the core was constructed to test all the equipment. During testing it was found that components of the restraint band were prone to trapping and breaking the saw blade. To overcome this, remotely deployed clamps were designed to hold the components in place until the saw cut was completed.

Campaign seven comprised the removal of the steel thermal shield that surrounded the graphite core and protected the pressure vessel from the heat of the nuclear reaction. The thermal shield was in the form of an open vertical cylinder 6 m diameter and 8 m high constructed of 14 courses of 12 interlocking steel bricks, held together by loose fitting fishplates. Each brick was formed from three 50mm thick steel plates bolted together to interlock with adjacent bricks on all sides. Most bricks retained their original lifting attachments and the preferred removal option was to re-use these pintels to remove each brick in turn using the 3 te. transfer hoist. Because there was uncertainty in respect of both the force required to free each brick and in the residual strength of the pintels, a number of tools were designed, manufactured and tested that could deal with the most likely risks. These were: a simple lifting device designed to use the pintels; a lifting device with three powered actuated plate clamps to use if the pintels were unsuitable; a jacking frame for both tools to increase the force from 3 te to 10 te. Other measures (a device to unbolt the plates forming the brick; a system for cutting the inner plate and releasing the brick) were designed but abandoned as the task became better understood. In practice only the first level of tools was necessary, and removal was completed without difficulty. In 3.5 months, 179 tonnes of waste were removed and encapsulated in 20 WAGR boxes. The maximum individual radiation dose was 0.11 mSv.

Campaign 8, the removal of the lower structures comprising the core support plates and associated steelwork, the diagrid, ring girder and tundish, was reprogrammed to better reflect on the operations to be carried out. This re-organisation produced a new campaign 7a for the core support plates and associated steelwork as this was broadly similar to campaign 7. Again the work was completed without difficulty, taking 1.5 months to remove and encapsulate 32 tonnes of steel in 7 WAGR boxes. The maximum individual radiation dose was 0.23 mSv.

The diagrid and the ring girder remain as Campaign 8 whilst the tundish will now be taken out as part of the work to remove the pressure vessel.

The diagrid has now been removed, however further work is progressing slowly as measures are investigated to reduce the impact of the iron enhanced oxyacetylene cutting method selected to cut the ring girder and later the reactor pressure vessel, on the HEPA (High Efficiency Particulate Air Filter) filtration system. Premature blinding of the HEPA filters has been observed, which may be due to iron fumes from the cutting tool, or may be a result of previous cutting fines being swept up into the system.

3.2.3 Lessons learned

The main experiences gained on the WAGR project to date have shown:

- The importance of good working relationship with all project stakeholders, including contractors, safety working party, the regulator.
- That where possible, direct manual intervention is generally quicker and often incurs a lower worker dose than the setting up and operation of remote tooling.
- That remote tooling should be as simple as possible and tested thoroughly in realistic full size mock-ups.
- The importance of developing contingency solutions and tooling to avoid potential delays (high costs) while alternative solutions are sought on-line.
- The need to adequately consider the impact of equipment on environmental system.
- The need for good housekeeping - clear away debris as it is produced.
- The importance of considering the cutting pattern to maximise waste disposal and waste material porosity and/or reactivity with the encapsulation grout.
- That non radioactive hazards (e.g. asbestos) and radioactive hazards should be considered of equal importance.

3.2.4 Bibliography

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3.3 Greifswald Nuclear Power Plant (KGR)

3.3.1 Description

On the Greifswald site there are in total eight reactor units of the Russian pressurized water reactor type WWER-440 (Wasser-Wasser-Energie-Reaktor).

Units 1 to 4 are model V 230 while Units 5 to 8 are the more recent model V 213.

After the reunification of the German States, the 4 operating units of the Greifswald Nuclear Power Plant were shut down and the trial operation of Unit 5 and all construction work for the Units 6 – 8 were also halted. In 1990 the decision was taken to decommission Units 1 - 4, followed by the same decision for Unit 5 in 1991.

The reactors are configured on a double-unit basis, i.e. two reactors are arranged in one reactor hall with certain mechanical equipment and secondary systems together. On the other hand, there is only one turbine hall (roughly 1 200 m long) for all reactors.

There are also three plants for treatment and storage of liquid radioactive waste. The solid waste is stored in concrete pits. Furthermore, there is a wet storage for fuel elements on site and a large hot workshop.

On the smaller site in Rheinsberg, EWN (Energiewerke Nord) is also decommissioning and dismantling a Russian prototype pressure water reactor "WWER-2".

Figure 33: Greifswald Nuclear Power Plant

3.3.2 Progress and achievements

The key KGR project dates are:

1989 – 1990	Units 1–5 shut down and construction of Units 6-8 halted.
1995 – 2009	Dismantling of equipment, Units 1-5.
1980	Decommissioning planning.
1998	Start of Interim Storage North (ISN) operation.
1999 – 2002	Demonstration remote dismantling of Unit 5.
2004 – 2007	Dismantling of reactor and internals, Units 1-4.

The basic principles adopted can be summarised as follows:

- Progression from lower contamination/radiation to higher and finally activated plant parts.
- Commencement of dismantling in Unit 5 and the turbine hall, followed by Units 1 – 4, in order to use the experience from work in a low dose rate/contamination unit.
- Use of "off-the-shelf" equipment as much as possible.
- Removal of as large as possible components or parts for decay storage and/or further treatment in the ISN.
- Dismantling on a room basis, i. e. not on a system basis.

In preparation for the dismantling, measures were taken to reduce the dose rate. First of all parts of the primary loops were decontaminated electrolytically and then hot spots were removed either by high-pressure water jet or mechanically. Before dismantling activities starts, insulation material containing asbestos is removed under careful control.

The strategy for dealing with reactor pressure vessels (RPVs) and internals of Units 1 - 4 was remote dismantling and/or storage as a complete component in the ISN.

Dismantling activities were carried out in the steam generator room, which is situated around the RPV. Here cutting (dry and wet), packaging and transfer areas were installed. The complete system was designed to be mobile and was first installed in Unit 5 for inactive testing before installation and commissioning in Unit 2. Inactive testing started mid 1999 and was completed by the end of 2002. The selected techniques to be applied are summarised below.

Cutting techniques for remote dismantling

Cutting area	Components	Techniques
dry	reactor pressure vessel	band saw
	upper part of protection tube unit	disc cutter
	upper part of reactor cavity	plasma arc
		oxyacetylene burner
wet (pool)	core basket	band saw
	lower part of protection tube unit	CAMC(1)
	lower part of reactor cavity	plasma arc
	cavity bottom	fret-saw

(1) CAMC = Contact Arc Metal Cutting

Figure 34: Removal, Cutting and Packaging of Reactor Components

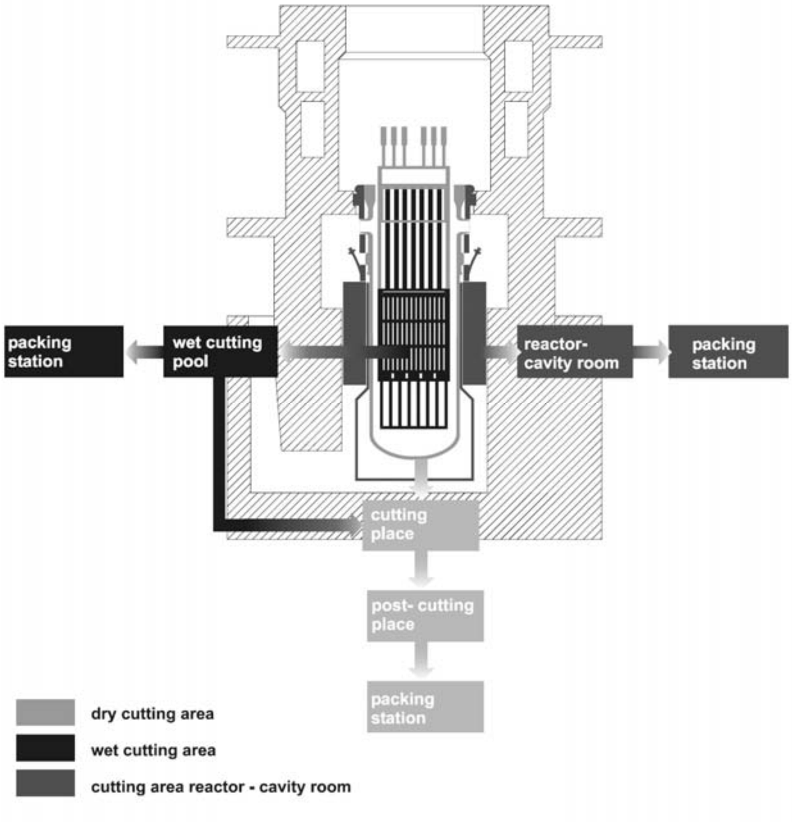


Figure 35: Dry cutting location with reactor pressure vessel bottom

Figure 36: Dismantling of activated components – wet cutting pond with band saw

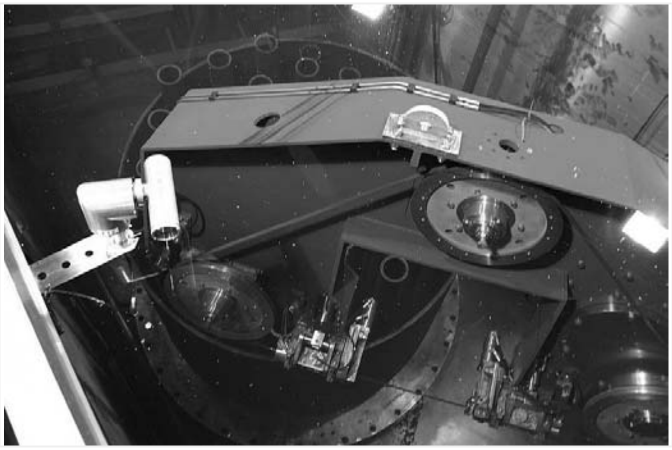


Figure 37: Dismantling of activated components – control station

Following the successful dismantling of the Unit 5 reactor pressure vessel, the following strategy was decided on:

- The RPVs of Units 1 & 2 without internals will be transported and stored as single pieces in the ISN
- The highly-activated RPV internals of Units 1 & 2 will be cut in the wet-cutting area in Unit 2. The dry-cutting area will be used only for the less-activated internal parts
- The RPVs of Units 3 & 4 will be transported with their internals to the ISN.

3.3.3 Lessons learned

After initial difficulties caused by a massive reduction in personnel combined with the introduction of a market economy and West German laws and procedures, EWN has succeeded in restructuring the company to arrive at a size suited to the task of decommissioning. The decommissioning and dismantling of the Russian WWER type reactors as such do not pose any specific problems. However, the size of the project and the resulting waste management task is vast. It can be concluded that dismantling of nuclear facilities is basically not a technical problem but rather a challenge to project management and logistics, once the legal and economic boundary conditions have been clarified. In order to achieve a safe and cost effective project, it is necessary that all stakeholders, i.e. operator/owner (EWN), authority and authorised experts, and the public, work together. To sum up, the lessons learned are:

- That the development of a comprehensive inventory is a necessary prerequisite for all planning.
- That social aspects and psychological effects must be taken into account.
- the requirement to have a clear licensing structure – a single license is preferred rather than several smaller licenses, if the project is not too large
- The importance of obtaining clear and realistic requirements from the licensing authority (related to real safety risks).
- That the overall project must be planned, i. e. from shut down to disposal.
- The importance of establishing a project structure which integrates all site activities.
- The communication of open public information is a key activity.
- The use of simple and sturdy tools/equipment, and use of mock-up tests if new or complicated technology is used.
- The benefit of strictly applying the ALARA principle when planning the project.

3.3.4 Bibliography

Innovative Remote Dismantling Techniques – Final Technical Report – February 2005

Energiewerker Nord Gmbh – The Greifswald site

3.4 Rheinsberg Nuclear Power Plant (KKR)

3.4.1 Description

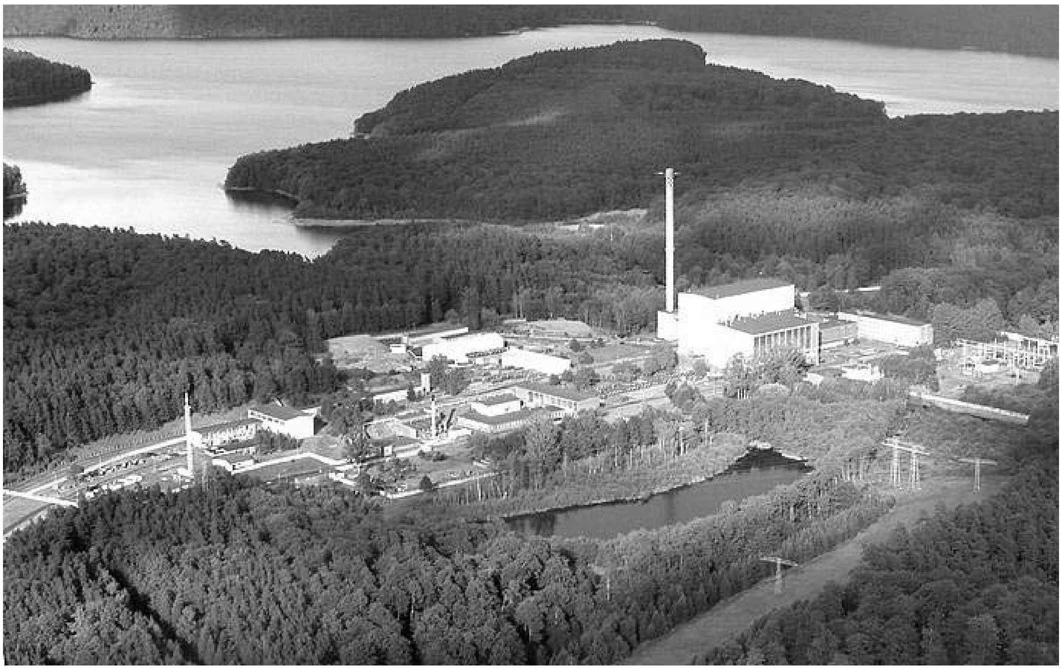
The Rheinsberg Nuclear Power Plant (Rheinsberg NPP, KKR) was designed and built in close cooperation between German and Soviet experts, under an agreement between the GDR and the USSR (Union of Soviet Socialist Republics) in 1956. It was equipped with the first Russian pressurized water reactor of the WWER-2 type to be built abroad. The main components of the plant were the reactor with the primary circuit, the turbine with the secondary circuit, the active water treatment system, the final store close to the surface as well as the associated infrastructure (energy, heat and water supply, connection to the traffic system). The share of the GDR (German Democratic Republic) industry in building the entire plant was about 70%.

On May 9 1966, the 70-MW unit was put into operation.

The KKR had to fulfil three tasks during its operation time:

- Generation of electrical power.
- Research work and scientific technical maintenance of the 440-MW power plant units.
- Education and further training.

Figure 38: Rheinsberg Nuclear Power Plant



A short time after May 5th 1966, when the power plant unit had been commissioned, it reached the designated parameters and was mostly run in base load generation.

Until its decommissioning on June 1 1990, it was connected to the grid for more than 130 000 hours. It achieved an annual average availability of 61.3 % on average. The total gross output (from 1966 to 1990) was about 9 000 GWh.

The use of nuclear fuel was around 14 MWd/kg uranium on average. The measures of maintenance and reconstruction, mostly carried out by in-house staff, and the material tests, especially in the area of the primary circuit including the reactor, made it possible to gain much experience which is also important for the decommissioning of a nuclear power plant.

During the commissioning and immediately thereafter, the scientific and technical issues demanded the creation of a special field of research. New solutions were developed, for example for the decontamination of the primary circuit, for the physical monitoring of the reactor core and for the leak tightness test of fuel elements. This know-how could also be used for the operation of the units in the Greifswald NPP. A number of research issues were worked on with international support.

3.4.2 Progress and achievements

The key KKR project dates are:

- Post Operation 1991 – 2001

  During the post operation period that covers the time between power operation, i.e. the production of electrical energy, and the removal of nuclear fuel from the power plant, the conditions for dismantling were being established.

- Site Operation 2001 – 2012

  During the time of site operation after the removal of the nuclear fuel, the infrastructure facilities, necessary for the upkeep of the site until the completion of dismantling, were being operated.

- Dismantling steps

  The dismantling was divided into eight steps to get manageable workflows, with the preparation of the necessary documents, the licensing procedure as well as the practical realization.

- In the frame of the respective licenses there will be, according to the following rules and schedule:
    - Dismantling Outside the Controlled Area (step 1): since 1995.

      The technical and electro technical facilities of the secondary circuit, which are no longer required (main focus turbine hall), have been dismantled since 1995, while maintaining the buildings including the transport and supply facilities to be used for the further dismantling of the NPP.

    - Dismantling Inside the Controlled Area (steps 2 to 6): since 1996.

      The equipment has been dismantled step by step, starting with the less contaminated parts and continuing on to more highly contaminated/activated parts through to the disassembling of the reactor pressure vessel.

    - Dismantling the Buildings (steps 7 and 8): until 2012.

      This has started with the dismantling of contaminated building parts.

Installing the cutting technique for the internals of the reactor pressure vessels was the key issue in the years 2005 and 2006.

Because these components had been inside the core zone, they were highly activated. Due to the resulting radiation the cutting was carried out under water.

To do this, the cooling pond was changed into a cutting workplace. The cutting started in 2006 and is carried out remotely from a central control station by manipulators.

Figure 39: Constructing the wet cutting workplace

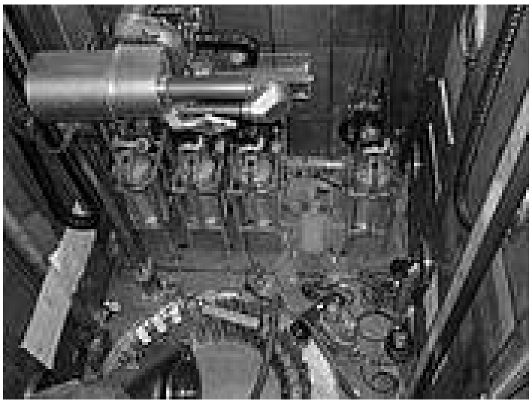


Figure 40: Band sawing under water

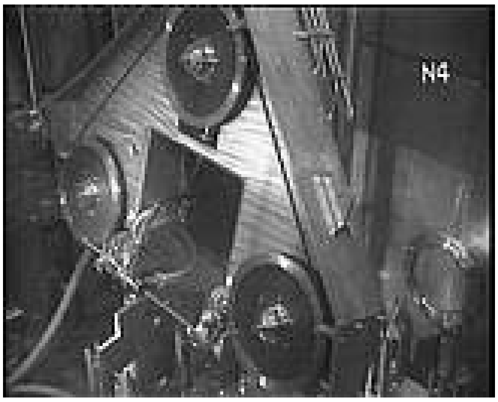


Figure 41: Moving the reactor cavity

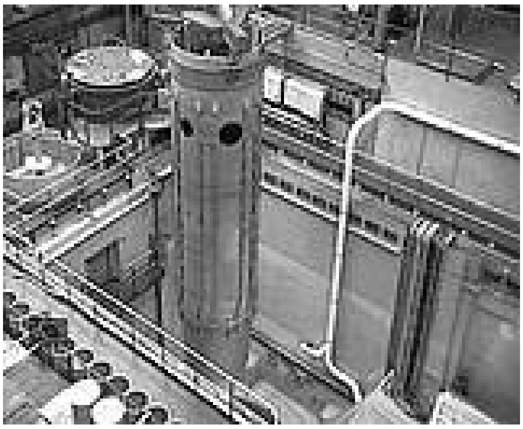


Figure 42: Plasma cutting

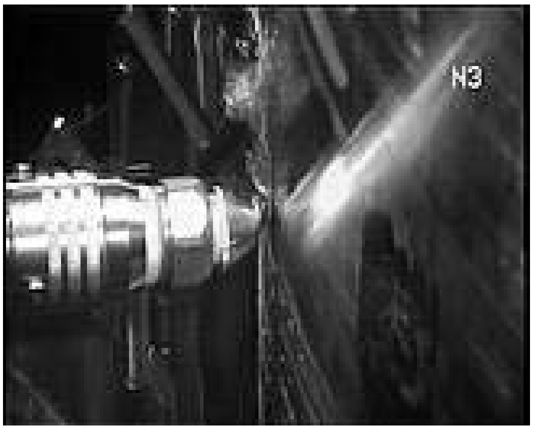


Figure 43: Sawing the reactor cavity

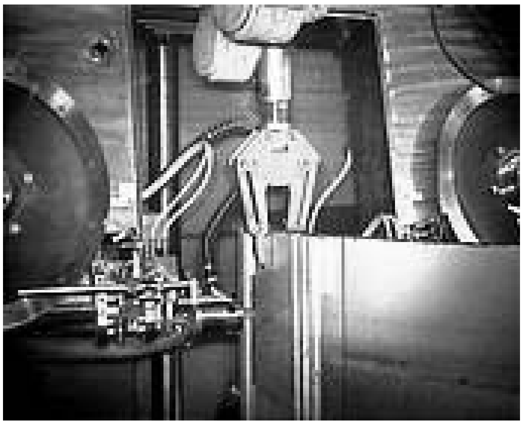


Figure 44: Removing a cut segment

Figure 45: Control station

2.4.3 Bibliography

Energiewerker Nord Gmbh – The Rheinsberg site

3.5 Compact Sodium-cooled Nuclear Reactor Facility (KNK2)

3.5.1 Description

The KNK (Kompakte Natriumgekühlte Kernreaktoranlage) plant was a compact sodium cooled reactor with an electrical gross output of 21 MW, erected on the premises of the Karlsruhe Research Center, used to develop sodium technology.

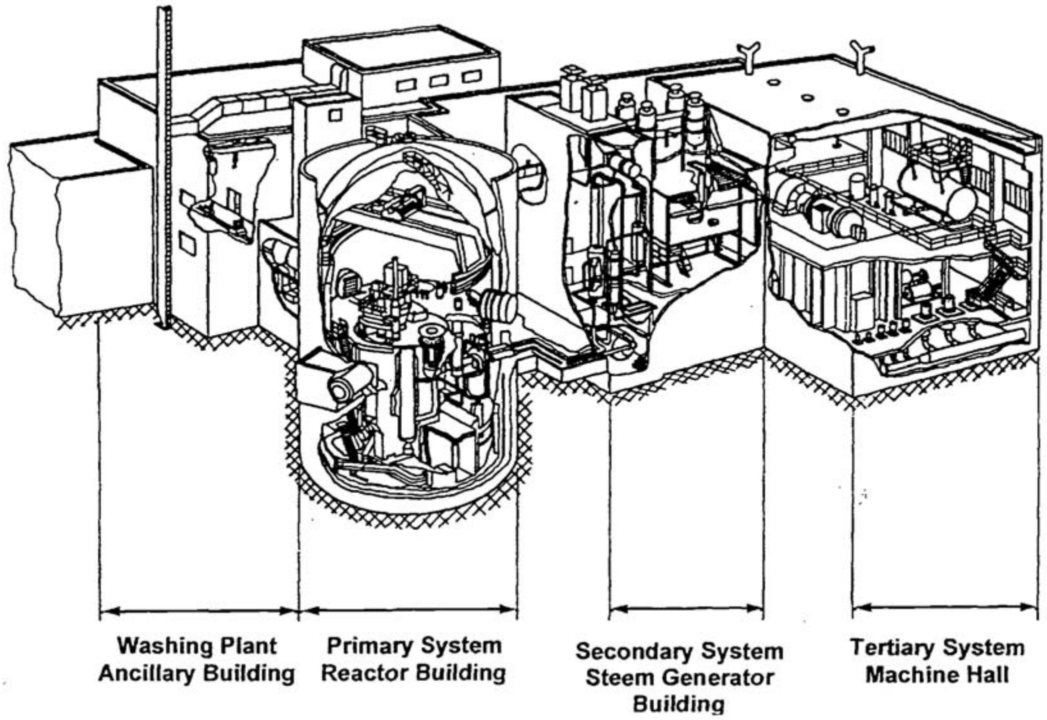
Initially, between 1971 and 1974, the plant was operated with a thermal core, referred to as KNK I. From 10th October 1977 onwards it was run with a fast core under the name KNK II.

On 23rd August 1991 it was shut down as Germany dropped out of fast breeder technology.

Starting in 1993, the plant is to be decommissioned completely in ten steps, i.e. under the corresponding ten decommissioning permits, to reach green field condition at the end of 2018. To date, nine decommissioning permits have been issued.

The decommissioning and demolition activities of steps 1 to 8 have been completed. Under the 9th decommissioning permit removal of the reactor vessel with its internals was completed in April 2008. The following steps of the 9th permission include the dismantling of the heat insulation, the primary shield and the activated part of the biological shield.

Figure 46: Compact Sodium-cooled Nuclear Reactor



3.5.2 Dismantling of the reactor vessel

Due to the exposure to fast neutrons, the reactor vessel and its internals were very highly activated (maximum dose rate at the beginning of step 1 in 2002: 27 Sv/h, maximum Co-60 activation: 10 E7 – 10 E8 Bq/g).

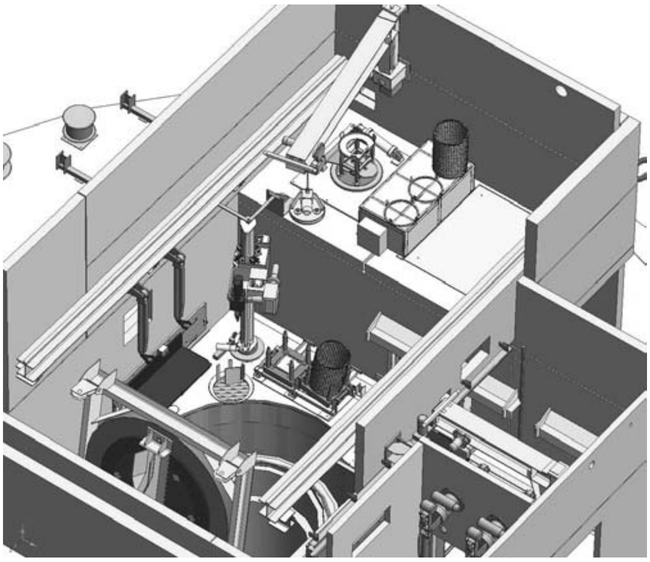
This was the reason why the use of remote handling technique was decided on. There were also severe restrictions concerning the choice of dismantling strategy and cutting techniques because of the presence of sodium. The residual sodium volume in the reactor vessel was estimated to be approximately 30 liters. The oxygen concentration during the dismantling therefore had to be less than 2.5%

Because of this, an enclosure, with a total weight of 500 tons and steel walls up to 350 mm thick, was built above the reactor. The enclosure met two needs, namely to provide a shielding for the cutting process and the first conditioning steps of the waste/dismantled parts, and to create a closed area with a nitrogen atmosphere. The enclosure was provided with an independent ventilation system maintaining a pressure of – 70 Pa, referred to as the containment (also to prevent contamination of the containment).

Cut pieces of the vessel as well as the swarf had to be cleansed of residual sodium in a washing facility in another part of the KNK plant. In order to transport these to the washing facility with a shielding bell, they also had to be packed in baskets and removed from the enclosure by remote handling.

The cutting, transport and conditioning steps presupposed the following equipment inside the enclosure:

- Disassembly manipulator (Milling machine).
- Crane to carry the disassembly manipulator within the enclosure and lower it into the vessel.
- Load manipulator for the handling of cut pieces and tools.
- Second crane for the handling of the transport baskets.
- Double lid system to transfer baskets with sodium free pieces directly into containers for further transport.
- Shielding valve to deliver parts to the specially-adapted shielding bell for the transport of sodium-contaminated pieces to the washing facility.
- Shielding lid to close the reactor vessel for manual interventions within the enclosure.
- Master slave manipulators for the handling of mills and other tools.



As the handling of sodium-contaminated parts is rather uncommon and the handling and transport of radioactive waste is a well-known practice, the following report concentrates on the technical requirements and lessons learned about the milling process.

3.5.2.1 Milling machine (ZWZ) for the dismantling of the reactor vessel

The decision for the use of a milling machine to cut the reactor vessel was based on a multiplicity of restrictions and circumstances that greatly reduced the range of potential cutting techniques:

- No wet or thermal cutting techniques allowed, because of the sodium residues.
- Restricted space in the vessel (diameter 2m).
- Complex geometry of the built-in components (for instance reflector, grid plate).
- High material thickness of single components (reflector).

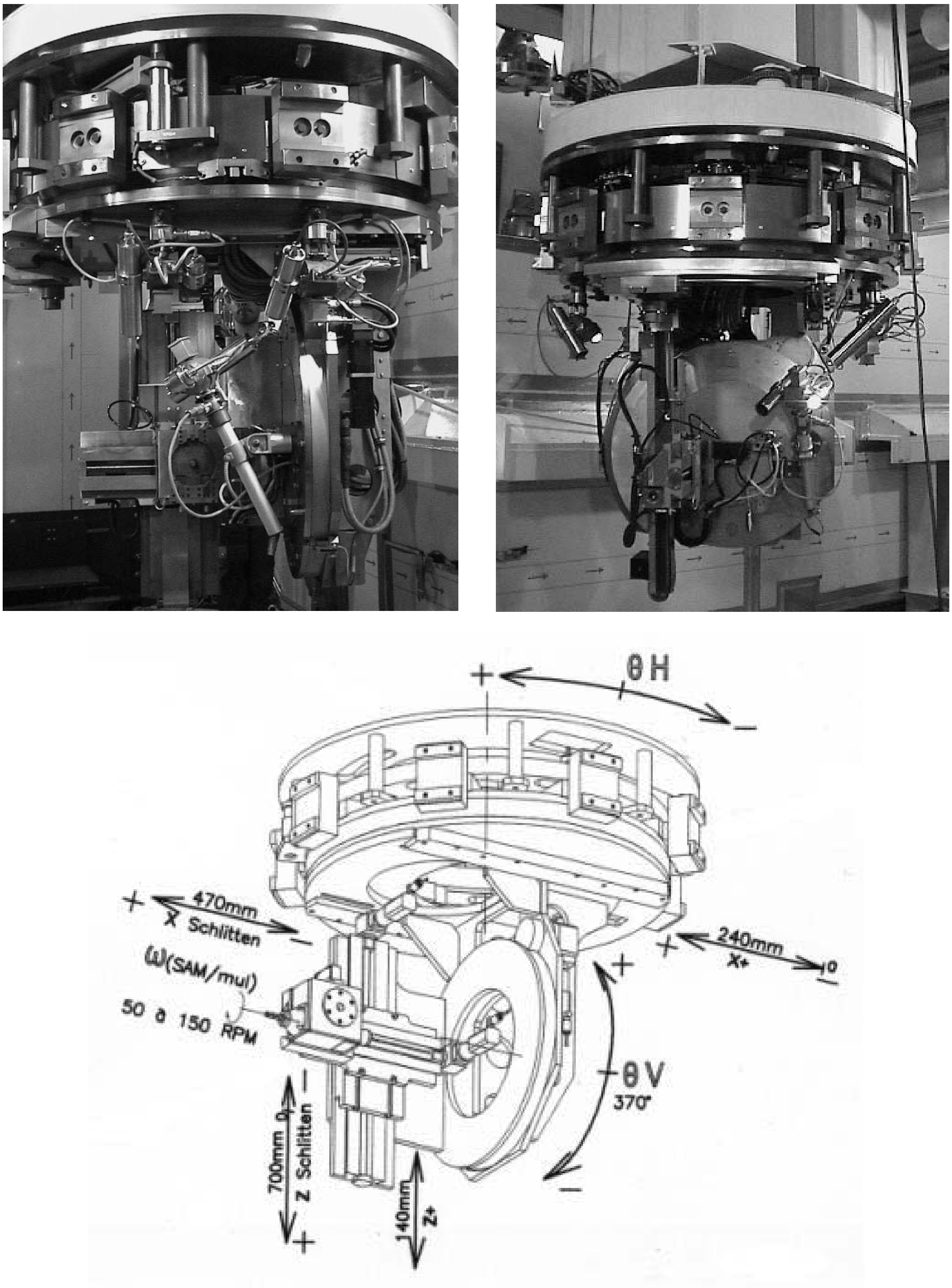
The internals of the reactor vessel had to be dismantled from the inside out. The inner vessel and the outer vessel had to be removed top down because they were suspended from the top flange. All cuts had to be made in such a way that the parts could be packaged in 150 litre drums or baskets, which were then remotely loaded into shielded transport containers.

Geometry and activation of the reactor vessel and its internals

Component	Height (mm)	Thickness/diameter (mm)	Mass (Mg)	Max. activation of Co-60 as per Jan. 1, 2001 (Bq/g)
Reflector	2310	70-170	11.8	3.1 E+7
Thermal shield	2310	80	7.8	4.8 E+6
Thermal shock baffle	6500	12	3.8	4.2 E+6
Internals	-	-	2.8	1.2 E+9
Inner vessel	10,500	16	11.8	4.0 E+6
Outer vessel	9500	12	4.8	2.2 E+6
		Total	**42.8**	

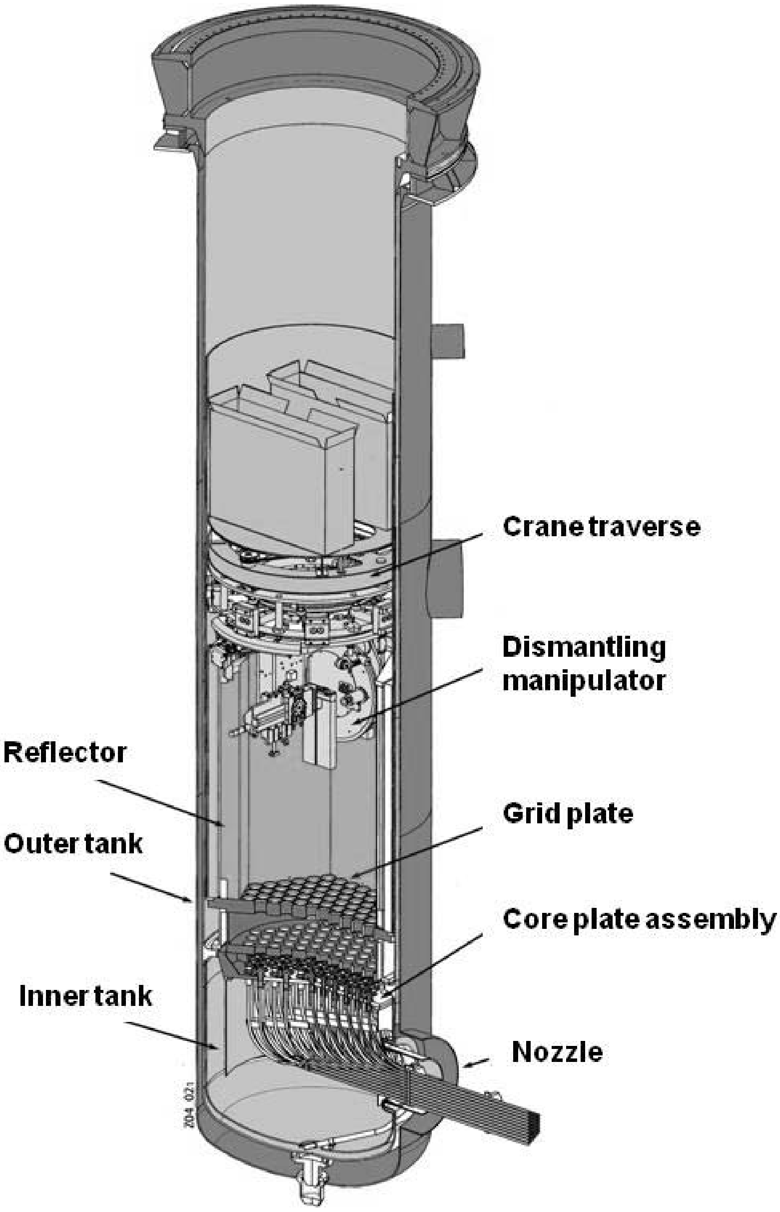
All these circumstances led to the development of a disassembly manipulator provided with 6 axes to be able to reach all cutting positions using either end mills or side milling cutters to dismantle the KNK reactor vessel. Also pipe penetrations have been cutted with inner tube cutters. Altogether 12 tool modules (milling modules, hydraulic shears, oscillation brakes, magnet grip arms) have been realized, which have been changed remotely controlled likewise as the principle tools with the help of the load manipulator or master-slave manipulators. The milling process was performed completely dry.

Figure 47: Kinematics of the dismantling manipulator



The dismantling tool was positioned where necessary in the reactor vessel while suspended from the cell crane by a crosshead with three ropes providing a horizontal adjustment, and braced by 8 hydraulically operated brackets at the level of the cutting position.

The figure below shows the dismantling tool in the reactor vessel. The inner diameter of the vessel was 2m, with a height of about 10m.



The parts removed were put on a transfer station with the disassembly tool. They were then picked up by the loading manipulator, visually inspected for sodium residues by a video camera, and packed into the washing baskets. A loading crane took the washing basket either directly into the 200 litre drum under the double-lid lock or deposited it on the lock so that the basket could be pulled into the shielding bell, which was standing on the enclosure.

In total 1 360 parts with a cutting length of around 1 500m were segmented (Material 1.6770). The milling kerf material represented approx. 10% of the total mass of the reactor vessel, including internals.

The outstanding features of the dismantling machine (ZWZ) were:

- Hydraulic self-centering system, bracing itself within the reactor vessel.
- Electrical drives with coordinates H, V, Z, X, as well as pneumatic feed motions (x+ and z+).
- Hydraulic drives for milling modules with leakage volume supervision and limiter.
- Displacement and rotation sensors in resolver technology for all axes.
- Control console for pre-selection of process parameters and axle position coordinates.
- Video and audio monitoring of the milling process.

3.5.3 Lessons learned

The dismantling machine was extensively tested at the manufacturer's test facility using a 1:1 mock-up and approved by the independent technical supervision expert before it was delivered and installed in the KNK reactor vessel. In the course of the mock-up tests approx. 10% of the total cuts have been tested. Priority and especial attention has been paid to the cutting of overlapping areas and transition spots.

The following tasks and problems were analyzed and resolved:

- Cut/drill tracking system in cylindrical geometry (tank wall, hemispherical head, pipe nozzles) – > development of a new two-axle control system.
- Positioning accuracy (reproducibility) – > mechanical measures for the reduction of the axle play, no-load operation test routines for verification, reproducibility of the start coordinates.
- Re-design of the energy supply chain, reduction of the cable diameters to reduce the bending radii.
- recovery concept – > realization over mechanical direct access (detachment of brackets and fastening to cell crane) with the help of recovery bars with telescopic extensions.
- Improvement of the milling process – > milling concept and cutting plan over 5 cut depths; milling kerfs and milling cutter thickness decrease with increasing depth.
- Vibrations – > development and assembly of shock absorbers as well as development of special drills (adjustment of cutter head and cutting geometry).
- Chip problem (removal, collecting, pollution) – > development of special drills with chip removal slots, installation of encapsulations at the dismantling tool, protection of the spindle and spindle bearing.

During the dismantling at KNK, problems arose concerning the low durability of the milling tools and connected effects. In particular, the cutting of the thickest parts (reflector) took more time than estimated. Investigations showed that the problems were not caused by the milling tool itself but by the insufficient rigidity of the machine. This phenomenon increased with the dismantling progress as the bearings of the axes were suffering under attrition. Taking into account the number of axes, the sum of the single slackness led to a flexibility of the dismantling machine which prohibited an efficient milling process.

As one consequence of that, the milling tool became too hot and started glowing.

Taking a conclusive look at the mock-up tests was very helpful and necessary. In general acceptance tests, qualification and proving of the dismantling equipment and tools is a very important step that should be proceeded with in-depth and very carefully. Also, metrological investigations should be taken into account to identify weaknesses and failures which are sometimes not obvious in practical tests. If possible, well-proven conventional tools should be preferred and customized if necessary.

The dismantling of the reactor vessel was finished in April 2008.

3.5.4 Bibliography

WM´02 Conference, February 24-28, 2002, Tucson, AZ – Concept for dismantling the reactor vessel and the biological shield of the compact sodium-cooled nuclear reactor facility (KNK)

WM’02 Conference – Technical Meeting on “Operational and Decommissioning Experience with Fast Reactors” Cadarache, France, 11-15 March 2002

3.6 AT1 Pilot Facility

3.6.1 Description of installation

The AT-1 (Atelier de Traitement) pilot facility, situated near Cherbourg on the AREVA NC La Hague site, was built to reprocess fuels from fast breeder reactors. The plant operated for 10 years, from 1969 to 1979. Final closure in 1979 was followed by a 12 month campaign of plant wash out and an 18 month period of systematic decontamination of the circuits.

Figure 48: AT1 General view

The CEA/UDIN (Unité de Démantèlement des Installations Nucléaires) has been responsible for the decommissioning of AT-1 since 1982, with the objective of dismantling the facility to IAEA stage 3 (excluding civil works), specifically:

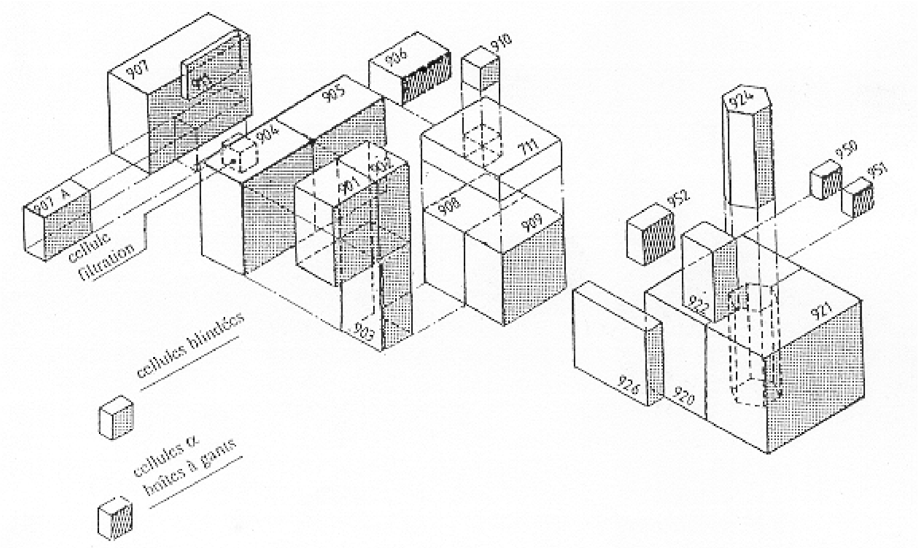
- To dismantle and remove all contaminated circuits and equipment
- To decontaminate the different shielded cells to a level that allows unrestricted access to the building.

The dismantling of all processing equipment and decontamination of the AT1 structure has been completed successfully. A brief description of the facility and the main activities carried out to achieve this are outlined below.

During its operational period, the following reprocessing steps were carried out in a series of concrete cells:

Cell 901	Spent fuel storage.
Cell 902	Fuel cropping.
Cell 903	Fuel dissolution.
Cell 904	1st Extraction cycle.
Cell 905	2nd/3rd Extraction cycle.
Cell 952	4th U/Pu separation cycle.
Cells 950/ 951/ 906	U and Pu concentration and Pu precipitation.
Cell 907	Liquid effluent storage.
Cells 920/908/ 909	Fission product storage.
Cell 911	Transfer pipes and demisters.

Figure 49: AT1 expanded view



3.6.2 Description of remote dismantling systems

Following plant washing, radiation levels in the shielded cells ranged from a few 10-2 Gy to 1 Gy. These high levels of radiation precluded any direct manual work in cells 903 and 904 and limited the working time in cells 902, 905, 908 and 909. In addition, cells 903, 904 and 905 were completely blind (without windows or manipulators) and it was necessary to design special equipment (the ATENA machine) to remotely dismantle these cells.

The main sequence of activities was as follows:

- Dismantling of unshielded alpha cells and glove boxes associated with the fourth cycle.
- Installation of the ATENA remote dismantling machine.
- Dismantling with the ATENA machine of the three main shielded blind cells; 905, 904 and 903.
- Dismantling of the various storage cells (liquid waste stored in cell 907, fission products in cells 908, 909 and in the extension building) general decontamination of the building.

The ATENA machine comprised an 11 metre remote controlled telescopic multi-jointed arm, which could retract into a very thick steel hood. The hood worked both as containment and as biological protection for the operators. The tip of the telescopic arm could be equipped with a cutting tool or with an MA 23 M or RD 500 type remote manipulator. On completion of the project, the ATENA machine was disposed of as waste.

Figure 50: ATENA machine

3.6.2.1 The ATENA Machine Hood

The hood of the ATENA machine is made up of black steel housing, in variable thicknesses ranging from 20 to 65 mm depending on the part of the hood, and has the following dimensions: height 7 650 mm, diameter 1 200 mm, weight 20 tons.

Inside, there is a telescopic vertical mast which ends in the multi-jointed arm, which then bears a tool or a remote-controlled manipulator.

The jointed arm and its remote-controlled manipulator penetrated and worked in the high-level radioactive cell (Cell 904 or 905) through openings made in the slabs of the floor of room 800. When at rest, the entire unit folds into the hood.

The hood was an integral part of a carriage mounted on a track which ran on both sides of room 800, providing access via the different entry holes into the high-level radioactive cells and to the maintenance station without breaking containment.

The carriage had the following dimensions and characteristics:

- Length: 3800 mm.
- Width: 2680 mm.
- Height: 890 mm.
- Mass: 10 tons.

The jointed arm on the ATENA machine was controlled from the control desk in the ATENA machine operations room.

In order to facilitate the manoeuvres of the jointed arm when working on the machine, a remote control room was set up near the shielded windows of the maintenance cell in room 734.

3.6.2.2 Protective caps

The opercules are devices placed above the cell openings which enabled the jointed arm on the ATENA machine to enter the high-level radioactive cell without loss of confinement. The protective caps also ensured closure of the cell when the ATENA machine was absent.

The main characteristics of the protective caps were as follows:

- Length: 4055 mm.
- Width: 1928 mm.
- Height: 1200 mm.
- Weight: 5 tons.

Two protective caps were used, one of which remained in the same position above the maintenance cell while the other could move to a position above each work station in the slabs making up the floor in room 800.

The protective caps were controlled from the ATENA machine control stand.

The ATENA machine was built by the "Atelier Chantier de Bretagne (ACB)" in Nantes, where tests in non-radioactive surroundings were conducted in late 1988 / early 1989 using the two MA 23M and RD 500 remote-controlled manipulators.

Figure51: ATENA machine control room

3.6.2.3 MA 23M and 500 remote manipulators mountable on ATENA

MA23M Remote Manipulator

The MA 23M is a master-slave remote manipulator with the master arm located in the ATENA machine control room and the slave arm on the ATENA machine to perform the dismantling operations in the high-level radioactive cell.

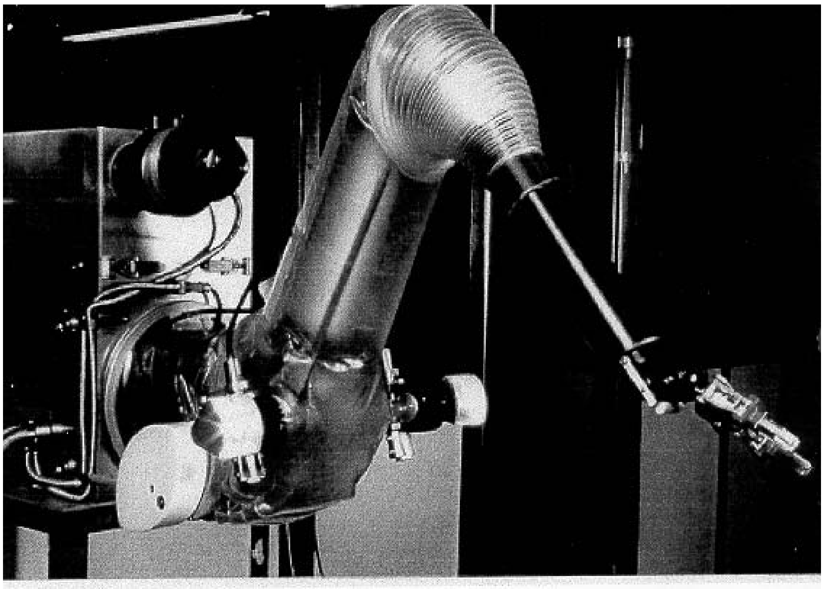
The slave arm, connected to the master arm by an electric cable, can hold a dismantling tool at the tip of its gripper.

Stainless steel bands provide for the transmission of movement inside the MA 23M.

Maximum effort for this type of remote manipulator is 23 daN.

This remote manipulator, developed for operations in reprocessing facilities, was tested in a radioactive environment on the dismantling project. After encountering several problems, it only became fully operational after more than 18 months.

Figure 52: Slave arm of the MA23M



The RD 500 Remote Manipulator

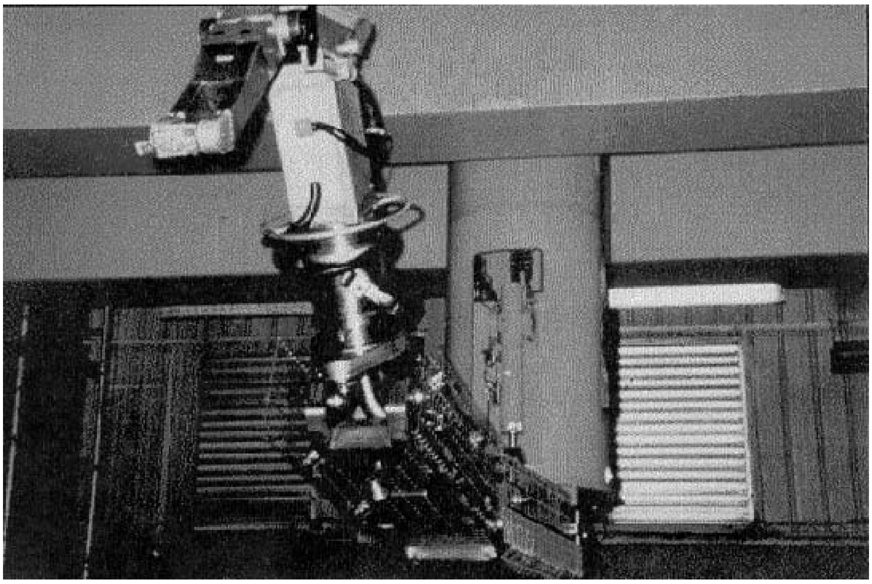
Based on experience acquired since 1982 with the PIADE machine on the ELAN IIB dismantling site, the CEA designed a new generation of remote manipulator which is heavier-duty and which can manipulate heavier loads than the MA 23M (25kg).

The RD 500 (50kg) is suitable for dismantling operations, whereas the MA 23M was designed for multiple interventions.

The RD 500 also benefited from technological progress made since the early 1980s:

- Possibility of building force feedback machines with engines.
- Possibilities, with programmable controllers, of having reliable, safe computer controls at highly competitive prices
- Possibilities of using ambient sensors
- Development of computer-assisted remote operators and cooperation robots able to perform autonomous or semi-autonomous work.

Figure 53: View of the RD 500.



3.6.3 Equipment Installation

3.6.3.1 Preparation of the ATENA machine working area

First, the zone located above the high-level radioactive cells (Cells 904 and 905) was cleared of all the equipment which had been installed there. In particular, this meant dismantling the filtration cell and Cell 911 which held the mist traps for the facility.

Then the civil engineering structures had to be modified. This primarily consisted in building two concrete foundations on both sides of Room 800 (on the east and west sides of the room), to:

- Support the new steel ceiling slabs for cells 904 and 905, which replaced the original cast iron slabs and which were better adapted for docking the ATENA machine.
- Hold the track for the double-beam truck
- Hold an upper track for the movement of the hood of the ATENA machine as it travelled between the various possible work stations.

The roof to the south of room 800 had to be specially modified to create an opening equipped with hatches and an airlock, to provide access to the ATENA machine and its equipment.

3.6.3.2 Construction of the maintenance shops and of the workshop cell

The following equipment was installed to provide for the maintenance of the ATENA machine:

- Three glove boxes
- One maintenance cell for the ATENA machine.
- One Workshop cell.

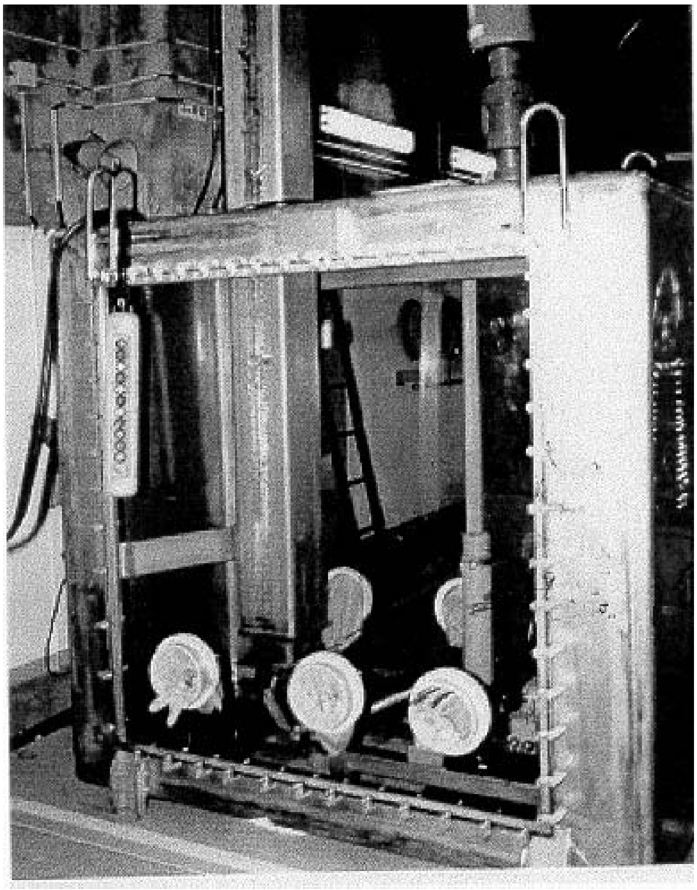
The glove boxes

The glove boxes were positioned on the openings in the biological protection slabs installed in Room 800.

In addition to maintenance, these glove boxes were used to insert the tools used to cut the equipment in the high-level radioactive cells, such as the disc saw, the plasma torch, and the hydraulic shear, and to install them at the tip of the jointed arm or the remote manipulator.

One of the boxes was equipped with a telescopic holder to lower an ambiance camera and a spotlight into the cells, to light the cell where the work was taking place (see Figure 54).

Figure 54: View of a maintenance glove box



The ATENA machine maintenance cell

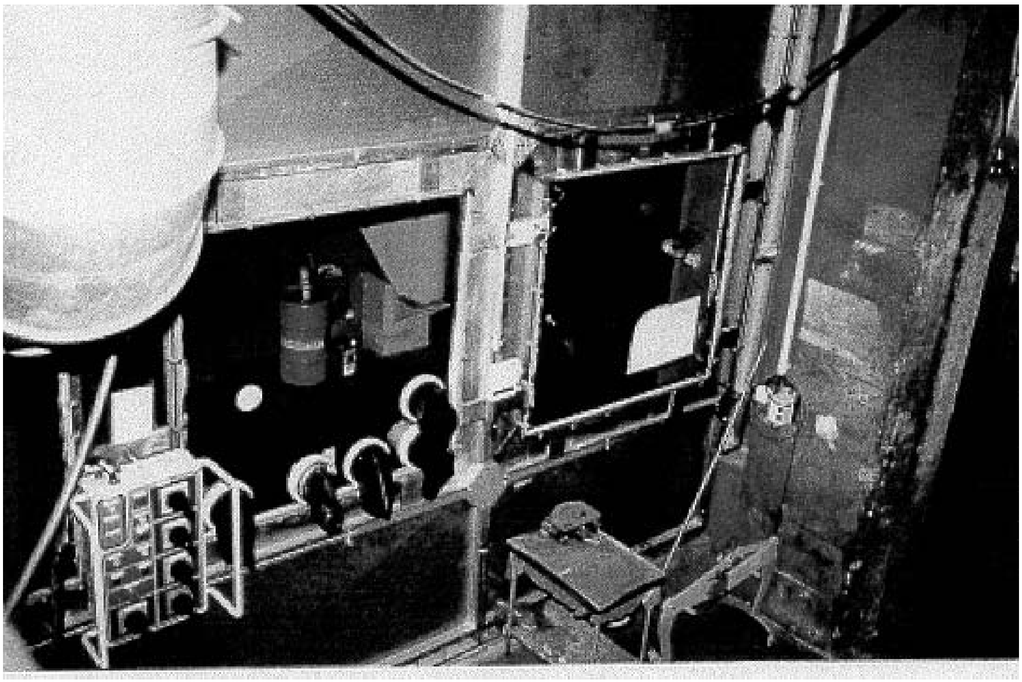
This cell (see Figure 55) was designed for the work which might have to be done on the ATENA carrier or on the ATENA remote manipulator, in particular to replace the steel bands which transmit the movement of the MA 23 remote manipulator.

This cell was located at the –4 m level of the building, in Room 734, below the ATENA machine work cell (Room 800).

The cell was also equipped with a jib crane with 20 kN lifting capacity, to perform all the necessary handling, and in particular to remove the remote manipulator from the jointed arm.

In addition to the wiping cleansing equipment, high pressure equipment was also available to the operators. The set-up included a spray ring located around the jointed arm entrance hole in the maintenance cell. The effluents produced were removed through a sump connected to the radioactive effluent reception tank.

Figure 55: View of the west side of the ATENA machine maintenance cell (modular panels)



In addition, this cell was also used to prepare a model of the cutting of a concrete wall.

The maintenance cell was ventilated by connection to the facility's High Negative Pressure extraction network. This cell started up in December 1989.

The Workshop cell

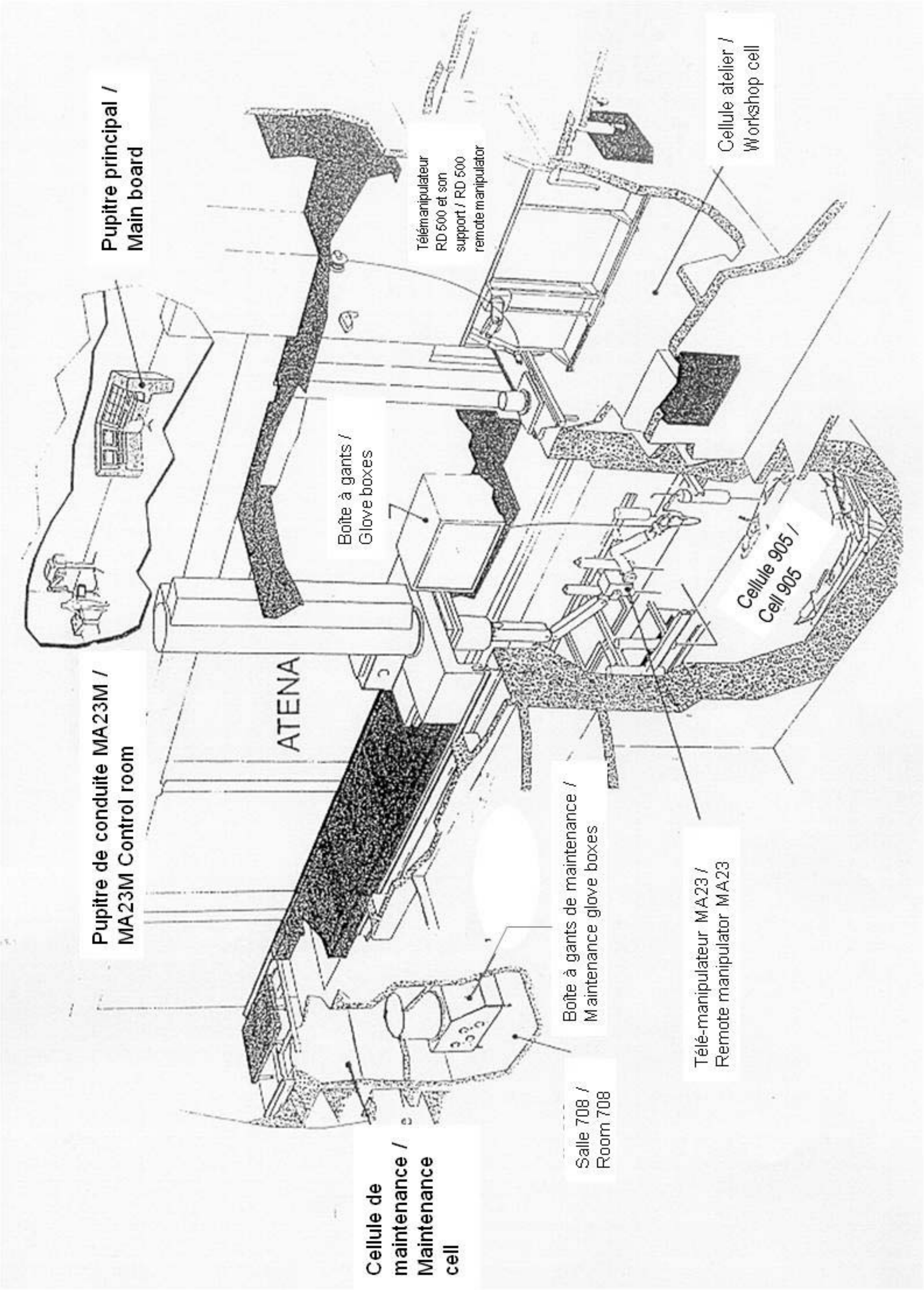
This cell was built along the same principles (existing walls and modular panels) as the maintenance cell described in the preceding section. It was partly located above Cell 905, to the north of Room 800.

3.6.4 Installation of the ATENA machine and equipment tests on site

3.6.4.1 Installation

A crane was used to install the ATENA machine (hood, carriage and opercules) through the opening made in the roof of the building, on the docking station connected to the maintenance cell in Room 800.

Figure 56: Detailed view showing the dismantling of Cell 905 and the maintenance station.



3.6.4.2 Preliminary tests

Tests focused on:

- Moving the entire unit.
- Electric power feed to the carrier.
- Monitoring means and the computer systems.

On 6 December 1989, the correct functioning of the ATENA machine's dynamic containment system was able to be verified following the successful docking of the ATENA machine on a work station in Cell 905. The ATENA machine was designed to ensure containment whenever it is disconnected from work or maintenance stations, by implementing its own ventilation set at -100 Pa during the tests; in working position, stand-alone ventilation is stopped and negative pressurization of around -100/150 Pa is provided by the high-level radioactive cells or the maintenance cell.

3.6.5 Worksite clearance

After the dismantling of Cells 903, 904 and 905, and the conditioning of the wastes from Cells 903 and 904, an in-depth cleaning of the cells was performed, which recovered approximately 80kg of particulates beyond the ANDRA (*Agence Nationale pour la gestion des Déchets RAdioactifs*) disposal site specifications and which were removed to the Cadarache plant in 2000. Radioactive mapping of these two cells was performed using a probe placed at the tip of the ATENA machine. Environments of 3 to 4 mSv were observed in Cells 904 and 903 respectively.

Next, the following operations were performed:

The ATENA machine, its protective caps, and its transfer trolley were removed from the building on 26 and 27 May 1994 using a 200-ton crane, by passing through a hatch created in the roof of the building,

The maintenance cell was dismantled during the period between June and December 1994. This operation recovered approximately 80m² of stainless steel modular panels, after cleansing.

3.6.6 Progress and achievements

The main progress and achievements can be summarised as:

1985 – 1990	• Dismantling of the alpha contaminated cells and the unshielded glove boxes. This work was carried out in a modular workshop by direct manual access.
	• Dismantling of the storage cells (wastes, fission products). This work was done by direct access with biological protective shielding.
1990–1994	• Dismantling of the high-level radioactive cells requiring the use of specially developed remotely operated equipment.
	• Removal of all reprocessing equipment.
1995	• Video inspections, mapping, sampling.
1996 – 2001	• General decontamination of the building and related monitoring.

From January 1990 until February 1993, the ATENA machine (with a MA 23 manipulator) was used for the dismantling operations carried out in hot cells 905, 904 and 903. Initial dismantling trials using the ATENA machine were carried out in Cell 905 utilising hydraulic shears. However, it quickly became clear that the task was too demanding for the MA23 manipulator and a circular saw, which proved lighter and more manoeuvrable, replaced the original shears. On completion of the ATENA trials in cell 905, the remaining dismantling tasks were carried out by direct manual access to enable the dismantling of Cell 904 equipment to be carried out as soon as possible.

In order to allow the introduction of the ATENA articulated arm into Cell 903, it was necessary to make an opening in the wall between Cell 903 and Cell 904: the opening dimensions were 1.2m by 4.5m. The radiation levels near the partitioning wall were too high to allow direct worker access, and so it was decided to remotely cut the concrete with a diamond disc saw. The minimal dimensions and weight of the tool enabled its direct mounting on the ATENA machine without the MA 23. The cooling of the cutting disc with liquid nitrogen avoided the generation of liquid waste.

A special workshop cell for conditioning the waste from high activity cells was built at the northern side of Cell 905. This cell was made of a concrete wall and stainless steel modular panels. The location of this workshop enabled communication with Cell 905 through removable slabs. The workshop cell was equipped with two hoists to perform all the handling work and in particular lifting the waste bins from Cell 905. In the cell, the remotely-operated tools included two M8 manipulators and the heavier duty RD 500 manipulator. In Cells 904 and 905, waste was put in bins, then removed by a monorail system via Cell 905. The bin was then lifted by the workshop cell hoist and tipped in the remote manipulators area for sorting and packing into 120 litre drums.

After completion of all dismantling operations, a programme to decontaminate the walls of high activity Cells 903, 904 and 905 was carried out. The initial technique selected and tested in Cell 905 was shot blasting, operated semi-remotely. Concrete was removed to a depth of 4 mm and the shot recycled to limit the amount of solid waste generated. A BROKK machine with scarifying tools was more successfully used later to remove contaminated surface layers within the concrete cells.

Where possible, dismantling operations were carried out by direct access methods. This included dismantling of Cells 901 and 902 (fuel reception and cutting) and the fission product storage Cells 920, 908 and 909.

Each of the Cells 908 and 909 contained a 15m^3 tank and its associated pipework. During shutdown operations, the fission product solutions were removed and the tanks rinsed aggressively. Radiation measurements showed ambient dose rates of 0.25 mGy/h with hot spots of up to 100 mGy/h. Dismantling of the tanks was carried out by linear shaped explosive charges and completed with traditional cutting.

Other dismantling operations carried out by direct worker interventions were:

- Cell 906 – cells and glove boxes.
- Cell 952 – extraction of U and Pu.
- Cell 911 – transfer pipes and demisters.
- Cell 907 – solvent washing.

To avoid dispersion of contamination and to protect workers, modular workshops were developed to carry out these operations. The workshops were built with stainless steel panels of standard dimensions. The panels' smooth surfaces were easy to clean and decontaminate, so that they could be reused.

3.6.7 Lessons learned

The dismantling and the cleansing of the AT1 building equipment and installations have been completed. Though some of the operations were conducted in the traditional manner using direct manual work by the operators, many of the tasks required the use of innovative techniques due to the high irradiation levels which were encountered.

As a result, the following techniques were tested and met with a fair degree of success:

- Remote dismantling of totally blind cells using the ATENA machine. This process enabled cutting of all the piping and equipment within 13 metres of the cell's entry point.
- Development of the stainless steel modular panels used to make the air-locks and cells, and which can be recovered after cleansing,
- Remote cutting of a concrete wall using the ATENA machine and a diamond-wheel saw,
- Cleansing of the contaminated concrete walls using a semi-automatic process which reduced the doses absorbed by the personnel working in the cell.
- Cutting of sheet metal equipment using explosive cords. This process reduced the operator intervention time in the cell, and thus significantly reduced the doses absorbed by the personnel. However, it did increase the volume of the waste (airborne particulate spatter) and spread contamination.

The implementation of some of these techniques caused, and continues to cause, some financial and technical problems. Overall, however, the work was satisfactory.

The dismantling of the AT1 fuel reprocessing facility was a very educational, informative operation. The scenario selected and the technique used – combining a holder and a remote manipulator equipped with tools, working together in remotely–controlled operations – proved to be effective for the dismantling of large-sized blind cells to IAEA (International Atomic Energy Agency) stage 3, in very good radiological safety conditions.

Important aspects concerning the evolution in the ventilation and the aging of the electrical network, which had not been considered at the outset, appeared at the end of the dismantling work.

Lastly, the good control of purchasing and supplier selection on the La Hague site, for which there are very few approved suppliers, contributed to the satisfactory completion of the work.

The fact that the dismantling/cleansing was programmed over a period of approximately 20 years (after 10 years of operation) meant some of the elements which were required for the project had to be replaced and also necessitated major maintenance for some of the equipment which was an integral part of the installation, at dates which were relatively close to the end of the operations. This meant that these major maintenance or difficult replacement actions could have been avoided if the dismantling program had been shorter.

- In 1995, the ventilation system filter casing had to be changed in emergency circumstances, following poor results from the efficiency/clogging tests. This emergency action cost more than 1 million French francs, made it impossible to carry out any cleansing work during a significant period of time, and could have had radiological consequences had it been less well controlled.
- The Radiation Protection Control Panel was only able to continue operating until the end of the work because faulty parts were replaced by "cannibalizing" replacements from equivalent equipment available from facilities which had already been shutdown. "New" spare parts were no longer available on the market. This unforeseen maintenance need is not satisfactory, and a shorter work time would have reduced this risk.

- The fact that the dismantling work was spread out over time, or the wait prior to launching such work, also made the facility very vulnerable to leak tightness problems on terraces, doors, and windows. The consequences of this type of contingency often caused shutdowns and generated significant extra cost.
- The electrical networks, safety-important elements either due to their safety function (fire protection) or because their condition can generate an accident risk (protection failure).
- Lot by lot dismantling presumes updated single-line diagrams to avoid the risk of cutting powered cables. One solution that protects from such a risk consists of installing work site power supply boxes, with all other power supply circuits numbered and dismantled as lots are finished.
- Spread-out dismantling/cleansing work requires updates caused by the changes in the standards and regulations in such areas as Labour Code, electricity, pressure instruments, lifting equipment, etc …
- Accordingly, for the AT1 project, work occurred with old equipment on the edge of operating limits. A dismantling project has to include these regulatory safety elements which cannot go ignored.

3.6.8 Bibliography

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Technical Report – AT1 decommissioning feedback experience fast breeder reprocessing spent fuel facility CEA/DEN/DPA/JGN 01-507

3.7 Karlsruhe Reprocessing Plant (WAK)

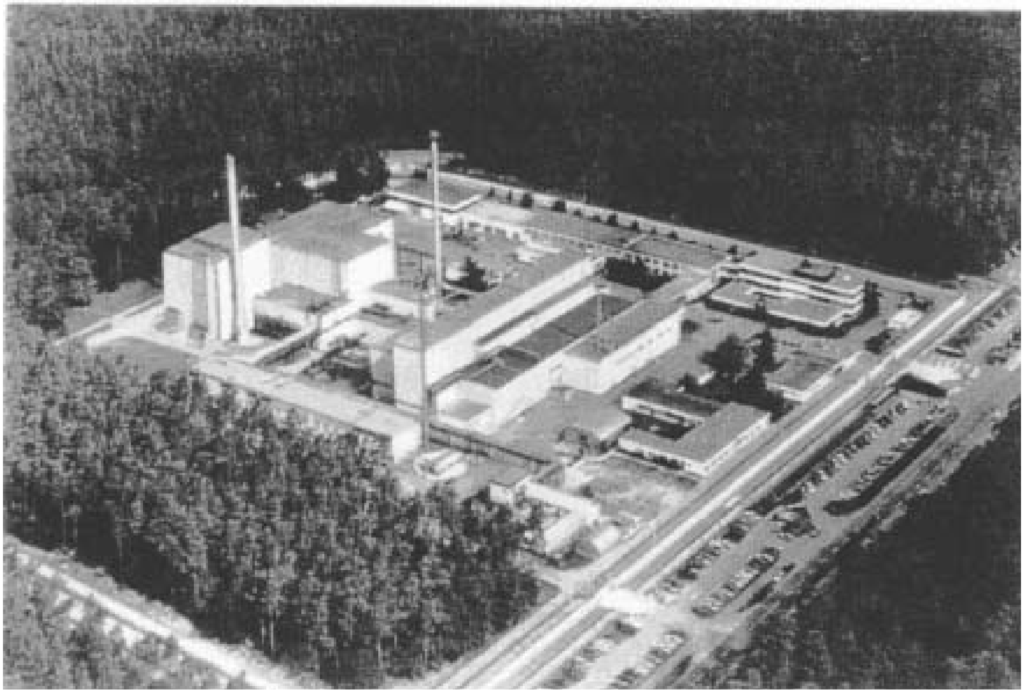
WAK : *Wiederaufarbeitungsanlage Karlsruhe*

3.7.1 Introduction

The Karlsruhe Reprocessing Plant (WAK), operated by the WAK–Betriebsgesellschaft (WAK-BG), was built between 1967 and 1971 by the former Nuclear Research Centre Karlsruhe. During its 20 years of hot operation, the WAK-plant processed 208 t of heavy metal, irradiated oxide fuel from research and power reactors. On June 30, 1991, the plant was finally closed down after a half-year nitric acid rinsing campaign.

The dismantling of the plant started in 1994 with the decommissioning of obsolete systems and will be finished with a green field status. The dismantling activities were carried out by hands-on techniques, remote techniques, or a mixture of both, depending on radiological conditions. 5 500 tons of contaminated solid waste, 3 200 m^3 of liquid waste, 130 canisters of HLW glass, and 75 000 tons of rubble were created from dismantling the plant.

Figure 57: Aerial view of the WAK



3.7.2 Progress and achievements

The project objective of a “green field” was to be reached in 6 technically independent steps:

1. Deregulation and shutdown of process areas that have lost their functions: This step has been completed.
2. First dismantling activities in the process building (15 systems): This step has been completed.
3. Further dismantling of the equipment in the process building using remote-controlled and manual techniques and elimination of the controlled area: All these activities have been approved of by granting partial decommissioning licenses. Work has advanced to a large extent.
4. Deregulation of the HAWC storage area of HWL/LAVA as well as of the VEK (Karlsruhe Vitrification Plant) upon HAWC (High Activated –liquid– Waste Concentrate) vitrification.
5. Remote-controlled and manual dismantling of the HAWC storage facilities, the VEK vitrification plant, and auxiliary systems, elimination of the controlled areas. First applications for licenses have been submitted.
6. Conventional demolition of all buildings and replanting of the site. As a prerequisite for the execution of steps 4 through 6, the HAWC still stored on the premises has to be disposed of. For the treatment of this waste, the VEK was built on the WAK site.

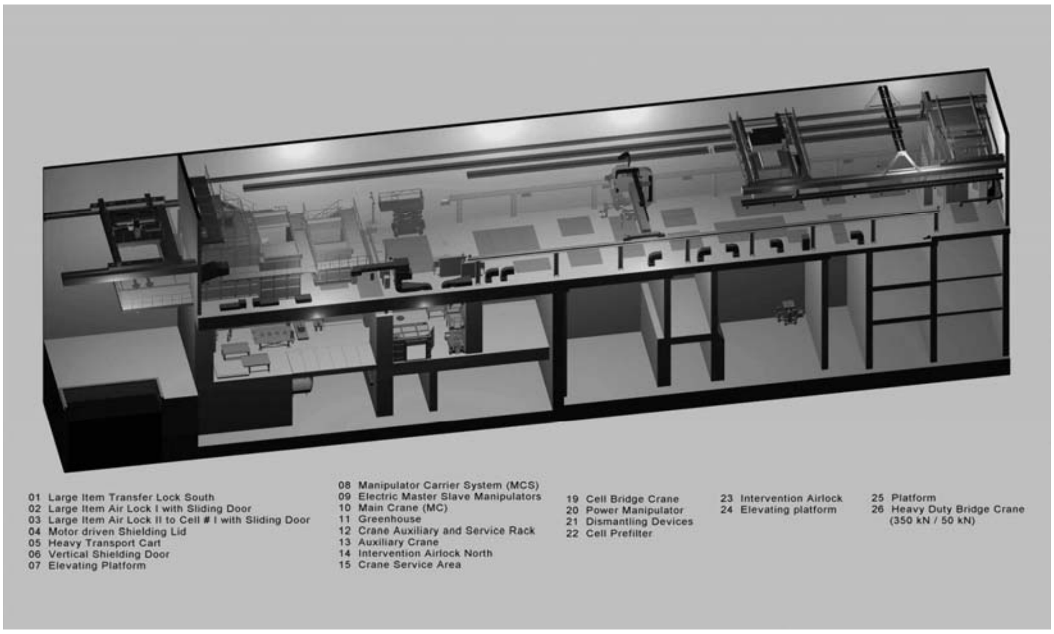
The components such as vessels, pipes, and evaporators etc. to be dismantled had the characteristics of a chemical plant, and were installed in process cells up to 12 m high. The components, which came in contact with the high activated (liquid) waste concentrate (HAWC), are so highly contaminated that the ambient dose rate of

≥ 0.5 mSv/h only allows remote controlled dismantling. Depending on the accessibility to the dismantling area, the disassembly of the components was carried out vertically or horizontally.

Vertical dismantling of four process cells

Figure 58 shows the WAK-Process cells and Figure 52 the manipulator carrier system used (MCS).

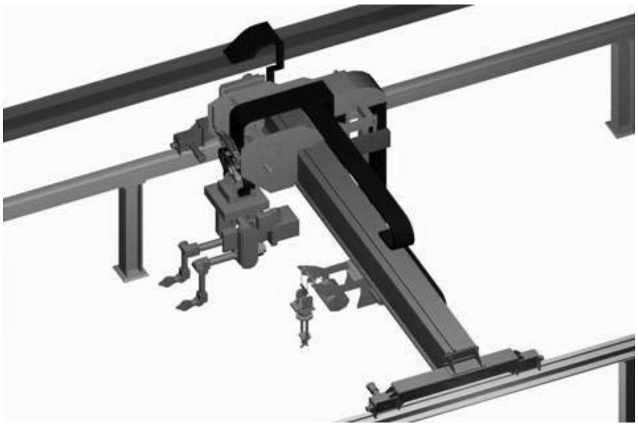
Figure 58: Virtual 3D view of the WAK main process building
Principle layout of the remote handling equipment



The outstanding features of the dismantling systems were:

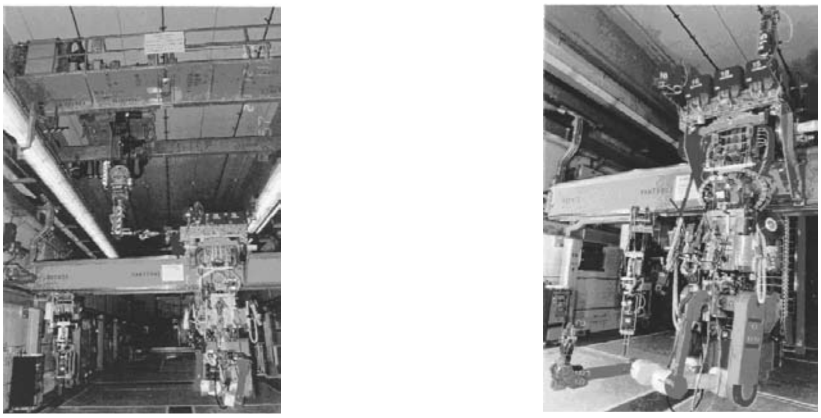
- Crane-like manipulator carrier system for two master slave manipulators.
- Two electromechanical master slave manipulators with bilateral force feedback.
- Manipulator-handled cutting tools and devices such as hydraulic shears, compass saw, disc grinder, etc.
- Crane with contamination protection housing to transport material free of contamination into the WAK main cell hall.
- Auxiliary crane and crane supported auxiliary manipulators for remote controlled recovery and repair work for the manipulator carrier system and master-slave-manipulators.
- Passing and packaging systems.
- Control room for remote controlled operation.

Figure 59: 3D view of the manipulator carrier system (MCS)



Using the above-mentioned remote handling equipment, approx. 102 mg of highly-contaminated material from the process cells with an activity of 2 E14 Bq and a surface dose of up to 100 mSv were successfully dismantled in 2000/2001. To ensure the performance of this project, all technical equipment as well as the dismantling sequences were tested between 1997 and 1999 in a test facility of the Research Centre Karlsruhe, where a 1:1 mock-up of cell was built. Through the previous tests of the dismantling sequences for all cells of the WAK, the whole process was optimized, thus leading to an availability in the range of 86 – 95% for the equipment during hot operation. The estimated dismantling time for all four cells of 3 047 h was insignificantly exceeded (3 281 h) and the work productivity obtained was 31 kg/h, compared to 34 kg/h during testing. The manual work productivity of around 3 - 3.5 kg/h is approx. 10 times higher on the other hand and the risks for work accidents or incorporation are also higher.

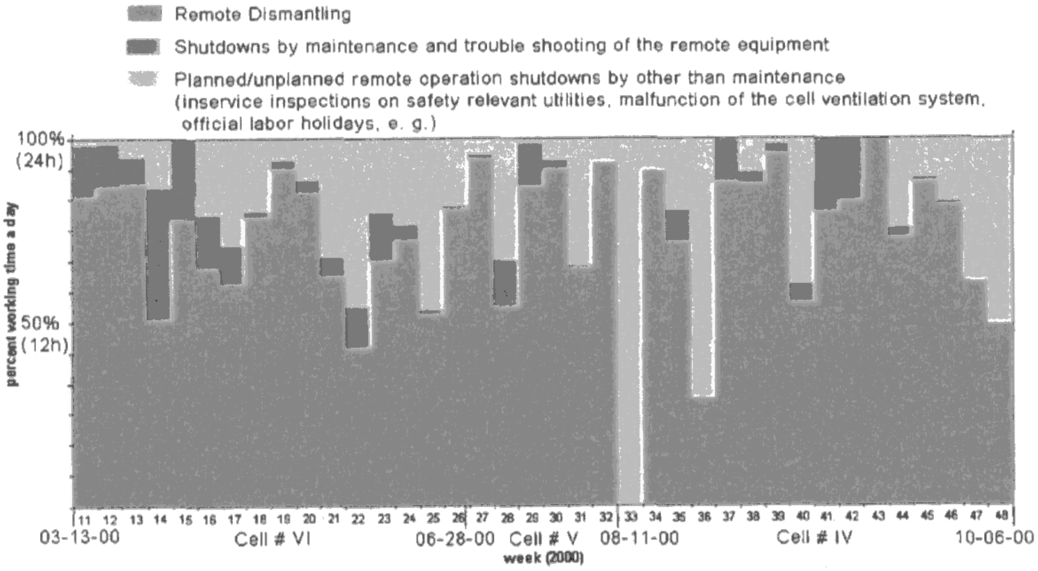
Figure 60: View of the system



3.7.3 Lessons learned

During remote dismantling of Cells IV, V and VI, no dismantling downtime occurred because of unknown (untrained for) dismantling situations. Furthermore, it was not necessary to create new tools and devices. Detailed dismantling manuals, procedures and time schedules that were developed during mock-up operation proved to be very suitable.

Figure 61: Work Loading Diagram Remote Dismantling Cell #IV, V and VI



The remote equipment chosen (e.g. cranes, manipulators, demolition technologies, transfer locks) showed a very high availability of nearly 90%. There was only one incident worthy of note, at the end of remote dismantling of cell V1. One of the slave arms of the EMSM3 suffered a forced rupture of the elbow joint. The broken arm was changed within 8 hours. To ensure manipulator system availability, WAK furnished five slave arms, four master arms and four EMSM3 control units.

Figure 62: Vertical Remote Dismantling Test Facility

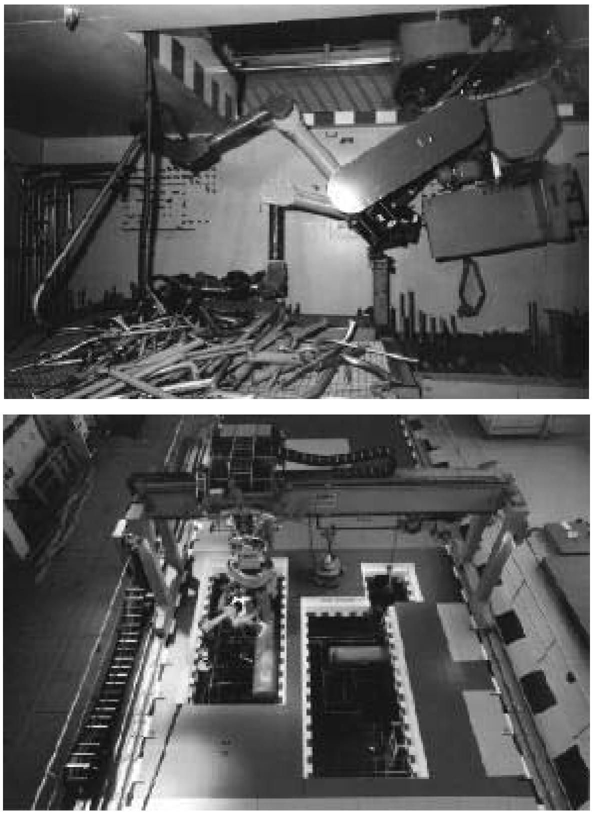


Figure 63: Crane hall above the cells, and the central control room

Based on the operation experiences at the Remote Dismantling Test Facility (TFD), detailed dismantling manuals and time schedules were developed and integrated into the WAK project time schedule. Very important for the time schedule evaluation and planning was the Remote Dismantling Productivity Factor (RDPF) developed at the TFD, which was determined for Cells IV, V and VI to be 34 kg/h on average. The achieved RDPF mean value for these cells was 31 kg/h. The minor loss of productivity was caused by restrictions in the use of the high speed diamond grinder during the dismantling of Cell IV, to avoid the ignition of minor solvent leakages into the cell from vessel and submerged pipe heels, and which could not drained (remotely) before remote cutting.

3.7.4 Bibliography

Lessons learned with the dismantling of the Karlsruhe reprocessing plant WAK – 2000, June 13-16, Knoxville, TN

Remote dismantling of four process cells of the German prototype spent fuel reprocessing plant Karlsruhe, lesson learned

3.8 Chicago Pile 5 (CP5)

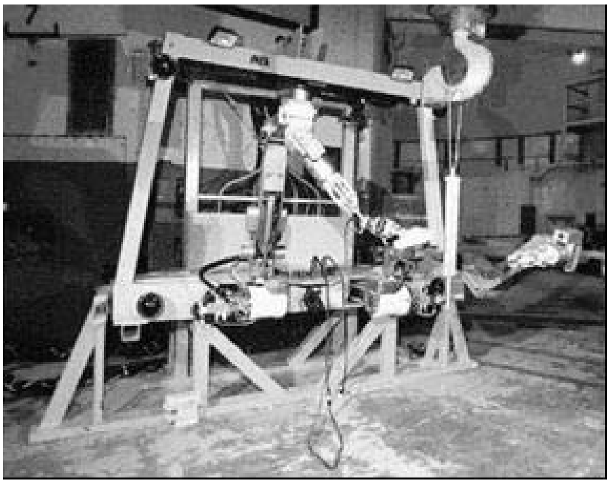
3.8.1 Introduction

The CP-5 reactor was a heterogeneous, heavy water cooled and moderated, enriched uranium fuelled, thermal neutron reactor designed to provide neutrons for research. CP-5 first achieved criticality in February 1954 and operated for twenty-five years until its final shutdown in 1979, when the fuel rods were removed from the reactor and the heavy water was drained from the system. After eighteen years of cool down, CP-5 contained significant activation and contamination problems representative of a nuclear facility.

Figure 64: Artist's rendering of the CP-5 research reactor

Several remote operation technologies were deployed at the Argonne National Laboratory (ANL) Chicago Pile 5 (CP-5) reactor for use in the dismantlement of this reactor. A major remote system was implemented at CP-5: the Dual Arm Work Platform (DAWP).

Figure 65: The DAWP (Dual Arm Work Platform)



The DAWP system was used to perform mechanical dismantlement of the radioactive reactor and bio-shield structures. The DAWP manipulated standard, commercially available tools (i.e., circular saws, jackhammers, etc.) using two Schilling Titan III hydraulic, teleoperated manipulator arms controlled from a remote location.

At the CP-5 reactor facility, the two arms were mounted to a steel work platform (DAWP) designed to hold the associated tooling, utilities, and cameras supporting the operation of the manipulator arms and providing a sturdy base for lifting the assembly into the reactor assembly using the facility's polar crane.

3.8.2 Technology description

The DAWP consists of a platform base, two Schilling Titan III six degrees of freedom (DOF) hydraulically driven manipulators, a remote viewing system, a lighting system, a tool control system, and a tether that supplies the hydraulics, power, and control signals to drive the DAWP functions.

3.8.2.1 Platform Base

The platform base provides the framework for the manipulators and remote systems in a crane-deployable package. The platform is fabricated of steel plate and has bolted and gasketed access panels to all of the internal hydraulic, electrical, and electronic components. The base weighs 4950 lb. Each manipulator is mounted on a 2 DOF actuator package that places a rotary actuator at the end of linear actuator. The linear actuators have 18 inches of range to extend the arm base out into the work space; the rotary actuators have 90 degrees of rotation so that the manipulator base can be moved from horizontal to extend the envelope down.

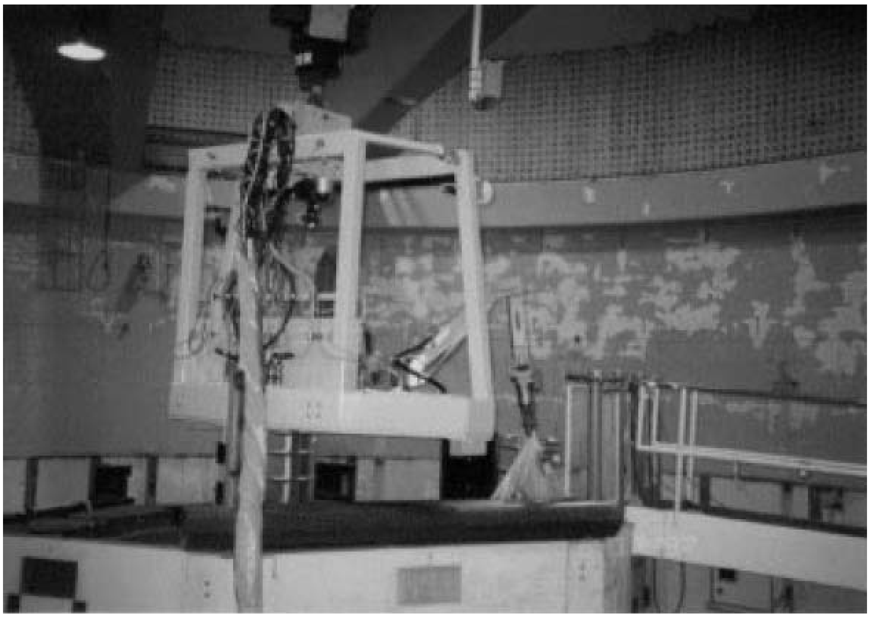
3.8.2.2 Schilling Titan III Manipulators

DAWP's manipulation capabilities are provided by two commercially available Schilling Titan III hydraulic manipulators. These manipulators have the "gamma" option, with smooth external surfaces for easier decontamination. Each arm has a maximum extension of 78 inches and a maximum lift capacity of 240 lb. at full extension. The gripper capacity when fully open is 6 inches; maximum grip force is 1 000 lb. Electrical cabling and hydraulic valving and routing are all done internally to the arms. Each wrist has a force/torque sensor to measure the contact forces applied to objects in the task space.

3.8.2.3 Tool Support

DAWP provides for control of five electrical and two hydraulic tools. The control system can control two electrical tools (or two functions on one tool) or one hydraulic tool at any one time. The electrical tools have environmentally sealed connectors located across the front center of the top of the DAWP deck. The control mode is on/off only. The hydraulic tool control ports are located on the top deck on either side of the row of electrical ports and have quick release "no leak" fittings. Valving internal to the DAWP provides bi-directional control of the hydraulic fluid for the tool.

Figure 66: DAWP suspended from the crane removes trash from the reactor top



3.8.2.4 Tether

The DAWP is designed to minimize (but not eliminate) the on-board electronics and hydraulic valving for radiation tolerance and decontaminability. Therefore, a relatively large diameter tether is required to link the platform to the hydraulics source and control system. The completed length between the basement-mounted power source and the DAWP was 100 ft, but the useable length after accounting for floor pass-through, cable routing, strain relief, and mounting at both ends was 60 ft. The tether was broken out into two bundles and wrapped with a canvas sheath. One bundle contained all electrical power and signal cables. Electrical power delivered through the tether to DAWP consisted of 110/220 VAC used for the tools, 110 VAC used for on-board power supplies, and 12/24 VDC used for the various on-board subsystems. The other tether bundle was hydraulic supply and return only. The two bundles were wrapped separately so that electrical cables would not be damaged in the event of a hydraulic leak. To avoid tangling, the two bundles were strapped together with cable ties to keep them parallel.

3.8.2.5 Field-mounted Control Hardware and Hydraulic Power Unit (HPU)

For CP-5, the control hardware rack and the hydraulic power unit (HPU) were mounted in the basement away from the radiation and contamination hazards expected in the reactor shell. DAWP uses a commercial Schilling-supplied HPU, mounted on wheels so that it may be readily moved. A cooler is provided in the circuit to keep the hydraulic fluid at an acceptable temperature at all times. The hydraulic fluid used in the DAWP (manipulators, base degrees of freedom, and hydraulic tooling) was Houghto-SafeTM 620 water-glycol. Maximum useful operating temperature of the fluid is 140 degrees F.

3.8.2.6 Operator Control Station

The DAWP operator control station consisted of a video console, control chair, master controller station, and the Virtual window stereo viewing system.

The master control station provided a mount for the two Schilling minimaster controllers.

DAWP deploys two colour stereo camera systems and seven standard NTSC auxiliary cameras. The stereoscopic camera was found to be more of a hindrance than a benefit during the D&D (Decontamination and Decommissioning) activities as the stereoscopic camera does not have the ability to zoom, and the stereo vision was found to cause headaches after prolonged use.

Figure 67: DAWP operator control room

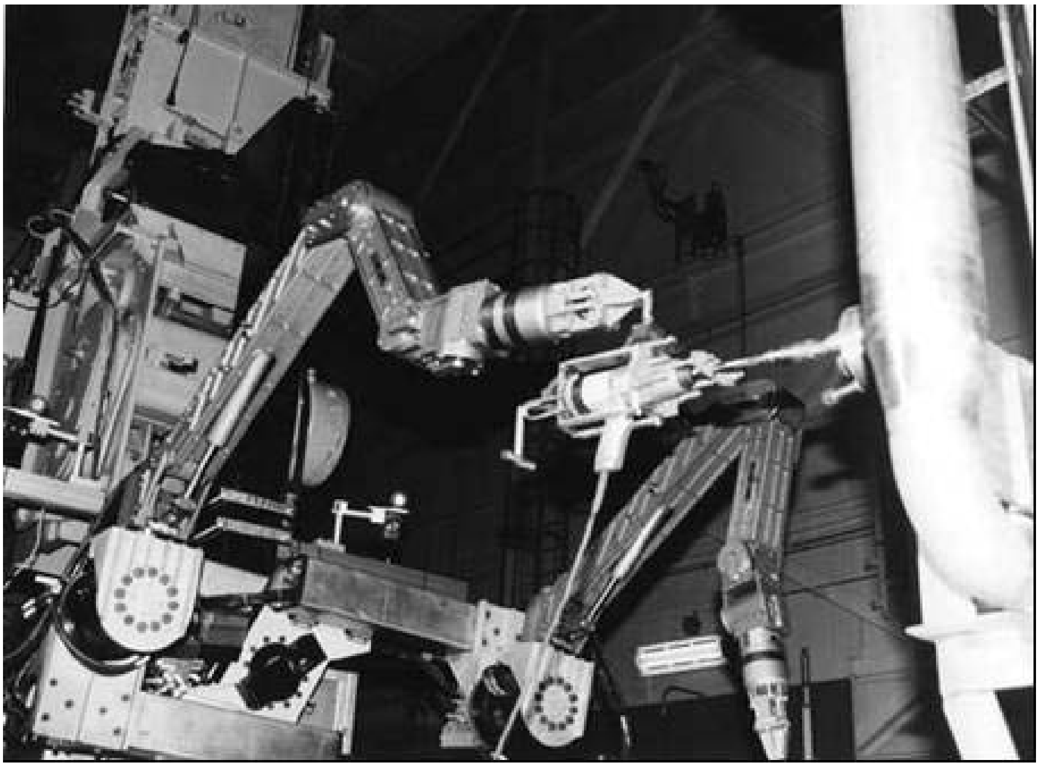
The DAWP software included an IGRIP computerized representation of the reactor and the individual components. This model could be used to experiment with different dismantling techniques and sequences prior to actual D&D. However, the computer model was based on existing facility drawings, which were often inaccurate. Because the source drawings were inaccurate, the IGRIP model was inaccurate. Therefore, while this could potentially be a very helpful tool, the IGRIP model was rarely used during the demonstration.

3.8.3 DAWP demonstration

The DAWP demonstration focused on the use of the DAWP to segment and dismantle the CP-5 reactor tank and surrounding bio-shield components (including the graphite block reflector, lead and boral sheeting) and to perform some minor tasks best suited for the use of teleoperated robotics. The DAWP was provided by a consortium of national laboratories and industry manufacturers. Individual components and subassemblies were purchased from or provided by Schilling Robotics Systems, RedZone Robotics, ORNL (Oak Ridge National Laboratory) and INEEL (Idaho National Engineering and Environmental Laboratory).

The demonstration was performed at the Argonne National Laboratory (ANL) CP-5 Research Reactor from June through September 1997. The DAWP's ability to remotely cut and dismantle the aluminium reactor tank, disassemble the graphite, boral, and lead subassemblies, and transfer these materials to a staging area was tested. The system could be operated by someone approximately 250 feet away without direct line-of-sight.

Figure 68: DAWP at work



ORNL provided an initial set of tools: impact wrenches, a powered right-angle drive, side grinders with cut-off wheels, reciprocating saws, circular saws, a router-based milling head, and drills. As time went on, ANL became more involved in tool selection and modification for remote use, including hand-held band saws, heavy-duty circular saws, and impact chisels. Cutting tools used vegetable oil-based lubrication systems to extend blade life. No flame based cutting was allowed, and the use of pneumatics was discouraged because of concerns over the spread of contamination.

The key results of the demonstration are as follows: the DAWP

- Removed 5300lbs. of graphite blocks, 1400lbs. of lead sheeting, 620 lbs. of boral, 2 000 lbs. of carbon steel;
- Untorqued and removed 26 of the 36 carbon steel studs in the reactor tank's top flange;
- Size reduced and dismantled a significant portion of the aluminium reactor tank (following approximately 200 linear feet of cuts through 3/8 - 3/4" aluminium plating), and removed the resultant 600 lbs. of aluminium plate from the reactor tank assembly.
- Was controlled by two operators working in an adjacent control room. This way, personnel could maintain a safe distance from the radiation in the CP-5 reactor. The DAWP was operating in a radiation field averaging 0.75 to 2.0 R/hr for the duration of this work. By using this remote system, conservatively speaking, approximately 15 person-rem of exposure was saved.

- Obtained data concerning the training of previously untrained technicians into competent DAWP operators. This demonstration showed that technicians were considered trained after an average of approximately 8 hours formal training and approximately 40 hours of mock-up training.
- Can be moved to a low dose or protected area for maintenance operations, reducing personnel exposure during these procedures. The DAWP is capable of disengaging and re-engaging tools remotely, so that a variety of tasks can be performed without down time or removing the robot from the hazardous environment.
- The DAWP did experience numerous troubles on start-up. The primary problem arose with the hydraulic fluid. Each arm had to be decontaminated and sent back to the manufacturer to be rebuilt. It is believed the Houghto-SafeTM either disintegrated o-rings in the arm or otherwise caused damage within the arms. The result was often heavy leaks which required the cession of work. The DAWP was able to function with only one arm. However, for future operations the purchase of a spare arm, to be attached if an arm in use breaks down, is highly recommended.
- Other problems occurred with the overheating of the system (a second heat exchanger was added, solving the problems), some software glitches, and minor troubles with manipulating the tools. As operational knowledge of the robots and the proficiency of the operators increased, most of these problems were solved.
- Having an on-site technician capable of performing routine and preventative maintenance is essential in avoiding costly decontamination of parts.

The DAWP continued to serve as the mechanism for dismantling the reactor vessel and remove the graphite moderator.

3.8.4 Costs

The cost analysis compares the relative costs of the innovative technology of the Dual Arm Platform to a baseline technology of manual dismantling.

The manual method is assumed to use a robotic arm which is suspended from a crane. The baseline method was not demonstrated, but is developed from previous budget estimates for the D&D of the reactor core and the test engineer's experience with previous manual demolitions.

Summary of unit costs and production rates observed during the demonstration

DAWP			Baseline technology		
Cost Element	**Unit Cost**	**Production Rate**	**Cost Element**	**Unit Cost**	**Production Rate**
Cut reactor tank	354 $/m	0,91 m/h	Cut reactor tank	505 $/m	0.82 m/h
Dismantle graphite and Boral	14.4 $/kg	22,7 kg/h	Dismantle graphite and Boral	25.2 $/kg	14.5 kg/h
Remove Debris	5.2 $/kg	63,5 kg/h	Remove Debris	6.7 $/kg	63,5 kg/h

The unit costs and production rates shown do not include mobilization, set-up, maintenance/repair or other losses associated with non-productive portions of the work (such as suit-up, breaks, etc.). The intention of this table is to show unit costs at their elemental level which are free of site specific factors (such as work culture or work environment influences on productivity loss factors).

Another issue for DAWP is its cost to build. The $1.21 million for labor and materials required to build DAWP may be beyond the budget available for some DOE (Department of Energy) sites. This cost analysis was based on an amortized cost for DAWP over 20 years of continual work (with annual repairs of $10,000).

Finally, the costs shown do not consider the learning curve required for workers to become skilled in using the DAWP. The workers in this demonstration required a significant amount of time to become proficient with the DAWP.

3.8.5 Lessons learned

Although the DAWP is a viable D&D tool, it is not a commercially available product at this time. The CP-5 implementation was its first application. Numerous areas for improvement were found. Some are lessons learned, and some will require improvements in the technology, to be included in subsequent generations of the DAWP. The following are highlights:

- Setup time and complexity were considerable; a commercial version should consider the use of a control trailer for the operator station and standardized pallets for in-facility control hardware to minimize impact on the facility where the equipment is to be used.
- The greatest problem was associated with leaks within the arms, due primarily to the use of Houghto-SafeTM, a glycol-based non-hazardous hydraulic fluid. Houghto-SafeTM was used to prevent introducing hazardous materials into a radioactive environment. However, the commercially available Schilling manipulator arms were not designed for this fluid, and many leaks and resulting downtime occurred at the beginning of the demonstration. It is believed that the Houghto-SafeTM degraded the fittings in the arms. While there was no operations or personnel safety concern, this was the primary reason for these leaks and resulted in very significant downtimes. However, waste acceptance criteria appear to be tightening against glycol, and testing at CP-5 showed that water-glycol is corrosive to electrical connections internal to the manipulator. A mineral oil-based fluid would be a better choice in future systems.
- Some maintenance activities required the manipulator arm to be sent back to Schilling for repairs, and a considerable source of downtime was attributed to shipping out one or both arms for maintenance. Commercial users of the DAWP are strongly encouraged to purchase a third spare arm, and if possible, train a nuclear technician in the maintenance of the DAWP. This will save downtime, decontamination of the arms, and vendor costs.
- The greatest weakness was the system’s tether management. The tether is the lifeline for this system. Movement of the system required careful attention to tether manipulation. Additionally, if a break in the communication between the CPU and the arms occurred (through a break in the tether or a computer glitch) the arms would automatically release grip tension, thus dropping any tools, materials, etc. into the reactor. A commercial version should consider a custom made tether and tether management system.

- The training of a core group of operators (4) and one supervisor required over 200 hours of cumulative operating time.
- The controls architecture was chosen and designed to have extensive capability to support research activities; however, this required a high degree of hardware and software complexity that is not conducive to the operations environment. Operators were frequently overwhelmed by too many choices in the controllers, remote viewing, tooling, etc. and the level of computer literacy was radically different from that of the research staff. While this was expected and while an attempt was made to compensate for this difference in the initial design, the typical operator still had difficultly adapting. Controls should be simplified further, and operator choices limited.
- Relatively expensive, environmentally sealed electrical connectors were used for the electrical tool connection to the base platform in order to permit wash-down decontamination of the system. Practical experience in operation and decontamination showed that standard covered AC outlets rated for outdoor use should be sufficient.
- Commercially available dome cameras were used on DAWP in order to control cost and to permit greater field of view coverage. These cameras had some problems with glare and bloom due to the lighting in the reactor shell and also had mechanical failures in the motorized lenses. More robust cameras could be considered but have a cost increase factor of roughly three. The cheaper cameras did not have any radiation-related failures.

Ultimately the benefits of a remote controlled system such as the DAWP must be weighed against the cost of such a system. In high exposure projects, the DAWP can be extremely useful for performing tasks while reducing doses to personnel.

3.8.6 Bibliography

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U.S. Department of Energy - Office of Environmental Management Office of Science and Technology – Innovative technology summary report DOE/EM-0389

3.9 Tokai 1

3.9.1 Introduction

Tokai-1 (GCR, Gas Cooled Reactor), a nuclear power plant of the Japan Atomic Power Company (JAPC), started operation in 1966 as the first commercial nuclear power plant in Japan, and ceased its operation in 1998 after 32 years. JAPC launched Tokai-1 decommissioning in December 2001.

3.9.2 Progress and achievements

The key Tokai-1 project dates are:

1966	Commercial operation started.
1998	Reactor permanent shutdown.
1998-2001	Fuel discharged and shipped.
2001-2005	First phase of decommissioning project.
2006-	Second phase of decommissioning project.

3.9.3 Technology description

SRUs (Steam Raising Unit) and primary gas ducts outside of safe-storage area have been dismantled since 2006. Each of the four SRUs is nominally 25 m in height, 6 m in diameter and 750 t. After peripherals such as feed water and steam piping, drums, and gas ducts were removed, preparatory work for SRU removal including the installation of remote cutting systems and a jack system were completed. Now it is under final mechanical adjustment state.

3.9.3.1 Description of the remote dismantling system

(1) Primary cutting system

A primary cutting system, consisting of following devices, has been installed on a SRU for the remote cutting of the SRU shell and internals. Access to objects, cutting, and transportation are managed by the system.

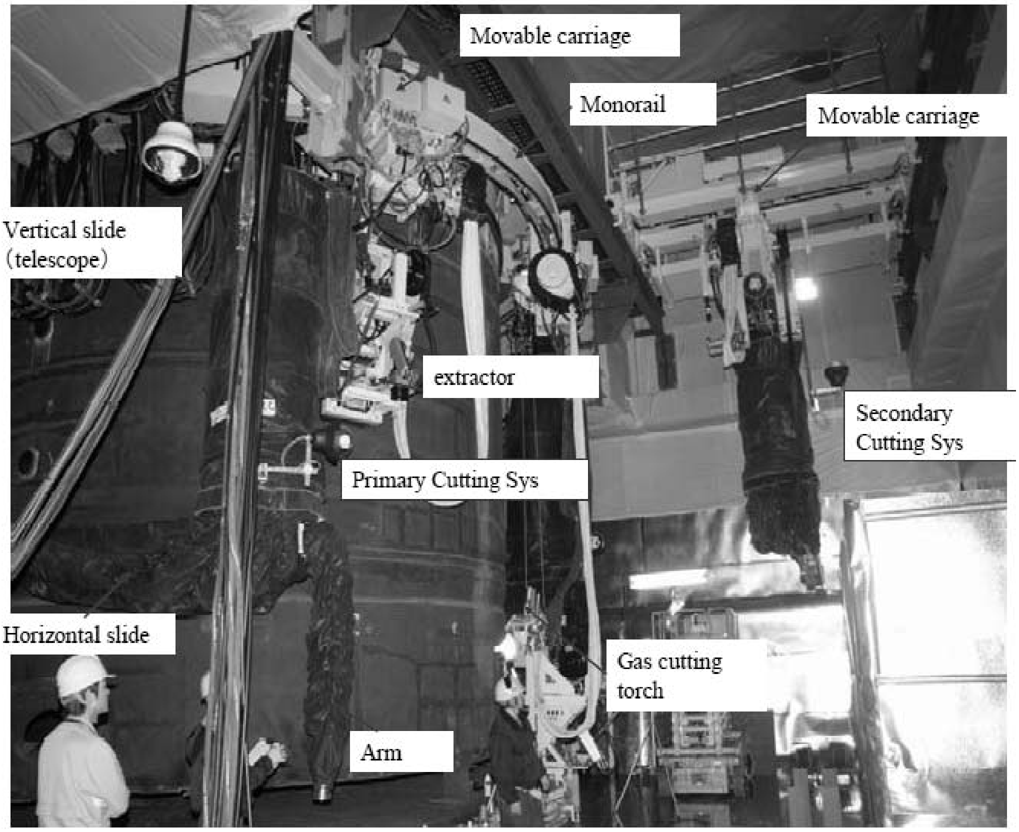
① Devices

- Monorail and electric carriage.
- Vertical slide machinery.
- Rotating mechanism at the bottom of slide and horizontal slide.
- Manipulator arm.
- Extractor.
- Control system;

② Tools

- Gas cutting torch.
- Hydraulic pressure disk and electric disk.
- Camera for visual confirmation of internal cutting.
- Power brush.
- Gripper.

Figure 69: View of the system



(2) Secondary cutting system

Segmented units cut by the primary cutting device are then cut by the secondary cutting system into sizes that can be put into their transportation cask.

The secondary cutting system consists of the following devices:

①. Devices

- Movable rail and electric carriage.
- Vertical slide machinery.
- Rotating mechanism at the bottom of slide and horizontal slide.
- Manipulator arm.
- Remote gripping and transport device.
- Control system.

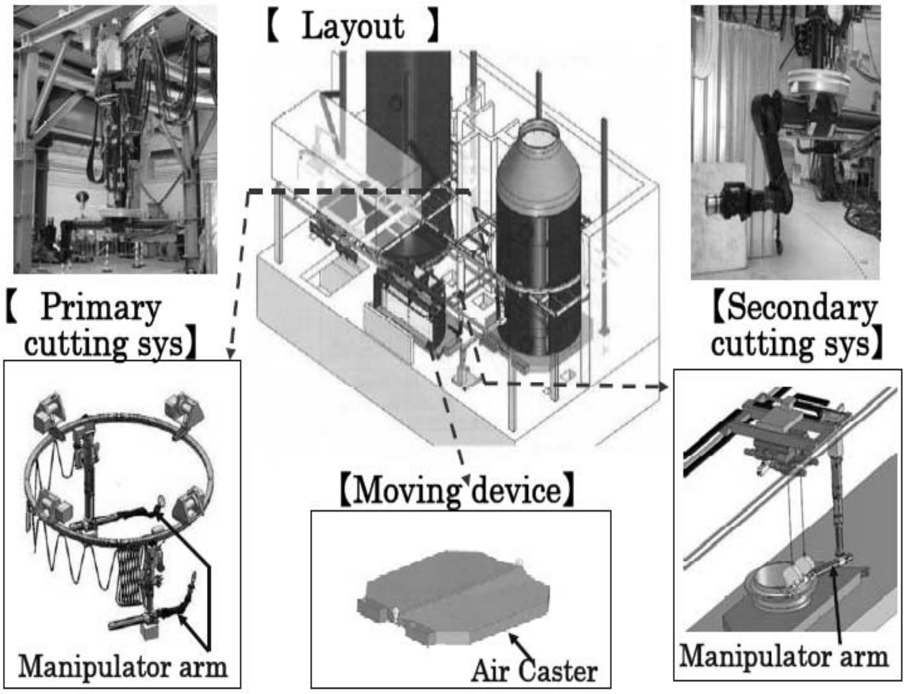
②. Tools

- Gas cutting torch.
- Hydraulic pressure disk.
- Gripper.

(3) Additional equipment

An air caster transports units segmented by the primary cutting device to the secondary cutting area.

Figure 70: The remote cutting device



3.9.3.2 Mechanism of the remote cutting device

(1) Mechanism of the primary cutting device

①. Monorail and electric carriage

The monorail holds two primary cutting devices each weighing 10 tons. The monorail is hoisted by the monorail hoist from a frame structure monorail support. The monorail can correct its position in response to SRU movement while the SRU is jacked up and jacked down. The carriage has an electrical variable speed motor.

②. Vertical slide machinery

Cylindrical extendable vertical slide machinery is attached to the electric carriage. The extendable part has one fixed part and two flexible parts, operated by hydraulic jacks. A two metre flexible range permits flexible cutting.

③. Rotating mechanism at the bottom of slide and horizontal slide

A rotating shaft and horizontal slide mechanism is installed at the bottom of the vertical slide. The electric motor-driven rotating shaft allows manipulator arm positioning by rotating the horizontal slide.

A two meter horizontal slide mechanism, non extendable, allows the manipulator arm to access the centre of the SRU while cutting SRU internals.

④. Manipulator arm

The hydraulically operated manipulator arm consists of six axes. These six axes provide the flexibility necessary to complete all the cuts required to dismantle the SRUs.

⑤. Extractor

Before cutting the SRU internals, the SRU shell surface was cut to make windows for access to the internals. The extractor is a device fitted with an electrical magnet to hold, remove and then transfer SRU shell surfaces in order to make these access windows.

⑥. Control system

The entire remote cutting system is controlled by the control system. It consists of a manipulator arm control table, a 3D monitor, a monitoring camera and a joystick.

(2) Tool details

①. Gas cutting torch

The gas cutting torch, capable of cutting 200 mm/minute in the range of 50 mm to 170 mm thickness carbon steel, was used for SRU shell cutting. LPG (Liquefied Petroleum Gas) and oxygen gas were used. The torch was able to cut some parts of the SRU shell with attached 70 mm thickness parts.

②. Hydraulic pressure disk and electric disk

Each disk is capable of cutting 30 mm/minute carbon steel of 5 mm thickness. The disks were mainly used for SRU internals. An electric disk was especially used in narrow areas.

③. Camera for visual confirmation of internal cutting

This is a camera used to confirm the status of internal cutting.

④. Power brush

This is a tool to remove rusts on the surface of an SRU window before the extractor gripped the segmented window with its electrical magnet.

⑤. Gripper

This is a tool to remove extraneous material.

(3) Details of the secondary cutting system

The secondary cutting system is a device to cut pieces segmented by the primary cutting system into smaller pieces. Therefore, the secondary cutting system has the same basic mechanisms as the primary cutting system, but does not include the access mechanisms for the internals which the primary cutting system has.

Remote gripping and transport device

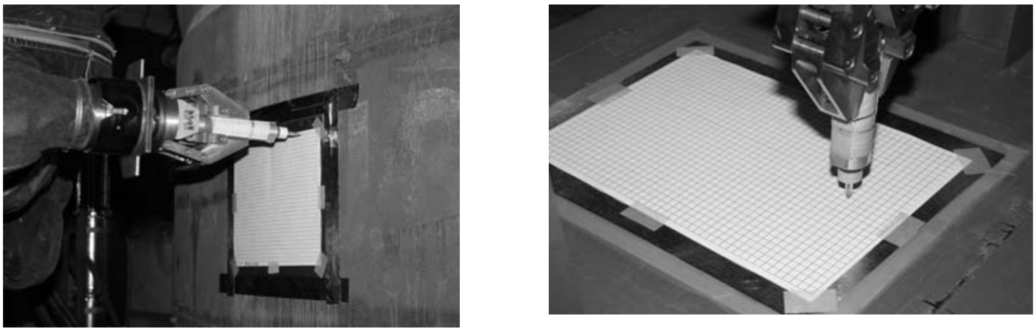
The remote gripping and transport device has three kinds of gripper, with two grippers of each kind. One gripper is able to transfer 1 ton carbon steel plate in the range of 50 mm to 170 mm thickness. Another is a magnet to transfer 0.3 ton carbon steel plate 5 mm thickness. A third device is used to move heat transfer tubes.

(4) Details of additional equipment

①. Air Caster

It is capable of transferring items (max 75 tons) segmented by the primary cutting devices from the primary cutting area to the secondary cutting area.

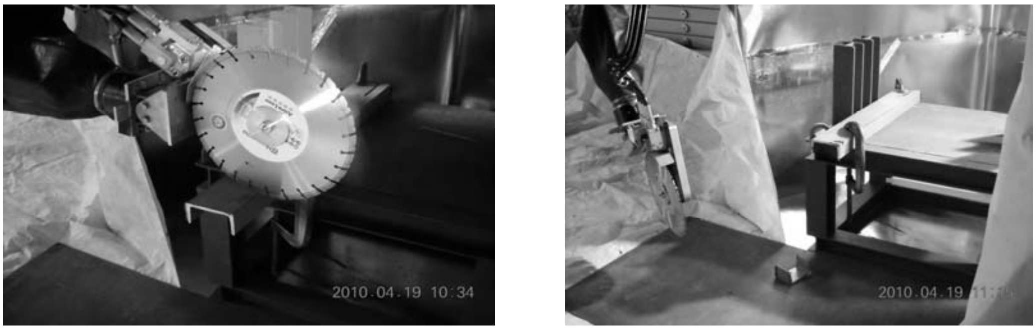
Figure 71: Linearity movement test



X direction

Z direction

Figure 72: Cutting test (diamond disk cutter)



Before cutting

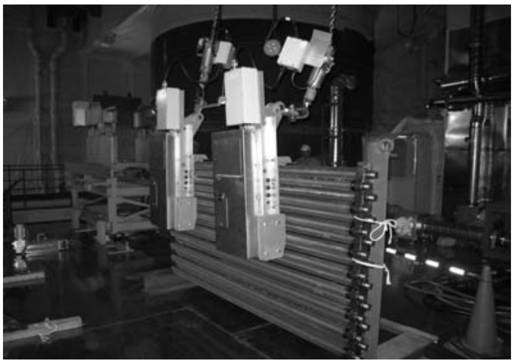
After cutting

Figure 73: Remote grip and transfer device - Handling tests using test pieces

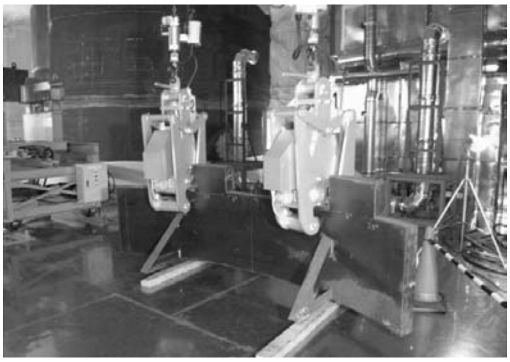
Test Shell lift by Gripper system

Test plate hold by Magnet system (Baffle plate)

Test tube grasp by Clamp system
(Boiler tube)



Test Shell grasp by Gripper system



3.9.4 Lesson learned

(1) Improvement of equipment

The following improvements were carried out during the design and manufacturing phases, to improve user friendliness:

①. Development and introduction of high pressure gas cutting device

The gas cutting device can cut an object stably if the length between the end of the torch and object is less than 10 centimeters. This enables the SRU wall to be cut with any juts in a single passage.

②. Addition of collision prevention function

In addition to an automatic shutoff device in case of overload, there are collision prevention zones in the 3D model of the SRU and its building, to stop movement automatically if a cutting device goes into the collision prevention zone for the primary cutting system. As well as a collision prevention zone between cutting devices and transport devices (KPS products) in the 3D model for the collision prevention function, the secondary cutting system has an automatic stop device based on sensors between the devices.

③. Increased extractor suction power

The power of the cut piece suction has been increased, to prevent cut pieces being dropped because of dross generated while cutting (100kg•550kg).

④. Introduction of the latest robotic control

The latest control devices simplify movement simulation, collision prevention, operation procedure input and movement.

⑤. Monorail structure change

The monorail was originally designed as an all-in-one unit that would require lengthy maintenance if a breakdown occurred. Changing to a part-based structure shortens maintenance time and enables part procurement in Japan.

(2) Improvement of testing conditions

①. Addition of test parts

Areas where there are many objects and parts which are difficult to cut were selected for the cutting test at the factory. But additional cutting objects were manufactured to cover all types of conditions, and tested.

②. Change of test conditions

Cutting test conditions (gas pressure, disk cutting feed speed, with or without lighting) were varied to get data for a large number of parameters.

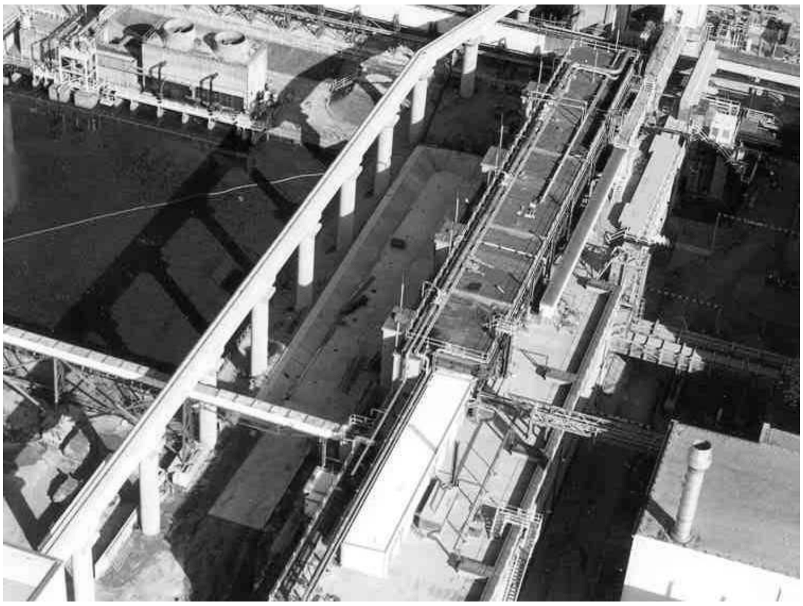
③. Device improvements

Another monitor camera and a zoom function for the SRU internal cutting monitoring camera were added, as factory tests had shown that clear visibility while cutting is important.

3.10 Caesium Extraction Plant (CEP)

3.10.1 Introduction

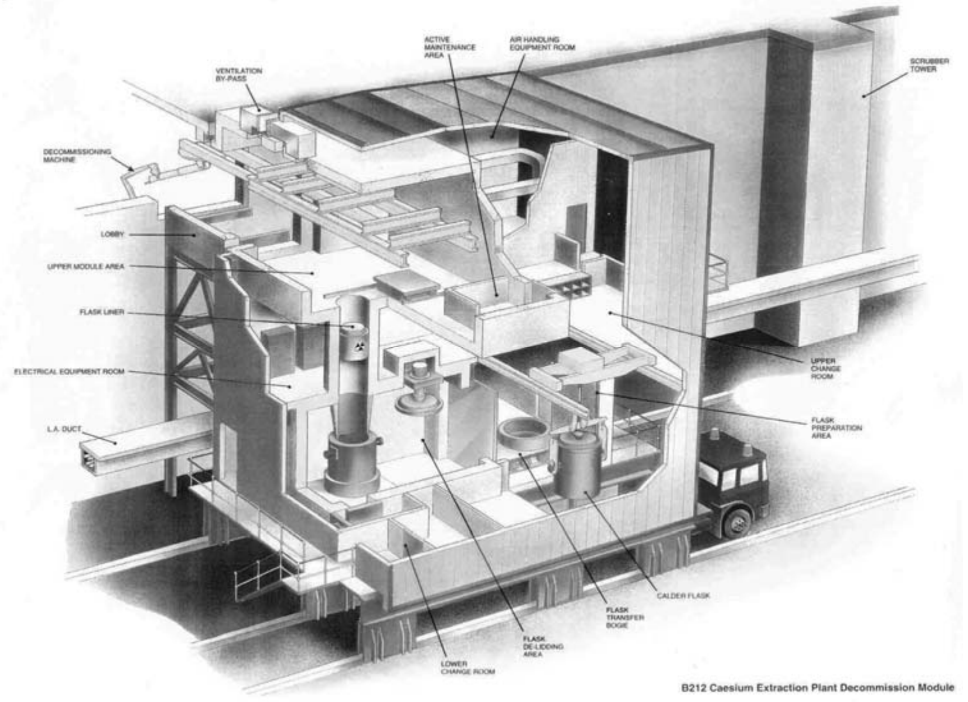
The Caesium Extraction Plant (CEP) at Sellafield was built in the mid 1950s as part of the expansion of the UK civil nuclear power programme. The CEP was designed as a pilot plant to produce a small number of caesium sources for radiotherapy purposes using highly active liquor, a product of reprocessing, as the feedstock for the process. The plant was also used to produce caesium, strontium and raffinate solutions for transportation to the Radiochemical Centre at Harwell Laboratories.



Following operational difficulties, the plant was closed in 1958 and following minimal decommissioning of pipework and control faces, it remained under storage status with no further work other than monitoring and cosmetic improvements to the associated plant rooms.

A Nuclear Installations Inspectorate assessment in 1986 identified the caesium extraction plant as a high hazard area, with significant levels of radiation and contamination being contained in a poorly ventilated, ageing building. This initiated the decommissioning of the plant inventory, beginning with plant inspections in the early 1990s and with initial waste retrieval operations beginning in 2000.

This was achieved using a 900 tonne decommissioning module, mounted on rails to allow entry into 4 areas within the B212 building. The module housed the decommissioning machine (DCM), associated tooling, cask and waste handling equipment and sub change areas.

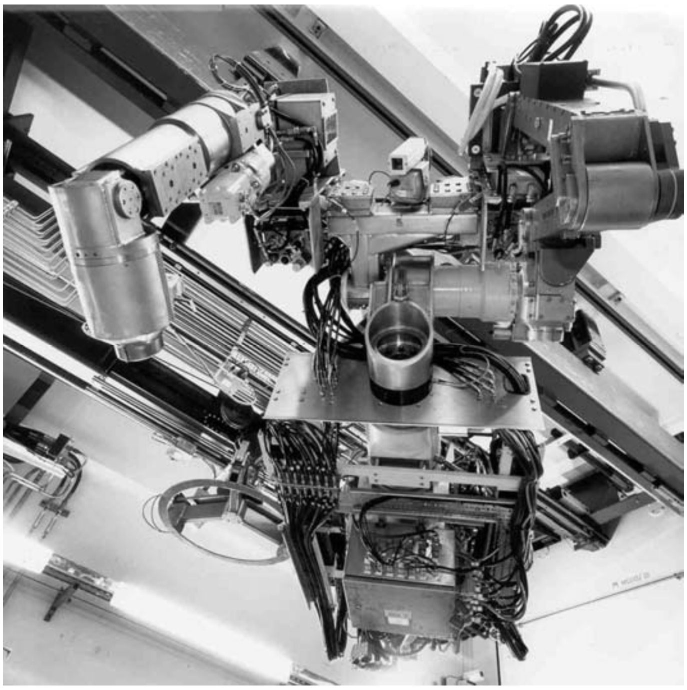


B212 Caesium Extraction Plant Decommission Module

3.10.2 Decommissioning machine and tooling

The decommissioning machine is essentially a tool deployment system mounted on a cantilever section beam over 5 metres long, and which is suspended from a carriage that runs on rails within the module. On the end of this beam is a slewing ring, on which is mounted a large extension cylinder over 2m in length and extending by another 2 metres.

A tilting table then allows the mounting of two large tools such as a Schilling Rigmaster and a Tool Deployment System (TDS). The rigmaster is a basic grab and hold manipulator with a payload approaching 250 kgs, and the TDS is an equally capable deployment system that can carry 110Volts AC, 200 Bar hydraulics, as well as many 24 Volt signals to smaller dedicated tooling at the front end via a remote coupling system known as the Arterial Connection System (ACS).



3.10.3 Typical remote operations

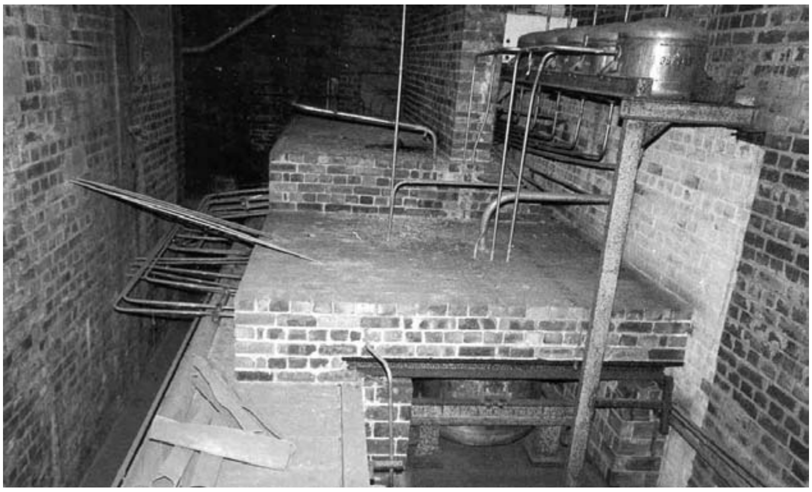
The process of decommissioning involved the size reduction and removal of brickwork, structural steelwork, stainless steel pipework and vessels.

This work took place within void areas that still contained active pipework essential to operations for highly active liquor evaporation and storage across Sellafield Site. The inability to substantiate the building integrity also called for a very gentle decommissioning strategy, with minimal impact on the structure of the tank cells below.

Cell 1 shown below housed stainless steel process equipment with large vessels up to 1.5m diameter possibly holding residual liquors.

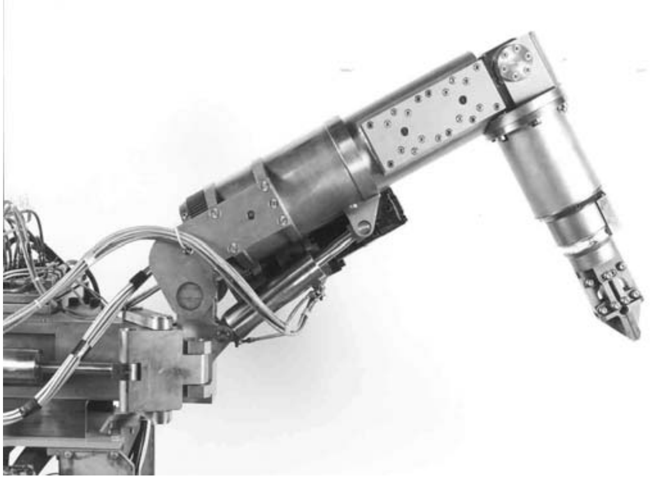
Cell 2, shown below, housed many glass vessels, again with the potential for residual liquors, as well as ion exchange columns, and castner kellner cells which could have contained significant quantities of mercury. Radiation levels in this cell were in the region of 5 Svhr^{-1}.

The feed and effluent cell, currently being decommissioned, involves a greater amount of material removal to gain access to the process equipment, with large amounts of brickwork and steelwork. This puts an additional strain on both the front end tooling and the decommissioning machine structure.



3.10.4 Tool deployment system (TDS)

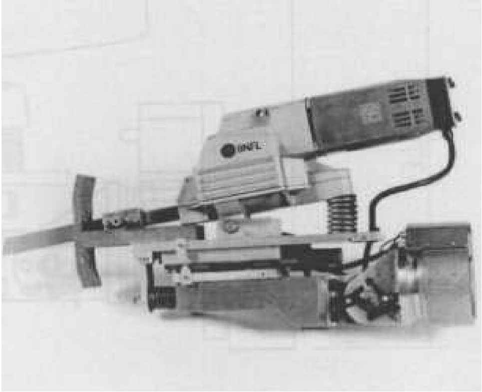
The majority of the decommissioning work was undertaken by a bespoke tool deployment arm. The TDS is capable of a payload of over 250kgs and can deliver 200 bar hydraulic supply, 110 volt AC, and several 24 volt DC signals to smaller tooling at the front end. The smaller tooling is connected via an arterial connection system design which can be remotely latched for in-cell tool changes.



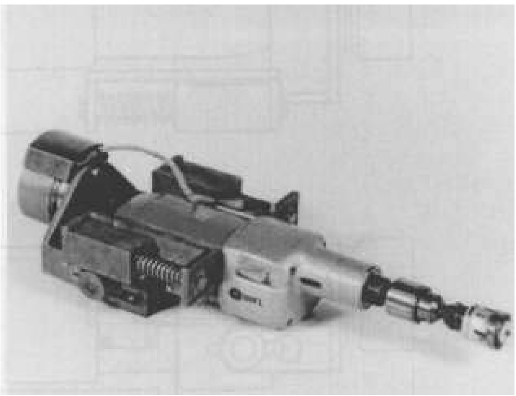
The cost of the TDS was in the region of £75,000 in 2004, and included the tool change base on which it is mounted and the control valve assembly which sits directly behind the arm.

Smaller tooling deployed on the front of the TDS via the arterial connection system included jaws, reciprocating saw, core drill, hydraulic shear, concrete breaker, and glass vessel handler.

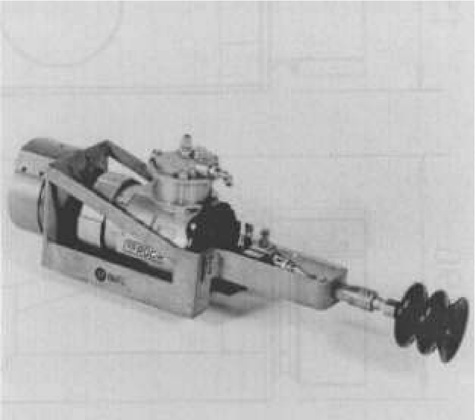
FEIN Reciprocating Saw 110V AC



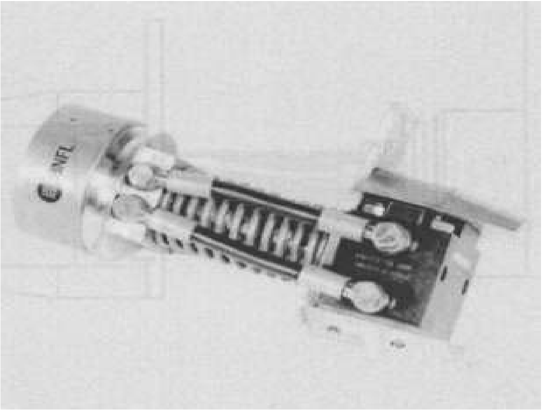
FEIN Core Drill 110V AC



Glass Vessel Handler 110V AC



Hydraulic Brick Burster 200 bar



3.10.5 Lessons learned

3.10.5.1 General

The B212 CEP Decommissioning Project went through extensive inactive trials at an off site facility, with the main deployment machine being set up in front of cell mock ups to trial accessibility and tooling design.

Whilst this generally proved to be a successful approach, many of the tools have been upgraded or indeed not used since operations began. Tooling maintenance has had to be reconsidered almost from scratch, with very little evidence of it having been included in the design process.

3.10.5.2 Tooling

When the project was taken into active commissioning, the front end tooling consisted of many different types, which have offered varying degrees of success. Some are off the shelf tools with minor modifications, simply mounted onto a compliant assembly, whereas others are bespoke tooling designed for the project.

Off the Shelf

- General purpose jaw.
- FEIN reciprocating saw.
- FEIN core drill.
- HILTI hammer chisel drill.
- HILTI concrete breaker.
- Vacuum glass vessel handler.
- HILTI nail gun.
- Modified rebar cutter.

Bespoke

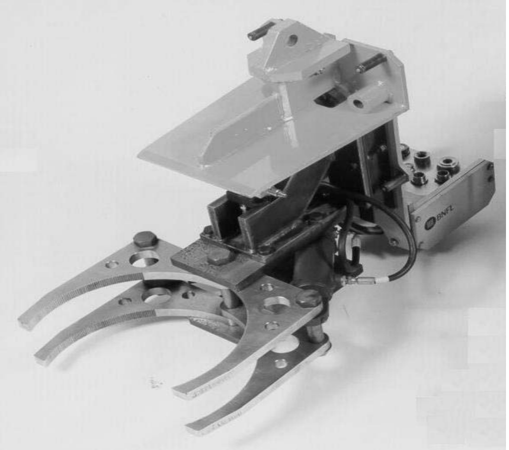
- Brick burster.
- Magnetic lifter.
- Lead brick grab.
- Shield wall splitter.
- Brick removal tool.
- Vacuum system.
- Scrapers and shovels.
- Peristaltic liquor pump.
- Sampling dipstick.
- Granule dispenser.
- Spreader.
- Debris collection device.

What can be seen here is an attempt at the design stage to solve every problem with a particular design solution. However, experience has shown that the majority of the tasks could be undertaken with the simpler, more robust tools.

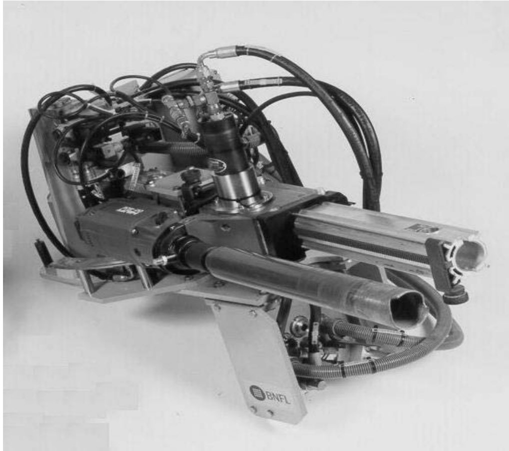
The tooling that did the majority of the work includes the saw, drill, jaws, breaker and vacuum glass vessel handler. A hydraulic shear was also introduced since active commissioning, and was used to cut a large proportion of the small bore pipework in each of the 3 cells completed.

Larger front end tooling was also designed and trialled, such as a bespoke furnace grab, and a concrete coring drill, both of which could be mounted on the front of the decommissioning machine instead of the manipulators.

RTC Furnace Grab



RTC Coring Drill



RTC: Radio Transmission Control.

Neither of these tools was used during the decommissioning of Cells 1, 2 and 3.

It is now the project's view that initial design and trialling should have concentrated on the robust design of a smaller selection of tooling, with consideration for maintenance and part replacement being given equal importance with the operation of the tool itself. The majority of the successful tooling had minimal alterations other than attachment to a compliant mount. Not only do these tools work better and last longer, but spares remain readily available.

Bespoke tooling designed from scratch, such as the lead brick grab and the brick removal tool, proved unreliable and expensive, and was not used actively on the project.

3.10.5.3 Maintenance

The front end tooling doing most of the work was the Tool Deployment System shown previously. Whilst cleaning and handling of the unit had some consideration during the module design, its maintenance was not given much thought

During active operations it became obvious that any work on the TDS would halt operations, as it had to take place in the upper module cell which housed the decommissioning machine.

Later design of handling equipment and use of sub change areas allowed the front end of the TDS to be removed separately and worked on outside the active cell. A quick front end arm changeover method was worked up, which kept the disruption to front end operations to a minimum.

This approach has been successful because of the efforts in keeping the upper module and associated tooling clean with weekly clean-downs. This redesigned approach would not have worked if the tooling had become more contaminated.

The operator/maintainer teams were also a factor in the success of the ongoing design changes. The same personnel used during on and off site commissioning of the decommissioning machine were responsible for its day to day maintenance, troubleshooting, repairs and the introduction of tooling improvements. This resulted in significant cost savings, reduced downtime compared to plants with dedicated maintenance teams, and increased efficiency for operations.

3.10.6 Conclusion

The unknown areas involved in many decommissioning projects are at the work face itself, and it is the front end tooling that connects at this point and determines whether the task is completed in a satisfactory way.

However, it is this tooling that is perhaps given the least thought or scrutiny during the design process. Cask and liner handling equipment, ventilation systems and process equipment can all be designed with a good degree of confidence in their operation, but front end tooling can involve a lot more of a “try it and see” approach. The B212 CEP decommissioning project would have benefited from a smaller range of tooling being designed and developed to a better standard before operations began. This would have allowed the team to concentrate on the real unknowns within the operations environment.

4. Conclusion

During the D&D process, the handling of highly radioactive materials, the deployment of tools and sensors and the dismantling of components built from many different materials can be a long, labor-intensive process that has the potential for high exposure rates, heat stress and injury to personnel.

Mobile robotics systems provide solutions to these hazards. Such remote handling systems are required to perform tasks within budget and on schedule while justifying the expense by a saving in cumulative doses received by project personnel. To reach this goal, the following are additional factors that need to be evaluated when preparing a project:

- System and peripherals must be operator-friendly. Ideally, the system must be designed to allow personnel currently available for the D&D project to become trained as operators within a reasonable time frame.
- The operating and control system should be user-friendly. Controls should be well laid out, with ergonomics suitable for numerous personnel with differing levels of experience, and normal operations should be logical and easy to execute. System parameters and alarm indicators must be accessible and easy to evaluate and respond to.
- The equipment must be able to perform all tasks within its capabilities safely, effectively and efficiently with little downtime and no failures that would jeopardize personnel safety or place the system or task in a non-recoverable position.
- The system must be flexible and easily adapted to changing conditions, tooling requirements and operational needs.
- The system must truly be remotely operated. Adequate distance or shielding must be available to operators such that exposures to radiation, hazardous materials and conditions are minimized.
- Preventive maintenance must be minimal with only moderate to long term frequencies (minimum 3 to 6 months) under normal or expected operating conditions. When the need arises, the maintenance should be simple and straightforward with a duration of less than one work shift. Replacement parts and common wear items should be available at a reasonable cost.
- Reliability is of paramount importance. Downtime and system or component failures translate into additional costs, possible personnel exposure, and if unexpected, possible safety impact.
- The systems, if possible, should be able to perform remote tasks nearly as rapidly as conventional practices would allow OR have the ability to perform tasks that would otherwise be difficult, impossible or impractical to perform.

We hope that the lessons learned from a number of dismantling projects and shared in this report will enable future projects to make choices which will avoid foreseeable errors and their associated waste of precious time, energy and funding. Remember that "those who do not learn from history are condemned to repeat it" …

5. Acronyms

ACS	Arterial Connection System
ALARA	As Low As Reasonably Achievable
ANDRA	Agence Nationale pour la gestion des Déchets Radioactifs
ANL	Argonne National Laboratory
AT-1	Atelier de Traitement
BR3	Belgian Reactor 3
CAMC	Contact Arc Metal Cutting
CEA	Commissariat à l'Énergie Atomique
CEP	Caesium Extraction Plant
CP5	Chicago Pile 5
DAWP	Dual Arm Work Platform
DCM	Decommissioning Machine
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DOF	Degrees Of Freedom
EDM	Electric discharge machining
EWN	Energiewerke Nord
GCR	Gas Cooled Reactor
GDR	German Democratic Republic
HAWC	High Activated -liquid- Waste Concentrate
HEPA	High Efficiency Particulate Air Filter
HPU	Hydraulic Power Unit
HPWJC	High Pressure Water Jet Cutting
HLW	High Level Waste
ILW	Intermediate Level Waste
INEEL	Idaho National Engineering and Environmental Laboratory
ISN	Interim Storage North
JAPC	Japan Atomic Power Company
KNK	Kompakte Natriumgekühlte Kernreaktoranlage (Compact sodium-cooled nuclear reactor)
KGR	Greifswald Nuclear Power Plant

KKR	Rheinsberg Nuclear Power Plant
LLW	Low Level Waste
LPG	Liquefied Petroleum Gas
LWR	Light-Water reactor
MCS	Manipulator Carrier System
MDM	Metal disintegration machining
MEDOC®	Metal Decontamination by Oxidation with Cerium
NST	Neutron Shield Tank
ORNL	Oak Ridge National Laboratory
PWR	Pressurized Water Reactor
R&D	Research & Development
RDM	Remote Dismantling Machine
RPV	Reactor Pressure Vessel
RTC	Radio Transmission Control
SRU	Steam Raising Unit
TDS	Tool Deployment System
TFD	Remote Dismantling Test Facility
UDIN	Unité de Démantèlement des Installations Nucléaires
UK	United Kingdom
USA	United States of America
USSR	Union of Soviet Socialist Republics
WAGR	Windscale Advanced Gas-cooled Reactor
WAK	Wiederaufarbeitungsanlage Karlsruhe (reprocessing plant)
WWER	Wasser-Wasser-Energie-Reaktor
3D	Three Dimensional

6. Useful websites

6.1 Decommissioning

OECD Nuclear Energy Agency
http://www.oecd-nea.org/rwm/
http://www.oecd-nea.org/jointproj/decom.html

Co-ordination Network on Decommissioning of nuclear installations (CND)
http://ec-cnd.net

International Atomic Energy Agency
http://www.iaea.org
http://goto.iaea.org/decommissioning/

United Kingdom Atomic Energy Authority
http://www.uk-atomic-energy.org.uk/

UK Nuclear Decommissioning Authority
http://www.nda.gov.uk

Japan Atomic Power Company
http://www.japc.co.jp/english/

CEA
http://www.cea.fr/english_portal

U.S. Department of Energy
http://www.em.doe.gov

U.S. Nuclear Regulatory Commission, Decommissioning
http://www.nrc.gov/info-finder/decommissioning/
http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html

Energiewerke Nord GmbH
http://www.ewn-gmbh.de

Argonne National Laboratory, Decontamination and Decommissioning
http://www.dd.anl.gov

6.2 Remote Handling

American Crane & Equipment Corporation
http://www.americancrane.com

Ameasol
http://www.ameasol.com

Brokk
http://www.brokk.com

Schilling Robotics
http://www.schilling.com

Kraft Telerobotics
http://www.krafttelerobotics.com

NUKEM - ANSA
http://www.nukem.de/fileadmin/pdf/english/ANSARemoteHandlingTechnology.pdf

Wälischmiller
http://www.hwm.com

Cybernetix
http://www.cybernetix.fr

SIT
http://www.s-i-t.com

SA Technology
http://www.satechnology.com

PaR Systems
http://www.par.com