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Seven storeys of decommissioning – the complete decommissioning of a chemical engineering building

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Synopsis
Early in 1997, one of the largest active buildings on UKAEA's Harwell site was demolished. The seven storey Chemical Engineering Building housed experimental and production-scale equipment used to explore all aspects of the nuclear fuel cycle, from fuel fabrication and zero energy reactors to reprocessing, high level liquid waste vitrification and decommissioning. In 1991, nearly 200 separate areas designated under the IRRs contained a variety of chemically and radiologically contaminated equipment and facilities. Since then all hazards have been removed from the building under a planned and carefully managed decommissioning and demolition programme. Seven examples from the programme are described.

1. INTRODUCTION

1.1 Background

In 1946 the teams at Harwell and Chalk River decided that a large building was required to house plant and equipment for a new chemical engineering group working on the separation of nuclear materials. The initial design of Harwell's Building 351 was for a heavily shielded facility that would routinely contain fissile material. The pressure to build production facilities lead to this design evolving into B204 (at Windscale). The redesigned B351 became a more versatile building with a tall, open, galleried hall allowing large pre-fabricated concrete cells to be built and interconnected through pipe-work laid in floor ducts. Columns rising from the cells could be accessed at different levels from the galleries for sampling, related experiments and processing. At one side of the building was a long covered Storage Pit containing high, medium and low active liquid effluent tanks (Figure 1). External delay tanks held up liquid waste before it was pumped to site active drains. A two-storey Analytical Laboratory supported the work programmes. The main curtain wall that ran down one side of the building was heavily glazed so that it might act as a large bursting disc - relieving pressure loadings from possible rig explosions that could damage the building structure. The building covered an area of 115 metres by 50 metres and was seven storeys tall.

During construction, it was clear that large-scale active separation experiments would have to be carried out at Windscale, on the production facilities. Building 351's mission evolved from that of a dedicated pre-production separation test bed to an experimental facility with a brief to explore all aspects of the nuclear fuel cycle from fuel fabrication and zero energy reactors to reprocessing, high level liquid waste vitrification and eventually decommissioning.

1.2 Old experiments

In the early 1950s solvent extraction of natural uranium and thorium was investigated. Thorium blanket rods from the Windscale Piles were de-canned and chopped in a plant submerged in two 12,000 gallon water-filled tanks located in the east end of the Storage Pit. The ^{233}U product extracted in Pilot Plant No 6 was used to produce light and heavy water solutions for criticality investigations in the homogeneous aqueous zero energy thermal reactors ZETR and HAZEL, also housed in Building 351. The ^{233}U was recovered from the heavy water and was transported to other sites for further research into these types of reactor.

Elsewhere in the building, high temperature experiments took place with the melting of fission product material in a suite of lead cells known as Hotspur and with early attempts to form small uranium spheres in a rudimentary shot tower. In the 1960s work on blending and vacuum packing uranium dioxide and thorium oxide powders supported the fuel preparation programme for Advanced Gas Cooled Reactors. Thoria slurries were routinely handled in rigs on several of the extended gallery floors. In the late 1960s and early 1970s, uranium/thorium mixed oxide and 20% enriched ^{235}U oxide spheres were produced for conversion to nuclear fuel for PFR research. The success of the work lead to a production plant being built in the old cubicles that had contained ZETR and HAZEL.

In 1991, all that remained of those experiments was contaminated cubicles, ventilation duct-work and pipework, stocks of materials, and fixed contamination on walls, floors, steelwork, old shielding concrete and lead blocks. Reliable records were not easy to find. Virtually all of the staff who worked in Building 351 before 1965 had retired. Those that could be traced had scant memory of the precise nature of the old operations since working and security conditions had prevented staff from knowing details about projects even in adjacent areas.

1.3 Recent experiments

As the nuclear power programme matured, work in Building 351 changed. Research into waste disposal focused on vitrification techniques beginning with the Fixation in Active Glass of Active Liquors (FINGAL) experiments in the 1960s which used realistic active liquors from Windscale. Later experiments investigated the problems posed by large scale batch and continuous production of simulated vitrified waste using melters and rotary calciners. Reprocessing was examined in large experimental dissolvers and key experiments on a high temperature high pressure corrosion loop validated the design parameters of components for the Prototype Fast Reactor. Sodium mass transfer rigs gave information to support UK and international programmes on fast reactor technology.

The building structure has been modified many times since final commissioning in 1952. A two storey extension was added in the late 1950s at the west end of the main building and steel floor extensions to the galleries were added at every level. The Storage Pit area was enclosed and active ventilation systems were rearranged to suit changing patterns of work. Enclosures, temporary walls and partitions were used to compartmentalise areas, sometimes acting as containments, in addition to the many cubicles, gloveboxes and fume cupboards.

The last two decades saw a diversification away from the nuclear mission. Separation technology was applied to chemical processing. Gel processing was used for pharmaceutical production. Pilot plants were built for desalination and heat transfer research. Large scale applications of microwave heating were investigated, including decontaminating concrete.

1.4 Commercial realities

In 1990 areas in Building 351 were managed by six of the nine UKAEA businesses created at that time. The costs of working in a "nuclear" building did not sit easily with attempts to run commercially viable non-nuclear R&D projects. As a result, equipment used in non-nuclear work was moved to other buildings at Harwell. Funding for long term nuclear projects was reducing rapidly. Attempts to find new uses for the building failed and in 1991, an Outline Decommissioning Plan and review concluded that the most cost effective solution would be to decommission the many rigs, laboratories and experimental areas as quickly as reasonably practicable, leading to demolition of the building and a return to a green field site.

2. THE DECOMMISSIONING PROGRAMME

The Plan contained estimates for labour needed to decommission every area of the building and for quantities of waste that would be generated. These estimates were built into a strategy for decommissioning which lead to a phasing of the work against the Department of Energy (and later, Department of Trade and Industry) DRAWMOPS Programme Letter (now the Safe Environmental Remediation (SAFER) programme). Basic parameters describing the building are shown in Table 1.

Table 1: Building Parameters

Building Dimensions		Building Fabric	
Height	27m	Asbestos Cladding	3,500m^2
Width x Length	50m x 115m	Amount of Concrete	4,000m^3
Enclosed Volume	44,600m^3	Amount of Brickwork	900m^3
Total Floor Area	10,351m^2	Depth of Basemat Concrete	2.1m
Lab & Office Area	4,030m^2	Amount of Structural Steel	1,200te
Length of Ductwork	4,200m	Length of Lagged Pipework	2,500m
Floor Area Covered by Lino	3,600m^2	Area of Metal Floor Plates	1,700m^2

The variable standard of building housekeeping and stockpiling of redundant material and apparatus meant that each area undergoing decommissioning had to be carefully analysed for potential hazards. Different approaches had been taken to mothballing old experiments and labs, ranging from a well documented status following successful post operational clean out to near abandonment. Areas that were still operational in 1991 were well managed with substantial safety documentation. The decommissioning project and safety management team remained the same from 1991 until 1997 which ensured continuity of approach and a thorough understanding of the building characteristics and hazards(1). Initially the decommissioning was carried out by dedicated UKAEA teams managed directly by the project team, but by mid-1993 competitive tendering was applied to individual packets of work. During the seven year period of decommissioning many standard techniques were developed to cope with large scale operations. Seven examples of the decommissioning and demolition programme are included in this paper.

3. BUILDING CLEARANCE

Because of the uncertainty surrounding the history of the building and the surrounding areas, preparations for decommissioning and clearance always involved preliminary radiological surveys, service isolations and where necessary, further COSHH and safety assessments. A dedicated Housekeeping team of two Decommissioning Technicians and two Health Physics Surveyors was used to reduce the hazards in each area by clearing the free-standing equipment and materials (Figure 2), and by safely disconnecting and isolating the process services (air, steam, gas, water etc.). These preliminaries were always managed directly by the UKAEA Project Team, with specific Permits to Work and agreed method statements. The use of dedicated staff with knowledge of the building for isolation (especially electrical) proved to be one of the most important factors in the management of safety and adequately compensated for any lack of records. Work on individual areas was often split into discrete stages to manage risk, minimize uncertainty and hence reduce the total costs of competitive tenders.

3.1 Analytical Laboratory decommissioning

Post operational clean out of the Analytical Laboratory complex was performed by the last occupants. Moving equipment allowed access to a contaminated void store which had been inaccessible for at least twenty five years The Labs originally contained thirty two built-in fume cupboards with their own dedicated active extract system which ran up to the main building Sixth Floor Plant Room. In about 1957 the Labs were refurbished, half the fume-cupboards were removed and the active extract was relocated to the plant room directly above.

Initial clearance involved isolating and removing old electrical supplies (severely embrittled rubber-insulated cables) and removing lab furniture, benches and shelves. Hidden behind the benches was contaminated ductwork that ran into vertical wall voids. The ductwork was sampled and found to contain low levels of loose ^{137}Cs contamination. Old photographs showed the Lab with suites of gloveboxes which must have been removed during the refurbishment, ventilated through the ductwork that was left behind.

Table 2: Work Phases for the Analytical Laboratory

Work Phase	Carried out by
Initial clearance & radiological surveys	Occupants, building surveyors
Service isolation	Building electricians, Site Services
Exposure of hidden hazards	Decommissioning contractor
Removal of asbestos from pipe voids	Specialised contractor
Decommissioning of fume cupboards and active ventilation systems	Contractor from Competitive Tender
Floor and wall scabbling	Term contractor
Strip out of electric cables from roof void	Building electricians
Removal of asbestos from roof voids	Specialised contractor
Demolition (with main building)	Contractor from Competitive Tender

Table 2 shows the main steps associated with the clearance and decommissioning of the Analytical Laboratories. Work was completed in 12 weeks. The entire wing was designated a controlled area and handed over to the contractor. The ductwork was wrapped and stored for later size reduction in the building. Fume-cupboard steelwork went to landfill as chemically-contaminated waste or as low level waste via the building HISO route (see below). Floors and walls were scabbled and scarified to remove areas of fixed contamination. Asbestos insulation was removed from roof and pipe voids under controlled conditions.

3.2 Mild Steel Loop

The Mild Steel Loop was a non-radiological, complex steam/water test facility used to measure corrosion at high temperatures and pressures. Operating records were not clear regarding the possible presence of kilogram quantities of sodium in a number of test sections. The test sections were safely isolated from the main loop which was dismantled using hydraulic shears to cut the steel pipework into manageable pieces. Radiological monitoring and sampling confirmed the absence of radioactivity and the steel was recycled. The sodium test sections were removed and sentenced to an authorised disposal service with the expertise to handle sodium wastes.

4. FINGAL - AN ABANDONED VITRIFICATION CELL

The FINGAL Cell housed a pilot scale vitrification plant which had processed approximately 20 TBq of fission product activity during the early 1960's. The processing equipment (liquor storage tanks, vitrification furnace, annealing ovens, off-gas filters etc.) was enclosed within a lead cell, surrounded by massive concrete shielding. After work stopped in the mid-1960s, the FINGAL Cell had been sealed off and left. Decommissioning was accomplished in three phases: removal of the vitrification plant; removal and decontamination of the massive (20 tonne) concrete roof blocks; removal and decontamination of the concrete wall blocks. Inspections and surveys were carried out using remotely deployed miniature CCTV cameras and telescopic radiation probes. Access to the cell was via a narrow labyrinthine corridor.

A ventilated modular containment system (MCS) was sealed to the cell entrance to provide a working area, avoiding the need to size reduce plant items within the restricted confines of the main cell. The narrow cell entrance meant that any large equipment required to support the decommissioning work could only be taken into the cell in pieces. For example, a proprietary electric stacker truck was modified(2) to enable suited operators to reassemble and operate it to dismantle the lead cell (constructed from 150kg blocks). A half-height ISO (HISO) container loading facility was installed adjacent to the MCS (Figure 3). This permitted bulk items to be dispatched as low level radioactive waste (LLW), without unnecessary size reduction.

The removal of the roof and wall blocks was conducted in a containment due to the presence of ^{137}Cs contamination. Extensive decontamination (using standard scabbling techniques), core sampling and radiochemical analysis rendered the blocks suitable for unrestricted reuse. All operations inside the MCS and FINGAL cell were monitored using CCTV. A two-way audio link ensured that supervisors could help and advise operators during complex tasks.

5. MARK I GEL PRECIPITATION LABORATORY AND PLANT

The Mark 1 Gel Precipitation Plant was used to prepare U/Th spheres for fuel fabrication studies and had been moth-balled when experimental programmes finished in the 1980's. The gel process used solutions of U/Th nitrates (in strong nitric acid), organic solvents and ammonia. Residues remained in the moth-balled plant and its storage/preparation facilities. Correct choice of PPE was crucial in ensuring operator safety. Concentrations of organic solvents, ammonia and radioactivity in air were monitored continuously. Removal of gel plant, feed solution preparation equipment and ammonia storage tank were phased to avoid potentially hazardous interactions. Work was completed in 16 weeks.

The Gel Precipitation Laboratory floor and walls were also contaminated. The floor was essentially a 6mm thick steel "catch-tray" pinned into the concrete beneath. The radiological status of the concrete was unknown. The wall dividing the laboratory from the main building was four storeys tall with contamination within the cavity. Both the wall and floor were removed as part of the decontamination of the laboratory over a period of 20 weeks.

6. SEPP AND THE URANIUM EVAPORATOR

The solvent extraction pilot plant (SEPP) was used to investigate the recovery of uranium during fuel reprocessing. The plant consisted of:

- Cubicle 1 – constructed of plastic cladding bolted to a steel framework, enclosing $80m^3$, running from the ground to the 5th Floor. It housed 12m tall extraction columns (ranging in size from 25mm to 125mm diameter) and a boiler unit, located on the 3rd Floor;
- Cubicle 2 – was located on the 1st Floor and it contained the mixer settler plant and a series of liquor storage vessels of up to 300 litres capacity;
- Evaporator Plant – both cubicles were connected to an evaporator plant which was located in the Storage Pit. The evaporator was used to concentrate uranyl nitrate solutions for recycle to the extraction plant. The main ($2m^3$) liquor storage vessels were also located in the Pit.

Plant decommissioning was straightforward but was dominated by the potential for falls through the open floor areas within Cubicle 1. Strict controls were necessary to prevent operators working directly below the dismantling work and CCTV was used to check progress. Approximately $3m^3$ solvent (20% tributyl phosphate in odourless kerosene) contaminated with low levels of uranium activity was left from plant operations, stored in two steel tanks in the Pit. There was no disposal route for this material without the removal of the radioactivity. An ion-exchange material and process were developed to treat the solvent. This was successful and the $3m^3$ of cleaned solvent was sent for incineration at a licensed disposal site. The ion-exchange material was grouted and sent to Drigg as LLW.

7. CDFR DISSOLVER

The CDFR dissolver was installed to study the dissolution of spent fast reactor breeder fuel. Experiments were conducted on 200-300kg of unirradiated pins containing depleted UO_2. The dissolver was housed within a large $100m^3$ ventilated cubicle which extended over two floors. The cubicle also contained off-gas treatment equipment (condensers, NO_x scrubbers, demisters etc) and the large liquor storage vessels (concentrated HNO_3, NaOH, uranyl nitrate).

Limited post operational clean out had been completed by the previous operators. However, significant volumes of liquors remained within the plant. These were recovered, analysed, conditioned and sent to the appropriate disposal route (chemical waste/radioactive effluent). The cubicle was then adapted to provide the containment for plant decommissioning. The solubility of the contamination greatly assisted decontamination and a significant proportion of the material recovered was demonstrated to be radiologically clean. Plasma cutting techniques were used to size reduce the main dissolver in-situ. Local, high volume, ventilation/filtration systems maintained aerosols within the cubicle at acceptable levels. The final phase was to dismantle the cubicle and the large volume liquor catch-trays.

8. MAIN ACTIVE VENTILATION SYSTEMS

Building 351 was served by a number of extract systems installed for the removal of potentially contaminated air. The extract fans and filter systems were located on the 6^{th} floor. The fume-cupboards, active plant and decontamination facilities were connected to the fans by approximately 4km of mild steel ducting (sizes up to 3m x 3m). The possible presence of radioactive contamination within the ducting resulted in the need to undertake the dismantling operations within specially erected scaffold/PVC enclosures. This was particularly important where a number of suspect contaminated ducts were routed outside of the building. Lifting aids enabled the PVC-wrapped ducting to be safely lowered to floor and ground levels.

A specially designed size reduction facility was set-up to process the ducting and other components. Decontamination was always used where it was proven to be ALARP. The ducting which could not be decontaminated was size reduced using cold cutting techniques (nibblers, band saws, etc) to produce "flat packs" of wrapped waste for disposal in HISO containers as LLW. This approach reduced waste disposal costs by a factor of 50.

9. BUILDING DEMOLITION

The strategy for decontamination and demolition of the building structure was to use conventional methods wherever possible. The demolition of the two storey West Wing extension was used as a trial for the main building and was completed in August 1996. This provided valuable information regarding the overall approach, but more importantly it finalised the methodology for radiological clearance surveys. For example, it highlighted the need to remove the metal floor plates to fully expose the floor support structures and proved the success of using "cherry pickers" to access high level surfaces. Long range surveillance, remotely steered, CCTV was tested and became an important tool in management control.

An environmental impact assessment was conducted prior the demolition of the main building. Dust and noise were highlighted as potential problems as Building 351 was adjacent to the site boundary fence and the main NRPB and MRC buildings. Its closest neighbour on the Harwell site was the main post irradiation examination facility. Vibration controls were therefore necessary to protect that building's zinc bromide-filled cell windows.

The project management team moved from the main building in March 1997. Contractors and project temporary offices were placed close to the building and the site was fenced in. Four CCTV cameras were fixed to towers at the periphery of the building and local and remote monitors were installed. Control of all the cameras and video recording was done at the main project office which was within sight of the main building. Demolition commenced in April 1997 with the demolition of the Office and Analytical Wings. The asbestos/cement cladding panels were removed from the main building by carefully cropping the retaining bolts and lowering the panels to ground level for disposal to an authorised landfill.

Demolition of the main steel/concrete superstructure proceeded by collapsing the roof and gallery floors using a wrecking ball suspended from a crane, and cutting the main steel supports as they were exposed. Continuous environmental monitoring and radiological surveys provided reassurance throughout. All demolition work was completed in August 1997 but the concrete base-mat and below ground storage facilities remain on Care and Maintenance.

10. WASTE MANAGEMENT

Rigorous radiological monitoring and sampling ensured that the wastes generated were correctly segregated. Decontamination techniques were employed to minimise the volume of radioactive material dispatched to the Harwell Radwaste Service (HRS). The application of these techniques was always judged on safety (ALARP) and economic grounds. The radiological fingerprint of the waste from individual tasks was determined prior to decommissioning and measurements that were made included gross activity, with β analysis and α and γ- spectrometry to identify the isotopes present. This data was then used to ensure that LLW disposals complied with the requirements for material dispatched to Drigg.

Any compactable waste, such as barrier waste (coveralls, gloves, overshoes etc), was sentenced to 200 litre bins for super-compaction. To ensure cost-effective HISO container filling, size reduction was employed to improve packing factors, and the wastes from different tasks were blended to minimise the voidage within the HISO container. Waste management procedures were subject to rigorous audit and monitoring.

Approximately 1 tonne of nuclear material (uranium and thorium) was dispatched to HRS as contact handled ILW. This material was originally used in the Gel Precipitation and Dissolver programmes and had to be re-packaged into standard 50 and 100 litre waste bins and 50 litre carboys for disposal. LLW and ILW volumes dispatched to HRS are summarised in Table 3. The 1991 Outline Plan estimate for LLW anticipated improved decontamination processes from scaled-up R&D that did not materialize. Nevertheless predictions were adequate for planning.

Table 3: Low and Intermediate Level Waste Disposals

	Low Level Waste disposals (m^3)				LLW Totals (m^3)		ILW (litres)
Financial Year	**PVC Wrapped**	**100 Litre bin**	**200 litre bin**	**HISO container**	**Actual**	**Estimate from 1991 Plan**	**Actual**
1990/91	5.3	5.0	0.27	N/A	10.5	N/A	**540***
1991/92	13.2	17.2	1.6	N/A	32.0	46.7	0
1992/93	2.1	6.7	14.8	N/A	23.6	26.5	1,227
1993/94	3.0	13,6	20.0	18.0	54.6	33.0	30
1994/95	0.6	4.9	100.6	133.5	239.6	262.7	0
1995/96	2.8	0.5	27.7	58.5	89.5	27.9	2,450
1996/97	0	0.1	23.8	133.2	157.1	135.0	100
1997/98	0	0	47.0	44.4	91.4	75.0	100
				TOTAL	**698.30**	**606.80**	**3,907**

*** Remote Handled ILW from FINGAL**

All unidentified chemicals were analysed prior to their disposal. Many thousands of analyses were carried out on substances ranging from small (~ 5 ml) to large (tonne) bulk quantities. Chemical waste was sentenced through the Hazardous Disposal Service of AEA Technology. The disposal arrangements operated by this service were subject to regular UKAEA audit to ensure the maintenance of Duty of Care.

Non-hazardous waste was dispatched (after monitoring by Health Physics) in skips for land-fill or on trailers for possible re-use or sale as scrap. Many tonnes of redundant copper cable was recovered and sold. The proceeds from the sale of the main steel support structures were set against the costs of the demolition of the building superstructure. The bulk of the concrete and brick rubble from the superstructure was crushed and used as in-fill on the Harwell site.

11. CONCLUSIONS

The demolition of a contaminated seven storey building was completed successfully, to plan and within budget. Despite the lack of documentation and operational records from the early experimental programmes, safe decommissioning of large, complicated, contaminated facilities within the building complex was possible because all operations were carefully planned and managed by the resident UKAEA project management team. The continuity of the project management team membership ensured that the decommissioning work was to a consistent standard and that there was a common approach to the use of contractors.

The management and control of contracting and working methods ensured that the project was completed within the budget profile and predicted timescales.

An early decision was made to process LLW within the building using a dedicated HISO container facility, rather than using 200 litre drums. This solution was initially driven by the practicalities of dealing with waste from FINGAL decommissioning but produced significant cost advantages both in volume cost and less need for size reduction. The processing of the building's active extract ventilation ductwork in a containment close to the HISO facility minimised risk of contamination migration and reduced the complexity of waste movements.

All tasks were subject to rigorous safety assessments and were controlled by Method Statements and the Permit to Work system. This ensured that those at the working level were fully aware of specific hazards and had immediate access to the documentation that defined the task execution. All contractors underwent site induction and building specific training. There were no serious incidents or accidents.

Where areas could not be easily observed, cctv systems provided more information and improved levels of confidence. Cameras were used for plant inspection where human access was difficult or impossible. Installed surveillance systems inside containments gave supervisors and UKAEA managers direct views of work in progress and controllable overview cameras inside and outside the building were used to observe progress safely from a distance.

The techniques developed and used in this project and the lessons learnt have been applied to other UKAEA decommissioning projects and operational work with equal success.

12. REFERENCES

1. E Abel and C Hamblin, "Dismantling a Chemical Engineering Building", Atom (426), Jan/Feb 1993, p34-39.
2. E Abel, C Hamblin and AC Rose, "Re-engineering a Stacker Truck to Decommission a 30-Year Old Vitrification Cell", Proc. ANS Sixth Topical Meeting on Robotics and Remote Systems, 5-10 Feb 1995, Monterey, California.

Figure 1 Main view of the Chemical Engineering Building

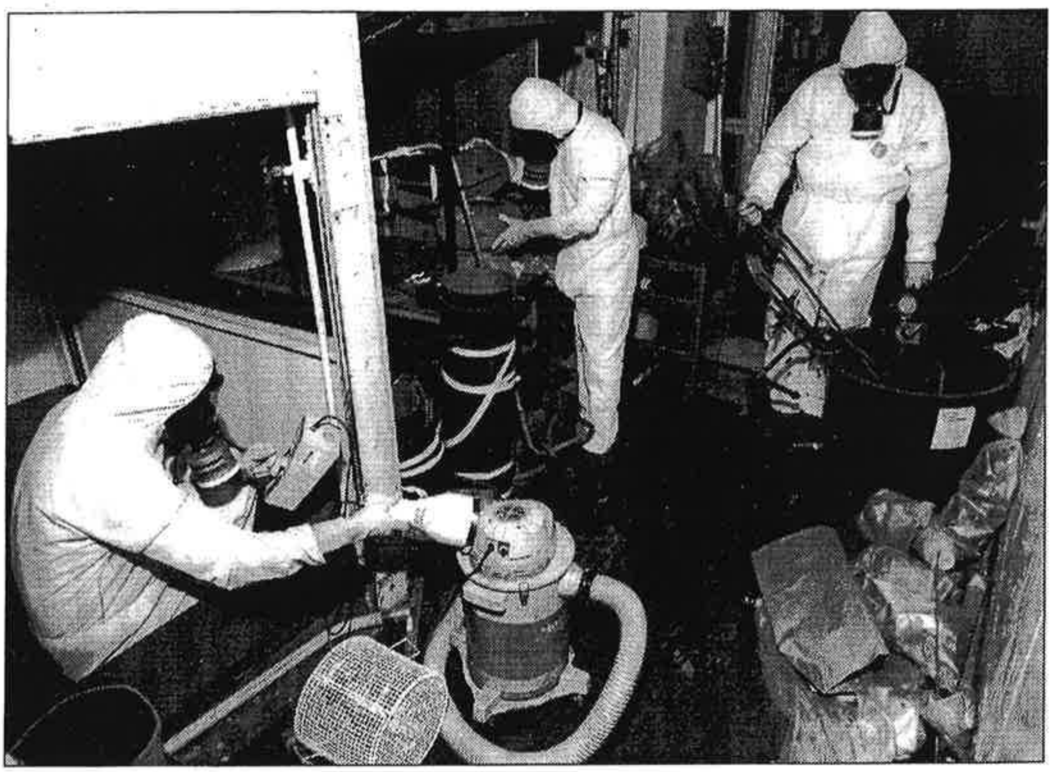

Figure 2 Clearance of contaminated items from cubicles and gloveboxes

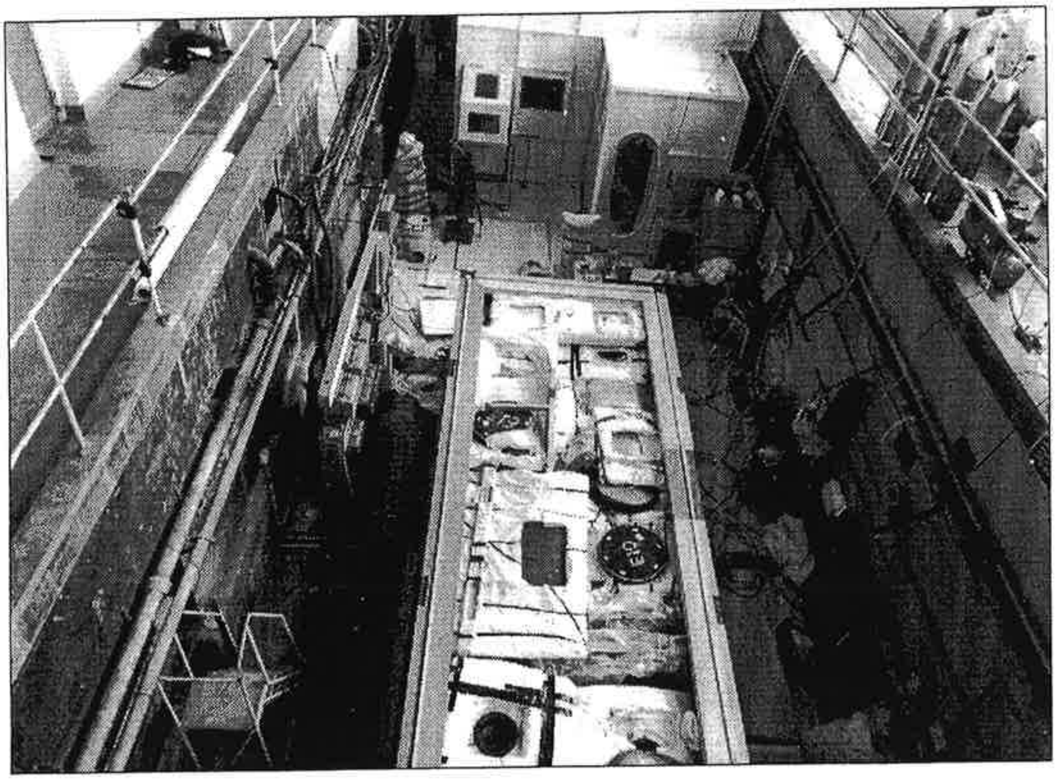

Figure 3 **Half-height-ISO container for low level waste**

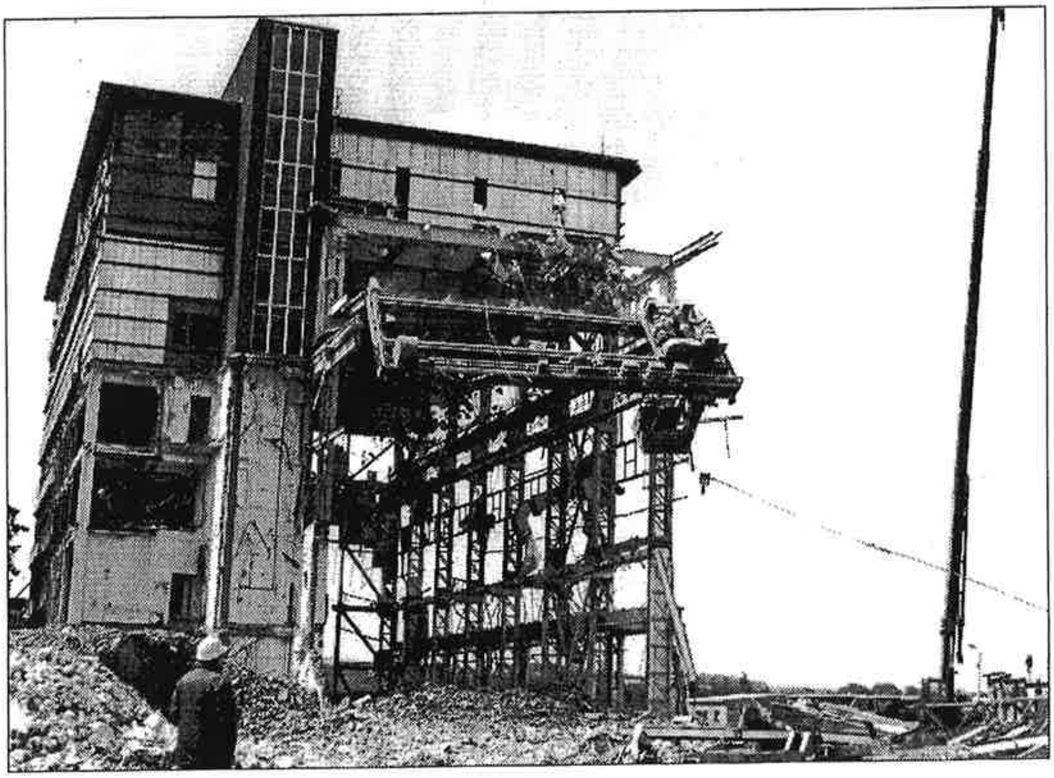

Figure 4 **Demolition - removal of the 50 ton crane**