Annex I

NATIONAL AND PROJECT EXPERIENCE

The examples provided in this annex provide practical experience of policies and programmes for the delivery of decommissioning of smaller facilities in situations of limited resources in various Member States. The examples given are not necessarily best practices; rather, they reflect a variety of situations that have been met. Although the information presented is not intended to be exhaustive, readers are encouraged to evaluate its applicability to their situation.[1]

[1] National annexes reflect the experience and views of their contributors and, although generally consistent with the guidance given in the main text, are not intended for specific guidance.

Annex I.A

EXPERIENCE OF THE COMISIÓN NACIONAL DE ENERGÍA ATÓMICA, ARGENTINA

I.A–1. INTRODUCTION

Argentine experience is concentrated on the planning phase of decommissioning, as no definitive shutdown is foreseen for any nuclear facility. Decommissioning planning has concentrated on the Atucha I nuclear power plant (a 357 MW(e) pressurized heavy water reactor designed by Siemens) and on the RA-1 research reactor. For the latter, a procedure was established to be applied in decommissioning planning and prediction of total dismantled waste from the other five research reactors and critical assemblies operating in the State.

During the period 2001–2003, Argentina suffered its deepest economic crisis, which had an influence in stressing the need to save as many resources as possible — without negative effects on safety — in the proposed decommissioning alternatives and in the planning itself. In what follows, some policies are presented resulting from the need to 'squeeze' resources.

I.A–2. WORKING WITH LIMITED RESOURCES

I.A–2.1. Develop human resources through international cooperation

Labour is the main cost in planning decommissioning projects, and one of the most significant cost items in actual decommissioning projects. International cooperation, mainly with the IAEA but also via some bilateral agreements, has resulted in:

(a) Training of the facility's own staff in different decommissioning areas (planning, radiological characterization, quality assurance, decontamination) through an IAEA technical cooperation project and bilateral agreements, which saved Comisión Nacional de Energía Atómica's (CNEA) resources.
(b) The saving of resources by using IAEA experts rather than hiring consultants.
(c) The same channels may be used to train the operator's staff.

Developing regional advice, assistance and cooperation on decommissioning may be another way of maximizing the return from scarce resources. It is felt that experts from the region may be more acquainted with the problems, and may find it easier to establish an open dialogue regarding a given Member State's problems in decommissioning small facilities. A way of identifying the needs and problems, and providing advice, could be to establish regional networks on decommissioning. Technical and financial support (i.e. travel expenses, expert's allowances) may be necessary from the IAEA or from regional organizations.

I.A–2.2. Work from the very beginning with the regulator

In States without decommissioning experience, the regulator must also learn about the subject and develop staff and a regulatory framework. Working from the beginning in close relationship with the regulator will:

(a) Help to foresee regulatory changes that can result, in some cases, in additional (and significant) costs;
(b) Add mutual confidence (meaning cost reductions due to more fluid relations);
(c) Help to develop a safety culture in the decommissioner, which in the long term will also reduce costs.

I.A–2.3. Break down technology packages and contract by parts

Argentine experience in the nuclear business shows that large cost reductions are obtained if, instead of contracting large packages covering all phases of the project, the CNEA keeps the management of the work (meaning that adequate human resources have been developed) and breaks down the project into smaller subcontracts.

I.A–2.4. Financing from international organizations

In the past, except for Eastern Europe, international financial institutions have been reluctant to finance nuclear projects. However, in recent years the World Bank has started financing a project on uranium mining sites restoration in Argentina.

This financing source usually means lower financial costs, due to low interest rates and extended payment periods. International organizations also usually demand independent environmental impact assessments, thereby giving more confidence to the local community about the safety of the project.

I.A–2.5. Look for decommissioning skills, experience and techniques within the organization

The CNEA has performed many tasks and developed (and used) many techniques closely related to decommissioning in non-decommissioning projects. Examples are modifications and upgrading of facilities where radiological characterization, decontamination, cutting, dismantling and waste management were necessary activities. Contracts and training are saved if these skills are used in decommissioning. This implies identifying those skills, and some training, mainly to help people make the switch from operation to decommissioning.

I.A–2.6. In future facilities, carefully select materials, especially concrete aggregates

Most decommissioning waste in research reactors and small facilities is activated concrete rubble, in many cases low level waste with long half-lives (due to ^{152}Eu, ^{166m}Ho, ^{3}H and ^{36}Cl) whose disposal is problematic and expensive owing to the long times involved. For long lived nuclides, it is important that both concentrations in the waste and the total inventory be kept below storage/disposal limits. Long lived radioactivity due to activation can be greatly reduced by proper selection of concrete aggregates and cement during the construction of facilities.

I.A–2.7. On-site storage

When nothing else can be done, closing the facility undismantled may be the only valid alternative. This may also result from lack of clarity of future activities in the facility, a situation that has occurred with a critical assembly in Argentina. In that case, the CNEA's experience shows that:

(a) Some safety related tasks must be accomplished. In the case of the critical assembly, fuel was removed from the core and stored on the site as a way of eliminating criticality incidents.

(b) It should be taken into account that in many cases safeguards will demand the maintenance of surveillance and physical protection on the site. This will also prevent unintentional intrusions, removal and losses of activated materials, etc.

(c) If no safeguards are involved, for example a research reactor where fuel has been removed from the site, the main danger is dilution of responsibility with the consequence of intrusion, looting and spread of activity, littering, use for other purposes without radiological control, etc.

(d) If control of the site can be guaranteed for a long time, on-site storage may be implemented and the facility may also be used for storage of waste from other sources.

Annex I.B

BR3 DECOMMISSIONING PROJECT, BELGIUM: EXTENSIVE USE OF CONVENTIONAL TOOLS FOR DECOMMISSIONING PURPOSES

I.B–1. INTRODUCTION

BR3 is a small pressurized water reactor of 10.5 MW(e). Since the beginning of the 1990s, high activated components have been dismantled and removed. Contaminated equipment has largely been decontaminated for unconditional release. As a medium size facility, it has been proven that the accumulated experience can be applicable both to large decommissioning projects and small facilities.

This annex lists and explains some successful activities carried out throughout the project based on technologies and tools that are available worldwide from international companies in the building or the mechanical engineering sectors. As they are usually mass produced, they can be considered as cheap technologies in the decommissioning world, because they are not marketed specifically for ‘nuclear’ purposes. It is clear that similar approaches can be used for smaller facilities where large technology investments are not compatible with the available funds.

Note that although the BR3 project also required and used high technologies to carry out some parts of its programmes, these are not in the scope of this annex and hence are not described here.

I.B–2. REMOTE DISMANTLING OF HIGHLY ACTIVE COMPONENTS

During the dismantling of the internals of the reactor and the reactor pressure vessel itself, the main cutting was carried out using large and/or expensive machines. However, some activities were carried out using industrial tools that were adapted to work remotely under water, since the strategy foresaw underwater working for highly irradiated components.

The cutting of highly activated pipe from the reactor internals was carried out using hydraulic shears. It was possible to cut stainless steel pipes of up to 56/42 mm size. The shears employed were usually used by the site rescue team. They were fixed to the end of a long handling pole to work 5 m below the water level and the handle was modified to allow remote hydraulic actuation. Figure I.B–1 shows an underwater view of the shears in operation.

As the control rods of the reactor, their extensions and their shroud tubes were too large for the shears, appropriate equipment was built by the BR3 mechanical workshop. The cutting equipment is based on a reciprocating saw, again available in a tool shop. As the saw is pneumatically driven, some modifications were made for the pressured air intake and exhaust. The saw is fixed on the vertical axis of a frame that clamps the rod or pipe to be cut. The cut is generated by the rotation of the saw around the vertical axis. To keep the equipment simple this rotation is generated only by pulling a fine cable using the building crane fitted with a dynamometer. The cable is connected to the former handle of the saw via a pulley. Figure I.B–2 shows the machine during installation in the BR3 pool.

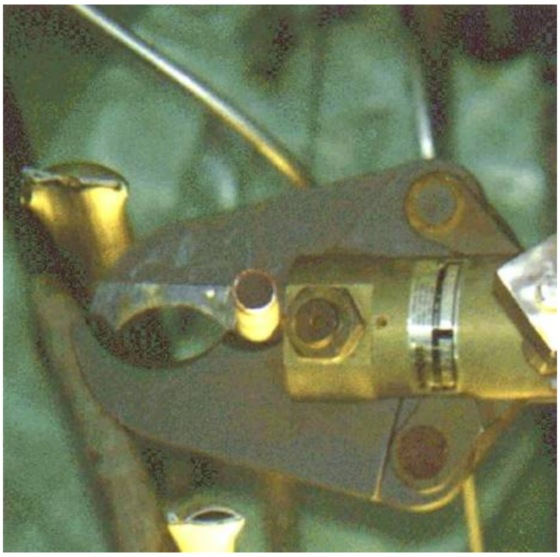

FIG. I.B–1. Underwater view of rescue team shears in operation.

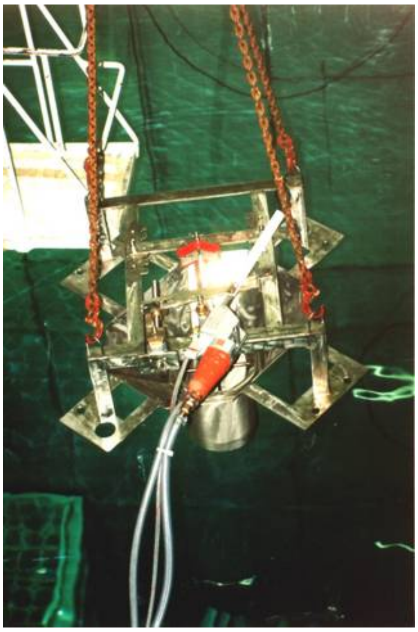

FIG. I.B–2. Installation of a reciprocating saw in the BR3 pool.

At several points in the dismantling of the internals of the reactor and pressure vessel, separation into subcomponents without cutting has been recognized to be the most effective approach. This generally meant unbolting. The BR3 team built several devices in order to reach the fastening bolts and to unscrew them. Hydraulically and pneumatically driven equipment was built and used successfully. Challenging uses included top–down screws for which the positioning of the socket on the screw head was only possible with great concentration on the part of a skilled operator holding the tool delivery pole and looking at a camera–monitor system. Figure I.B–3 shows a pneumatic shock unbolter more usually met in a car maintenance garage.

FIG. I.B–3. Pneumatic shock unbolter.

A groove on the equipment allows the orientation of the unbolter for top–down screws. A counterweight guarantees a well balanced and vertical perch system.

During remote dismantling, a recurring problem, as important as the cutting itself, is the manipulation of the cut pieces. Therefore, the BR3 team has made extensive use of automatic clamps generally used in steel plate shops. As some models are dedicated for thick plate, a large variety of components can be handled using them. Some clamp models are automatically actuated as they are positioned on the plate. The single modification made concerns the adaptation of the lever to make it possible to deactivate the clamp by pushing on the lever using a long rod.

I.B–3. DECOMMISSIONING OF CONTAMINATED EQUIPMENT

As good practice, it is recognized that the decommissioning of equipment located in a radioactive environment should, after any radiation field reduction by decontamination, consist of a cutting/dismantling phase in order to allow transfer of subcomponents into a dedicated size reduction workshop where the exposure field will be less and the safety of the operating team and confinement better. In there, the subcomponent can be further cut into pieces meeting the acceptance criteria of the potential routes for and after removing material from site. Using this approach, the BR3 team preferred mechanical cutting machines for the first step (dismantling) to allow the cut to be carried out without specific confinement arrangements as mechanical cutting does not produce any aerosols. Thus the biggest components are simply dismantled using the classic mechanic's tools and the piping is cut using small hands-on reciprocating and band saws. Both devices are cheap and come from 'do it yourself' stores (Fig. I.B–4) and are suitable for equipment up to an equivalent of 100 mm pipes.

FIG. I.B–4. Typical 'do it yourself' tools used in dismantling.

For the second part of the operation, a further segmentation in the size reduction workshop, attention is paid to efficiency. Therefore, the common grinder was extensively used. For thicker components, plasma and oxygen gas torches were preferred. Figure I.B–5 shows operators cutting pipe inside the size reduction workshop.

FIG. I.B–5. Operators cutting pipe in the size reduction workshop.

When cutting quite thin metallic components, such as some tanks, the nibbling technique is attractive. As the cutting process is similar to mechanical cutting, no aerosols are produced and the physical form of the secondary waste looks like coins that can be easily brushed up at the end of the work. Figure I.B–6 shows the decommissioning of a stainless steel tank. Again, this kind of equipment is distributed by international tools companies at relatively low cost.

FIG. I.B–6. Decommissioning of a stainless steel tank.

I.B–4. DECONTAMINATION OF METALLIC PIECES

Huge quantities of materials are generated by decommissioning. At BR3, a large proportion is decontaminated, measured and finally free released. One of the simplest and cheapest ways to decontaminate metallic components is to grind the total surface using an electrical grinder. The grinders used at BR3 are those for polishing from 'do it yourself' stores. Even if this operation is heavy and time consuming it has shown its cost effectiveness for a wide range of components.

I.B–5. DECONTAMINATION OF CONCRETE

The largest amount of material arising from decommissioning of a reactor such as BR3 is concrete. At the present stage in BR3 decommissioning, the project is just facing this and experience is still limited. Nevertheless, interesting works have already been carried out on concrete from the BR3 buildings. This concerns large concrete blocks extracted (cut) from walls in order to create accesses for effective dismantling. Large concrete shielding blocks were also removed, decontaminated, measured and finally free released. For such applications, international best practice is often stated to be use of diamond tipped tools, but scabbling can also give acceptable results, and the investment cost is much lower than that for diamond tipped tools. In the same way, an air jack hammer can give acceptable results in removing encased structures inside concrete blocks and in removing deep contamination. Figure I.B–7 illustrates both these simple techniques.

FIG. I.B–7. Concrete dismantling using simple techniques.

For shielding purposes, thousands of I shaped small blocks were used during operation of the reactor. As they have a more complicated shape, the surfaces are not consistently contaminated, and as there are many blocks it was not immediately clear which strategy would be the most effective or economic. Therefore, a small comparison has been carried out on a representative number of blocks to collect information prior to a final decision. Tests have been carried out using the available BR3 abrasive blasting unit and the manual diamond grinding machine. Similarly, fixed prices have been sought from contractors for automatic abrasive and sponge jet blasting. Finally, a study was carried out by a student to evaluate the cost of automating the available BR3 abrasive blasting system. The results were the following:

(a) If the number of contaminated sides of the blocks is less than or equal to two, then the most economic way to proceed is using the hand diamond grinder. This result took into account a preliminary measurement of contamination on each side.
(b) If more sides are contaminated, the block should preferably be sent to a contractor having an automatic abrasive blasting facility.

Again, very simple techniques (hand diamond grinding) can be optimal in some circumstances. Figure I.B–8 shows the blocks and the hand grinding machine and the operator at work.

I.B–6. CONCLUSIONS AND LESSONS LEARNED

The BR3 project, which is currently under way, has demonstrated that:

(a) A large proportion of decommissioning tasks can be safely carried out using conventional tools available in the non-nuclear market. Some of these tools require adaptation in order to work remotely or to avoid the spread of contamination.
(b) The majority of the required adaptations could be made using on-site creativity, skills and workshops.

(c) Even though human resources costs could be considered as very high in Belgium, manual operations can be more cost effective than automated ones. This will be even truer where lower human resources costs apply.

FIG. I.B–8. Cutting I shaped concrete blocks.

Annex I.C

STRATEGY FOR DECOMMISSIONING OF A FORMER FACILITY AT THE NATIONAL INSTITUTE OF ONCOLOGY AND RADIOBIOLOGY IN CUBA

I.C–1. INTRODUCTION

Before 1990 no centralized storage facility for radioactive waste was in operation in Cuba. A former medical facility at the National Institute of Oncology and Radiobiology (INOR) was therefore used as a storage facility for disused sealed sources arising from nuclear applications in medicine and industry. One or more ^{137}Cs sources stored there were leaking, causing radioactive contamination in the area.

Decontamination and dismantling activities were carried out in the facility between 1988 and 1999, but, for a number of reasons, the requirements established by the regulatory authority for decommissioning could not be achieved. Hence, the facility was closed because of the remaining contamination and could not therefore be released from regulatory control.

Final decommissioning activities were performed in 2004. The strategy selected for decommissioning is described below. Due to the limited resources available for this task, financial constraints were a key issue in determining the decommissioning strategy.

I.C–2. DESCRIPTION OF THE PROBLEM

The contaminated areas comprised eight rooms (maximum size 30 m^3) and a garden (see Fig. I.C–1). Initial dismantling and decontamination activities were carried out in 1988, when water and detergent solutions were used for decontamination of walls and floors. However, the use of pressurized water jets caused the spread of contamination to other areas not previously contaminated, for example the garden and underground drainage pipes.

In 1997 INOR requested permission from the Centre for Radiation Protection and Hygiene (CPHR) to decommission the facility. The radiological situation was evaluated and an initial decommissioning plan was prepared. The area had remained contaminated and isolated for more than 20 years. Characterization carried out in 1999 demonstrated that the contamination was dispersed in walls, floors, soil below the floor tiles and the garden. Some dismantling and decontamination activities were also carried out in 1999, and the radiation and contamination levels were significantly reduced.

Due to the high levels of contamination in the area and strict requirements established by the regulatory authority for clearance (surface contamination <0.4 Bq/cm^2), decommissioning and free release of the facility would be extremely expensive. The cost would be mainly related to management of large amounts of very low level radioactive waste.

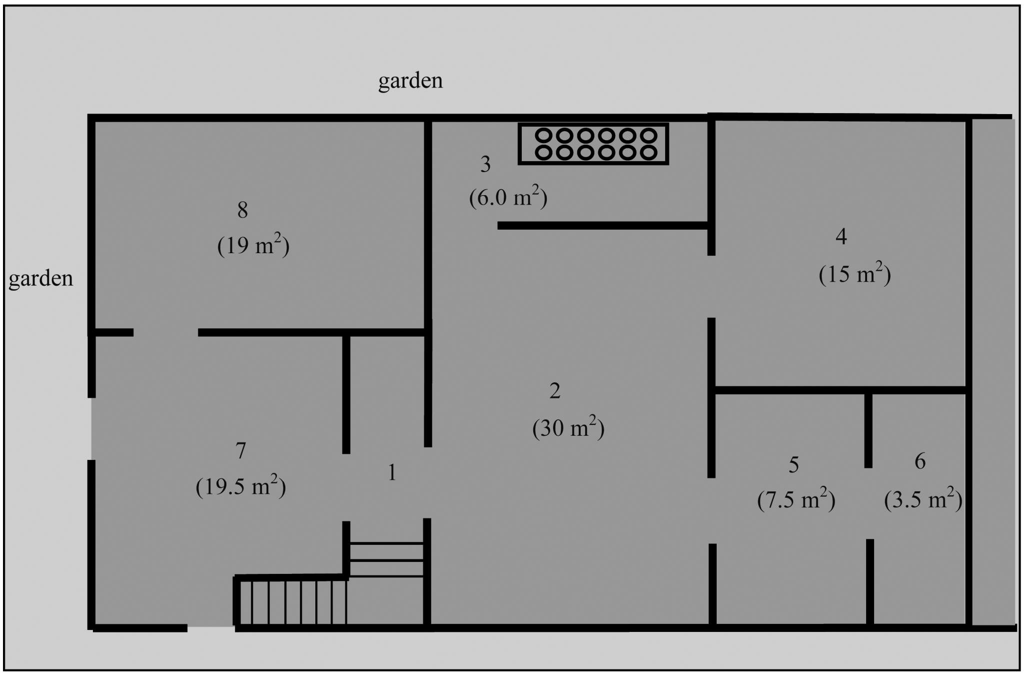

FIG. I.C–1. Diagram of contaminated areas at the National Institute of Oncology and Radiobiology.

It was therefore decided not to continue decontamination activities but to establish a new decommissioning strategy based on more realistic criteria such as annual dose for the members of the public who will stay in the area after decommissioning. The new decommissioning plan was prepared and presented to the regulatory authority, which approved these criteria, and INOR subsequently received the authorization for decommissioning in 2003.

I.C–3. TECHNICAL AND FINANCIAL CONSIDERATIONS

Since insufficient funding was available for decommissioning during the operational life, financial aspects were also a key issue to consider in the decommissioning strategy. Decommissioning activities were supported with limited financial resources by governmental authorities.

Due to the cost associated with waste management and the limited capacity of the storage facility, the minimization of waste generation was given a lot of attention. Two main issues were considered to minimize the volume of waste:

(a) Agreement with the regulatory authority that some contamination could remain in the facility. The criteria for clearance being that the annual dose received by members of the public should not exceed 0.3 mSv above the natural background;

(b) Radioactive waste generated during dismantling and decontamination should be carefully segregated, in order to evaluate the possibility of conditional clearance of waste with lower activity levels.

I.C–4. STRATEGY ADOPTED FOR DECOMMISSIONING

I.C–4.1. Derived clearance levels for decommissioning

The radiological criterion proposed to the regulatory authority in the decommissioning plan was that the annual dose received by members of the public should not exceed 0.3 mSv above the natural background. Following these criteria, operational reference levels were derived:

(a) Dose rate: The dose rate at 10 cm from any surface (walls, floors tiles and roofs) should not exceed 0.1 μSv/h above the natural background.
(b) Activity concentration: The specific activity in the soil (in the garden and floor filling material) should not exceed 1 Bq/g. The occupancy factor, the dimensions of the contaminated area, as well as the depth of contaminated soil were estimated taking into account conservative assumptions.

The committed effective dose from a hypothetical consumption of food produced in the area of the garden, contaminated with ^{137}Cs (1 Bq/g), was evaluated for the following scenarios:

(i) Ingestion from the consumption of milk and meat, considering the pasture in the area of the garden;
(ii) Ingestion of vegetables directly produced in the garden.

The doses calculated in the assessment were trivial because of the low concentration of the radionuclide (1 Bq/g) as well as the very small extent of the contaminated area in the garden.

I.C–4.2. Initial general considerations for decommissioning

The derived operational reference levels were evaluated and approved by the regulatory authority. The strategy adopted for the decommissioning of the facility was to remove contaminated tiles, soil, parts of the walls, etc., until the dose rate at 10 cm from the surface was below 0.1 μSv/h above natural background. Criteria based on specific activity were used to evaluate whether the removed soil should be considered as radioactive waste or not.

A cycle was executed of repeated activities (evaluation–dismantling–evaluation, etc.) in which the requirements for waste management, radiological control to the public and workers, and control of releases of radioactive material to the environment, as well as emergency planning, were taken into consideration.

A specific procedure was developed and implemented for the characterization and decommissioning of underground drainage pipes. Decontamination and dismantling activities started in the most contaminated rooms and zones, in order to reduce the dose rates. This was important from a radiological protection point of view and also to facilitate the evaluation of contamination levels in less contaminated areas. The spread of contamination to other areas was avoided.

An important factor was minimization of radioactive waste. All contaminated materials (tiles, debris, filling material, etc.) removed from the area were carefully collected in plastic bags. Each bag was monitored and segregated according to the radiation levels at the surface. Materials with lower contamination were separated from the rest in order to evaluate the possibility of conditional clearance. All radioactive waste was transported to the centralized waste storage facility.

I.C–4.3. Requirement for changing the initial strategy

Although a considerable amount of contaminated material had been removed, the reference levels established for free release could not be achieved in all the areas; for example, room No. 3 was the most contaminated and all the floor tiles and filling material had to be removed. A concrete layer of approximately 10 cm was removed from the floor. Below the concrete was soil, a sample of which was taken, measured and shown to be contaminated. A study of the activity concentration in the profile of the soil was then carried out. An area of 30 cm × 30 cm was selected in the centre of the room, where the concrete had no cracks that could have facilitated earlier direct entrance of contaminated water. Samples of concrete and soil up to 20 cm depth approximately were taken. The samples were analysed in a gamma spectrometric system.

According to these results, and for achieving the reference level (1 Bq/g, in terms of activity concentration), it would be necessary to remove all the concrete from the floor of room No. 3 and a layer of soil of about 15 cm depth. That would generate a considerable amount of very low level radioactive waste.

A similar situation occurred beneath the doorframes in most of the rooms as well as in some areas of the garden. A huge amount of contaminated material had been removed, including floor tiles and the construction filling material up to 20–40 cm depth. The radiation levels were significantly reduced; but the reference level in terms of activity concentration was not achieved.

As the dose rate levels were not significant (7 μSv/h was the maximum dose rate at the surface of the holes), and considering that continued removal of contaminated soil would generate a considerable amount of very low level radioactive waste, the strategy for decommissioning was changed to spot entombment. That strategy was based on the fact that some construction works were needed in any case for the release of the facility from regulatory control. The ‘holes’ were filled with soil or other material, which at the same time served as shielding. The depth of the holes was calculated in order to guarantee that after filling with new material the reference level in terms of dose rate would be achieved.

Special consideration was given to the underground drainage pipes. As appropriate equipment for characterization of underground pipes was not available, activity was estimated using a model described in detail in Ref. [I.C–1]. No drawings of or technical details about the underground pipes were available at the facility. The criterion for clearance (0.1 μSv/h) was achieved and it was assumed that the pipes were not contaminated or that the contamination levels were very low and it was decided to leave the pipes in the facility.

In summary, the main reasons for changing to the new strategy (spot entombment) were: (a) the radiological impact was negligible and therefore the radiological criteria for the release of the facility from regulatory control could be reached; (b) considerable minimization of radioactive waste; and (c) financial considerations.

I.C–5. FINAL RADIOLOGICAL SITUATION IN THE FACILITY

Once decontamination and dismantling activities were concluded, a final radiological survey was carried out. It included dose rate measurements at the surface of floors, walls and roofs. The reference level in terms of dose rate was achieved in almost all the areas, except around the doorframes, where the dose rate at floor level was 1.0 μSv/h. An assessment of the radiological situation in each room was performed.

Owing to the dilution of ^{137}Cs in the water used in previous decontamination activities and its penetration through the fissures existing in the floor (e.g. beneath the doorframes), it was not reasonable to achieve the reference levels (0.1 μSv/h at 10 cm from the surface) in these zones other than by removing contaminated material. The long deferred decommissioning period had also had a negative effect.

After removing contaminated tiles and construction filling material, the dose rate at 50 cm and 100 cm from the surface of the floor was measured in the centre of each room. The dose rates at the surfaces of the walls and roofs were below the reference levels, but in some places the measurements were influenced by the residual contamination from the floor.

From calculations it was possible to assume that, if the holes were filled with concrete (more than 20 cm in all the zones), dose rate levels would be reduced more than 10 times. Consequently, the dose rates at the surface of the floor would be less than 0.1μSv/h.

Two situations were considered for evaluation of annual dose:

(a) Residential condition (the exposed person lives in the room): the occupancy factor is 2/3.
(b) Working condition: the exposed person is inside the room 8 hours per day, 5 days per week and 50 weeks per year.

As expected, the estimated annual effective dose in all the rooms and in the garden, for residential as well as for working conditions, was below the radiological criteria of 0.3 mSv/a established for the decommissioning.

The collective effective dose was also estimated, as a global indicator of the radiological risk for the public. As the total area of the facility is 104 m^2, it was assumed that around 10 persons would stay systematically in the facility, for residential as well as for working conditions. The estimated collective dose for the residential condition was 1.11×10^{-3} man Sv and for working conditions 0.38×10^{-3} man Sv. The obtained collective doses produce an annual rate for appearance of fatal cancer of 5.55×10^{-5} for the residential condition and 2.0×10^{-5} for the working condition. These values are of the order of 10^7 times less than the annual rate for appearance of fatal cancer in the State due to natural radioactivity levels.

I.C–6. POSITION OF THE REGULATORY AUTHORITY

Once dismantling and decontamination activities were finished, the new strategy adopted for decommissioning was presented to the regulatory authority for approval, which evaluated the proposal and carried out an inspection of the facility. It was considered that dismantling and decontamination activities could be stopped, taking into consideration that subsequent decontamination and dismantling activities would not achieve significant reductions in the radiation and contamination levels. As a result, the following requirements for decommissioning were established by the regulatory authority:

(a) The dose rate from any surface should not exceed 0.1 μSv/h above the natural background. Necessary shielding should be guaranteed where this level was not reached.
(b) Contaminated material should be isolated from the public.

Regarding the underground pipes, it was agreed that no further maintenance or repair activities should be performed in the contaminated area. Consequently, the drainage in the contaminated area should be closed and a new drainage system constructed. The existing drainage should not be used.

I.C–7. MANAGEMENT OF RADIOACTIVE WASTE GENERATED FROM DECOMMISSIONING

The amount of radioactive waste that was generated during decommissioning activities at INOR was:

(a) 18 m^3 of non-compactable solid radioactive waste;
(b) 1 m^3 of compactable solid radioactive waste;
(c) 5 m^3 of non-radioactive waste.

The strategy for the management of radioactive waste has also been influenced by limited financial resources. Compactable radioactive waste did not represent a problem, as the amount was very low and it could be reduced. However, the volume of non-compactable solids represented approximately 20% of the operational capacity of the centralized storage facility. Moreover, if this waste was conditioned, the volume would be double.

Since most radioactive waste generated during decommissioning was very low level waste, conditional clearance and release was considered as an appropriate strategy for its management.

I.C–7.1. Characterization of radioactive waste

Detailed characterization of generated radioactive waste was essential in defining the possibility of clearance. During decontamination and dismantling activities, non-compactable solid waste was collected in plastic bags and stored in 90 standard 200-L drums. The total activity in each drum was estimated from the maximum dose rates measured at a certain distance from the drums, in accordance with the methodology described in Ref. [I.C–2] for extended sources and cylindrical geometry. Knowing the weight of the drums, the specific activity was also estimated.

The results of characterization show that the higher activity waste was generated in the first dismantling activities (first drums). In general, soil contains lower activities than concrete. According to national regulations, the unconditional clearance level for solid materials containing ^{137}Cs is 0.3 Bq/g [I.C–3]. All the drums contain waste with activity concentrations above this value. Therefore, it was necessary to evaluate the possibility of conditional clearance and to propose this possibility to the regulatory authority.

I.C–7.2. Assessment of the radiological impact

Clearance of radioactive waste with very low activity and release of cleared material to a conventional landfill was considered the most appropriate method for the management of this type of waste. The scenario for conditional release considering human intrusion as an important factor has been carefully selected. As the waste contains soil and debris, it was recommended to release it on a specific road between the existing trenches. This zone was less frequented by intruders. In order to assess the radiological impact, the following scenarios were considered:

(a) The release of radioactive material on the road between the trenches;
(b) The scattering of the material along the road;
(c) Human intrusion in the landfill.

A brief description of the radiological impact assessment for each scenario is given below.

I.C–7.2.1. Release of radioactive material on the road between the trenches

This operation would be carried out by an occupational exposed worker. In order to estimate the dose, it was considered that the release would be carried out from a truck containing the drums with solid material. Therefore, the operator would be exposed to radiation from the drums placed in the truck. The effective dose for the operator from external irradiation would be 0.5 mSv. Taking into account that an occupational exposed worker would carry out this operation, this value was considered acceptable.

I.C–7.2.2. Scattering of the material along the road

This operation would be carried out by a worker of the facility (landfill) using appropriate equipment for conditioning of ordinary waste. It was considered that the effective dose due to external exposure from contaminated material would be insignificant. Inhalation of contaminated aerosols was the pathway considered for dose estimation. The effective dose commitment obtained was 0.2 μSv/a. This value of dose was considered acceptable for the worker.

I.C–7.2.3. Human intrusion in the landfill

For this scenario, the external exposure was considered to be the most significant factor that could cause some doses to the individual. An annual dose of 10 μSv was the basis to calculate the conditional clearance level.

Using an agreed formula, the dose rate at the surface discharging the material on the road between the trenches was estimated as 11.3 μSv/h, assuming it as a plane source with activity concentration of 1 Bq/cm^3 in the volume of released material.

The conditional clearance and release under defined and evaluated conditions of 49 drums with activity concentration less than 307 Bq/cm^3 was proposed to the regulatory authority. It was demonstrated that the annual dose for the public will not exceed 10 μSv.

I.C–8. LESSONS LEARNED

The key lessons learned during these decommissioning activities are the following:

(a) Immediate dismantling and decontamination is the most appropriate strategy for the decommissioning of small facilities.
(b) It is important to consider decommissioning and planning aspects at the design, construction and commissioning of a facility. It is also essential to maintain drawings and appropriate records about the construction and operation of the facility.
(c) Wash cleaning using a considerable amount of water or any solution for decontamination should be carefully evaluated in advance. This method is not always efficient, since, even when it might be effective in reducing gross contamination levels, the spread of contamination can make it difficult to achieve the approved decommissioning levels, mainly when soluble compounds such as caesium salts are involved.
(d) The strategy selected for decommissioning should take into account regulatory and technical aspects as well as financial considerations. The conditional clearance of very low level radioactive waste is a valuable solution that should be considered.

I.C–9. CONCLUSIONS

As a result of dismantling and decontamination activities, the reference levels for decommissioning were achieved in most areas.

It was not reasonable to continue with decontamination in places where these levels where not met, because of:

(a) The radiological criteria for the release of the facility from regulatory control, which could be reached by final engineering and simple reconstruction works;
(b) The required minimization of radioactive waste;
(c) Financial considerations.

It was demonstrated that conditional clearance and release could be considered as an appropriate strategy for the management of very low level radioactive waste.

REFERENCES TO ANNEX I.C

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[I.C–2] JAEGER, R.G., Engineering Compilation on Radiation Shielding, Vol. 1, Springer Verlag, Berlin (1968).
[I.C–3] CENTRO NACIONAL DE SEGURIDAD NUCLEAR, Guide 01/2004: Unconditional Clearance Levels for Solid Materials with Low Radioactive Content and for Liquid and Gas Discharges to the Environment, CNSN, Havana (2004).

Annex I.D

REMEDIATION OF OLD ENVIRONMENTAL LIABILITIES IN THE NUCLEAR RESEARCH INSTITUTE, ŘEŽ PLC, CZECH REPUBLIC

I.D–1. INTRODUCTION

After 50 years of activities in the nuclear field, there are many environmental liabilities to be dealt with at the Nuclear Research Institute, Řež plc (NRI). There are three areas of remediation: (a) decommissioning of old obsolete facilities (e.g. decay tanks, liquid radioactive waste (RAW) storage tanks, old RAW treatment technology and the special sewage system); (b) processing of RAW resulting from operation and dismantling of nuclear facilities; and (c) removal of spent fuel from research reactors. The goal is to deal with these liabilities and eliminate their potential negative impact on the environment. Consequently, optimal remedial actions have been selected and recommended. Remediation of the environmental liabilities started in 2003 and will finish in 2010. Cost effective technologies and planning methodologies are being used.

In 1993, the government of the Czech Republic approved the financing of the remediation of the liabilities of the NRI through the National Property Fund (NPF). The so called ‘ecological contract’ between the NPF and the NRI was signed in 1996. Due to the limited funds available, an external contractor was not selected and activities to eliminate the most serious hazards were performed by the NRI between 1996 and 2000. In 2002 the NRI was selected as the most qualified contractor and in 2003 the contract was signed but with a limited budget.

Based on the results of the characterization of the facility, a new budget was prepared and submitted for government agreement. Before the decision, the remediation was being performed as a so called ‘crisis variant’. This means that the remediation of only the most hazardous liabilities would be performed. Information is provided in this annex about selected items of the environmental liabilities.

I.D–2. SPECIAL SEWAGE SYSTEM

The special sewage system (Fig. I.D–1) was used for transfer of liquid RAW from various facilities (research reactors, radiochemical laboratories) to a RAW processing facility. The system consisted of a stainless steel pipe network with a total length of 410 m situated in an underground concrete corridor. The integrity of the system has never been tested. The total amount of contaminated metal parts is approximately 5000 kg. The system is contaminated by fission and corrosion products, mainly by ^{137}Cs, ^{60}Co and ^{90}Sr. Leakage from piping was identified as the main risk to the environment.

The remediation procedure started with the removal of soil and opening of the corridor. The pipes have been removed and sent for processing. Limited parts of the surface of the concrete corridor were contaminated because of small leaks. The contaminated surfaces were removed and RAW was processed. A new sewage system will have to be installed. To reduce costs, the old concrete corridor will be renovated and used for this installation. The system will be equipped with a leakage monitoring system.

FIG. I.D–1. Special sewage system during and after decommissioning.

I.D–3. DECAY TANKS (BUILDING 211/5)

Building 211/5 (decay tanks) was designed in 1958, and had been in use since 1961 (Fig. I.D–2). The building was designed for storage and decay of concentrated short lived RAW, but RAW containing long lived radionuclides was also shipped there. Transfers of RAW stopped in 1990.

The building is underground on three sides. It contains two cylindrical tanks (length 9.5 m, diameter 3 m, weight approximately 10 000 kg), each with a capacity of 63 m^3 and placed into two separate concrete bunkers located partially underground. The decay tanks are made from structural steel jacketed by stainless steel inside the vessel. The design life of these tanks has now been exceeded. The walls of the bunkers are 1 m thick. A masonry building is located above the bunkers with tank inlet pipes, equipment for ventilation and equipment for taking water samples from the tanks.

Tank A contains 4.5 m^3 of liquid with an activity of 0.5 MBq/L. The main identified radioisotopes are ^{137}Cs and ^{152}Eu. Tank B contains 2.5 m^3 of solid RAW and 8 m^3 of liquid with an activity of 21 MBq/L (Fig. I.D–3). The main identified radioisotopes are ^{60}Co and ^{137}Cs. However, up to 2 g of ^{239}Pu may also have been deposited in the tank at some time. The solid RAW consists of tins containing sample residues of irradiated measuring probes and impact and stretching test bodies from the reactor vessels as well as tins containing fission material from spent fuel. The maximum dose rate of approximately 2 Gy/h is above the pile of solid RAW.

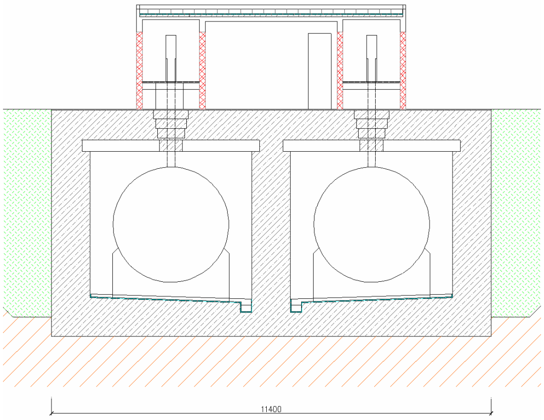

FIG. I.D–2. Building 211/5: decay tanks (section).

FIG. I.D–3. RAW stored in decay tank B.

Originally, the project was going to comprise:

(a) Construction of a facility above the storage tanks for accommodation of technology for removal of RAW and its processing equipped with hot cells and manipulators;
(b) Removal of RAW from tanks and its direct conditioning in the facility;
(c) Decontamination and dismantling of the tanks and processing of RAW;
(d) Decontamination of the building.

However, the project has been changed because of a lack of funds. Liquid RAW will be removed from tank A by pumping and from tank B by an air dryer installed inside the building. It is envisaged that removal of the liquid from tank B will take approximately one year. The contents of tank B will be stabilized to eliminate the risk of leakage. Future remediation activities will not be affected by this change in approach and will start when resources are available. The building will not be demolished and will be used for other purposes. The construction of the facility was planned for 2006, with removal and processing of RAW in 2007. Decontamination of the building will be carried out in 2008.

I.D–4. LIQUID RADIOACTIVE WASTE STORAGE TANKS IN BUILDING 211/3

Three steel tanks of the same design as the decay tanks described above are located in concrete bunkers with 1 m thick walls (Fig. I.D–4). The tanks are aged beyond their design life. All three tanks are contaminated by fission and corrosion products, mainly ^{137}Cs, ^{60}Co and ^{90}Sr. Leakage or spillage from these tanks was identified as the main environmental risk.

FIG. I.D–4. Underground bunker with a storage tank.

According to the original project, the remediation procedure would comprise decontamination and dismantling of tanks and processing of RAW; new tanks for storage of liquid RAW would then be installed. However, a new concept was evaluated whereby the tanks would be decontaminated and after investigation of the state of the tanks a polyethylene lining would be installed inside, which would save on the costs of size reduction, RAW processing and the installation of new tanks.

I.D–5. RAW STORED AT THE RELOADING SITE (BUILDING 211/6)

Building 211/6 was initially constructed as a temporary reloading site to handle conditioned RAW, but later was also used for storage of various RAW before processing. RAW is stored in eight concrete boxes each with dimensions of 5.5 × 8 × 4 m (1400 m^3 total capacity) (Fig. I.D–5). The bases of the boxes are 4 m below ground level and are drained to four closed sumps. The building has a steel roof. The total volume of stored RAW is approximately 600 m^3. An incomplete inventory is available that gives only a very general description of the RAW contained in the boxes. The RAW is contaminated mainly with ^{137}Cs, ^{60}Co and ^{90}Sr. Leakage of liquid waste in boxes, wash-off of contamination from RAW by rainwater and direct irradiation from in situ material were identified as the main risks to the environment and/or to employees.

FIG. I.D–5. RAW stored in the reloading site (building 211/6).

The hall above the reloading site has already been constructed with a crane and auxiliary technology. RAW will be sorted and transported for processing (size reduction, decontamination and conditioning). RAW will then be disposed of or released to the environment. Building 211/6 will be used as a new RAW store after old RAW removal and reconstruction of the building. It will not be necessary to decontaminate the building for free release (Figs I.D–6 and I.D–7).

FIG. I.D–6. Building 211/6 before reconstruction.

FIG. I.D–7. Building 211/6 with a new hall.

I.D–6. RAW STORED AT THE RED ROCK STORAGE SITE

Storage of RAW at the Red Rock site started in 1988. The stored waste includes RAW arising from the reconstruction of the VVR-S research reactor (e.g. the primary circuit and ventilation system components), which is stored in ISO shipping containers (Fig. I.D–8), and also old RAW processing equipment (heat exchangers, tanks and filters). The total storage area is 300 m^2. The total amount of RAW is approximately 90 000 kg. The RAW is contaminated mainly with ^{137}Cs, ^{60}Co and ^{90}Sr. Rain wash-off from contaminated equipment to soil and groundwater and irradiation from in situ material were identified as the main risks to the environment and/or employees.

FIG. I.D–8. Red Rock storage site.

RAW will be transported for processing (size reduction, decontamination and conditioning) and then disposed of or released. This item is an example of a decommissioning activity performed without knowledge of what to do with RAW produced from the reconstruction of a research reactor. As a result, RAW processing will be much expensive than it could have been in the past.

I.D–7. PROPOSED NON-STANDARD DISPOSAL OF SOLID RAW

The total amount of RAW resulting from remediation for processing will be approximately 1500 m^3; at least 200 t of RAW is expected for release after treatment, and the rest will be size reduced and conditioned by cementation into 200 L drums and then disposed of. A new concept is now being prepared for direct disposal of large pieces into the cells of the repository. It will require fewer cutting operations, be less time consuming and a lot of resources will be saved. It will be also advantageous from the point of view of radiation protection.

I.D–8. CONCLUSION

Despite limited available resources, the remedial actions in the NRI are being carried out without a negative impact on personnel, public and the environment.

Annex I.E

DISMANTLING AND DECONTAMINATION OF NON-NUCLEAR FACILITIES IN GERMANY

I.E–1. INTRODUCTION

This annex covers the decommissioning of facilities in Germany in which radiological hazards have been present due to material other than nuclear material. The relevant facilities include medical, industrial and similar facilities. The discussion concerns, in particular, the dismantling and decommissioning of buildings and parts thereof for unconditional release in accordance with the German Radiation Protection Ordinance. The presentation is in the form of a brief description of a sequence of the basic tasks to be undertaken.

I.E–2. PROBLEM AND ACTUAL ANALYSIS

Identification of the extent of the task and initial estimate of the effort involved and initial coordination with the responsible authorities and stakeholders.

I.E–3. ORIENTATION MEASUREMENTS

Before a dismantling concept can be drawn up, the contamination status will be established by means of orientation measurements and the nuclide vector and/or the main nuclides will be determined. In addition, an inventory list of the movables, plants and building to be evaluated will be prepared.

I.E–4. PREPARATION OF THE DISMANTLING CONCEPT

In agreement with the responsible authorities and taking into consideration the results of Sections I.E–2 and I.E–3, a dismantling concept is prepared. This includes a description of all relevant steps as well as a detailed description for the preparation of a final measurement survey. This also complies with all relevant safety regulations and DIN standards.

I.E–5. DECONTAMINATION AND DISMANTLING

All movables are either released by means of decontamination (cleaning or ‘chip removing’ measures) and subsequent evaluation by measurement technology or they are appropriately conditioned and transferred to a State owned intermediate storage facility or an authorized third party. The conditioning is either done on site or in suitable decontamination cells of the authorized company. Parts of buildings are decontaminated and dismantled on the site.

I.E–6. MEASUREMENT SURVEY AND RELEASE

This includes:

(a) Preparation of a measurement survey covering the whole area and taking into consideration the main nuclides or the nuclide vector;

(b) Evaluation of samples of the building parts to be released;
(c) Measurements according to DIN 25457 and DIN ISO 7503 parts I and II.

The material is released after the documentation of the measurement survey has been reviewed by the responsible authorities. The references mentioned below quote key regulations, guidelines and standards to be complied with in Germany.

I.E–7. STANDARDS

The work to be undertaken must be in accordance with the Radiation Protection Ordinance (StrlSchV) [I.E–1]. The relevant specific parts of StrlSchV are:

(a) StrlSchV para. 29 (release);
(b) StrlSchV para. 44 (contamination and decontamination);
(c) StrlSchV chapter 3, para. 8 (radioactive waste);
(d) Guidelines for the practical application of para. 29 StrlSchV of the German–Swiss Radiation Protection Association, Waste Management Working Group [I.E–2].

REFERENCES TO ANNEX I.E

[I.E–1] ATOMGESETZ MIT VERORDNUNGEN, Nomos Verlagsgesellschaft, Baden Baden (2001).

[I.E–2] ASSOCIATION FOR RADIATION PROTECTION, Rep. FS-05-138-AKE (2005), http://osiris2.pi-consult.de/userdata/l_2/p_25/library/data/freigabeleitfadenausgabe3_druckfassung.pdf

Annex I.F

CIRUS REFURBISHING, INDIA: RESOURCE OPTIMIZATION

I.F–1. INTRODUCTION

CIRUS, a 40 MW(th) tank type, natural uranium fuelled, heavy water moderated and light water cooled research reactor is located at the Bhabha Atomic Research Centre, Mumbai. The reactor was commissioned in 1960 and after successful operation for over 37 years it was shut down in October 1997 for refurbishment activities. The refurbishment activities were completed in 2002 and the reactor was recommissioned. During the refurbishing period, the reactor core was defuelled, which is similar to the first stage of decommissioning. This opportunity was utilized to carry out extensive data collection [I.F–1] for the future decommissioning of the reactor.

During this period, several part decommissioning activities were carried out; details of some that resulted in cost optimization are given below.

I.F–2. PIPELINE DECOMMISSIONING

I.F–2.1. Layout

The reactor has a network of pipelines carrying primary coolant and radioactive liquid waste. Due to the layout and design features of the reactor, these pipes run for several kilometres and are laid overground in the various buildings in the reactor complex and underground at a depth of 4–5 m between the buildings. The majority of the pipelines are constructed of carbon steel and are 15–300 mm in diameter.

I.F–2.2. Challenges in decommissioning

The site is in a coastal area and therefore the groundwater table is high. Underground pipes, which are laid at a depth of 4–5 m below grade, are therefore always submerged. Any work on the pipelines needs excavation of soil above these pipes for access and continuous dewatering of the excavated region. Decommissioning activities that need cutting of the pipes and dismantling also need to ensure that the radioactive contamination is contained. The overground pipes are often close to other equipment and floors, walls, etc., restricting the space around them for easy access.

I.F–2.3. Objectives

The objectives were:

(a) To remove the pipes with minimum effort and time;
(b) To reduce the dose to the workers and spread of contamination as per ALARA;
(c) To minimize the cost of removal and disposal.

I.F–2.4. Methodology

There are several different cutting techniques that can be employed. However, depending on the site conditions and local availability of the equipments, simple common techniques were used.

I.F–2.4.1. Mechanical cutting

Decommissioning of these pipes involved dismantling by cutting on the site, removal from the site and disposal. Of the two most common techniques of pipe cutting (viz. mechanical or tool cutting and thermal cutting), mechanical cutting is slower but has the advantage of minimizing airborne radioactivity.

A simple mechanism was made using a cutting wheel set-up that could accommodate pipes up to the size of 150 mm diameter with a manually operated lever to control the feed of cutting. Trials were conducted on uncontaminated pipes to optimize operations. These showed that a feed of up to 12 mm per minute did not pose any problem of overheating or of the tool getting stuck. Cutting could be done by a single operator and each cut would require up to 12 min for a pipe of 150 mm size. Pipes of 80 mm and 150 mm size were cut in this manner. Since the pipes were contaminated, arrangements were made to collect the cutting debris. The pipes were cut in lengths of 750 mm and disposed of as radioactive waste. Although this method is slower, it has several advantages, such as no elaborate set-up and portable tools and hence can be easily deployed at the site and moved from one place to another. Only a power connection is necessary at the place of use.

This method, however, had limitations, as this could not be used:

(a) For large pipes;
(b) Where dose rates were higher and needed either faster or remote/semiremote methods;
(c) Where site constraints did not permit installation of the set-up (e.g. pipes laid close to the floor, walls or other pipes and equipment).

Thermal cutting of the pipes were considered in such situations.

I.F–2.4.2. Thermal cutting

Thermal cutting of pipes has the inherent advantage of being fast and not requiring much space around the pipe. Since this method spreads airborne radioactivity, a local air filtration system was used to avoid the release of airborne radioactivity to the environment.

I.F–2.4.3. Filtration system

The requirements of the filtration system were:

(a) To enclose the area where the pipe was required to be cut and to accommodate two persons for cutting operations within the enclosure;
(b) To maintain negative pressure within the enclosure with respect to the surroundings;
(c) To provide enough flow rate to contain airborne radioactivity;
(d) To be simple, mobile and cost effective.

These requirements were met by a filtration system consisting of a thick transparent PVC sheet enclosure of approximately 1.8 m × 1.8 m × 1.5 m height. This was connected to a high efficiency particulate air (HEPA) filter housing through a 250 mm diameter non-collapsible hose. The HEPA filter housing was connected to a blower motor through a flexible joint. They were mounted on a frame with wheels and a locking arrangement. A commercially available HEPA filter is rated for 1700 m^3/h of air flow and a maximum differential pressure of 150 mm; accordingly, a blower with these characteristics was selected. A 250 mm diameter non-collapsible hose was connected to the blower discharge and arrangements were made for measuring the differential pressure across the filter. This simple set-up could be placed away from the workplace and the exhaust of the blower could be led to a nearby building ventilation exhaust or to the atmosphere (Fig. I.F–1).

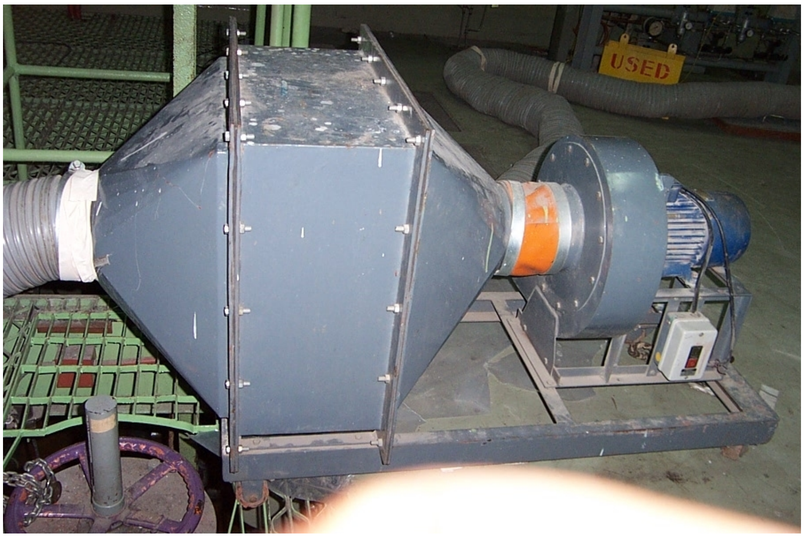

FIG. I.F–1. Local air filtration system.

A typical cutting of a 300 mm nominal bore pipe, lying very close to the floor, is detailed below.

The pipe was carrying primary coolant with a specific activity of 40–70 Bq/mL long lived radioactivity. The water was drained from the pipe and a radiation survey showed dose rates of about 0.15–2.0 mGy/h with hot spots up to 7 mGy/h near the workplace. Cutting of this pipe by mechanical tools would have meant a longer time and a higher dose uptake by operators. It was decided to use an oxyacetylene torch for cutting the pipe. The area where the pipe was to be cut was enclosed in the PVC sheet enclosure described above. The suction of the HEPA filter was taken from inside the enclosure but sufficiently away from the torch to avoid sparks being carried to the filter. An operator with protective gear (i.e. full face plastic suit and fresh air mask) went inside the enclosure. After starting the blower a small trial cut was taken to evaluate the extent of air activity around the enclosure. No rise in the air activity levels was noticed and hence the full cutting was completed. The 300 mm diameter pipe could be cut in 6 min; it would have taken around 40 min using tool cutting.

Observations during the process were as follows:

(i) The activity levels within the temporary enclosure were 1090 Bq/m^3;

(ii) Air activity outside the temporary enclosure did not show any significant increase, implying the exhaust fan is adequate to prevent spread of activity;

(iii) Air samples at the outlet of the exhaust fan showed below background level radioactivity during the entire job, indicating no release of activity to the environment.

This method was used for cutting of the pipes where site restrictions demanded or the dose rates were higher, necessitating a minimum time of work.

I.F–3. DECOMMISSIONING OF PRIMARY COOLANT HEAT EXCHANGERS

Often during decommissioning, a decision is required to be made on whether to decontaminate materials to the clearance levels, to reduce them to small pieces and dispose of them, or simply to dispose of them in one piece. Resource optimization (person-hours, cost and dose) could be the deciding factor. The following is a case study of decommissioning of the CIRUS primary coolant heat exchangers.

These heat exchangers are of a shell and tube type with a floating head. The tubes and tube sheets are of 70:30 copper–nickel alloy and the corresponding channel covers are made of silicon bronze. The shell, including bottom covers, is made of copper bearing carbon steel. The heat exchangers are about 4 m in height and 1.2 m in diameter. The weight of each tube bundle is about 3500 kg and the complete assembly weighs about 5000 kg. Severe erosion of the tubes of the heat exchanger was experienced and hence it was decided to replace the tube bundles of all the heat exchangers as well as two shells. A typical heat exchanger tube bundle is shown in Fig. I.F–2.

Radiological characterization studies were carried out on scrape samples removed from the inside of the shell and the outside of the tube, as they are the regions that come into contact with the radioactive primary coolant. The analysed results of the scrape samples taken from inside the shell are given in Table I.F–1.

TABLE I.F–1. HEAT EXCHANGER SHELL SCRAPE SAMPLE RESULTS

Gross specific activity (Bq/g)	Fission products	Activation products	Major nuclides contributing to gross activity
100	55%	45%	^{60}Co (25%) ^{137}Cs (22%) ^{152}Eu (15%) ^{125}Sb (16%)

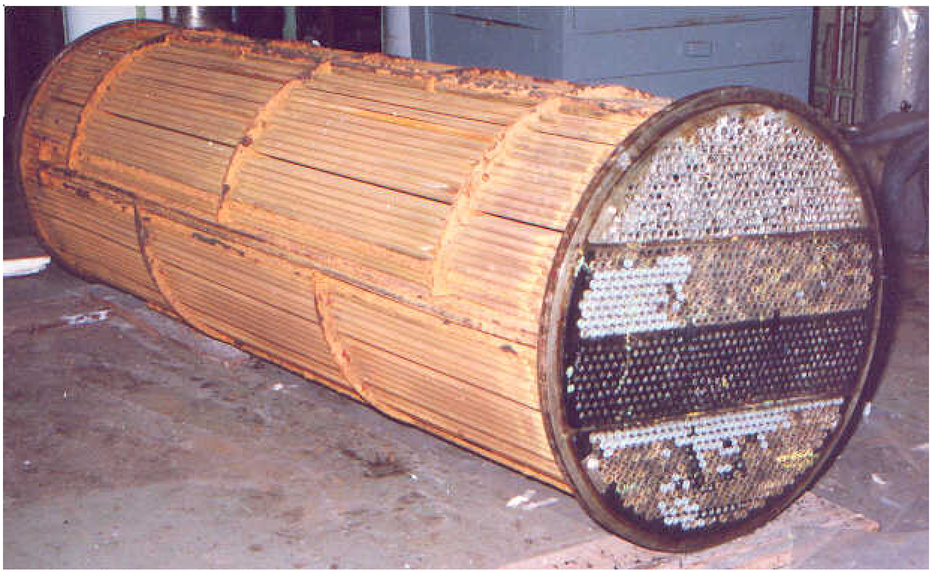

FIG. I.F–2. Primary coolant heat exchanger tube bundle in interim storage.

The possibility of decontaminating these tube bundles using high pressure water jets or chemical decontamination was studied. Although the outer surfaces could be decontaminated, complete decontamination was not possible as access to the outer surfaces of the inner tubes was not available. Furthermore, removal of the contaminants from the tube to tube sheet joints and tube to baffle joints was not possible in the assembled tube bundle. Any effort to decontaminate these tube bundles to clearance levels would have meant complete dismantling of the tube bundle to its individual components (viz. tubes, tube sheets, baffles, tie rods, etc.) and subsequent decontamination. This would require facilities for cutting and decontamination, handling large quantities of decontaminants and liquid waste and a remaining uncertainty over whether the material could be released as cleared. It was therefore decided to dispose of them as solid waste.

The conventional method of radioactive solid waste management is to pack the active waste in disposal drums of 200 L capacity and to seal it before disposal. For this purpose, the components needed to be cut into pieces of less than 78 cm in length and to a maximum diameter of 52 cm to fit inside the drum.

Each heat exchanger has 1368 tubes and is 304 cm long. Hence for drum disposal of the tubes, each tube needs to be cut at five places. The cutting of the cupro-nickel tubes can be done by a portable cutting wheel. Taking an average time of 3 min per cut, the total person-hours spent in one heat exchanger would be about 340 person-hours. Also, the cutting of the tube bundle would need to be done in a separate room with appropriate ventilation arrangements to minimize the dose received by the personnel. Further work would involve the cutting and disposal of the mild steel shell of 16 mm thickness, 102 cm diameter and 283 cm length. This would involve cutting 30 segments of 50 cm × 70 cm area, and thereby give an additional dose to the workers. The last item of the task would be to dispose of the cupro-nickel top and bottom tube sheets of 3.5 cm thickness and 104 cm diameter.

Considering the amount of human resources involved in the cutting job and initial decontamination efforts, and the dose to the personnel, it was prudent to opt for alternate methods of disposal. Disposal of the tube bundle as a whole avoided the above mentioned activities and was the favoured option. This involved handling the 3500 kg tube bundle with adequate sealing to prevent the spread of contamination during transport. Existing near surface disposal sites could accommodate the heat exchangers, which occupy a volume of 3.13 m^3 each. This is far less than the volume of 5.89 m^3 of drum space required for handling the cut pieces of a heat exchanger tube bundle, with a loading of 150 kg per drum. Hence this method was adopted to dispose of the heat exchanger tube bundles during the refurbishing.

I.F–4. LESSONS LEARNED

The following lessons have been learned from an optimum resource utilization point of view:

(a) Tool cutting can be employed for the dismantling of pipes, where dose rates are lower and site conditions allow, using simple mechanisms adapted to suit the application.

(b) Thermal cutting is preferable over tool cutting for pipes with higher dose rates when coupled with a local filtration system to avoid the spread of airborne radioactivity.

(c) The disposal of large equipment as a single unit is preferable over cutting into segments and disposing of in containers, due to savings in costs and doses.

REFERENCE TO ANNEX I.F

[I.F–1] SANKAR, S., et al., "Generation of database for future decommissioning of CIRUS", Decommissioning Techniques for Research Reactors, IAEA-TECDOC-1273, IAEA, Vienna (2002) 91–118.

Annex I.G

DECOMMISSIONING OF SALASPILS RESEARCH REACTOR, LATVIA

I.G–1. INTRODUCTION

The IRT research reactor was built at the Salaspils site near Riga, the capital of Latvia, and went into operation in September 1961. The research reactor was originally built according to a former USSR design as a pool type light water reactor with a nominal thermal power of 2 MW. From 1975, after physical reconstruction of the reactor, the nominal thermal power of the reactor was increased to 5 MW.

In May 1995, the Cabinet of Ministers made Order No. 263 to shut down the Salaspils research reactor (SRR) after its final two years of operation. The decision prohibited obtaining fresh nuclear fuel.

The relevant technical cooperation project for 1997–1998 on decommissioning the research reactor was submitted to the IAEA. There were five expert missions from the IAEA from July 1997 to June 1998. In accordance with the Order of the Ministry of Environmental Protection and Regional Development, a steering group was founded in January 1998 for the promotion of Salaspils Nuclear Research Centre (NRC) reorganization and reactor decommissioning studies.

In June 1998, the reactor was taken out of service and some fuel assemblies were removed from the core. From 2001, the State agency RAPA became the operator. The German firm Preussag Noell started the SRR decommissioning and dismantling conception studies in July 1998. Prepared concepts [I.G–1, I.G–2] were accepted with Order No. 57 of the Cabinet of Ministers in October 1999, which defined the option of direct dismantling of the SRR to greenfield conditions, with the start of decommissioning and dismantling in 2001. The decommissioning of the SRR is described further in Ref. [I.G–3]. After environmental impact assessment (EIA) studies in 2003–2004, an upgrade of the concept was performed and accepted by the Government of Latvia.

I.G–2. INITIAL CONCEPT FOR THE DECOMMISSIONING AND DISMANTLING OF THE SRR

The concept for decommissioning accepted by the Government of Latvia in October 1999 was used for the preparation of the projects for the decommissioning and dismantling of the SRR.

The most important conclusions on the concept are listed below:

(a) A final disposal facility for irradiated fuel or a contract for the transport to other States does not exist at the present time. Therefore an interim storage facility for irradiated fuel elements in Latvia is necessary.
(b) A final disposal facility for radioactive waste is available in Latvia and is in operation.
(c) The option of decommissioning to greenfield conditions is the best strategy for the decommissioning of the SRR considering economic and safety aspects.
(d) Approximately 2200 t of different materials has to be treated, of which approximately 60% can be measured for free release, while the rest has to be conditioned for final disposal.

(e) The required techniques for decommissioning and dismantling of the SRR as well as for the fuel reloading are available on the international market.
(f) The estimated costs for the total dismantling to greenfield conditions amount to $20 million (price base is 1998).
(g) The dismantling can be done within nine years.

I.G–3. UPGRADED CONCEPT FOR THE DECOMMISSIONING AND DISMANTLING OF THE SRR

The Government of Latvia in November 2004 accepted the upgraded concept of the decommissioning [I.G–4], which includes the main recommendations from the EIA for the decommissioning of the SRR [I.G–5]. The basic changes in the decommissioning strategy were connected with the definition of a different final status for decommissioning — reuse of the site for radiation related technologies.

Conclusions (a), (b) and (e) in Section I.G–2 remained unchanged. The others were now:

(c) The change to the option for reuse of the site is the best strategy for the decommissioning of the SRR considering economic and safety aspects.
(d) Approximately 1500 t of different materials has to be treated, of which approximately 45% can be measured for free release, while the rest has to be conditioned for final disposal.
(f) The estimated costs for the decommissioning of the SRR with the reuse of buildings and territory amount to $12 million (price base is 2004).
(g) The dismantling can be done within five years.

I.G–4. ORGANIZATION OF DECOMMISSIONING

The funds were not available at the beginning of the SRR’s decommissioning. According to Order No. 57 of the Cabinet of Ministers of 26 October 1999, the Ministry of Environmental Protection and Regional Development (MEPRD) must incorporate the decommissioning activities into the annual State budget and the operator, RAPA Ltd, must prepare the projects and submit them to the Environmental

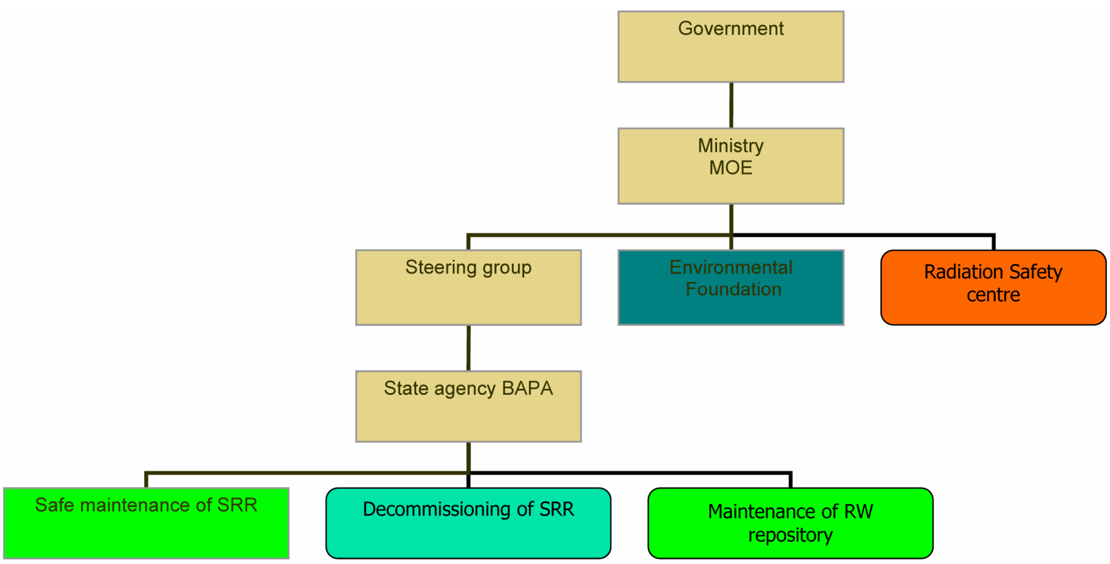

FIG. I.G–1. Organizational structure for the decommissioning of the Salaspils research reactor.

Protection Fund of Latvia (EPFL). It has been shown that a suitable organization promotes decommissioning activities [I.G–6–I.G–8]. According to the policy of MEPRD, the steering group included the representatives of interested organizations of MEPRD, as well as the representatives of the Ministries of Internal Affairs, of External Affairs and of Traffic. The steering group coordinates and the Radiation Safety Centre (RSC) controls all these activities. The structure of the decommissioning organization is shown in Figs I.G–1 and I.G–2. This enables all decommissioning measures to be carried out with the necessary control and optimization of investments.

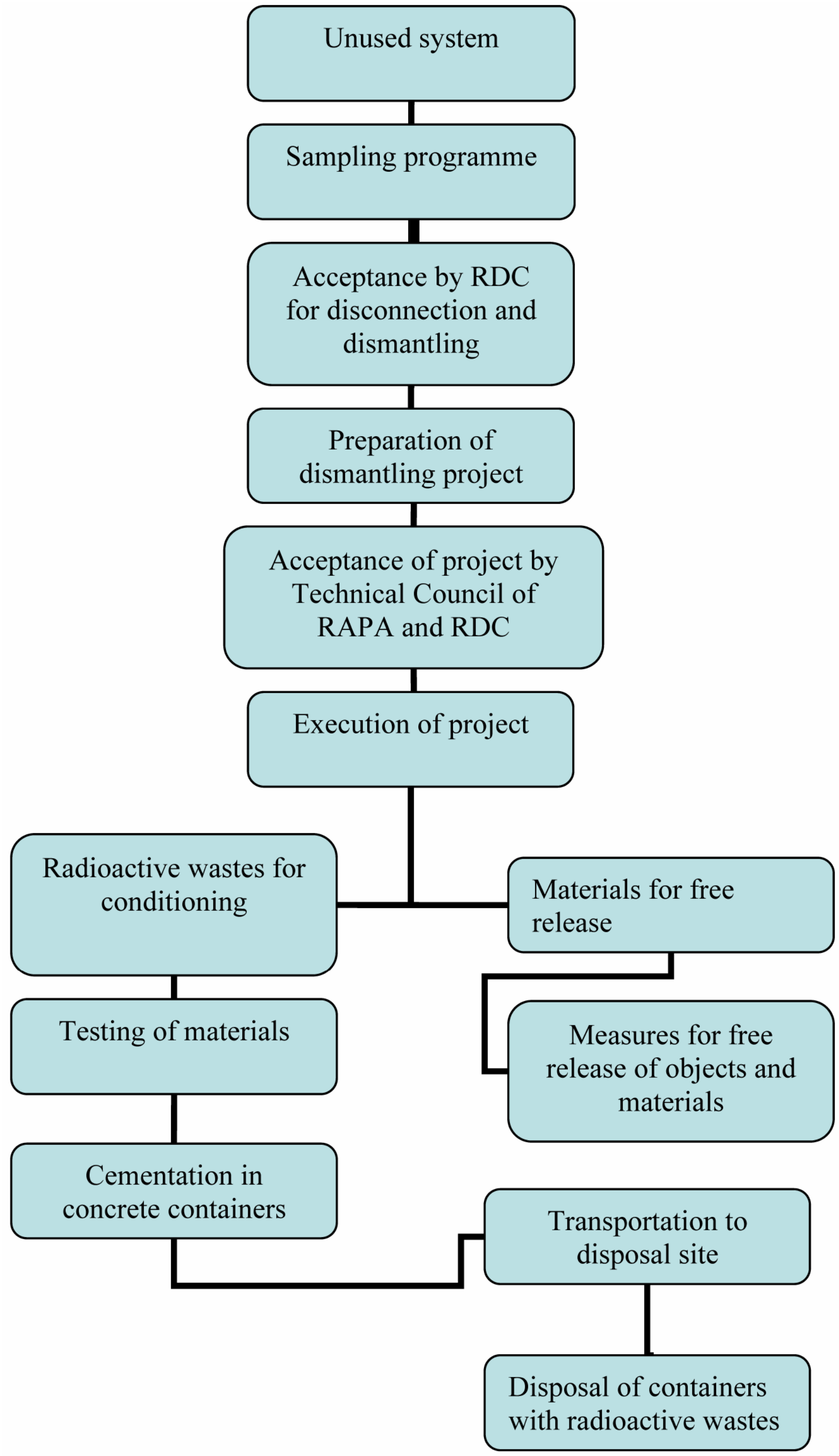

FIG. I.G–2. Organizational structure for dismantling unused facilities and reactor systems.

I.G–5. COST EFFECTIVE DECOMMISSIONING OF THE SRR

The decommissioning activities of the SRR were performed under the following constraints:

(a) Decommissioning of nuclear facilities had never before been performed in Latvia;
(b) The infrastructure for decommissioning does not exist in Latvia and, following the collapse of the former USSR, former connections to and support from institutions in the Russian Federation were no longer available;
(c) Staff, especially top managers, did not have the relevant knowledge and experience of decommissioning.

Therefore the SRR decommissioning activities would be challenged by limited resources in terms of funds, infrastructure and skills. Several principles were developed to significantly reduce the total decommissioning costs as described below.

I.G–5.1. Drawing on international experience

This principle was used from the beginning of decommissioning activities and can be divided as follows:

(a) Preparation of initial decommissioning plan. This provides a very important direction, governing the effectiveness of all later decommissioning activities. The initial decommissioning plan was performed by experts from Preussag Noell [I.G–1, I.G–2] and verified under the PHARE programme by experts from AEA technology (United Kingdom) and INITEC (Spain) [I.G–3]. The dismantling plan for the SRR was prepared by the experts of ENRESA (Spain) under the scope of the Transition Facility programme of the European Commission.
(b) Training of staff. This is a key factor for effective implementation of decommissioning plans. The decommissioning team was created and trained in 1998 with the support of the German government. The decommissioning team included a project manager, site manager, health protection engineer and quality assurance engineer. The decommissioning team was extended with a procurement manager, fire and industrial safety engineer and radioactive waste manager.
(c) Technical support of decommissioning. At the start of decommissioning one of the basic problems was upgrading of infrastructure to enable safe and effective decommissioning activities in accordance with the initial decommissioning plan. Many technical questions were unclear and in some cases the solution of technical problems was postponed due to lack of financial resources. The general technical problems were:
    (i) Upgrade of the radioactive waste repository;
    (ii) Management of 150 t of tritiated liquid radioactive waste (Fig. I.G–3);
    (iii) Upgrade of the radiation control and protection system, including stack monitoring and area monitoring systems (Fig. I.G–4);
    (iv) Radiological characterization of the biological shield;
    (v) Development of cutting systems for dismantling the SRR;
    (vi) Shipment of fresh and spent nuclear fuel for reprocessing.

FIG. I.G–3. Installation of a waste cementation facility in the reactor hall.

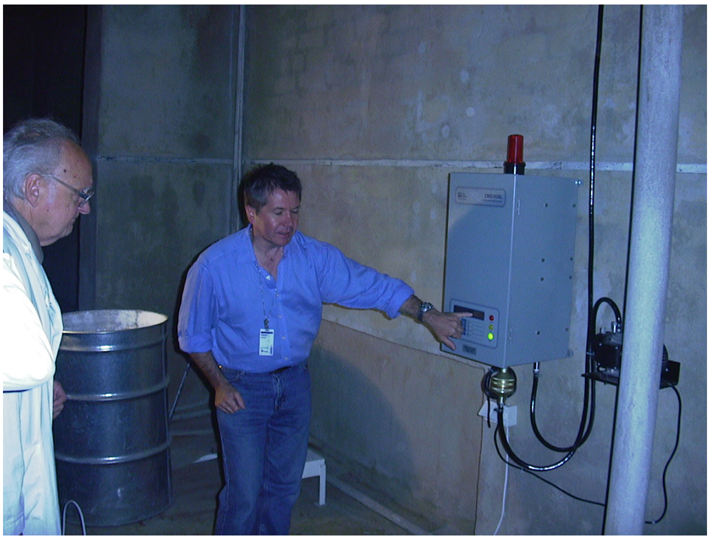

FIG. I.G–4. Installation of a tritium monitor in the reactor hall.

There were many counterparts involved in the solution of these technical issues. The main activities were performed by the IAEA (ii–vi), the United States Department of Energy and Mayak (Russian Federation) (vi), the European Community (i), Denmark, Sweden and the USA (iii).

I.G–5.2. Splitting the initial decommissioning plan into annual activities and smaller projects

This principle significantly promoted the implementation of the SRR decommissioning measures, since all measures were prepared like projects for submission to the annual State budget and EPFL. The following decommissioning measures were implemented in the following way:

(a) Collection and verification of data on the SRR for decommissioning;
(b) Decontamination and renovation of the reactor hall;
(c) Collection, sorting and treatment of historical radioactive waste;

(d) Disconnection and dismantling of unused reactor systems;
(e) Upgrade of the radiation monitoring system on the SRR site;
(f) Establishment of a material testing laboratory;
(g) Upgrade of the radioactive waste transport system.

I.G–5.3. Splitting all activities according to material flux from decommissioning

Planning of the SRR's decommissioning was performed taking into account radiological data on objects and materials. To reduce the costs of material management, all objects and materials were divided into the following groups:

(a) Conventional objects and materials after free release;
(b) Weakly contaminated and activated objects and materials;
(c) Contaminated and activated objects and materials;
(d) Fresh and spent nuclear fuel.

All activities for group (a) were performed by external companies on a contract basis. As examples, the following activities can be reported:

(i) Collection and cutting of conventional scrap at the site of the SRR;
(ii) Dismantling of the second cooling tower;
(iii) Dismantling of the second cooling system pump basement (Fig. I.G–5);
(iv) Dismantling of the 400 m^3 tank at the SRR yard (Fig. I.G–6);
(v) Installation of the 240 m^3 water reservoir for fire protection purposes;
(vi) Construction of interim storage for the decay of radioactive waste and solidification of containers with radioactive waste;
(vii) Construction of interim storage for dismantled specific materials such as graphite, beryllium, etc., that do not meet the waste acceptance criteria of the repository;
(viii) Upgrade of the radiation protection, power supply and security systems of the SRR.

FIG. I.G–5. Dismantling of the second cooling system pump basement.

FIG. I.G– 6. Dismantling of the 400 m³ tank in the SRR yard.

All activities for group (b) were performed by external companies on a contract basis working with the licensee for activities with radioactive material. As examples, the following activities can be reported:

- Strengthening of the reactor hall walls;
- Decontamination of the reactor hall (Fig. I.G–7);
- Installation of a radioactive waste treatment facility;
- Dismantling of neutron beam protection structures.

FIG. I.G–7. Decontamination of reactor hall walls.

Materials and objects from groups (c) and (d) were fully managed by the staff of RAPA Ltd (transformed into the Hazardous Waste Management State Agency (BAPA) in 2005). As examples, the following cases can be reported:

- Collection and cutting of radioactive material from the reactor hall (Fig. I.G–8);
- Cleaning of radioactive waste interim storage (Fig. I.G–9);
- Dismantling of the primary cooling system;
- Dismantling of the zero power reactor;
- Renovation of the spent fuel pool;
- Treatment of radioactive waste in concrete containers using tritiated water (Figs I.G–10 and I.G–11);
- Transporting the containers with radioactive waste to the repository (Fig. I.G–12);
- Shipment of fresh fuel to the Russian Federation;
- Preparatory activities for shipment of spent fuel to the Russian Federation.

FIG. I.G–8. Cutting of the first cooling system pipes.

FIG. I.G–9. Cleaning of interim storage of radioactive waste using remote controlled equipment prepared by specialists of RAPA.

FIG. I.G–10. Dismantled radioactive waste in concrete containers.

FIG. I.G–11. Cementation of radioactive waste in a concrete container.

FIG. I.G–12. Radioactive waste in a concrete container ready for transport.

I.G–5.4. Reusing the SRR site for radiation related activities

During preparation of the initial decommissioning plan in 1999, the final decommissioning stage was planned as returning the site to a greenfield condition (in reality brown field, since there was no intention to demolish the buildings). In 2003–2004 the upgrade of the initial decommissioning plan was performed and the final stage of decommissioning was redefined as reuse of the site for radiation related technologies. During upgrading of the initial decommissioning plan, it was found that the change in the final stage could result in a $6 million saving due to a reduction in demolition activities on the site and exclusion of free release activities. EIA studies indicated that for the greenfield option site remediation activities had to be performed with total costs of up to $20 million. In any case, a 60 year institutional control period was defined by EIA studies after decommissioning of the SRR. Taking into account the results of EIA studies and the upgraded decommissioning plan, the Government of Latvia in August 2006 supported the construction of the National Multipurpose Cyclotron Centre at the site of the SRR. It means that the reactor building, with its special channels, ventilation, power supply, radiation monitoring and security systems, must remain after decommissioning, significantly reducing the decommissioning costs and increasing the effectiveness of the decommissioning measures.

I.G–6. SUMMARY OF DECOMMISSIONING ACTIVITIES

The results of the decommissioning activities can be illustrated by the material flux from the decommissioning. Table I.G–1 contains the information on dismantled material flux from the decommissioning of the SRR.

TABLE I.G–1. MATERIAL FLUX FROM DECOMMISSIONING OF THE SALASPILS RESEARCH REACTOR

	1999	2000	2001	2002	2003/4	2005/6	Total
Metallic scraps for reuse and recycling (t)	11	31	48	23	75	8	196
Concrete for disposal on the site (t)	9	64	230	51	39	13	406
Other material for disposal (t)	3	38	9	11	14	4	79
Conditioned radioactive waste (t)	2	7	16	16	14	22	77
Conditioned spent sealed sources and waste (TBq)	6.2	4.6	1.8	5.2	0.6	82	100.4

Taking into account the upgraded decommissioning plan, the remaining activities to decommission the SRR will concentrate on the following:

(a) Dismantling of the core reactor pool internals;
(b) Dismantling of the biological shield;
(c) Shipment of spent fuel to the Russian Federation.

All these activities are ongoing with the support of international stakeholders. Items (a) and (b) are supported by the European Commission Transition Facility programme and item (c) is supported by the United States Department of Energy and Mayak of the Russian Federation.

I.G–7. CONCLUSIONS

Despite the lack of decommissioning funds and other resource limitations the decommissioning of the SRR is being carried out successfully according to national and international legislation and standards.

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Annex I.H

NORDIC STATES — GOOD PRACTICES FOR COST CALCULATIONS

I.H–1. HISTORICAL PERSPECTIVES

The Nordic States of Denmark, Finland, Norway and Sweden were ambitious in the early development of nuclear technology. Iceland, with its very large resources of geothermal and hydropower, did not have the incentive to join and Finland had a special relation with the USSR after the Second World War that led to a different approach.

After the Second World War, Norway was in a unique position in that it possessed the heavy water that made it possible to build atomic piles using natural uranium. Thus the first nuclear reactor in the Nordic States, JEEP 1, was commissioned in the outskirts of Oslo as early as 1951, preceded only by facilities in Canada and in the four ‘great powers’ of France, the United Kingdom, the USA and the USSR. A similar heavy water research reactor was commissioned in Stockholm in Sweden in 1954. Denmark acquired two research reactors from the USA in 1956 and one from the United Kingdom in 1957. Finland commissioned a subcritical pile in 1956 and commissioned a TRIGA reactor purchased from the USA in 1962.

Although there was considerable secrecy around nuclear technology in the early years, the Nordic States sought openness and international cooperation throughout. The first international nuclear conference was organized in Norway in 1953. This was two years before the conference on the Peaceful Uses of Atomic Energy (the Geneva conference) held by the United Nations.

The programmes in Denmark, Norway and Sweden included full fuel cycle activities from mining to fuel manufacturing and reprocessing. Much of the work was carried out in cooperation between these States. Eventually, Denmark and Norway decided against nuclear power, while Finland and Sweden went ahead with programmes for light water reactors and enriched fuel. The national and Nordic cooperative programmes have left behind a large number of nuclear research facilities now in various stages of decommissioning. Details as well as references on the following can be found in Ref. [I.H–1].

I.H–2. PRESENT SITUATION

Some facilities have been decommissioned, such as one research reactor in Denmark, Norway and Sweden, one reprocessing pilot plant in Norway and the Active Central Laboratories at Studsvik near Stockholm in Sweden. Others have been taken out of operation and await decommissioning, such as the research reactors R2/R2-0 in Studsvik, Sweden. Some facilities are still used today, for example the boiling heavy water research and steam generation reactor in Halden in Norway and the TRIGA reactor in Helsinki in Finland.

Work is presently in progress in Denmark on decommissioning of all of its nuclear facilities at Risø near Roskilde to greenfield conditions within a period of up to 20 years. Approval for funding was made in a parliamentary decision in 2003 after which the organization Danish Decommissioning was formed. Planning is also in progress in the other States.

In Finland and Sweden such planning is made to meet the requirements of the systems for funding, the purpose of which is to ensure that adequate funds are accumulated today, when the benefits of nuclear energy are being reaped, to cover all future costs. This means that an estimate of all future costs has to be submitted to the authority/government agency for review and decision each year. The reviews are made based on the expertise of the officials as well as on the knowledge base compiled by various consultants.

It was soon found in such work [I.H–2, I.H–3] that financial planning is intimately related to decommissioning planning in general. In fact, the timing of various planning activities for decommissioning is largely dictated by the requirements of the cost calculations. It was also found that financial planning and cost estimations are necessary for the decommissioning planning in general, since the former are needed for, for example, selection of techniques to be applied.

It might be tempting to assume that the methodology developed for planning and cost calculations for nuclear power plants can be applied in a straightforward manner to old research facilities. It was found, however, that the existence of a nuclear power programme is of limited value for old research facilities since there are substantial differences. Actually, an uncritical application of power plant approaches is likely to lead to gross underestimates of the work as well as the costs due to several features related to research reactors:

(a) Lack of records in combination with limited or no access to the staff that designed and operated the facilities;
(b) Much less is known about an old research facility and thus the list of the items that costs must be summed over is incomplete;
(c) The dependence on volume is different since the volumes are small;
(d) The spread in design and operation features is much greater;
(e) Design features that are less suitable for decommissioning.

Instead, it was found that there are substantial common interests between owners of different research facilities in different stages of decommissioning:

(i) Comparisons can be made with similar completed projects so that adjustments can be made to compensate for the weaknesses referred to above;
(ii) Feedback of experience can be gained from completed projects on similar facilities to improve the approach on later projects;
(iii) Resources can be saved by joint efforts across projects.

Once these benefits of a joint Nordic work had been identified [I.H–2, I.H–3], the Swedish Nuclear Power Inspectorate took the initiative to propose a Nordic cooperative project. It was started in 2005 and remained in progress in 2007. The purpose of the work is to define good practice, to identify and develop cost estimation methodologies and to compile a knowledge base. The latter includes making old documentation available and searchable using modern digital techniques. The results of the work during 2005–2006 have been documented in Ref. [I.H–3].

The participants of the Nordic cooperative project are as follows:

- Danish Decommissioning;
- Institute for Energy Technology;
- Studsvik Nuclear AB;
- Technical Research Centre of Finland;

- Swedish Nuclear Power Inspectorate;
- Swedish Radiation Protection Authority;
- Tekedo AB (coordinator and consultant).

The work is financed by the participants (except Tekedo AB) together with Nordic Nuclear Safety Research.

I.H–3. COST CALCULATIONS

The main aim of the joint Nordic work is to find and develop appropriate and practicable approaches and methodologies for cost estimates and calculations [I.H–1–I.H–3]. Some prerequisites and findings of this work are presented below.

The main purpose of cost estimation is to obtain bases for decisions. One obvious such decision concerns the allocation of adequate funds to cover an entire decommissioning project, but decisions are also needed at different times and for different purposes. For example, cost calculations are required in order to make appropriate choices of technologies.

Cost estimates have been made for decades in the chemical process and other industries, at different stages and for different purposes. Textbooks on the subject (e.g. Ref. [I.H–4]) explain that there are two principally different types of methodology for cost estimates:

(a) Comparison with incurred costs for processes and other parts of facilities already erected, using various types of comparison factor, including scale factors;
(b) Summation based on known volumes of various items together with known costs per unit.

In the remainder of this annex these will be referred to as the comparison method and the detailed summation method, respectively.

At an early stage in planning, the detailed summation method can give rise to large systematic errors, since only a fraction of the terms to be summarized can be identified. Consequently, the comparison method is recommended for such situations, and in the first stage it can be expected to deliver a precision of +50/–30% (i.e. the actual cost is expected to lie in a range between 30% less and 50% more than the calculated estimate). Similarly, in the final stages of cost calculations, when the final detailed design has been completed and binding quotations have been received from all of the suppliers and contractors, the detailed summation method can be applied with a typical accuracy of ±5%.

Briefly, decommissioning planning has the following aspects:

(i) Defines the objective, including setting the final target;
(ii) Performs radiological characterization;
(iii) Selects technology;
(iv) Undertakes technical risk assessment and uncertainty analysis;
(v) Makes cost calculations;
(vi) Etc.

It should be noted that the process is iterative, at least partially. Thus cost calculations need to be made recurrently and in ample time before various decisions are needed.

The need for decisions at early stages in combination with the need for accurate cost calculations as a basis for such decisions raises the requirement that the cost calculations need to be sufficiently accurate even in the early stages.

Such requirements will clearly require greater accuracy than the +50/–30% indicated above for first stage calculations. As explained above, there are good reasons to expect the uncertainties to be considerably larger in the case of the decommissioning of small nuclear facilities. Thus methodologies need to be developed for these more accurate calculations to support decisions in the early stages.

Increased accuracy for early stage calculations might be achieved if one or both of the following could be achieved:

- Improved accuracy with the comparison method by using the incurred costs of similar facilities;
- Improved accuracy with the summation method by finding out more about detailed features of a decommissioning project that have a large effect on cost and/or a large uncertainty.

For owners of a limited number of small and dissimilar nuclear facilities, both routes call for cooperation and information exchange with external parties.

Experience shows that cost drivers more often than not have a profound influence on costs. Experience also shows that such cost drivers tend to reveal themselves during the course of the execution of a decommissioning task, thus frequently giving rise to high overruns in cost.

It is thus imperative that cost drivers be identified, preferably during the planning stages, but if this is not possible, as early as possible. In practice, the cost drivers can be identified in different ways, to varying degrees and at different times. It is helpful in this regard to attempt deterministic as well as probabilistic types of analysis.

Thus various features particular to old research facilities and limited resources might be analysed for their effect on costs (and checklists specifically designed for this purpose might also be compiled). Furthermore, methodologies applied in risk identification and hazard evaluation analyses may be applied in order to identify and evaluate the significance of features that might be associated with risks for cost increases.

REFERENCES TO ANNEX I.H

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Annex I.I

DECOMMISSIONING OF THE EWA RESEARCH REACTOR IN POLAND

I.I–1. DESCRIPTION OF THE EWA REACTOR FACILITY

The EWA research reactor, which is a WWR type, was constructed based on a former USSR design. Construction started in May 1956 and the reactor reached criticality on 30 May 1958. After commissioning, the reactor was put into operation on 14 June 1958. In the period from 14 June 1958 until May 1964, the reactor was operated at a nominal power of 2 MW(th) and was mostly used for radioisotope production, physical and technological research carried out using neutron beams from horizontal channels, and for other work with ionizing radiation.

In 1964, the first modernization of the reactor was accomplished by reconstructing the fuel assemblies, allowing an increase in the reactor thermal power to 4 MW. In 1967, a second modernization of the reactor was carried out. As a result of that upgrading, which comprised the overall refurbishing of the reactor core — with new fuel of WWR-SM type, a beryllium reflector, other technological systems and the secondary cooling circuit — the reactor reached a thermal power of 10 MW.

The reactor was operated until February 1995. The total operating time at power during the 37 years operating period was equal to about 118 000 h.

The main structural components of the EWA-10 reactor are as follows:

(a) Reactor core with fuel elements;
(b) Reflector with beryllium fillers;
(c) Vertical channels for the control rods;
(d) Vertical channels for irradiation of target material;
(e) Horizontal channels and thermal column for the neutron beams;
(f) Central reactor tank and biological shielding tank;
(g) Biological shielding.

An integral part of the reactor was a storage pond for spent fuel, situated in the reactor hall near the reactor concrete block. The major element of the reactor was its core of hexagonal shape with an inside diameter of 520 mm and a height of 600 mm. The core was surrounded by a stationary beryllium reflector with an outside diameter of 643 mm (the mean thickness of the reflector was equal to 40 mm). All the components of the reactor core were made of aluminium alloy PAR-1. The fuel elements were of types WWR-SM and WWR-M2 with ^{235}U isotope enrichment up to 36%.

The basic operational parameters of the EWA reactor were as follows:

(i) Nominal thermal power: 10 MW.
(ii) Average thermal neutron flux: 0.87×10^{14} n/cm^2/s.
(iii) Maximum thermal neutron flux: 1.25×10^{14} n/cm^2/s.

I.I–2. REASONS FOR EWA REACTOR DECOMMISSIONING

The following factors were the basis for the decision to decommission the EWA reactor:

(a) The technical condition of the reactor;
(b) The necessity to meet safety requirements;
(c) The completion of research projects.

After operation for 37 years, the reactor's systems required significant modernization. Tests carried out showed that the mechanical equipment (pumps, tubes, valves), as well as the instrumentation of the control systems, needed to be changed in order to meet contemporary safety requirements.

I.I–3. SCOPE OF DECOMMISSIONING

The scope of the decommissioning project comprised:

(a) Removal of the contaminated agents (coolant, ion exchange beds, etc.) from the reactor circuits;
(b) Dismantling of the reactor tank equipment (isotope channels, control and safety rod channels, neutron measurement channels, etc.);
(c) Dismantling of the core separator together with its structural elements (including the beryllium blocks);
(d) Dismantling of the thermal column along with the graphite blocks and cooling system;
(e) Dismantling of the reactor primary cooling system (heat exchangers, filtration facilities, circulation pumps, piping along with associated valves and gate valves);
(f) Dismantling of the core emergency cooling system components;
(g) Dismantling of the central and biological shield tanks.

The main goal of facility decommissioning was the removal of activated and/or contaminated elements and material, which constituted the integral parts of reactor technological systems. Dismantling techniques were selected, taking account of:

(i) Minimization of the radiation exposures for personnel directly participating in the dismantling work;
(ii) Minimization of radioactive waste quantities;
(iii) Maximum material retrieval for recycling;
(iv) Minimization of decommissioning costs.

A description of the project is given in Ref. [I.I–1].

I.I–4. PROGRESS WITH DECOMMISSIONING WORK

The decommissioning procedure started in 1996 with preparation of the Decommissioning Plan of EWA Reactor. After approval of the plan by the regulatory body it was necessary to produce the following documentation:

(a) Technological and operational procedures, including radiation protection problems;
(b) Quality assurance programme for decommissioning;

(c) Designs for appropriate equipment and tools;
(d) Detailed operation plan based on operational experience and calculation methods.

The decommissioning work started in 1997. Three groups of employees were engaged in the work:

(i) Permanent operational staff of the EWA reactor, who conducted supervision functions and prepared the necessary documentation and its authorization;
(ii) External company employees from the main subcontractor for carrying out the dismantling works;
(iii) A number of Institute of Atomic Energy (IAE) departments, including the Department for Analyses and Reactor Techniques, the Service Unit for Radiological Protection and the Department for Radioactive Waste Management, which were carrying out the work in compliance with the IAE's statutory duties.

For remote dismantling operations and high radioactive material safety storage, special tools were designed and manufactured in house, including:

- A cutting machine for the high radioactive channels of the control rods;
- Shielding containers for the high radioactive parts of the reactor core and the graphite blocks of the thermal column;
- A frame for transport of the reactor tank;
- Special equipment for unloading the reactor tank and reactor core parts.

All tools were designed and produced by local staff. The decommissioning process of the EWA reactor was completed at the end of 1999. The appropriate selection of technology, decontamination methods and job organization had a great influence on limiting the amount of radioactive waste. The total volume of solid radioactive waste amounted to about 42 m^3, including the 22 m^3 reactor tank volume. Significant quantities of material for recycling were retrieved (about 86 t of carbon steel, stainless steel and aluminium).

I.I–5. PLANNED REUTILIZATION OF THE REACTOR FACILITY

A preliminary study of the reactor facility has shown that after decommissioning it can be used as follows:

(a) A dry storage for nuclear spent fuel elements can be constructed in the reactor concrete shaft. This can potentially store the spent fuel from the EWA reactor (EK-10, WWR-SM and WWR-M2 fuel) and the spent fuel from the MARIA reactor (MR fuel) before sending it to the manufacturer for reprocessing.
(b) The hot cells can be used to encapsulate nuclear fuel elements and any other high radioactive waste.
(c) The hot cells may also be used for material examination or for other work with radioactive material.
(d) The administration/laboratory building of the reactor will be used as the radioactive waste management headquarters.

I.I–6. DECOMMISSIONING COST

The decommissioning expenditure was about €1.15 million, which can be considered good value for money. Owing to limited financial resources the following measures were applied:

(a) The documentation listed above for the decommissioning project was produced by IAE employees. A significant part of the work was carried out by EWA reactor operational staff.
(b) Detailed procedures and instruction for every operation were produced. The documents issued as the basis for radiological safety analysis allowed the employment of inexperienced workers from an external company.
(c) Good cooperation with the National Atomic Energy Agency. The documents concerning decommissioning were reviewed, discussed and approved with no delays.
(d) Good assistance from IAEA: expert missions and financial support for equipment for monitoring radiological hazards.
(e) Most dismantling work was performed by former EWA reactor operational staff with some minor assistance from a small subcontracted company.
(f) The staff of the MARIA reactor took part in dismantling work. Benefits were cost minimization and experience gained by the participants.
(g) Very good decontamination procedures were applied. The basis of the procedures was experience based on Paul Scherrer Institute (Switzerland) project work. As result significant quantities of material have been recycled.
(h) Both the IEA and the National Radioactive Waste Repository are government organizations, therefore there was no cost charged to the project for radioactive waste storage.

Some of the above factors are discussed in more detail in Ref. [I.I–2].

I.I–7. CONCLUSIONS

The low cost of the decommissioning project reflected the low direct costs of the dismantling work, which resulted from appropriate preparation of technological operations. Experience and good cooperation of all the specialist groups of the IAE and the external companies were of great importance.

Good cooperation with the IAEA and the regulatory body for nuclear safety was a beneficial factor during the decommissioning process of the EWA reactor. Apart from the fundamental tasks associated with the assessment of the provided safety documentation and facility auditing, a broad collaboration was maintained with inspectors during discussions and the production of the dismantling technology. This led to some alterations and improvements to planned operations being implemented.

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Annex I.J

EXPERIENCE OF DECOMMISSIONING RESOURCE OPTIMIZATION IN THE UNITED STATES OF AMERICA

I.J–1. INTRODUCTION

This annex has been prepared based upon the views of a decommissioning practitioner in the USA. It presents some methods employed to maximize the outcome achieved from the application of limited resources, a situation often encountered on a decommissioning project. In addition, it presents some philosophies for approaching decommissioning in general, as well as some examples of practical measures used on projects that might be useful on similar projects with similar circumstances elsewhere. US experience of small facility decommissioning is given in Refs [I.J–1–I.J–9].

Resource limitations can take several different forms: financial, technical or human resources constraints. In some instances combinations of these may be in effect; for example, a project may have stringent funding constraints with a fixed delivery schedule for the work to be completed.

Nearly any project — decommissioning or non-decommissioning — has some type of constraints placed on it and often these are not specific to that project but arise from the context in which the project is found. As mentioned above, the availability of resources is likely to be a limiting factor on all decommissioning projects as there will only be so much funding, time or qualified staff available to perform the project. In certain situations, a negotiated agreement or some other regulatory requirement may constrain or limit the available resources or timeframe for the work.

Resource constraints are usually recognizable early in the planning phase of smaller projects. Many of these projects must, on a daily basis, approach their work in a very thrifty manner rather than the preferred project view of resources — i.e. to identify and obtain whatever the project needs to accomplish its mission. This thriftiness can inspire the staff assigned to the work to identify opportunities to maintain or perhaps even enhance safety and the efficiencies of the operations (i.e. allow for some creativity) in how the decommissioning is actually implemented for a particular laboratory or other smaller facility undergoing decommissioning. This requires either or both of: (a) implementation of strong project management skills; (b) optimization of past project lessons learned, to look for opportunities to optimize scarce resources on the project.

Various conditions may constrain the resources available for performing a particular decommissioning job in specific project or work site circumstances. These conditions can include: facility type, staffing, project management skills, waste management, technologies, and site characterization and site release. The remainder of this annex will describe some practical approaches used in implementing decommissioning with resource constraints.

I.J–2. FACILITY TYPE

Often the type of facility (and its geographic location) will influence the availability of the financial and/or human resources to implement the decommissioning project. Most major decommissioning projects have most of the resources that they need to conduct their work. However, smaller licensees (laboratories or academic facilities) — and organizations operating on small margins

— may lack the means to perform decommissioning while still maintaining other operations on a site. The budget simply does not allow for additional staff to perform the decommissioning tasks, even in some cases on a temporary basis. This may require a more stringent approach in managing staff resources than at larger licensee sites. Certain staff may need to perform several different functions for the project team, including working on continuing operations.

I.J–3. STAFFING

The two most expensive aspects of any decommissioning project, whether it is large or small in scale, are often related to: (a) the cost of staff to perform the decommissioning activity; and (b) the costs for disposal of the waste from the activities. One way to optimize the use of the staff in a decommissioning project is to multitask various staff members rather than unnecessarily staffing the project with dedicated full time staff. One full time supported staff member may be able to perform the work of two or three part time project staff at a lower cost.

Another example is to make use of a working supervisor. In this case, the supervisor is a member of the management team but also performs, to some extent, limited amounts of hands on decommissioning work. The supervisor can oversee the work and even become a member of the project team in accomplishing the work — this stretches the project dollars. It is important to be sure that this condition does not cause the employee to avoid the responsibility of still serving as the supervisor nor doing the work safely and in compliance with workplace requirements.

Another opportunity might be to use some private consultants or retirees who can be retained to support a project on a short term or as needed basis. In this way, support is given to a project at a lower cost and better meeting schedule requirements. Consideration should be given to evaluating the possibility of use of outside workforces to perform the project 'hands on' work (if possible or allowed) rather than using a captive in house labour force. This generally results in a lower cost overall. This approach must be evaluated as to whether such workforces are readily available in the local area to support such an approach to a project. This approach has been used at several Department of Energy facilities in the USA, where personnel familiar with past site operations were able to be used to supplement other staff and contractor staff at a fraction of the cost. This same approach might be used to bring in supplemental staff to support decommissioning using hired engineers for specific tasks to accomplish the decommissioning — this way the staff are focused on critical tasks and used on an 'as needed basis' only.

At some larger facilities or research institutes with large organizations and significant overhead funded management and operational staff, it may be feasible to use engineering and/or labour resources from the central organization on a 'time available' basis. The project may be able to get some minimal cost support to accomplish the work. Of course, this may also mean the resource might be taken away from the project to perform work for the central organization at times. However, this does allow the project to avoid the costs of bearing this person on the project budget and allows for the use of the staff member's skill in performing the project work; for example, a central waste management operations organization may have some staff that can be added to a smaller scale decommissioning project for short periods without impacting other routine operations.

I.J–4. PROJECT MANAGEMENT SKILLS

Often the key aspect to being efficient and effective is implementation of key project management tools and skills for the project. These skills address how to optimize the use of key financial and human resource assets to gain maximal leverage in accomplishing the assigned task or project most efficiently. It may not be necessary for the project manager to have strong technical skills in the nuclear decommissioning area of work, since these skills can be supplemented by others of the technical staff. In fact, a project team often works best when an experienced project manager is brought together with people having the specialist technical expertise. This is often how even larger resource rich projects accomplish their work, as it maximizes the contribution of both. This has recently become a model for companies providing decommissioning services at various sites in the USA — a team consisting of a large management contractor working with several highly specialized services supporting them to perform the technical work.

The staff on a project may be incentivized to achieve a specific end point date with a fixed and limited budget. Certain technical objectives may be targeted in a contracted job, such as minimizing the radioactive waste generated in performing the work scope. The contractor would then receive a cash reward dependent on the money saved in avoided waste disposal costs. In this case more workers may be added to the project team or the approach modified to meet the objective and receive the incentive if the goals are met. This approach has been used on some larger nuclear facility projects in the USA. It is often used to counteract the effect of a licensed site terminating its operational activities and then witnessing the former research and/or operating staff leaving the site for other jobs and the loss of the institutional knowledge that accompanies the departing staff. A cash bonus for staying at a site is often an effective incentive for retaining key staff.

In some cases, short term staff may be able to be hired for a period to support a project. Once the work is completed the contracted staff member returns to their office for their next assignment. For smaller projects, this is often an effective means to accomplish the desired end result of the decommissioning process. This approach is often used by universities and other smaller licensees and even some larger licensees in the USA. The old adage of ‘why become an expert when you will only do it once’ applies here in such cases. These services are also available from many consultants and technical service contractors to support this sort of activity.

Regulators will often look at the project management style of the staff being used to manage the decommissioning activity — their credentials and training in managing projects. Is the team composed of staff that can work well as a team with all the necessary skill sets and credentials? Projects fail if they have poorly or inadequately qualified staff performing project management. In the USA there are now numerous well qualified staff members who work for various consulting firms and are attached to decommissioning projects of various sizes in order to bring a capability to optimize project performance.

The use of even basic planning and project management tools software and other project management tools allow for efficient and effective management of a project. Many and most of these are readily available from specialist software suppliers. There are many project planning and scheduling tools on the market; small projects can take advantage of the simplest and therefore cheapest of these.

Waivers of compliance for some facility or site environmental requirements (e.g. environmental monitoring) and other more onerous requirements may be able to be granted if requested from the regulator. If a facility is no longer operational (e.g. a research reactor with no fuel remaining on the site), a request for a change can be made related to the previous operating requirements.

I.J–5. SITE CHARACTERIZATION

Site characterization is necessary to properly protect workers, the environment and the public from radiological hazards in decommissioning. At some smaller facilities, it may be possible to characterize areas as work is about to begin in that area, rather than spending extensive amounts of time and funding on early detailed general characterization. Past operational records can be used to gain a working knowledge of an area without requiring any major additional characterization of areas. There are project risks from this approach, but where financial resources are limited this may be cost effective. It is most likely to be appropriate where only low levels of contamination are expected or where contamination may occur during decommissioning due to local refurbishment or nearby decommissioning work. The risks should be assessed as part of the project risk assessment and supported by an appropriate cost–benefit analysis.

I.J–6. WASTE MANAGEMENT

Careful consideration is required when addressing the topic of waste management; for example, is decontamination a cost effective approach for the specific facility the project is attempting to decommission? Are there other more cost effective means to perform the dismantling of old structures? Both of these decisions may influence the form and volume of the waste products to be treated, packaged and disposed of. In some cases, the investment of financial resources in some technologies — to be able to properly and accurately screen different waste as cleared, treatable or disposable as waste — might be a wise use of limited resources for a project. This is especially true in many research facilities, where much of the waste generated from the old operational equipment may be able to be screened, cleared and reutilized either intact or simply as clean scrap metals.

Some costs associated with the shipment of waste to a radioactive material disposal site — especially of the small volumes of lightly radioactive waste for a small scale project — could possibly be shared with other projects or waste generators. This allows the project to avoid the expense of shipping the waste and just bearing the cost by the project alone. This would be the case at a university or hospital, where costs could be reduced by sharing shipments to waste disposal sites with other waste generators.

Final waste disposal volumes and costs may be reduced by striving to release as large a volume of material for disposal as a lower category of waste material as criteria allow. One example of this approach might be the use of an alternative municipal landfill as a disposal site for some project waste, consistent with regulatory guidance from regulatory officials, instead of using a disposal site designed for more highly radioactive waste. Decontamination campaigns can be justified if the waste treated can be disposed of as a lower volume or lower category of waste. This approach can be used for low levels of residual radioactive contamination on equipment and structural material from a laboratory or a support structure or for other less contaminated waste streams that may not even actually meet the acceptance criteria for disposal as radioactive waste at the disposal site. This approach or a form of this approach was recently used at a commercial power reactor site undergoing decommissioning in the USA.

Certain other low level contaminated waste materials may be able to be disposed of as backfill at some sites to fill excavated areas. In other cases, lower level radioactively contaminated soils may be able to be shipped for disposal at non-radioactive but special hazardous waste disposal sites that can accept this sort of waste for disposal. An example of this was when some of the low level contaminated soil from a commercial reactor decommissioning and dismantling project was able to be shipped to a hazardous waste disposal site, rather than to a solely radioactive waste disposal site. The hazardous waste site's waste acceptance criteria were met by the waste, resulting in significant project cost savings. Opportunities should be reviewed for the use of an optimized approach for disposal rather than merely accepting the fact that the waste must be shipped to a radioactive waste disposal site. Again, an important point is that time needs to be spent on evaluating outlets for waste generated by the decommissioning process.

I.J–7. TECHNOLOGY CONSTRAINTS

The use of off the shelf and readily available technologies procured from vendors will facilitate conservation of financial resources. It will also be easier for project staff to use these off the shelf technologies, since detailed training on the use of a complex tool is not required, nor is training required on the methods of how to perform maintenance of the same.

It is most unlikely that a minimal project budget will be able to fund any technology research and development activities. There should be some time allocated to perfect and make field ready those tools to accomplish the decommissioning objective. Some time should be allowed for the workforce to train to use the tools and to perform some test operations using mock-ups.

I.J–8. SITE RELEASE

It may be possible to perform work to criteria that do not achieve free release status but that still may significantly reduce entry and work area requirements and allow for future use of the area until a true final site release or area release is needed or desired. This might be thought of as some sort of 'restricted release' concept for some areas or facilities/sites. A realistic end state use definition would also assist with cleaning up conditions to less than that of greenfield condition but still allowing for the space to be reused; for example, on some federally controlled sites where institutional controls will be maintained for an extended period of time, cleanup of residual contaminants to levels beyond that for industrial reuse is probably not realistic or practical.

I.J–9. TRAINING

Training is often looked upon as a cost when it should be viewed as an investment. It supports the performance of the project team by transferring the lessons learned from other similar projects and making the project staff better able to undertake their tasks. This is an area where a big pay-off could occur even with limited resources, if the investment were leveraged properly.

I.J–10. PRACTICAL EXAMPLES

Some practical examples can be found in the open literature in US technical papers and seminar papers [I.J–1–I.J–9]. One problem with some of the smaller projects and projects performed with resource limitations is that while the end result is an accomplishment to achieve, once completed the magnitude of the achievement may not be so clear to others. In addition, the technologies or the efforts surrounding it may actually be of little interest to anyone except a select group of those individuals with similar problems or that have routinely been required to also deal with such a situation. As a result, the experiences of small facility decommissioning may be underreported in the literature.

Accelerator facilities provide some good examples of how smaller facilities can be very economically decommissioned. In this case there is little radioactive contamination to be addressed at the facility and many of the components are easily reutilized at other sites, even outside of the State.

At some small research laboratory facilities it may be possible to comply with regulatory requirements for decommissioning by performing only a certain minimal number of required actions to release an area for further use after completion of decommissioning. At Nuclear Regulatory Commission regulated licensee sites, there is a definition of what actions are needed in order to close out and terminate licensed activities at a site. These actions are described in NUREG-1757 [I.J–9], and are probably best described as a proportionate risk based approach dependent on the radionuclides used and their form. With minimal radiological surveys and associated paperwork, a licensee can safely and easily terminate its licence and move on to resolving the next issue requiring attention.

I.J–11. CONCLUSION

While most decommissioning projects do not seek out to perform their work under limited resource conditions, these sorts of situations do regularly occur in the USA as well as in other States. It is worthwhile to note that although many projects may not explicitly face these limitations, it is the responsibility of the project manager and staff to find creative ways to reduce cost while still achieving the work objectives.

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Annex II

LESSONS LEARNED

The following examples of the lessons learned from research reactor and other decommissioning projects with limited resources include an outline of the problems/requirements encountered, solutions found and lessons learned. The situations described are typical of the issues that can arise in the planning or implementation of decommissioning activities. The reader is encouraged to evaluate the applicability of the lessons learned to a specific decommissioning project.

II–1. SIGNIFICANT COST SAVED BY DECONTAMINATING WITH HOME CARPET CLEANERS, HANFORD, USA [II–1]

II–1.1. Problem

As a result of teamwork planning at the T Plant facility, a cost effective decontamination method was developed for the 221-T canyon deck. Initially, the team considered using floor cleaners of a type that was relatively large, cumbersome and expensive (thousands of dollars). Using a smaller floor cleaner available off the shelf at many discount stores was proposed. This unit proved to be very effective in cleaning the floors and in collecting and handling the waste material.

II–1.2. Analysis

By using inexpensive floor cleaners, the work team was able to decontaminate the canyon walkway and portions of the deck at minimal cost with no spread of contamination. The liquid waste generated by the floor cleaners was simply solidified and placed in a waste box after the daily cleaning evolution.

Operations management purchased three machines for deck decontamination operations. Each machine was designated for operation in a ‘run to fail’ mode. When they fail they will be disposed of as waste after removing and solidifying liquids.

II–1.3. Lessons learned

Inexpensive home use floor cleaning machines can be very effective and cost efficient for decontaminating radioactively contaminated surfaces.

II–2. SHARED TECHNOLOGY INCREASES PRODUCTIVITY AND SAFETY, BECHTEL NEVADA ENVIRONMENTAL RESTORATION, USA [II–2]

II–2.1. Problem

Bechtel Nevada Environmental Restoration (BN/ER) was involved in the decontamination and demolition of a former decontamination facility. One of the technologies used at this closure site was a set of hydraulically actuated demolition shears (processors) for the demolition of the decontamination facility structure. This technology was transferred from the Bechtel Hanford decontamination and demolition project.

II–2.2. Analysis

The application of the hydraulically operated demolition shears indicated that a considerably more economical production rate of building removal could be achieved at the Nevada test site. The building was reduced to ground level in 2.5 h. Volume reduction of the demolished building was completed in less than 8 h. In addition to the speed of demolition, the equipment allowed for safer operations, as workers did not need to enter the building. Conventional methods would have involved a minimum of two weeks for the removal of the building, with workers inside the building at various times during the demolition. The hydraulic shears will be used at other BN/ER decontamination and demolition activities.

II–2.3. Lesson learned

The potential for technology transfer from sites that are engaged in similar activities to increase productivity and safety should be investigated.

II–3. TEAMWORK LEADS TO INNOVATIVE DECONTAMINATION, ROCKY FLATS, USA [II–3]

II–3.1. Problem

Bringing a beryllium contaminated, 3000 ft^2 (270 m^2) room with 18 ft (5.4 m) high walls to free release levels was a significant challenge. However, a cooperative effort between project management, industrial safety and steelworker Be Committee representatives and the B707 waste team resulted in an inexpensive and effective solution.

II–3.2. Analysis

Room 125 of F Module in B707 at Rocky Flats was contaminated with up to 1.46 $\mu g/100\ cm^2$ of surface beryllium. The action level for surface contamination is 0.2 $\mu g/100\ cm^2$. After previous decontamination efforts failed, the project came up with a new procedure for decontaminating the room using sticky tack cloths that are commonly used in the woodworking and auto painting industries to remove fine dust.

By using commercial tack cloths for the final wipedown of the area, the waste team members conducting the decontamination were able to bring the level of beryllium contamination in the room to less than 0.1 $\mu g/100\ cm^2$, which meets the unrestricted release criteria.

II–3.3. Lessons learned

Cost effective decontamination methods are possible by using commercial products. The contributions of all stakeholders are vital to success.

II–4. NEW SURVEY TECHNOLOGY SAVES TIME AND MONEY, HANFORD, USA [III–4]

II–4.1. Problem

A characterization survey of two air support buildings was required before the buildings could be decommissioned and dismantled. The survey could have taken several months to complete using conventional methods, but instead took just two weeks with the surface contamination monitor and survey information management system. This instrument captures both spatial and radiological data and replaces handheld Geiger–Müller counters. The detector collected approximately 18.5 million data points, compared with about the 10 000 that would have been collected by traditional methods, and was more accurate and picked up lower levels of radiation. Producing a characterization report following the survey can take up to 200 h using conventional methods. The software in the new system produced the report in 20 min, including two and three dimensional graphs, tables, release limits, drawings of areas missed and colour enhancements of contaminated areas.

II–4.2. Lessons learned

Using automated instrumentation and data collection during a characterization survey saved 6000 person-hours of survey labour. Note that this is particularly advantageous in a State where the cost of labour is high. In a developing State, the equipment cost may offset the labour cost savings.

II–5. HEALTH AND SAFETY STAFF EFFICIENCIES, US SITE [II–5]

II–5.1. Problem

Projects at a US site involved radiological remediation of buildings and soil, and building demolition. These projects needed full time health and safety (H&S) support, but could not support the cost of multiple H&S technicians to oversee the projects.

Most projects consisted of very small crews that performed sampling or inspection at remote sites where hazards were well known and controls were in place. Sending an H&S technician on these jobs was cost prohibitive and underutilized the safety professional. Field personnel were not qualified to provide H&S coverage for their crew or for subcontracted workers.

II–5.2. Analysis

For the projects in question, safety technicians were cross-trained to provide radiological and construction safety and industrial hygiene coverage for radiological remediation and demolition projects. One H&S professional was assigned as the safety point of contact for the project. Expert technical assistance was requested as the situation demanded. The H&S technician’s effectiveness was enhanced by handpicking construction/remediation crew members based on a variety of experience in construction and remediation projects and by their safe work ethic. These individuals served as the H&S technician’s eyes and ears, brought issues to the technician’s attention and suggested improvements. Daily project safety meetings served as a reminder to be aware of project specific safety hazards.

Worker safety and protection of the public has remained high due to the involvement and ownership of project personnel in safety issues.

II–5.3. Lessons learned

Safety professionals should be cross-trained in construction safety, radiation safety and industrial hygiene disciplines to produce well rounded safety professionals who can support small projects as the single H&S point of contact.

Field personnel for small, remote location projects should be trained to be responsible for non-radiological safety oversight without the need for full time support from the H&S organization, while continuing to involve H&S professionals in determining hazards and establishing controls during work planning.

Cross-training project field personnel and H&S technicians in radiation safety, industrial hygiene and construction safety disciplines provides cost effective health protection for small or remote projects with a limited budget.

II–6. COMMON SENSE COLLABORATIVE APPROACH TO DEACTIVATION SAVES TIME AND MONEY, IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY, USA [II–6]

II–6.1. Problem

The ROVER area was an inactive reprocessing facility for experimental fuel. The facility was shut down in the early 1980s, but residual uranium remained in the piping systems and processing vessels. In 1995, the facility was placed high on a list of Department of Energy (DOE) concerns during a spent nuclear fuel vulnerability assessment. A contractor was tasked with recovering the uranium-bearing material, which entailed dismantling the process piping and vessels. Since the project was viewed as a deactivation/decommissioning, decontamination and dismantling activity with no designated future use for the facility, the project team's approach was to design to — not beyond — the project's requirements. This team recognized the project's short term, low technology nature and was determined to get the job done cheaply and quickly while securing the health and safety of the environment and people. Although emphasis was placed on using off the shelf technology, many of the tools, methods and techniques developed on the ROVER project can be used on future projects.

II–6.2. Analysis

One of the keys to the project's success was running criticality safety, safety analysis, engineering and mock-up/remote development concurrently with maintenance and operations. Normally, these activities take place sequentially. The team reviewed upcoming activities on a case by case basis and determined which could be done concurrently. This may be one of the first projects in which these activities successfully took place concurrently, with only minor setbacks. Personnel played an important role in the project. The project team included representatives from areas including operations, engineering, projects, remote systems, maintenance, safety analysis, criticality safety and scheduling. The site plant engineering team was an important contributor to the project's success. The DOE's project manager during most of the project was able to obtain DOE approvals and decisions for safety documents on a three to seven day turnaround. Use of off the shelf technology, a commitment to working hands on and collaboration among the involved organizations also helped to ensure the project's success. Originally, the DOE Idaho Operations Office sought proposals from two independent contractors to deactivate the facility.

One contractor proposed estimates of eight years, $53 million and 1.77 man Sv to complete the job. With the project team selected to complete the job, the DOE saved up to $35 million, more than five years and 1.37 man Sv.

II–6.3. Lessons learned

Project design for decommissioning or deactivation projects should incorporate a common sense approach. Simple, proven technologies may be more cost effective because these projects are not designed for the long term.

Conducting criticality safety, safety analysis, engineering, mock-up/remote development, maintenance and operations concurrently may save significant amounts of time. Additional time may be saved if team members can provide a quick turnaround, especially on required approvals.

To ensure and enhance cooperation and effective teamwork, all affected organizations should be included in initial design activities. Team members should be involved early in planning and kept informed. The resulting synergy may help the team identify potential barriers before they result in unacceptable delays or costs to the project.

II–7. BEST USE OF SPARE TIME, US FACILITY

II–7.1. Problem

At a US facility, individual tritium contaminated gloveboxes were removed by maintenance forces when their other workload was not heavy. This is sometimes nicknamed the ‘nibble mode’ of cleanout.

II–7.2. Analysis

To the extent that there are surveillance and maintenance staff available (with health physics support), they can be assigned ‘targets of opportunity’ that can be pursued when there is slack time from other tasks.

II–7.3. Lessons learned

One part of decommissioning is to remove contaminated equipment and components from inside a facility prior to demolishing the building. In the ‘nibble mode’, a list of such items is created in advance, a key point being that each of the targets on the list is of sufficiently limited scope such that they can be removed and packaged in a few days and can be done without significantly affecting anything else in the facility that is important to keep in its current configuration (operating systems, access, etc.). If one is to take this approach, the work packages and any special procedures and/or checklists would have to be prepared in advance so that the paperwork for the work is already approved.

II–8. DR-2 REACTOR, RISØ LABORATORIES, DENMARK

II–8.1. Problem

Some experience with respect to decommissioning constraints was gained with the DR-2 reactor, Denmark. It was not specifically due to resource constraints, but because the decommissioning of DR-2 reactor had to wait until the other nuclear facilities at Risø reached the decommissioning stage.

II–8.2. Lessons learned

The project manager suggested the following based on his experience on DR-2. He would let the reactor remain closed for a year or two, after which he would remove the fuel. That may not be cheap, but it would remove the major part of the activity from the reactor. If this is not possible, for economic or other reasons, he would build a dry storage facility for the spent fuel a couple of years after final reactor shutdown.

Assuming a tank type or a pool type reactor, he would seal the reactor tank or pool and drain it and the primary circuit. The secondary circuit can be dismantled without any problems, since it is not active. Active components outside the reactor could, if necessary, be placed in the pool or tank. In the case of a tank type reactor, it may be necessary to get enough space to built a platform above the grid plate on which to put these components. The project manager would seal the tank/pool by covering it with a concrete lid. In the case of a pool, the lid would have to be built by use of a number of concrete beams. Next the manager would drain the reactor tank/pool and the primary circuit to decrease the risks of corrosion. The dry storage facility could possibly be built in the pool, but probably not in the tank because of space limitations.

This is what was done at the DR-2 reactor, except that there was a need to store active components in the reactor tank. Only components that belonged to the reactor, such as control rods, guide tubes, in-core irradiation facilities and reflector elements, were stored in the tank. Some other components were stored in the room below the reactor where the hold-up tank was placed. This approach worked quite well for more than 25 years. Since the main activity in most research reactors is ^{60}Co, the activity can be expected to decrease by a factor of 1000 in 50 years and a factor of a million in 100 years. After a hundred years the facility can probably be dismantled in the same way as a non-active facility. However, some of the material may still have to be treated as radioactive waste and stored in a repository. This is true, for example, for the graphite in the thermal column, if any.

There are obviously disadvantages with this approach. One is that after 50 or 100 years there will be little knowledge or expertise in the reactor field available at the university/institute. Thus it is essential to prepare full documentation of what has been done and what has been left in the pool/tank. This documentation has to be prepared and a number of copies placed at various places, so that one can be reasonably sure that the information will be available when the dismantling finally starts. The delayed decommissioning will not be without its costs since the reactor building has to be reasonably maintained, but the reactor hall once emptied of experiments could be used for other uses, for example engineering experiments or storage. It will be an advantage if the crane remains operational. The spent fuel, if stored in a facility in the pool, will still be quite active, even after 100 years.

II–9. POTENTIAL FIRE HAZARD USING INFERIOR LITHIUM FLASHLIGHT BATTERIES, USA [II–7]

II–9.1. Problem

On 14 February 2006 a worker discovered that a lithium battery powered flashlight had ignited during the night. Parts of the light and the lithium batteries were found scattered throughout the locker in which the flashlight had been stored. Scorch marks were found indicating the potential for a fire to ignite.

II–9.2. Analysis

The inferior lithium battery failed during the night, exploded and melted the nylon case it was in, and charred paperwork in the locker. The batteries had been replaced approximately two months prior to the incident. The light was not left on and the flashlight was being stored in a dry locker inside a building.

II–9.3. Lessons learned

Lithium battery powered flashlights and other devices, such as cameras and electronic equipment, should be checked and verified they have good quality batteries powering them.

The manufacturer's recommendations on the type and quality of battery for use in any type of electrical devices should always be followed.

In general, the use of inferior lithium batteries may create a fire or explosion and burn hazard. Although this event is not specific to decommissioning, it highlights the risk of using inferior material.

II–10. OPTIMAL INSTRUMENTS FOR RADIOLOGICAL CHARACTERIZATION

II–10.1. Problem

Radiological characterization is to be recommended before dismantling operations begin. This often requires gamma measurement, such as by gamma spectrometry. High quality gamma detectors are based on germanium crystals that need to be cooled with liquid nitrogen or by thermoelectrical processes — the latter option being more expensive.

Low cost sodium iodine detectors are commercially available. However, the quality of the spectra they provide is poor, especially in the case of compact detectors suitable for high count rates. Until recently, there was no spectrometric probe available that could address the following requirements:

(a) Low cost and much less expensive than germanium detectors;
(b) As compact as possible and easily decontaminated;
(c) Works in high radiation levels;
(d) Provides acceptable spectra resolution.

II–10.2. Solution

Over the last few years, CdZnTe detectors have been tested and qualified in various decommissioning projects, including power and experimental reactors, waste storage areas and reprocessing facilities. These probes are commercially available at affordable prices of a few thousand dollars, excluding the electronic board. Moreover, most of them can be connected to standard electronic devices and driven by common software.

The detectors are quite compact, about the size of a pencil or a board marker, depending on the crystal volume. As a result, these probes can be introduced in small collimators or components such as channels or tubes. The operating range is related to the volume of the detector. Basically, the largest volumes (several hundreds of mm^3) can be operated from a few µGy/h to a few hundreds of µGy/h; the smallest volumes (less than 1 mm^3) are suitable for high irradiation levels, up to 10 Gy/h (dose rates produced by high energy gammas such as ^{137}Cs or ^{60}Co).

As regards the spectra, these probes turned out to be suitable in decommissioning conditions, where most of the short lived isotopes have disappeared. The angular resolution (at 662 keV) ranges from 1.5% (smallest crystals) to approximately 3% (largest ones). Unlike germanium detectors, for which automatic spectra processing is quite reliable, CdZnTe spectra require manual processing, which remains a problem to be addressed. This is due to the photopeaks, which are not symmetrical.

II–10.3. Lessons learned

CdZnTe detectors were operated on various plants, and under different irradiation levels: they turned out to be quite useful and easy to operate thanks to their small sizes. The following presents some successful achievements:

(a) Characterization of hot spots remaining in the primary circuit of an operating power reactor (activation and corrosion products);
(b) Pre-characterization of old waste, so as to get initial information about the main isotopes (^{137}Cs and ^{60}Co);
(c) Underwater measurements of a reactor vessel (^{60}Co);
(d) Measurement of various highly irradiating components in contaminated areas (fission products).

In addition, germanium and CdZnTe spectra were compared on a limited number of cases (activation and corrosion products). As a general rule, germanium detectors identify more radioisotopes than CdZnTe detectors. However, CdZnTe detects the most significant radioisotopes, whose activities exceed approximately 10% of the gamma spectrum. Experience of CdZnTe for actinide related measurements (plutonium or uranium) is too small so far to report here.

REFERENCES TO ANNEX II

[II–1] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Significant Cost Saved by Decontaminating with Home Carpet Cleaners, 2004-RL-HNF-0007,www.eh.doe.gov/DOEll/ (available to subscribers only).

[II–2] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Shared Technology Increases Productivity and Safety, 2002-NV-NTSBN-012, www.eh.doe.gov/DOEll/ (available to subscribers only).

[II–3] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Teamwork Leads to Innovative Decontamination, RFETS-02-0025, www.eh.doe.gov/DOEll/ (available to subscribers only).

[II–4] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, New Survey Technology Saves Time and Money, 1998-RL-HNF-0017, www.eh.doe.gov/ll/lldb/llSearch.cfm (available to subscribers only).

[II–5] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Health and Safety Staff Efficiencies, 2001-GJO-0001, www.eh.doe.gov/ll/lldb/llSearch.cfm (available to subscribers only).

[II–6] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Common-Sense Collaborative Approach to Deactivation Saves Time and Money, INEEL No. 97315), www.eh.doe.gov/ll/lldb/llSearch.cfm (available to subscribers only).

[II–7] UNITED STATES DEPARTMENT OF ENERGY, DOE Lessons Learned Database, Potential Fire Hazard Using Inferior Lithium Flashlight Batteries, Lesson ID: 2006-KCP-FMT-KC-001, www.eh.doe.gov/ll/lldb/llSearch.cfm (available to subscribers only).

Annex III

DATABANK FOR DECOMMISSIONING OF RESEARCH REACTORS

A computerized research reactor databank was prepared and updated as part of this report. The information is presented on the attached CD-ROM in either Microsoft Excel or Microsoft Word format. The databank is based on the following sources:

(a) The IAEA databank on Nuclear Research Reactors in the World, published as Reference Data Series No. 3 [III–1];
(b) Questionnaires returned by Member States;
(c) Published literature;
(d) Internet sources;
(e) Private communications with experts from Member States.

This databank was first presented in 1994 [III–2] and updated during 2005 [III–3]. It reflects reactor status and information as of February 2007. It contains a list of all known research reactors and provides information on the planning and management of decommissioning projects for research reactors and detailed data from those projects where available. No detailed information is available for some of the projects presented, and only their existence is known. It is hoped that the missing information will be obtained in the future.

The CD-ROM contains the following files:

(i) Research reactors — main list;
(ii) Reported research reactor decommissioning projects — foreword;
(iii) Reported research reactor decommissioning projects — shutdown reactors;
(iv) Reported research reactor decommissioning projects — operating reactors;
(v) Detailed data from research reactor decommissioning projects — foreword;
(vi) Detailed data from research reactor decommissioning projects — table;
(vii) Detailed data from research reactor decommissioning projects — figures;
(viii) Summary table of research reactors by operating status and related data;
(ix) Summary table of research reactors by design type;
(x) References.

By noting the reactor type, power, decommissioning status and other parameters it should be possible to focus on one or more projects that have experience and data possibly relevant to the reader’s own project. However, caution is requested in extrapolating data, since many other unquoted parameters may influence a decommissioning project.

REFERENCES TO ANNEX III

[III–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Research Reactors in the World, Reference Data Series No. 3, IAEA, Vienna.
[III–2] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning Techniques for Research Reactors, Technical Reports Series No. 373, IAEA, Vienna (1994).

[III–3] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Research Reactors: Evolution, State of the Art, Open Issues, Technical Reports Series No. 446, IAEA, Vienna (2006).