6.5.1. Deployment systems

Deployment systems in this context are systems such as manipulators, XYZ frames or remotely controlled vehicles which can be used to deliver a tool to a worksite and deploy it. Considerable advances have been made in this field and these are described in brief in Table VII, along with the appropriate references [604–626] (Figs 41–44).

Deployment systems can be used to facilitate the decommissioning tasks and to reduce human exposure to radiation and contamination. In the selection of equipment the following should be considered:

- Work specification and task analysis
- Dimensions and location of the workplace
- Access and disposal route
- Size and weight of the component involved
- Type and quantity of generated waste
- Environmental conditions
- Available services and auxiliary systems

FIG. 41. NEATER 670 is a seven axis manipulator system.

FIG. 42. An ARTISAN hydraulic manipulator with a 200 kg load capacity recovering simulated graphite sleeves. This manipulator is being used for clearing silos at the Vandellos NPP in Spain.

TABLE VII. REMOTE DEPLOYMENT SYSTEMS

Name	Project/country	Description	Reference
WAGR manipulator	WAGR, UK	Custom built multiaxis manipulator with suite of tools for dismantling reactor internals	129, 445, 452, 475, 476, 604
B204, B209, B212 dismantling systems	B204, B209, B212, UK	Custom built deployment systems incorporating robotic arms, viewing and lifting equipment	305, 605
NEATER	General purpose, UK	Multiaxis remotely operated manipulator for use in nuclear environments	146, 394, 606 (Fig. 41)
SCHILLING	General purpose, Windscale piles chimneys, UK	System for removing insulation and filters from the top of the Windscale piles chimneys	607
ARTISAN	General purpose, Harwell variable energy cyclotron, UK	Multiaxis remotely operated hydraulic manipulator	350, 608, 609 (Fig. 42)
Remote underwater vehicle	Windscale piles, UK	Cleaning of sludge and fuel elements from water ducts	610
Advanced tele-operation controller	Trawsfynydd, UK	Robotic's controller	611
Dual arm manipulator module	ORNL, USA	Dual arm manipulator for characterization and D&D operations. Reconfigurable to meet different requirements	595
Automated remote dismantling system	CP-5, USA	Consists of a set of end effectors and number of auxiliary systems for task monitoring and remote control	596, 612

TABLE VII. (cont.)

Name	Project/country	Description	Reference
ROSIE	USDOE	Heavy manipulator and control system for a variety of tasks	613
Mobile, multitask system	USDOE (Pentek Wall Walker™)	System consisting of end effectors suspended from cables	87, 614, 615, 616
Electrohydraulic remote controlled impact machine	EBWR, USA	Excavator mounted system for dismantling and packaging waste	423
Underground storage tank technology demonstration	Environmental restoration and waste management programme, USDOE, USA	Remediation of underground storage tank	617
REMEX	Environmental restoration and waste management programme, USDOE, USA	Remotely operated excavator	617
Remote controlled manipulator system	KKN, Germany	Central mast based on bridge with a ring universal gripper used for tools on a moving platform. Manipulator has four degrees of freedom	67, 361 (Fig. 43)
ODIN 1	KRB-A, Germany	Underwater tool carrier system	598
Remote cutting system	KRB-A, Germany	Plasma torch deployment system for reactor core, RPV head and RPV steam drier	371, 377, 599, 618
ZEUS	Germany	Seven axes manipulator	598
FAUST	Germany	Free diving handling system	598
HYDRA	Germany	Wall climbing robot	598

TABLE VII. (cont.)

Name	Project/country	Description	Reference
EMIR	General purpose, Germany	Long reach extended multijoint robot	619
JAERI manipulator	Reprocessing plant, Japan	Robotic manipulator and plasma arc cutting device	133, 390, 620
JAERI multifunct-ional system	JPDR, Japan	Multifunctional robotic system	621 (Fig. 44)
ATENA and MA 23	AT1, France	ATENA — remotely operated XYZ cranes. MA 23 is a master–slave manipulator	98, 197, 332, 350, 602
RD500	France	Watertight master–slave manipulator	593
MAESTRO	CEA, France	Teleoperated hydraulic, heavy duty, force feedback master–slave manipulator	622
TAO-2000	CEA, France	Manipulator controller	622
Manipulators M-22, M-31, M-51, MEM	Under development by Ministry of Nuclear Power, Russian Federation	Manipulator for repair and D&D operations	244, 246
MASCOT IV system	ITREC plant, Italy	MASCOT IV based system for dismantling process cell	623
ENEA system	Eurex plant, Italy	Two arm force reflecting servomanipulator (MASCOT IV) inside a containment box	624
Long reach manipulator	Vandellos-1, Spain	Telescopic mast system with ARTISAN 200 attached	625, 626 (Fig. 42)

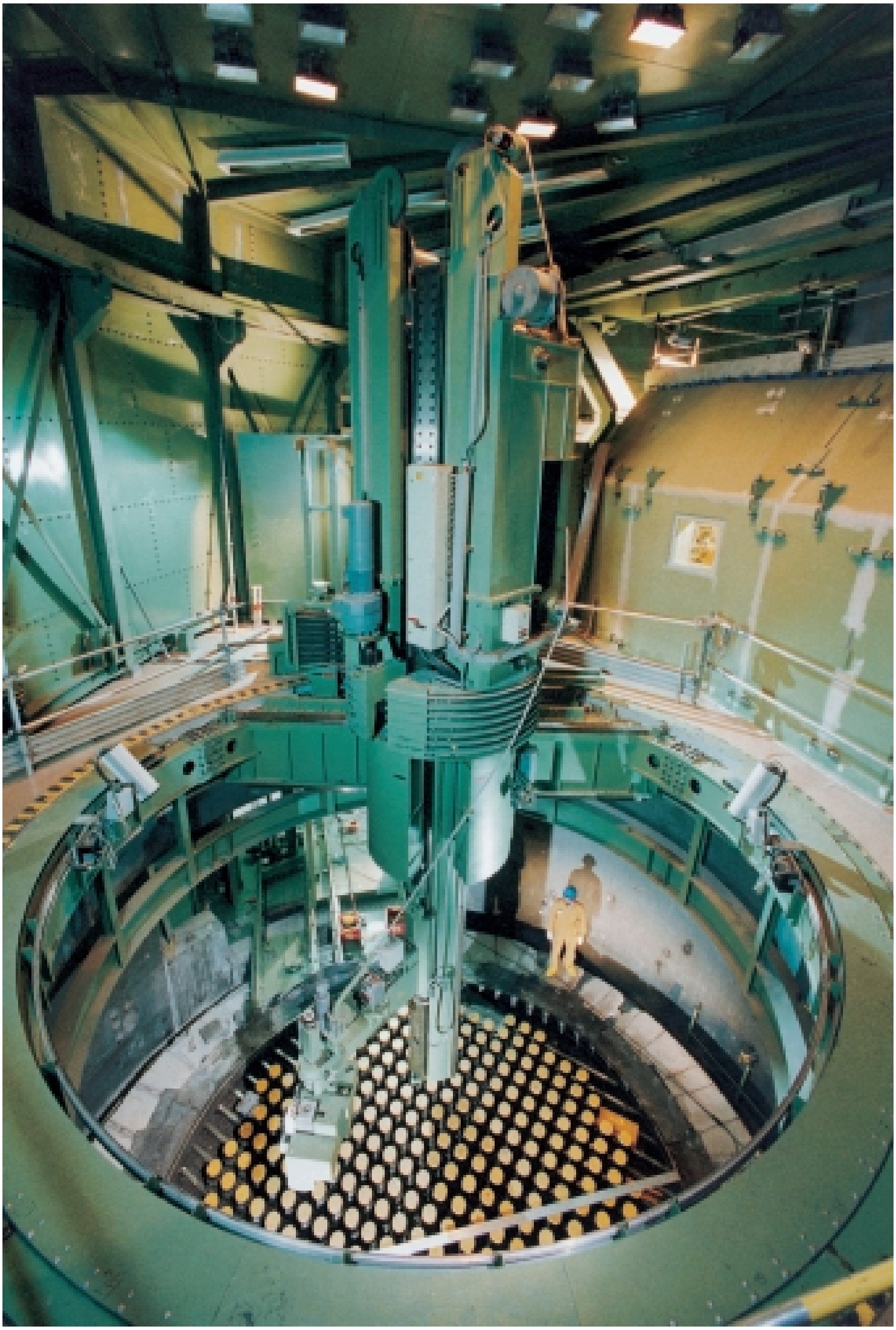

FIG. 43. Rotary manipulator used for the remote dismantling of the Niederaichbach (KKN) reactor.

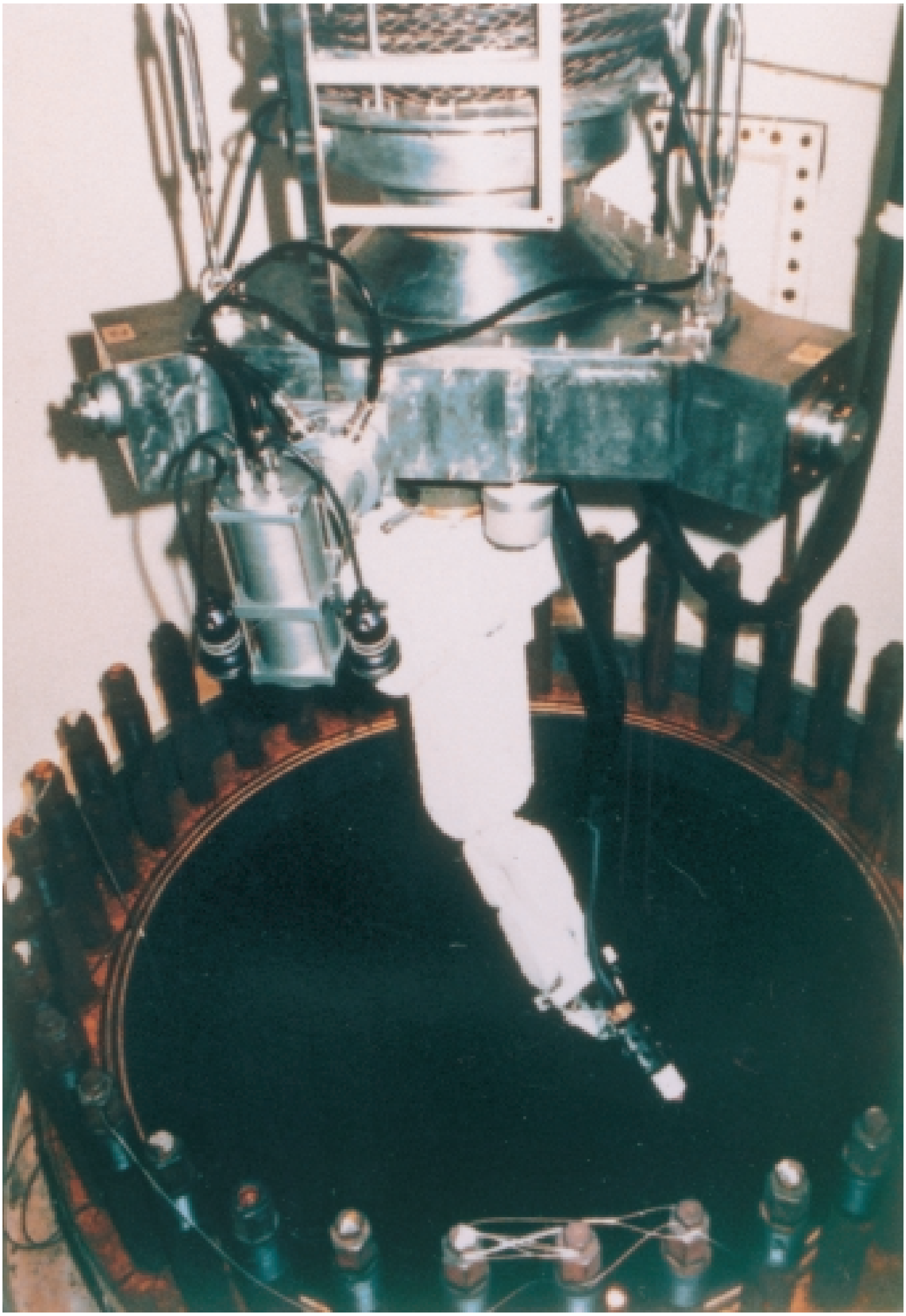

FIG. 44. Slave arm inside reactor vessel at the JPDR decommissioning project.

- Maintainability and reliability
- Failure recovery methods
- Safety and regulatory requirements
- Cost and schedule factors.

Other references of general interest are Refs [39, 87, 183].

6.5.2. Viewing and detection equipment

These are systems which allow the operator to view remotely the worksite or allow data and information on the operating environment to be collected without manual intervention. Advances in this field are listed in Table VIII [627–645] (Figs 45–48). Additional information on broader R&D programmes can be obtained from Refs [87, 197, 370].

6.5.3. Segmenting and disassembly equipment

The presence of high radiation fields or contamination levels often requires that segmenting and disassembly equipment be controlled and monitored remotely. A general discussion of the advantages and disadvantages of remote and manual operation is provided in Ref. [646]. Progress in electronics and sensor technology has led to considerable advances in the area of remote operation in both air and water. Considerable practical experience is now available and this is described in brief in Table IX, together with the appropriate references [647–652].

6.5.4. Decontamination equipment

The decontamination equipment described here is primarily for use as an end effector to a remotely deployed arm or other delivery device. As with the deployment systems described earlier, this is an area of considerable R&D activity and new advances are being made almost continuously. Table X gives an overview of recent developments in this field [653, 654] (Fig. 49).

6.5.5. Materials handling equipment

Remote materials handling equipment has been developed and used on various projects in the USA: the versatile remote handling system (LANL); the T-Rex materials system and a handling system, both being developed at ORNL [183]; a vehicle for autonomous waste transfer (Idaho National Engineering Laboratory (INEL)) [617]; and a mobile work system to be used specifically for retrieving Fernald K-65 silo waste [87, 617].

TABLE VIII. REMOTE VIEWING AND DETECTION SYSTEMS

Name	Facility	Description	Reference
Pipe explorer and characterization system	CP-5, Grand Junction, INEL, USA	System for carrying out radiological surveys inside pipes	87, 230, 231, 248, 350, 362, 627, 628 (Fig. 45)
Coherent laser vision system	General, USA	Three dimensional position and orientation data collection system	87
ALPHA contamination monitoring	LANL, USA	Long range alpha detector (LRAD) technology	629
Floor radiation surveys	CP-5, USA	Mobile automated characterization system (MACS) robot	(Fig. 46)
SIMON	SRS, USA	Robotic monitoring machine for carrying out floor surveys	77
Pipe crawler	SRS, USA	Visual and radiological inspection	630, 631
LDUA	Environmental restoration and waste management programme, USDOE, USA	Light duty utility arm	617
LARADS	Hanford C reactor, USA	Civil surveys and radiological detection	228, 632 (Section 6.1.2)
SCM/SIMS	Hanford C reactor, USA	Surface contamination monitor and survey information management	232, 632 (Section 6.1.2)
GRI	Hanford C reactor, USA	Building contamination survey	632
High precision monochrome CCTV system	General, UK		633
Stereo camera system	General WAGR, UK		197, 370

TABLE VIII. (cont.)

Name	Facility	Description	Reference
Semi-automatic contamination measurement system	AT-1, France		197
SOISIC	EDF/MENSI, France	As built modelling	634
ALADIN	CEA, France	Gamma and alpha imaging	635, 636, 637
Automated large scale radioactivity measurement facility	Germany	For use on low level waste	638
Remotely controlled data acquisition system	Reprocessing plant, Japan	Robot equipped with ITV camera to identify data, such as location and size of apparatus, as input to 3 D CAD system	390
GAMMA camera	General, UK, (C reactor, CP-5), USA, Russian Federation	Remote system for providing an image of active areas within a facility overlayed onto an image of the facility or internals	225, 226, 227, 639, 640, 641, 642, 643, 644, 645 (Figs 47, 48)

The development of long reach manipulators for the removal of waste from the vaults of the Vandellos-1 reactor in Spain is discussed in Refs [625, 626]. The system consists of:

— A containment bell,
— A telescopic mast,
— An ARTISAN 200 manipulator (Fig. 42),
— A range of manipulator end effectors,
— Equipment to position the above components,
— Shielding to protect operators.

A manipulator for removing slag, measuring temperature and taking samples during the melting of metals contaminated by radioactivity was installed at the

FIG. 45. Pipe Explorer™ being used to perform characterization of the CP-5 facility's embedded piping system. Courtesy Argonne National Laboratory, managed and operated by the University of Chicago for the US Department of Energy under contract No. W-31-109-ENG-38.

CARLA plant in Germany and following a campaign of inactive and active tests was then removed from the foundry for necessary modification and improvement [197]. A manipulator developed for assisting during scrap metal melting at Latina, Italy, is described in Ref. [650].

6.6. MISCELLANEOUS TECHNIQUES AND OPERATIONS

6.6.1. Water filtration

At the FSV reactor, the previously dry reactor vessel was filled with water to provide shielding and contamination control during the process of cutting open the

FIG. 46. The mobile automated characterization system robot being used for floor radiation surveys at the CP-5 facility.

reactor vessel head [68, 447]. A shield water system was constructed, tested off-site and installed to control water chemistry. The clarity of the shield water was maintained by treating the water with a flocculent and a polymer; the previous method of filtration and demineralization using polymers was not effective [68]. At the JEN-1 reactor, a filtration system for the pool water was designed and introduced to maintain water clarity [282]. Membrane filtering systems for water filtration have been tested at the CP-5 demonstration project, at INEL, at Hanford and elsewhere in the USA [248, 655]. At the Vandellos-1 NPP, two filtration systems for the decontamination, disassembly and emptying of fuel pools were designed and

FIG. 47. Gamma camera as used for gamma radiation field imaging at the CP-5 facility.

introduced to retain the remains of wire from the graphite sleeves and the graphite fines and sludges deposited on the bottom of the pools [656].

6.6.2. Ventilation/air filtration

Some D&D technologies may require modification to existing plant systems in order to allow dismantling operations to proceed. In particular, ventilation/off-gas systems may require modification prior to decommissioning because of the production of aerosols/fumes which did not occur during normal plant operation. This is an active R&D area [492, 657, 658].

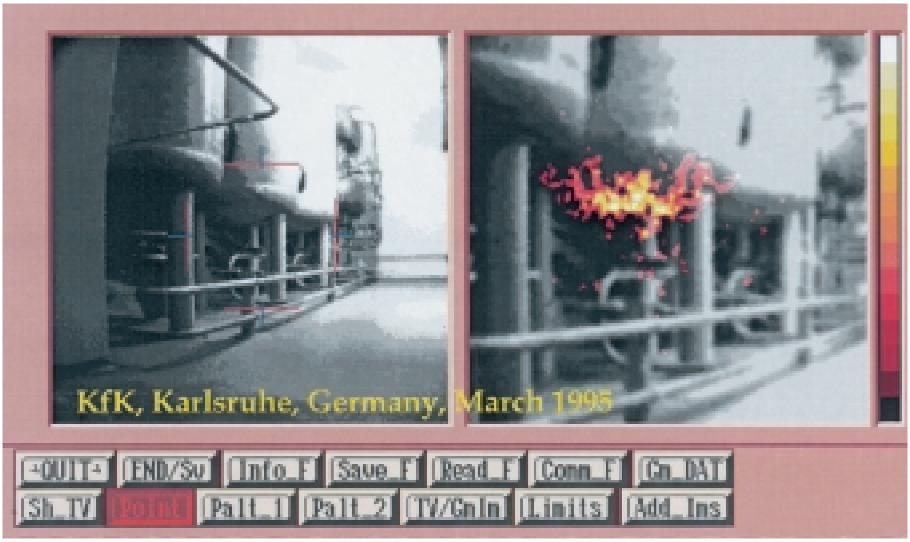

FIG. 48. Russian gamma camera images showing activity distribution within the water circuits of a nuclear reactor at Nuclear Research Centre Karlsruhe in Germany. Before measurements were taken, it was supposed that the activity was concentrated in one 'hot' point. In reality, the entire base of the middle reservoir is contaminated.

6.6.3. Diving

Divers were used at the FSV reactor to remove insulation and other components prior to the lifting out of the reactor vessel [68]. Development work has been carried out in France and Italy to produce and qualify a new diving helmet and a real time dose monitoring and data acquisition system in order to improve diver efficiency and safety [624]. In another development from France, cutting techniques such as plasma arc, saw and diamond wire were employed underwater by divers [659]; in Italy the fuel pond at ISPRA 1 reactor was cleaned by divers using a jetting system [660].

6.6.4. Worker protection

As well as actually performing the D&D activities, it is important that operations be carried out safely and that workers be protected from external hazards. In recent years there have been a number of developments in this field, examples include those in protective clothing, radiological monitoring, heat stress prevention and monitoring, and in fixative/stabilizer coatings.

TABLE IX. REMOTE SEGMENTING AND DISASSEMBLY EQUIPMENT

Name	Project/country	Description	Reference
USDOE development in remote segmenting equipment	USA	Various remote controlled segmenting and dismantling equipment	183
Remote dismantling	USA	Remote use of conventional segmenting equipment	647, 648
USDOE standardized tooling	USDOE	Remote handling system for performing various dismantlement tasks using overhead access facilities	596
Plutonium cells decommissioning	BNFL Sellafield, UK	Remote cutting systems for Pu handling	305
Windscale piles	Windscale piles and gas cooled reactor, UK	Chimney insulation and filter decommissioning; size reduction of pressure vessel; removal of refuelling channels; dismantling reactor internals	607, 649
Laser remote dismantling	Japan	Development of remote dismantling of reactor components using laser transmitted through optical fibres	515
Reactor internals	JPDR, Japan	Master–slave robotic manipulator–plasma arc cutting underwater	460
EMIR	Germany	Adaptation and testing of tools on telerobotic system: hydraulic hammer, hydraulic shears, crown drill, microwave scabbler, contamination monitor	619

TABLE IX. (cont.)

Name	Project/country	Description	Reference
RAMSES	KRB-A, Germany	Stand pipes cut with a plasma arc torch rotating automatically around the pipe	371, 618
Concrete dismantling	BR3, Belgium	Remote controlled jackhammer and shears installed on remote controlled excavator	266
Removal of steam generator tubes	Latina, Italy	Robotic system for the cutting and removal of steam generator tubes	197, 650
Cutting tool carrier and remote plasma torch cutting	JEN-1, Spain	Control system for fine positioning underwater dismantling of internals	282
Various remote underwater cutting tools for metal	BR3, Belgium	Underwater remote controlled plasma arc torch, EDM, circular saw, bandsaw for dismantling 2 sets of internals	267, 287
CLAUDIN	CEA/UDIN, France	Remote laser cutting	651
Concrete dismantling	EBWR, USA	Biological shield removal using electrohydraulic remote controlled impact machine	423

6.6.4.1. Protective clothing

In the USA there have been a number of developments with respect to protective clothing, e.g. the use of overgarments made from newly developed materials and the development of a liquid air 'backpack' to provide both oxygen and cooling air to the operator in the protective suit, which removes the requirement for an air supply umbilical. Tests performed at C reactor (Hanford) and at CP-5 (ANL) are described in Refs [217, 661–665]. Another interesting development is the use of an anti-dust helmet at the Kjeller reprocessing plant in Norway [424] (Figs 50, 51). Details of work undertaken in Belgium are described in Ref. [292].

TABLE X. DECONTAMINATION EQUIPMENT

Name	Project	Description	Reference
Concrete shaving	Eurochemic, Belgium	Automatic displacement shaving machine	136
Remote control underwater vehicles	Windscale piles, UK	Cleaning water ducts	610
Electropolishing head unit	Belgium, Germany, Japan and UK	Improved surface decontamination	336, 370
Vertical wall scabbler system	USDOE Office of Technology Development	Vertical wall decontamination	87, 652, 653
Remote operated vehicle	USDOE Office of Technology Development	CO_2 blasting of concrete surfaces	87
MOOSE™ decontamination robot	TMI-2 and other D&D projects	Concrete floor scabbling	654 (Fig. 49)
Hot cell decontamination activity	West Valley, USA	Remote decontamination	183
Tokai reprocessing facility	Tokai, Japan	Dissolver cell decontamination	183
Water jets GM-IM, GM-7, GEM	Under development by Ministry of Nuclear Power, Russian Federation	Remote flushing of tanks, vessels, canyons	244, 246
Steam injector heads GP-22, GP-31, GP-51, GP-MEM	Under development by Ministry of Nuclear Power, Russian Federation	Washing of premises and equipment with assistance of manipulators	244, 246
LOTOS	Under development by Ministry of Nuclear Power, Russian Federation	Decontamination of equipment by mixture of saturated steam and chemicals	244, 246

TABLE X. (cont.)

Name	Project	Description	Reference
COMPLEX ALPHA	Under development by Ministry of Nuclear Power, Russian Federation	Preparation of remote application and removal of strippable coatings	244, 246
Steam washing system	Under development by Ministry of Nuclear Power, Russian Federation	Removal of contamination from metals, brick and concrete by steam–abrasive mixture	244, 246

6.6.4.2. Radiological monitoring

A wireless remote monitoring system has been tested as part of the C reactor large scale technology demonstration project at Hanford [666]. The system allows supervisors, remote to the work area, to monitor in real time, by means of radio transmitters carried by the workers, the dose uptake of operators as they perform a variety of D&D tasks. The transmitters also allow communication between the operators and the supervisors.

6.6.4.3. Heat stress prevention and monitoring

In hot climates, the requirement for workers to wear additional protective clothing to protect them against radioactive contamination can cause them to overheat and suffer heat stress. A system for taking real time physiological measurements of the operators as they performed a variety of D&D tasks has been tested at C reactor [667]. The system requires the operator to carry a radio transmitter linked to sensors on the worker's body which measure heart rate, movement, skin temperature and core temperature. The data are then transmitted to a monitoring station remote to the work site which allows a supervisor to monitor constantly up to eight workers simultaneously and to advise them on their physical condition. Further progress in this field at Hanford is described in Ref. [668].

A separate development tested at Fernald [669] is a garment containing water cooling channels which are fed by chilled water from an ice pack. The suit is worn against the worker's skin and a pump on the ice pack forces chilled water through the cooling channels, thereby keeping the operator cool. Other technologies to alleviate heat stress are described in Refs [663–665, 670].

FIG. 49. Scabbling robot at work.

6.6.4.4. Fixative/stabilizer coatings

Various agents can be used as coatings on contaminated residues in order to permanently fix or stabilize the contaminant on the substrate, even though no removal of contaminants is achieved. These coatings may be used on PCB, explosive and radioactive contamination [183]. At Fernald Plant 7, after washing to remove gross decontamination, an acrylic latex coating has been used to fix any remaining loose surface contamination [423].

Aerosols containing capture polymers are a recent development. As the aerosol ‘condenses’, it covers all exposed surfaces in airlocks, gloveboxes or ventilation ducts with a viscous, tacky coating. This allows the capture of various contaminants in situ without necessitating human exposure [671].

6.6.4.5. Contamination containment

For short term operations, standard industry practice has been to construct a temporary tent-like enclosure from plastic sheeting. However, the tent’s construction may impose operational constraints and create additional quantities of secondary waste.

FIG. 50. Protection helmet to prevent the inhalation of radioactivity. Clean pressurized air is fed into the back of the helmet and passes over the wearer's head, thereby preventing the inhalation of loose radioactive particulate. An additional advantage is that the air flow prevents condensation forming within the helmet.

A significant development in this field took place in UK with the introduction of the modular containment system (MCS). The MCS consists of prefabricated glass reinforced plastic panels which can be bolted together to form a self-supporting enclosure of the required size. Strippable coatings are applied to the walls and ceiling of the MCS for sealing purposes and contamination control. MCS applications to decommissioning activities are described in Refs [324–326]. Details of temporary airlocks and containments used in the Russian Federation are contained in Refs [244, 246].

6.6.5. Handling and lifting equipment

Normally, during decommissioning, use can be made of the handling and lifting equipment of the plant, if still serviceable. However, the dismantling and decommissioning operations are often very different from the ones carried out during

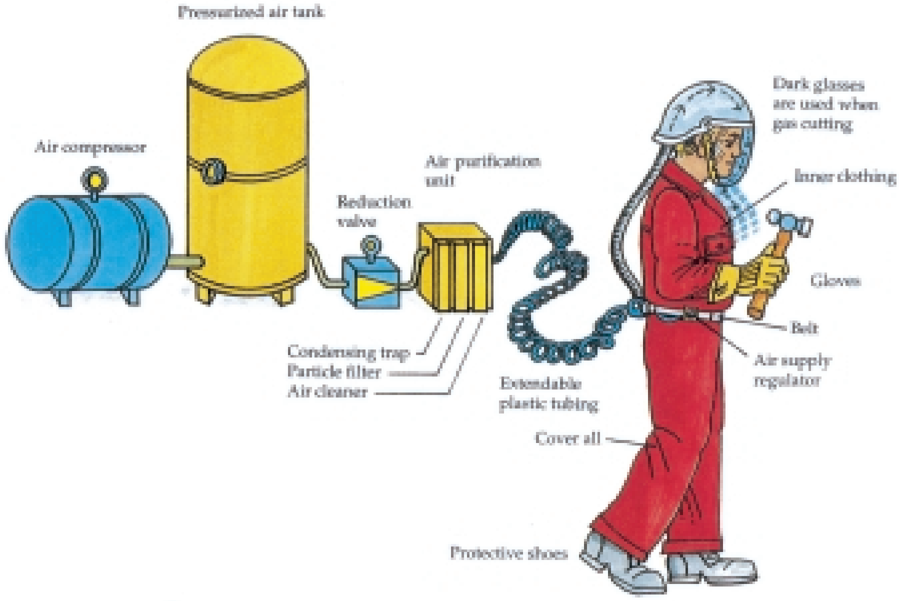

FIG. 51. Anti-dust helmet and protective clothing worn by operators.

plant operation. Therefore, new systems often have to be installed to cope with the additional requirements, e.g. the one-piece removal of a reactor vessel. Moreover, for high radiation areas, e.g. inside hot cells or reprocessing cells where no (or few) handling devices have been installed for normal operation, remote controlled cranes, hoists or lifting systems can be required.

Lifting yokes and hydraulic jacks were used to lift the core support floor at the FSV reactor as the existing reactor crane did not have the required capacity for this operation [68]. Hydraulic jacks were also used to lift the top biological shield at the WAGR [445].

Improvements in the payload capacity of telerobotic arms (see Section 6.5) can also help avoid the need for additional lifting systems and can allow the cutting of larger sized pieces. The shielding requirements for the transportation of activated or heavily contaminated sections often demand that the disposal routes be able to support the weight of the additional shielding as well as the item itself.

6.6.6. One-piece removal of large components

One-piece removal of large components has been performed at a number of nuclear facilities as a means of simplifying the dismantling or waste disposal processes.

FIG. 52. Removal of the WAGR top dome.

The benefits of this approach are reduced project costs, reduced time-scales, lower operator dose uptake and increased operator safety. This technique is especially attractive when there is close/ready access to either water or rail transportation facilities. One-piece removal can be divided into two distinct categories:

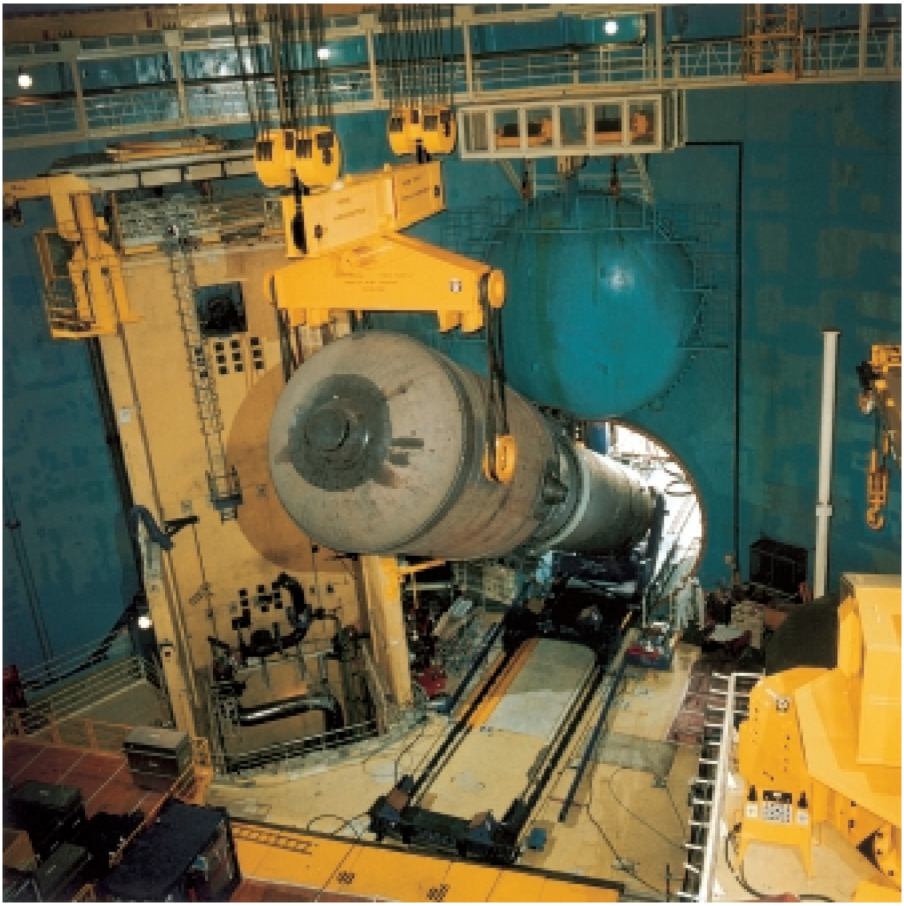

FIG. 53. Handling equipment used for removing a corrosion damaged steam generator at Dampierre (1990). Note the size of the main hatch which allows the one-piece removal of the unit.

- Removal of a large component to an adjacent facility, e.g. waste processing facility or special purpose containment, in order to reduce operator dose uptake and/or improve access in order to simplify subsequent size reduction processes. Examples of where this has been done are given in Refs [150, 423, 445, 672]. Figure 52 shows the removal of the WAGR top dome and Fig. 53 the one-piece removal of the Dampierre steam generator in France.

- Removal of a large component and one-piece disposal, i.e. after being lifted out the component is transported to its final disposal site and/or encapsulated

FIG. 54. A heat exchanger being removed from the WAGR.

without any further size reduction. Examples of where this has been done are reported in Refs [62, 65, 423, 487, 673–677]. One-piece removal could prove, in some cases, to be more cost effective and result in less radiation exposure than if the vessel were segmented. The removal of the four steam generators through the containment dome at WAGR was achieved using the biggest stand-alone crane existing in Europe [678] (Fig. 54). The transportation of these steam generators to the disposal site through narrow village roads also required the use of a special transporter.

The one-piece removal of the RPV at Shippingport [675], Trojan [65, 679] and Yankee Rowe [674] in the USA required a dedicated crane and cradle for handling and transportation to the disposal site. Sketch descriptions of one-piece reactor block removal projects at Shippingport and Hanford are given in Figs 55 and 56 (see also Ref. [680]). Additional references to specific techniques used for one-piece removal are provided in Refs [681, 682].

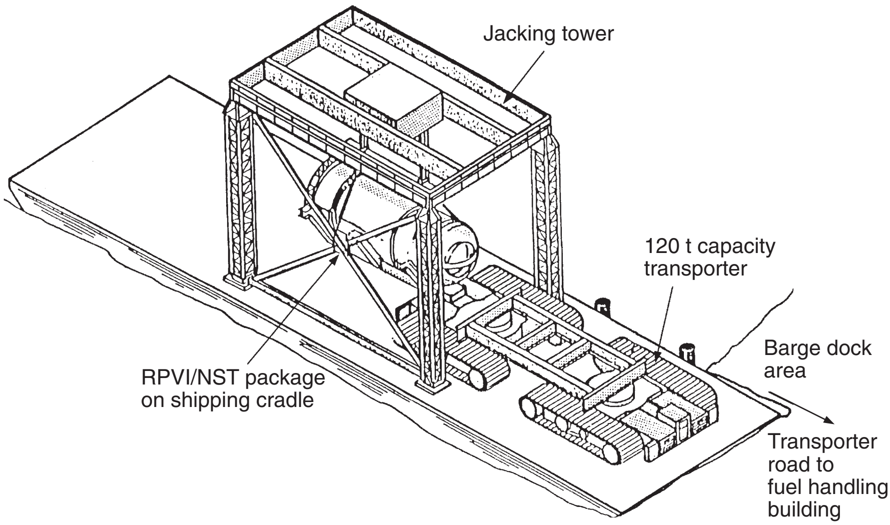

FIG. 55. Reactor block being loaded onto the barge during the Shippingport Station decommissioning project.

6.6.7. Use of mock-ups

Many problems can be solved by the use of mock-ups, such as:

— Training of personnel to perform the planned work.
— Positioning of remotely operated tools to optimize the planned work processes.
— Adjusting and testing the performance of remotely operated tools, etc. [25, 445].
— Selecting and defining the cutting/operating parameters of tools and equipment.
— Optimizing radiation protection according to ALARA principles, which allow the identification of procedures and operations that can cause excessive operator dose uptake and which allow the modification of working practices to eliminate these.

Special remote controlled units were developed and tested on full-scale mock-ups before they were used for dismantling the KNN reactor [367]. Similar work, also in Germany, is being undertaken at the Wiederaufarbeitungsanlage reprocessing plant [683]. All the underwater cutting equipment (plasma torch, EDM, mechanical saws, shears, etc.) was tested on simplified full-scale mock-ups at BR3 in Belgium, as were dismantling techniques for the biological shield [130]. Reduced size simplified

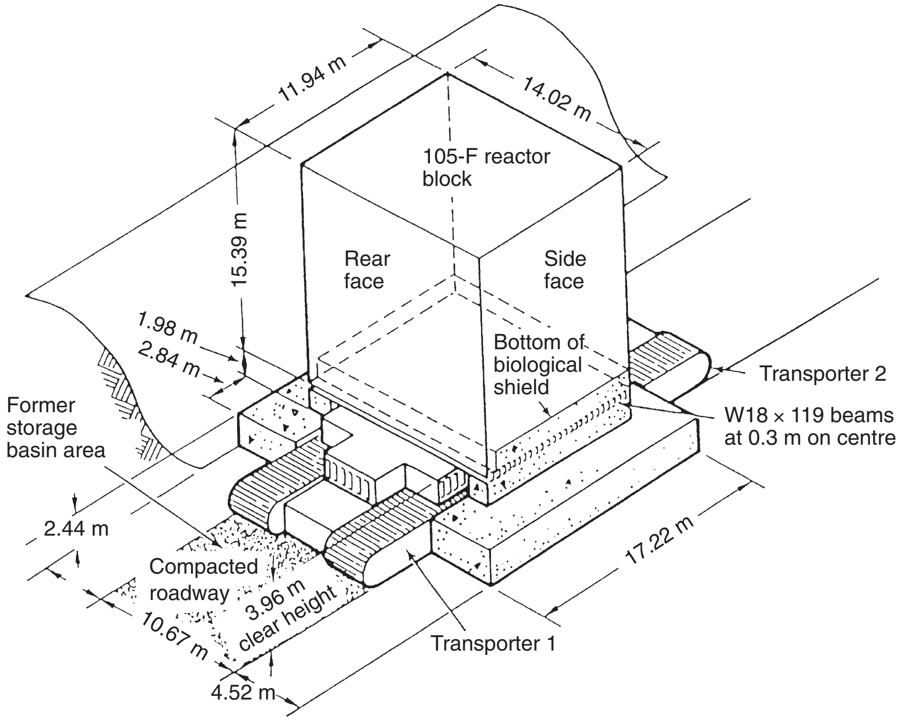

FIG. 56. Sectional view of the transporter in the excavated opening under the Hanford 105-F reactor block.

full-scale mock-ups were also used at WAGR [452] for training personnel and testing remotely operated tools for dismantling the internals of the reactor.

6.7. SOFTWARE TOOLS

There are currently several commercially available computer programs which can be helpful in planning and carrying out decommissioning. Such programs are sometimes also made available through organizations such as the IAEA, the OECD/NEA [684] and the USDOE. These software tools can be helpful in a very wide range of activities, from radiation protection optimization [685] including detailed shielding checks, exposure pathways [686] and estimated radioactive inventory [687], to more general tasks such as record keeping, operator training [688], computer mapping of facilities [689], project planning [690–692], data management [693], decision making [237, 246, 694, 695] and actual operation [268, 632]. A general discussion on the subject is given in Ref. [121].

7. GENERAL LESSONS LEARNED

Experience in the decommissioning of large nuclear facilities gained during the 1980s and 1990s has been evaluated and important lessons have been learned. Although the following list is not intended to be exhaustive, it may contribute to drawing the reader's attention to aspects important in decommissioning planning and management. Compilations of experience and lessons learned can be found in Refs [39, 117, 183].

7.1. GENERAL

- Decommissioning should be kept simple and should not be made overly complex. Mature, commercially available technologies should be used wherever possible to help decrease costs and optimize performance. However, oversimplifying decommissioning projects in the early planning phase should be avoided.

- Use of mock-ups and computer models is essential for operator training, dose reduction (ALARA), safety, feasibility and maintenance.

- Availability of accurate and complete records of facility operation and decommissioning is essential.

- Plant operators must be conscious of the need for the decommissioning activities. Personnel must recognize that this is a key part of the facility's life-cycle.

- Re-training and restructuring for decommissioning must take place at all levels in order to make decommissioning successful.

- Continuous quality improvement should always be a goal. This process should be driven by the facility operator and staff.

- Full use of existing, available structures and facilities (i.e. cranes, etc.) should be made.

- Good decommissioning requires some flexibility. The regulatory framework should not be unnecessarily complicated.

- Dose budgets are difficult to calculate and often overestimated.

- Alarm dosimeters have contributed greatly towards allowing operators control their own dose uptake.

- Handling and lifting equipment is not a minor item where decommissioning is concerned and must be considered in the initial planning phase.

- R&D should focus mainly on dose reduction, waste minimization and cost limitation.

7.2. CHARACTERIZATION

- Estimation of activation and contamination levels are often far from the actual values. Sampling is necessary to assess real values.

- Characterization can be expensive and cannot always be all-inclusive. In addition, if too exhaustive it may not be consistent with the ALARA principle. However, it must be thorough, carefully planned and well executed.

- There is a need for improvement in the area of direct radiation field measurement of facilities and in the fast characterization systems for waste and waste packages.

- Characterization and measurement for release is a critical area where there is still a need for further R&D.

7.3. DECONTAMINATION

- Often a combination of decontamination technologies is needed rather than just one particular technology.

- An evaluation must be made in order to optimize the decontamination needs of a project. Issues such as dose uptake, secondary waste generation and waste disposal can impact this.

- On-site decontamination is to be preferred if it is not inconsistent with optimization of dose uptake, costs and waste disposal routes.

- Current technologies for chemical decontamination are still case specific. Efforts should be made to enlarge the direct applicability of existing processes.

- Most of the processes used for decontamination are proprietary. In this case, special attention must be given to the analysis of specific chemical decontamination solution capabilities and resulting waste prior to selection for a given application.

- For closed systems, one stage decontamination and treatment processes generally produce the smallest volumes of secondary waste.

7.4. DISASSEMBLY

- Plasma arc and all other thermal cutting systems tend to spread contamination and require a means to contain it. Therefore, while mechanical cutting may be slow initially, it could prove to be more efficient in the longer term. All the advantages and drawbacks of the different methods (cutting speed, overall speed, secondary waste generation, dose uptake, cost, etc.) should be balanced.

- Underwater cutting (for highly irradiated pieces) is very efficient and the dose uptake does not depend significantly on the specific activity of the workpiece.

- The appropriate tool should be used in its proper place. Investment costs are minimal when compared with waste and staffing costs and should not be the driving factor in tool selection.

- Maintenance, tool replacement and ease of decontamination are important factors in selecting a tool.

- The amount of planning required for power supplies, support systems and a central cable network should not be underestimated. Flexibility is essential if unplanned events are to be accommodated.

7.5. WASTE MANAGEMENT

- The waste route, waste storage availability and acceptance criteria (with related constraints) should be established prior to starting operations. This can lead to staff savings and dose and waste volume reductions.

- The logistical requirements for removing the waste and packaging, and the requirements for temporary storage should not be underestimated. Transport, throughput and storage logistics must be clearly defined and agreed prior to starting operations.

- The sorting of waste items and streams should be done as soon as possible, preferably at the point of waste generation. This will allow optimization of waste management activities. Also, close monitoring of this process is critical to ensuring compliance with regulatory requirements.

7.6. ROBOTICS AND REMOTE OPERATION

- The use of robotics should be considered only after a thorough analysis of other options has been made. This statement reinforces the general message, which is to keep decommissioning simple.

- Few projects require telemanipulators or sophisticated tools. Simple tools, having only a few degrees of freedom, are often sufficient for most operations. Remote tools need to be user-friendly, readily adaptable and robust.

- To be useful for decommissioning applications, manipulators need a sufficient payload capacity and must be robust. In addition, in the selection of tools, it is good practice to allow for contingencies arising from reaction forces and other factors. Control of manipulators when operating at full payload capacity is often poor.

- Stereo viewing systems are beneficial for use with machines having several degrees of freedom.

- Umbilical and cable management is always a problem. This has been partially solved in some recent applications, but improvements are still needed.

7.7. LONG TERM INTEGRITY OF BUILDINGS AND SYSTEMS

- A cost–benefit analysis should be performed to determine which systems are worthy of being maintained as opposed to those that are easier to replace at decommissioning (e.g. ventilation equipment, cranes).

8. CONCLUSIONS

A significant amount of practical experience has been gained over the last 15 years in the wide range of technologies used in decommissioning nuclear facilities. Beginning with the decommissioning or dismantling of smaller plants and facilities, such as pilot or test reactors and small nuclear fuel cycle facilities or their constituent parts, there has developed a broad range of:

— Decontamination techniques,
— Dismantling and cutting techniques for metal and concrete,
— Options for segmenting or shipping intact large components,
— Tool deployment and support systems,
— Waste management approaches.

Over the last few years it has become apparent that an increasing number of large nuclear facilities worldwide have become candidates for decommissioning in the short term. For these kinds of facilities, a wide spectrum of measures and means are available which have been proven in previous decommissioning projects. However, for some nuclear facilities it is still necessary to have solutions related to special problems such as the management of graphite and sodium materials or alpha contaminated waste. Future R&D work will also be helpful in enhancing public acceptance before selecting any of the technologies identified in this report or before taking any course of action. Development in the field of international standards for clearance levels of materials and final site clearance is promising and will be of considerable assistance to practitioners. For planning decommissioning work, strategic factors should be taken into account, such as:

— Policies and regulations
— Future use of the site
— Availability of a waste storage or disposal site
— Impact on other decommissioning operations.

Preparatory work should be done before any planning or execution of decommissioning operations. This includes:

— Assessing the availability and operational status of items such as cranes, radiation monitoring systems, ventilation systems and waste treatment facilities;
— Undertaking a survey of dose rates and contamination levels and their radionuclide composition.

Only after this work has been carried out should the project staff consider the following items, which are the focus of this report:

- — Which methods are available and able to be used;
- — Whether any additional R&D work is necessary for a given method;
- — What the advantages and disadvantages of a measure or method are (e.g. the choice of a certain decontamination method based on its production of secondary waste and its cost effectiveness).

Current technologies can cope with almost all the needs of decommissioning. This report helps familiarize the reader with the state of the art in such technologies. Some techniques still need R&D to enable them to reach maturity or to reduce dose uptake or the amounts of waste generated or the costs. Lessons learned through current or completed projects advise the reader of specific actions to take, or to avoid, when selecting or using technologies for particular applications.

Appendix

EXAMPLES OF SPECIFIC LESSONS LEARNED FROM DECOMMISSIONING PROJECTS

The following examples of the lessons learned from decommissioning projects include brief technical information on the facility involved and an outline of the problems/requirements encountered. The situations described are typical of the issues that can arise in the planning or implementation of decommissioning activities. The following general categories of events/issues may be highlighted:

- *Environmental protection:* (i) KKN, unexpected presence of tritium; (ii) Atomic Weapons Establishment (AWE), end points and constraints.
- *Occupational radiation protection:* (i) various UK installations, control of operator dose uptake during decommissioning operations; (ii) various UK plutonium facilities, optimal strategy to dismantle plutonium facilities; (iii) Magnox reprocessing plant B205, refurbishment strategy; (iv) Building 212 (ANL), contamination control during dismantling; (v) EBWR (ANL), internal contamination; (vi) various Belgian facilities, worker protection in decontamination.
- *Lack of as built drawing, complicated geometries:* (i) KKN, grinding of pressure tube welds; (ii) KKN, removal of shielding spheres out of the reactor neutron shield; (iii) various UK plutonium facilities, optimal strategy to dismantle plutonium facilities; (iv) DIDO highly active handling cell, various operational issues.
- *Robotics:* (i) reprocessing plant B204, need for remote handling operations; (ii) DIDO highly active handling cell, various operational issues.
- *Decontamination and dismantling technologies:* (i) DIDO highly active handling cell, various operational issues; (ii) post-irradiation examination caves (Berkeley), refurbishment/decommissioning strategy; (iii) Fernald Plant 7, building demolition; (iv) EBWR (ANL), underwater cutting issues; (v) BR3, primary loop decontamination; (vi) various UK installations, reuse of existing facilities and services.

Although the information presented is not intended to be exhaustive, the reader is encouraged to evaluate the applicability of the lessons learned to a specific decommissioning project.

Facility name: **KKN, Germany**
Requirement/problem: **Unexpected presence of tritium**

In the shutdown phase from 1974 to 1976, the primary circuit and moderator tank were emptied of heavy water and gas. The system was then purged using hot deionized water and dried with hot air before the reactor was declared 'free of D_2O'. Subsequent to this, the tritium release limit for the reactor exhaust was reduced by a factor of 10^4 compared with the operational limit and an absolute annual release limit for tritium agreed with the regulator.

In 1987–1988, in the dismantling of the small bore tubing used to sample the primary coolant and moderator during reactor operations, it was realized that the purging had not cleared this pipework of tritiated water. In total, some 100 L of D_2O remained and this released a significant quantity of tritium into the reactor containment, causing the annual tritium release limit for the facility to be reached within a matter of days. This resulted in dismantling work being postponed until the D_2O could be removed in a controlled manner and new release limits agreed with the regulators.

Lesson learned:

Caution should be used in decommissioning in reducing release limits with regard to the operational phase. Although, in general, total activity releases are expected to be considerably lower than in the operational phase, surprises are always possible.

Facility name: **KKN, Germany**
Requirement/problem: **Grinding of pressure tube welds**

The first remote controlled dismantling step on the reactor was the removal of the pressure tube internals. Following this, the side welds connecting the 351 pressure tubes with their respective shield sleeve at the lower neutron shield had to be opened. For this purpose a tube grinder unit was used.

The tool was lowered down inside the pressure tube by means of a purpose-made lifting attachment and positioned at the vertical level of the side weld to be treated, approximately 6 m below the upper end of the pressure tube. The grinding process was performed as planned, followed by an inspection of the weld, which was meant to be removed. However, although extensive mock-up tests at the factory had demonstrated that the process was effective in removing the weld, the inspection showed that this was not the case in practice. Further investigations led to the conclusion that the side weld had not been carried out as indicated in the drawing (3 mm wide) but was, instead, a seam 9–16 mm wide.

To remove the weld a second cut had to be performed. This created problems with respect to further increases in temperature at the cut position, and delays to the project programme arising from the need to reduce the dust produced by cutting and the need to replace grinding wheels.

Lesson learned:

The design of the pressure tube reactor was complicated and the internals could not be readily viewed. Therefore, in spite of the mock-up tests, each remote controlled dismantling step had to be carefully planned and the tools used made as flexible as practicable so that modifications could be carried out in a simple and fast way.

Facility name: **KKN, Germany**
Requirement/problem: **Removal of shielding spheres out of the reactor neutron shield**

The chambers which form the neutron shield of the reactor are filled with a large quantity of steel spheres which had to be removed to allow decommissioning of the neutron shield to progress. To remove the spheres the decision was taken to use a high velocity vacuum system to suck them into a transport/disposal container. The vacuum system used had an oscillating suction tube and a small inlet orifice (max. 38 mm diameter) through which individual spheres could be sucked. Development trials using mock-ups of the spheres led to the inclusion of an oscillating tandem suction tube and proved that the system should perform adequately during actual operations on the reactor.

When the system was deployed, problems were experienced for the following reasons:

- The spheres did not correspond to the design drawings and were in fact crude stampings, unsymmetrical in shape and having burred edges.
- The spheres had a resin-like coating which caused them to stick together to form a solid structure.

The consequence of the above was that removal rates dropped to one tenth of those achieved during mock-up trials, and a number of spheres could not be removed. These subsequently caused problems during removal of the shield girders as they tended to become trapped in moving parts. For removal of the lower neutron shield the unit was modified to improve suction capacity and the performance of the vibration device and suction tubes. These improved the efficiency of the operation such that the project programme could be maintained.

Solution/lesson learned:

The lesson that can be drawn from this case is similar to that described in the previous example and emphasizes the need for visual inspection of components, especially on old plants where the design drawings are very often not reflected in a plant's as built status.

Facility name: **Various UK installations**
Requirement/problem: **Reuse of existing facilities and services**

The use of existing facilities for carrying out reactor defuelling operations following final shutdown is accepted as standard practice. However, careful and detailed planning of the overall decommissioning sequence early on can lead to significant savings, since structures that would otherwise have been removed can be retained and reused in order to simplify later operations.

With cranes and other purpose-built lifting structures, it is often obvious where they may benefit subsequent operations, but for some other features this is not always the case. Two examples of this are:

- The removal of the top biological shield of the Windscale advanced gas cooled reactor was achieved by retaining the gantry and drive assembly of the refuelling machine after the rest of the machine had been dismantled. This was then used with a set of servo-controlled jacks to lift the bioshield plug and transport it to a purpose-built cell for size reduction. This led to a lower operator dose uptake than if it had been cut into sections in situ over the reactor in the direct shine path of radiation from the reactor internals [696].
- The existing water in the fuel ponds of the steam generating heavy water reactor was used to assist operators in accessing the fuel pond walls and for containing contamination during cleaning of the walls. This was achieved by using pontoons to support the operators on the surface of the pond and water jets to remove loose contamination below the water level [697].

Solution/lesson learned:

The lesson that can be learned from these experiences is that careful consideration should be given to the uses a structure may be put to prior to its being ultimately decommissioned as this can lead to considerable project savings in the longer term.

Facility name: **Various UK installations**
Requirement/problem: **Control of operator dose uptake during decommissioning operations**

In any decommissioning task which requires operator entry into a radiation area, the minimization of the radiation dose received by the operator is of primary concern. To minimize the potential dose prior to operator entry to the worksite the following steps in the radiation protection plan are usually carried out to meet ALARA principles:

— All aspects of the operation are planned in detail, including the tooling required, operator access and exit points, and the actions to be taken for abnormal occurrences. These form the basis of the operators' working instructions and the safety regime under which the work will be carried out.
— Operators are trained using inactive mock-ups of the work site to build up detailed experience of the operating conditions, e.g. setting up and operating times.
— The work site is surveyed and detailed radiation maps made highlighting any areas of concern. These are then used to calculate the theoretical operator dose uptake for carrying out the work and form a basis with which dose uptake during actual operations can be compared.

However, despite this careful planning of the operations and the detailed estimation of the likely operator dose uptake, the following is often observed:

— Operator dose uptake is considerably lower than that calculated on the basis of the measured radiation fields in the work area. This is particularly the case when there are a number of 'hot spots' present.
— Individual operators or teams can receive widely varying dose uptakes when carrying out the same task in the same radiation area and having received the same level of training.

The reasons for this are attributed to the points below and have been borne out during decommissioning operations on various UK facilities:

— Most operators behave in an intelligent manner when working in a radiation area in order to limit their own personal dose uptakes. This means operators, when not required for a task, retire to the lowest radiation area and do not stand watching others work. Also, when working, operators position themselves in the lowest available radiation field. The development of personal electronic dosimeters with audible rate alarms has assisted greatly in promoting this practice.

— Discrepancies between the dose uptakes of individuals or teams carrying out similar operations are usually due to working practices. Experienced operators tend not to rush when performing the work, therefore ensuring that the tasks are completed correctly the first time around. Also, the positioning of tooling relative to the operator and the use of secondary shielding are major factors. In many cases, for experienced teams, secondary shielding increases dose uptake rather than reduces it since there is a dose penalty associated with its installation and removal and it can restrict the operators' work space.

Solution/lesson learned:

In conclusion, even with careful planning, a major factor in minimizing operator dose uptake is the intelligent behaviour of the operator during actual operations. Those operators who fully understand why the work is to be performed and who plan and refine their working practices within the scope of the operational safety requirements usually complete the operation faster, safer and with lower operational dose uptake than those who simply follow instructions without questioning why. These operators should be identified and placed with other individuals in order to provide 'on the job' training and to promote best working practices throughout the operator teams.

Facility name: **Various UK plutonium facilities**
Requirement/problem: **Optimal strategy to dismantle plutonium facilities**

Plutonium handling facilities do not, in financial terms, form a very major part of the total UK nuclear facility dismantling programme. However, they suffer from progressive increase in radiation levels as a result of americium in-growth, and containment standards deteriorate on unused plants. All UK operators of major plutonium facilities have given containment standards a high priority in their programmes.

The objectives of the current programmes are therefore to remove redundant facilities, maintain safety and reduce surveillance costs. Additionally, and especially with the initial projects, it has been the aim to use these as testing grounds for experience and techniques, and to develop bases for more accurate assessment of decommissioning costs.

Positive lessons learned:

The range of UK Pu projects so far undertaken has provided experience in several areas:

— Containment and control of contamination. This is of particular significance in plutonium plants. In all radioactive facilities inadequate control of the spread of contamination causes significant increase in costs. This is due to increased decontamination needs, active waste volumes, and the likely increase in waste disposal costs as these relate to contamination levels in the wastes. In plutonium facilities, however, this consideration takes on greater importance owing to the stringent requirements for control of loose alpha activity on surfaces or as airborne particulates. Onerous, and expensive, working conditions and protective clothing requirements are necessary if activity levels are not maintained as low as possible.
— Waste handling and minimization. The difference in costs between intermediate level waste/plutonium contaminated materials and low level waste handling/storage/disposal requires stringent controls to minimize the former, together with segregation or assay and decontamination where appropriate. Control of the spread of contamination and the degree of plant clean out are major contributors.
— Material hold-up and nuclear safety. Accurate assessment of the radioactive material inventory is a problem in planning the decommissioning of any redundant facility. Again, this is particularly significant for facilities which have handled tonne or even kilogram quantities of fissile materials such as plutonium. In these cases, accumulation of residues which represent only a small fraction of plant throughput may be a criticality hazard if their configuration is changed or a moderator is introduced. The location and quantification of fissile residues in such a facility before and during clean out and dismantling are essential.
— External and internal radiation hazards. External radiation dose to operators has become a major concern in plutonium plants. The situation has been made worse by a reduction in the permitted annual exposure and in this particular context by the need to dismantle, within current dose limits, facilities which were designed to older standards.
— Decommissioning project planning. These uncertainties can be coped with by phasing detailed design, costing and safety studies throughout project life — this has been especially effective for larger projects. Effective planning tools are emerging, such as 3D modelling and varying databases and expert systems.

Negative lesson learned:

Detailed investigation at project startup cannot reveal features for areas which cannot be entered. Early plans must be based on available drawings and information, with adequate regard for likely inadequacies and a project plan for suitable hold points and changes in policy.

Facility name: **Magnox reprocessing plant B205, BNFL, Sellafield, UK**

Requirement/Problem: **Refurbishment strategy**

— To provide Magnox reprocessing well into the first decade of the 21st century additional dissolving capacity is required. Alternative proposals were examined ranging from in situ repair to 'greenfield' site replacement prior to the decision to refurbish the existing south dissolver facility and ancillary equipment.
— Cell access was a consideration. The largest item to be replaced was the dissolver vessel. This required an opening in the east wall of the cell measuring 4 m high × 5 m wide at the 5 m floor level. In addition, personnel doors 1 m × 2 m were required at four locations.
— Removal and replacement of all vessels and pipework within the cell on the 'hot streams' of the process were carried out.
— Refurbishment of the charge machines, various operational ejector containments and relevant instrumentation was undertaken.
— The condition of the vessels, pipework and equipment was fully assessed in order to decide on the extent of the replacement necessary. Some are being replaced and duplicated but one will be repaired in situ. Remote cutting, welding and inspection techniques have been developed to enable the refurbished plant to be reconnected to the existing highly active in-cell pipework using specially developed manipulators.

Positive lessons learned:

— An essential part of the project has been the establishment of the project control centre. This is the focal point for access and for all information relevant to the site work. The centre has been structured to enable personnel to enter the cell at all working levels from outside the building. This adequately segregates the extensive project engineering activity from the day-to-day operations within the plant. At each of the four access points a change room has been constructed, linked by enclosed corridors and an access tower to surveillance and conference facilities.
— The adoption of rigorous radiation dose assessment, control and recording procedures has brought about the introduction of a number of new techniques to cope with data handling on a scale (in this field) not previously undertaken.
— The investment in extensive modeling, both physical and computerized, in addition to detailed planning of activities, extensive briefing of the workforce prior to their undertaking in-cell work, provision of good audio contact and visual surveillance links have together been responsible for eliminating hold-ups, and for minimizing the dose uptake of the workforce.

— The highly radioactive plant has been decontaminated to a level where engineering work can be carried out manually. A sequence of alternate washing (hot and cold) was carried out using water, various acids and caustic solutions to reduce the radiation within the cell by a factor of 10^4 over a period of 4 years.

Negative lesson learned:

Where decontamination was not possible, the radiation source was either removed or shielded. A total of 65 t of shielding has been installed within the cell.

Facility name: **Reprocessing plant B204, BNFL, Sellafield, UK**
Requirement/problem: **Need for remote handling operation**

— Provision of cost effective technology, particularly utilizing available, robust and well proven techniques and including a mobile, long reach, heavy duty remote handling system.
— Provision of access for dismantling equipment, for personnel and for removal of materials in a cost effective manner.
— Upgrade existing ventilation systems to meet current aerial discharge criteria during decommissioning operations.
— Provision of remote size reduction facilities which use industrial robots and plasma arc cutting. Operating software to cope with plasma generated interference.
— Radiological design standards to be adopted are those currently applicable to existing BNFL plants. In particular, the targets for individual dose uptake will be a maximum of 15 mSv in one year and 150 mSv over a ten year period.

Positive lessons learned:

— A combination of remote handling capabilities with manual operations results in the development of ‘fit for purpose’ manipulators. Utilizing this, the contact deployment remote operation seeks to gain an acceptable and cost effective mix of humans and machines. Contact deployment and maintenance is employed, but equipment is operated from a central remote facility, which provides a better working environment for operatives.
— Use is made of a water/glycol hydraulic system to avoid detrimental effects on the building effluent treatment system in the event of leakage.
— A comprehensive manipulator system using proprietary components is employed, comprising:

i) A rail mounted bogie system to enable longitudinal deployment of the remote handling equipment on each floor of the cell.

ii) A 6 m extension telescopic arm fitted with a hoist to provide 3 t lift capacity at full extension. The telescopic arm is mounted on the rail bogie via a slew ring to provide 270° arc coverage.

iii) A 2 m reach hydraulic manipulator, with 100 kg lifting capacity, mounted on this arm by means of a self-levelling tilt table.

— Waste conditioning includes size reduction, sorting and packaging carried out at the robot work station. Two industrial robots capable of independent or synchronous operation are provided with plasma arc cutting capability. Supporting, gripping and turning operations are carried out utilizing a turntable. Size reduced items may be packed in disposal containers or removed for sampling and waste categorization tests.
— Decontamination facilities in the waste handling facility consist of lidded stainless steel tanks provided with electric heating, ultrasonic agitation, sampling, recirculation and ventilation systems. Provision is made for the use of nitric acid or other specified decontamination agents as required. Test tanks in the sampling facility enable trials to be carried out in order to maximize decontamination efficiency for specific items.

Negative lessons learned:
— Although the majority of waste from medium active areas was expected to meet acceptance criteria for land burial, the spread of alpha contamination was greater than expected, requiring some decontamination to make best use of this route.
— The adaptation of proprietary remote handling hardware proved easier than modifications to corresponding software, especially those made to cope with radio frequency interference from plasma arc cutting.

Facility name: **DIDO highly active handling cell, Harwell, UK** [698]
Requirement/problem: **Various operational issues**

— Decommissioning to Stage 3 of highly active cell used to support materials testing operations,
— Very high contact radiation levels as a result of processing ^{60}Co,
— Inadequate drawings and records.

Positive lessons learned:
— Value of robotic decommissioning (using the NEATER robot) as a way of making savings in terms of costs, dose and staffing,
— Value of mock-up trials of the robot before specific operations,

— Need for improvements in containment and ventilation before starting dismantling operations,
— Speed and convenience of oxyacetylene cutting.

Negative lessons learned:
— Need for extensive (and expensive) refurbishment of services after a period of minimal care and maintenance,
— Problems of hydraulic oil spillage resulting from attempting to operate long disused equipment,
— Ventilation problems of plasma arc cutting method.

Facility name: **Post-irradiation examination caves, highly active caves (6) for post-irradiation examination of reactor fuel and components, Berkeley Nuclear Laboratories, Nuclear Electric, UK** [699]
Requirement/problem: **Refurbishment/decommissioning strategy**

— Caves being refurbished for new duty;
— Caves 1, 2 and 3 to remain in use whilst 4, 5 and 6 are decommissioned and refurbished;
— D&D of in-cave equipment, ventilation systems, water treatment and caesium removal plant.

Positive lessons learned:
— Dose lower than expected,
— Convenience and speed of plasma arc cutting,
— Operator rotation to low active work.

Negative lesson learned:
Need for plans to be adaptable at all stages in order to cope with changes found to be necessary during actual decommissioning operations.

Facility name: **Various actinide and depleted uranium handling facilities, AWE, Aldermaston, UK** [700]
Requirement/problem: **End points and constraints**

— To remove the radiological toxic hazard (in a given facility) to a predetermined engineering/hazard status end point;
— All work to be pre-planned in accordance with current legislation;

— Key performance constraints are safety requirements, facility availability and Ministry of Defence programmes.

Lessons learned:

— Process facilities used for producing components to support the weapons programme generally consist of multiple glovebox suites and fume cupboards in which machine tools and equipment are housed and operated either by remote control or through conventional glovebox ports.

— Research and development facilities, consisting of multiple glovebox and fume cupboard suites, are often used for liquid/chemical research. Such facilities present a different decommissioning challenge, particularly with regard to the potential spread of contamination and the cleanup capability.

— In some cases a complete temporary ventilation system is installed and commissioned before work on removing the existing system commences. This maintains building containment and integrity throughout the decommissioning operations phase.

Facility name:	**Fernald Plant 7 (uranium conversion plant), USA** [701]
Requirement/problem:	**Building demolition**

Instead of the original concept of piece by piece removal (i.e. reverse construction) of the structure, it was proposed that the structural support columns of Plant 7 be cut using controlled detonation. By using a specialized steel cutting method comprising linear shaped charges with sequential charge detonation, the building was anticipated to fold within seven seconds. Plywood boxes and conveyor belting would be placed around the charges to prevent dispersion of material upon detonation; no toxic dust or fumes were anticipated from the detonation. The steel would then be size reduced, monitored for radiological contamination, and packaged once on the ground.

Prior to controlled detonation cutting of Plant 7, the interior and exterior walls, asbestos containing and asbestos contaminated materials, piping, equipment, west canopy, south shed and elevator were removed and packaged. Plant 7 was reduced to a simple structural steel skeleton and floor decking.

On 10 September 1994, the demolition contractor detonated 156 linear shaped explosive charges placed in 50 locations and intended to bring the building down. Approximately 416 copper clad, linear shaped charges were used as the primary steel cutting method. The net weight of RDX explosives was approximately 29 kg. Non-electric detonators of various internal delays were used to initiate the detonations of the explosives. Forty per cent strength ‘gelatin dynamite’ charges were utilized to displace structural columns after severance by steel cutting explosives charges. A redundant non-electric blasting system was used. The use of a non-electric system is much safer because there are no concerns with radio frequency or electricity hazards. All systems were designed and assembled in accordance with guidelines suggested by the manufacturer.

The first two floors of the building collapsed as planned. However, splice plates that had been pre-cut on the third and fifth floors did not separate as anticipated. The building dropped approximately 7.6 m instead of the planned 23.8 m. Following the partial take down by controlled detonation, the area was secured. The rigid steel structure was stable and leaning approximately 15° to the northwest. Following an extensive examination of the partially fallen Plant 7 structure, a decision was made to use shaped explosive charges to complete the take down on 17 September 1994. The successful take down occurred at 9:40 p.m. and utilized 260 shaped charges placed in 120 locations.

Lesson learned:

Safety benefits realized by the dismantlement method utilized included the following: reduced site worker risk to additional torch cuts, reduced worker time in high locations, ability to perform the controlled fall of Plant 7 on a weekend to ensure a reduced number of workers in the area, and reduced need for heavy lifts. The explosive demolition technique was successful and will be considered in future projects to significantly reduce worker risk, cost and schedule. Even with the need for the second explosive charge, the project will cost nearly $5 million less than alternative techniques and finish 7 months ahead of schedule.

Facility name:	**Nine laboratories housing plutonium gloveboxes for R&D within Building 212 at the ANL-East site, ANL, USA** [702]
Requirement/problem:	**Contamination control during dismantling**

During the preparations for the dismantling of more than 60 plutonium gloveboxes, an identified major item of concern was the release of any residual material during the size reduction of the gloveboxes and even more so during the removal of the neoprene window gaskets of the gloveboxes. In order to ensure that the release of any airborne contamination was minimized and was adequately addressed in work planning, some proactive procedural contamination control measures were incorporated into the work plan (1994–1995).

Solution/lessons learned:

Actions that were taken to contain airborne contamination events during dismantling of the gloveboxes were as follows:

— Tool effectiveness and the general operations were tested on a mock-up in a clean area.
— The glovebox cutting tool was vacuum cleaned after each use, therefore minimizing the generation of radioactive dust.
— Use of a clear plastic shield between the operator and cutter minimized the scattering of any contamination onto worker personal protective equipment.
— Local exhaust ventilation was used for radioactivity capture during the cutting of gloveboxes.
— Aggressive decontamination techniques were used only where other techniques were ineffective in removing oily stained areas of radioactive contamination.
— Administrative hold points were incorporated into the dismantling work processes to provide the opportunity to improve upon future glovebox dismantling based on recent operational lessons learned.

All of the above solutions combined to allow the project work to be completed with minimal airborne release events to the size reduction containment enclosure and minimal contamination of worker protective clothing.

Facility name: **EBWR, ANL, USA** [703]
Requirement/problem: **Underwater cutting issues**

During the process of performing the underwater size reduction of the EBWR reactor vessel internals using plasma arc cutting, several difficulties were encountered in the period 1993–1995. These included:

— Inability to strike and to maintain an arc,
— Water chemistry and pool clarity problems.

These problems quickly became a significant impediment to the project schedule. Not only did the labour force have to do the underwater cutting, but this was further complicated by the water clarity and conductivity problem.

Solution/lesson learned:
A water chemistry expert advised of several rather inexpensive simple approaches to solving the problems. One consisted of changing the composition of the gas supply used for the plasma arc cutting from 100% nitrogen to a blend of 95% argon and 5% hydrogen. After this there were no further problems with maintaining an arc. The water clarity and chemistry problems were addressed by adding between 1.9 L and 3.8 L of hydrogen peroxide per day to the fuel pool water circulation system. After this there were no problems with water clarity or conductivity.

Facility name: **EBWR, ANL, USA** [703]
Requirement/problem: **Internal contamination**

On 2 September 1994, ANL Dosimetry and Analytical Services notified the area health physicist that there were two individuals who had positive indications that an uptake of tritium and ^{241}Am/^{238}Pu had occurred since their baseline urine samples had been collected. Uptakes of transuranics were not expected. Work activities continued pending confirmation of bioassay results. On 9 September 1994, analysis of a faecal sample from one of the contract personnel confirmed the presence of ^{241}Am. D&D work inside the EBWR shell was immediately halted. Investigative work and health physics survey efforts proceeded to determine the cause for this and locate the source of the ^{241}Am. Required surveillance and critical maintenance, such as changing filters in air and water systems, were enacted to maintain a safe work environment and to protect operating equipment. Additional bioassay samples were taken to determine the number of people affected. Eventually, a total of seven contractor personnel had positive results for ^{241}Am and detectable levels of other nuclides.

Analysis of fuel pool water and fuel pool water filtration system filters indicated the presence of fission products (^{137}Cs, ^{90}Sr) and transuranics (^{241}Am). Analysis of air samples taken on 19 July 1994 near the fuel pool during control rod cutting operations indicated the presence of fission projects (^{137}Cs) and transuranics (^{241}Am, ^{238}Pu and ^{239}Pu). Previous characterizations had not reported these nuclides. The use of bioassays, daily air samples and administrative controls resulted in an accurate reconstruction of events. Six of the seven affected workers were involved with plasma arc operations in or above the fuel pool. The uptake occurred over a four-day period, with the greatest uptake in individuals working longest with the cutting operations. Speculation remains as to the source of the americium. It may have been a product of a ^{241}Pu foil lost in the EBWR facility during experiments run in 1967. The ^{241}Pu would have decayed into ^{241}Am, although no trace of ^{241}Pu was found. Another scenario is that although no fuel element failure was reported, undetectable microscopic cracks may have allowed the release of transuranics over the lifetime of the EBWR. Two of the contract personnel received approximately 3 mSv from the uptake of ^{241}Am. The remaining personnel are estimated to have received 500–600 μSv from the uptake of ^{241}Am. No personnel exceeded authorized limits.

The unexpected uptake of ^{241}Am in some workers caused major delays and cost increases that would not have been incurred otherwise. This problem reinforces the need to maintain and review all records and historical operational data. This information is essential in performing a complete characterization of a facility before initiation of D&D activities. The following are lessons learned which apply to all D&D projects in general.

Lessons learned — Prevention and early detection:

- — Monitor to detect nuclides reasonably expected based on past operations, even if they are not found in characterization;
- — Acquire a thorough knowledge of historic operations as this is the key factor of quality characterization, especially at experimental facilities;
- — Establish personal protective equipment levels conservatively;
- — Expand use of scheduled bioassays;
- — Ensure bioassay data reaches key managers in a timely fashion;
- — Use better quality air monitoring and dosimetry equipment as this is both desirable and cost effective.

Lessons learned — Recovery issues:

- — Investigation committees should be preselected, trained and dedicated to the investigation function.
- — Improvement in recovery procedure roles is desirable.
- — 'Surge' analytical capability is needed for sample analysis.

Lesson learned — Management issues:

Clear consensus on balancing internal exposure against other health and cost variables.

Lessons learned — Noteworthy practices:

- — Exposure was mitigated by prompt response of laboratory project manager.
- — Entry and exit bioassay data were extremely valuable.
- — Air sample archiving was key to dose assessment and event reconstruction.
- — Events were better understood and reconstructed by keeping excellent records.

Facility name: **BR3 prototype PWR, Mol, Belgium** [704]
Requirement/problem: **Primary loop decontamination**

The decontamination of the primary loop was carried out in 1991. The decontamination was performed using the CORD process. The primary loop was therefore closed and slightly pressurized, and the process used the primary pumps and different loops and equipment of the plant to circulate the chemicals. The contaminants were trapped on ion exchange resins, mainly located in the existing exchange columns of the plant.

The full system decontamination reduced the dose rate of the contaminated equipment on average by a factor of ten. The ambient dose rate amounts are now about 0.08 mSv/h in the containment building where the primary circuit and most of the auxiliary circuits are located. The total dose for the decontamination operation amounted to 0.16 man·Sv; 85% of this dose was received during the preparatory phase of the operation including the 'manual' closure of the reactor head. The chemical decontamination appears to be very cost effective in man-sievert exposure reduction when dismantling of the primary loop is considered, a dose saving of more than 4.25 man·Sv is estimated.

Lessons learned:

— The process applied is a smooth one, only a few minor operational problems were encountered. This could only be achieved by careful and detailed preparation. It requires a primary system in a sound operational condition and experienced operators from the plant.

— The estimation of the secondary waste quantity is not easy; more waste (mainly ion exchange resins) was produced than originally estimated owing to higher than anticipated crud content.

— The decontamination had an important impact on the dismantling operations of the reactor internals:

Firstly, a negative effect. Pollution of the reactor pool occurred during the unloading of the reactor internals, resulting in high turbidity and poor visibility. This pollution was due to the presence of insoluble ferrous oxalate and loose crud still present on the internals.

Secondly, a positive effect. The internals were remarkably clean. This greatly facilitated the subsequent dismantling operations and even allowed the disposal of some activated pieces at the upper part of the reactor as low radioactive waste (dose rate <0.2 mSv/h) which would not have been possible without the decontamination.

As a general lesson for future plants, it would be very helpful to include at the design phase features to allow for future decontamination, so that later modifications (in a high dose rate field) can be avoided. Moreover, progress still has to be made in the process chemistry in order to minimize the secondary waste arisings.

Facility name: **Various Belgian facilities (nuclear fuel factory, NPP, phosphate industry)**

Requirement/problem: **Worker protection in decontamination**

During qualifying tests on a carbon dioxide blasting process, many tests were conducted on the removal of epoxy paint from concrete and radium contaminated phosphate crud layers in piping. For these tests, in order to avoid the production of unnecessary quantities of waste, a small polyethylene tent was built in each case. Owing to the small volume of air (approximately 15 cubic metres), the use of the CO_2

pellet blasting system (pellets at –80°C), quickly reduced the temperature inside the tent, which fell below 0°C within a few minutes. A major consequence of this significant temperature decrease (apart from the uncomfortable working conditions for the operators) was the cracking and failure of the PVC inflatable suits worn by the operators. This resulted in the loss of individual protection (clothes contamination and inhaled air) and the operators having to evacuate the work area. Another consequence of the temperature decrease was that the mobile ventilation system quickly froze owing to humidity in the air. The pre-filters and the high efficiency particulate air filters froze, the ventilation system was automatically shut down and the dynamic confinement lost.

Solution/lessons learned:

The following improvements were brought into the decontamination process:

— Using larger volume rigid containment systems to avoid a rapid temperature decrease and to decrease the volume of the secondary waste produced,
— Stopping CO_2 blasting every 30 minutes for a 10 minute period to allow the temperature in the containment to increase,
— Providing operators with special clothes and gloves to protect against the cold,
— Procuring a synthetic inflatable suit more resistant to low temperature ,
— Providing pre-filters and high efficiency particulate air filters with a pre-heating unit at the entry of the mobile ventilation system (to dry the air and increase the temperature of the air entering the filters).

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