COST-EFFECTIVENESS IN MANAGING DECOMMISSIONING PROJECTS FOR RESEARCH REACTORS AND OTHER SMALL NUCLEAR FACILITIES

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ABSTRACT

Most of the existing literature on decommissioning addresses the technological and other aspects of decontaminating and dismantling large nuclear facilities such as nuclear power plants, reprocessing plants and other relatively large nuclear fuel cycle facilities. However, the majority of nuclear facilities world wide are smaller in size and complexity and may present a lower radiological risk in their decommissioning. Such facilities are often associated with the erroneous perception that their decommissioning is a trivial, low priority activity. Under these circumstances the possibility exists that even minimum requirements and strategies may be disregarded in decommissioning, resulting in unnecessary costs, delays, and, possibly, safety issues such as loss of radiation sources.

There are several dozens of old research reactors world wide which are candidates for decommissioning in the near term. There are also many other small ageing nuclear facilities. Many of these reactors / facilities are situated in developing countries or institutions (e.g. universities) that do not have resources and technologies at hand for planning and implementing state-of-the-art decommissioning projects. An additional problem is the cultural change requested from operators in moving from operation to decommissioning. For example, a team of researchers may find it difficult to convert their attitude from research to industrial demolition. The above-mentioned difficulties often result in a no-action strategy being taken. Eventually, no action may end up with the semi-abandonment of the plant and the gradual loss of expertise and records, structural deterioration and lack of interest.

In this paper, special emphasis is given to the following aspects:

- timeliness of planning for decommissioning activities;
- identification of technological needs and priorities;
- market search;
- cost estimates and financing issues;
- proprietary concerns;
- management of decommissioning projects including organization and scheduling;
- R&D aspects;
- training; and
- operating experience and lessons learned.

The paper ultimately focuses on selecting decommissioning techniques and methodologies, i.e. how to optimize technical, financial and human resources and achieve timely and cost-effective completion of a decommissioning project without compromising safety. It is supported by several examples of international decommissioning projects the IAEA was involved in and related lessons learned**.**

INTRODUCTION

The decommissioning of research reactors and other smaller specialist nuclear facilities is a complex task, not to be underestimated and may, under certain conditions, be as equally challenging as decommissioning of power reactors due to the special circumstances involved. The intent of such facilities was to conduct research or investigate a particular reactor design for experimental purposes. Typically, decommissioning was not a consideration at the design stage. Within the overall overview of the nuclear industry, decommissioning plays a special role. It should be noted that, because of the natural life cycle of nuclear facilities, decommissioning was the last component of a nuclear programme that necessitated attention in most countries. Even today, there is a perception in certain environments that decommissioning is an easily manageable activity, which can be implemented at any time needing no advance planning. This inaccurate perception was established in the years of a flourishing nuclear industry, when the focus was on construction and operation of nuclear reactors, and planning for shutdown and decommissioning was relegated to a distant (yet unknown) future year.

In its international role, the IAEA is faced with a wide variety of national situations and different availability of technical, human and financial resources. While it is recognised that nuclear decommissioning is a mature industry in some developed countries, and may soon become a routine activity, the situation is by no means so clear in other countries. In addition, transfer of technologies and know-how from developed to developing countries is not a spontaneous, straightforward process, and will take time and considerable efforts [1]. Constrained resources are a major component of the difficult planning and implementation of decommissioning projects in a number of IAEA Member States.

Generally, for larger scale projects e.g. NPPs, decommissioning proceeds on a ‘one-off’ project basis with specific solutions developed for the work undertaken. However, in parallel with the larger power reactor decommissioning projects, where economies of scale can be achieved on ‘many-of-a-kind’ plant, similar lessons can be learned from the experiences of others particularly in the research reactor field. A good example of this is in the area of Former Soviet Union (FSU**)** designed systems (VVR, IRT tank and pool type research reactors) where tens of units have been built and operators share common decommissioning problems as the systems come to the end of their operational lives. While a range of possible decommissioning options has been identified for such systems, that cater for local needs and constraints, the associated problems of spent fuel and radioactive waste management benefit from common approaches.

The scope of this paper does not encompass only developing countries, but also institutions from industrialized countries such as universities where limited resources (usually, financial) pose serious constraints to smooth, timely, and cost-effective conduct of decommissioning. This paper identifies four major areas where constraints heavily affect decommissioning and actions aimed at cost-effectiveness may be crucially needed. These are: early strategic planning including infrastructure building and the need for it; concrete planning for decommissioning during construction, operation, and shutdown phases; technological aspects; and management and organization. The following sections expand on these aspects.

Early Strategic Planning

The most important issues on the need for early strategic planning are to be found in the areas of: regulations; end-state definition; and availability of technical and human resources. These will be dealt with in the following sections and examples from the experience of IAEA Member States provided. As one example of strategic difficulties, it should also be mentioned that political changes e.g. the creation of new independent states in the FSU led to disruption of traditional links including the availability of services and specialists.

Regulations for Decommissioning

The regulatory process in developing countries and associated legislation is generally not set up to deal with nuclear decommissioning. Even in countries with nuclear power programmes, the emphasis has been on regulations which support the siting, design, construction and operations of NPPs and the associated radiation protection issues with decommissioning regulations left largely undeveloped. In some countries, decommissioning regulations are either non-existent or are drawn analogically from regulations originally developed for the construction or operation of nuclear installations. Decommissioning-oriented regulations such as clearance levels are typically missing. Inadequate regulations often result in a convoluted approach, unclear responsibilities and ultimately undue delays and costs [2]. While much progress has been made in some areas by developing new regulations over the last 10 years to redress this imbalance e.g. FSU, those countries running only research reactors have not had this benefit generally. In effect, customized regulations are needed to be developed to deal with such ‘one-off’ requirements. The lack of regulations for decommissioning such as for site clearance and release of materials is often compounded by the lack of clear organizational structures and defined responsibilities for those bodies which have a role to play e.g. overlap of roles of key ministries in the process. A developed regulatory framework including the provision of decommissioning oriented laws and regulations will prevent hiatus when decommissioning starts and lead to cost savings by clearer definition of regulatory requirements and expectations.

Another regulatory issue is that there is potentially a tightening of regulatory requirements applied to decommissioning activities commencing at the planning stage and continuing throughout the decommissioning period. The impacts can be significant after initiating a project, as exemplified in the application of environmental assessment policy as part of the regulatory process for the Whiteshell Laboratories, Canada [3]. A further issue is the additional conservatism applied to clearance criteria for solid materials. This is particularly critical if clearance criteria were not in place at the inception of a decommissioning project and may result in additional costs.

End-State Definition

It is a most important early decision to define the end point of decommissioning via option selection e.g. is the objective for unrestricted site release (green field) or restricted release (some controls remaining, sometimes called brown field). Typical questions include: will the site be re-used?; will partial decommissioning and re-build be required?; will any institutional controls remain in place? Justification and 'buy-in' for the option selected is generally required by the project stakeholders. Site re-use is expected to partly offset the decommissioning costs, in addition to having other social and economic benefits.

In many cases, continuing use of a site for nuclear operations may be a logical and natural destination of a site after decommissioning, and entail financial benefits. This is due to advantages such as re-employment of a qualified staff, public acceptance of nuclear activities, available characterization of the site (both physical and radiological), local availability of customized nuclear and conventional services etc. Also, difficulties to identify new sites for nuclear installation may lead to this strategy. Options may include the following and others:

- to collect radioactive waste from a number of national applications into one decommissioned site, which then becomes a centralized national waste storage facility. If a disposal option does not materialize, this might be the case for the Paldiski reactor building (named technological building) in Estonia housing two prototype reactors encased in concrete and relatively large amounts of radioactive waste from other onsite facilities;
- an irradiator facility in place of a research reactor (RV-1 reactor, Venezuela);
- to convert a nuclear facility to a nuclear museum or nuclear exhibition centre. Conversion to a nuclear museum can also be a convenient way to release part of the site for unrestricted public access while allowing radioactive decay of remaining structures. One point of caveat is that environmental cleanup and historic preservation might be incompatible in times of tight budgets. There are a number of examples of nuclear museums established on the site of (partly) decommissioned research reactors including:

- FR-2 research reactor, Germany
- the ORNL graphite reactor, USA
- the B reactor at Hanford, USA
- the EBR-1 reactor, INEEL, USA
- the HTRE reactors, INEEL, USA

A lot of other examples of decommissioned reactors converted to new, productive (nuclear or non-nuclear) uses, factors and criteria related to these conversions are given in [4].

Resource Issues

In developing countries the general problems of competition for scarce financial resources, the focus on competing environmental issues and lack of an appropriate regulatory structure for decommissioning are often compounded by a dearth of available technical expertise in the decommissioning field. It is necessary to encourage active participation in international co-operative programmes, regional programmes and bilateral agreements which foster both assistance and an exchange of information for the benefit of participants. This is of particular benefit to developing countries which have neither a developed nuclear infrastructure nor a technology base.

Concrete Planning for Decommissioning

The areas in decommissioning planning detailed below warrant additional attention as areas whereby a small decommissioning project constrained by resources may affect savings.

Importance of Early Planning

The importance of early planning and adequate characterization cannot be over emphasised. Ideally, planning starts at the design phase by careful attention to choice of constructional materials which will avoid unnecessary activation and by attention to plant layout and design detail. Resources committed early in this respect will pay dividends later. In the particular instance of an unplanned shutdown (e.g. an accident or a political expedient) then an expensive hiatus to the programme will be alleviated if decommissioning plans are available and the transition from operations to decommissioning can be achieved smoothly.

Refurbishments

Much benefit can be gained from the experiences gained and the documentation generated from previous refurbishment exercises. Many research reactors have undergone power upgrades requiring replacement and refitting of both activated and contaminated components e.g. reactor tanks and liners, heat exchanger units. This experience is equivalent to ‘partial decommissioning’. Such activities were performed generally using in-house expertise and support from local contractors. It is most important to preserve this knowledge base via documentation – e.g. the dose uptake records give a useful insight into subsequent doses that will be incurred during the later decommissioning of similar components.

Record Keeping

Maintenance of operational records and contamination control during the operational and pre-decommissioning phase are important factors which will impinge on later decommissioning. For experimental plant, often built to support specific operations or R&D objectives, the recording process is particularly important since novel materials may have been used and the radionuclide contamination field could be significantly different from that normally anticipated during a power reactor decommissioning project. Similarly, ‘as-built’ drawings and other documentation emanating from the design, construction and operations stage must be preserved. Several examples are available in the published literature on research reactor decommissioning [5]. To assist in the proper alignment of the thermal shield of the Ames Laboratory reactor during its construction, the six vertical plates were tack welded together at several locations on the top and ends of the shield. The existence of the end welds was not anticipated as they were not shown on drawings. When visually checked, one could clearly see that the top welds were broken, but the end welds were not visible. On attempting to transfer the plates to the pool, the end welds between the five inside plates were found to be intact. Efforts by the contractors to break the welds in the tank were not successful, and the five plates were transferred to the pool as a unit. Eventually the welds were separated with a plasma arc torch operated from above 6 ft (1.83 m) of water. All these unplanned activities had a significant cost impact.

Characterization

Characterization is the most important technical step in the planning process – since radioactive wastes and the potential health detriment caused by irradiation differentiates nuclear decommissioning from conventional demolition projects. Hence, the importance of adequate early, ‘up-front’ characterization cannot be over emphasised and will lead to future cost savings and avoid later ‘surprises’. Characterization in order to develop an inventory of radioactive materials and the associated process of waste categorisation should be conducted on a fit-for-purpose basis with early input from the regulatory bodies to qualify expectations. To mention one example of the undesirable consequences of poor characterization, the decommissioning costs for the Cintichem research reactor in the USA escalated to US $ 100 million, owing to the lack of information on the soil and groundwater contamination discovered during the actual dismantling work [5]

House Keeping During the Operations Phase

For research reactors it would be unusual if some limited fuel failure had not occurred during operations adding fission products to the contamination field normally arising from corrosion and erosion mechanisms. Such contamination incidents provide an opportunity for the uncontrolled spread of radioactive materials if remedial action is not taken early. Decontamination exercises will prevent build up of activity and alleviate problems for later. General ‘house keeping’ activities should be emphasized and employed via routine monitoring surveys to identify contamination hotspots around the plant and provide for their early removal.

Technological Aspects

Issues in this field concern areas where early development of technologies and technical infrastructure oriented to decommissioning are expected to assist in later decommissioning activities and reduce related costs. There is clearly a desire for individual Member States to develop their own decommissioning technologies for use in their organizational and regulatory arenas. In part, this is due to the need to understand the effects of decommissioning under site specific conditions in order to satisfy the nuclear regulators, but also it is due to the fact that many available processes are proprietary formulations and expensive to buy in the open market. In some Member States, it is very difficult to implement full decommissioning for these reasons and the costs associated with such a project are relatively high. Achieving the proper balance between developing project and country specific technologies (supposedly at the lowest cost), and purchasing technologies in the open market remains a serious challenge for many countries. Timely allocation of decommissioning funds is important to alleviate these concerns and minimize delays in project implementation.

Important technological areas include: spent fuel management; radioactive waste management; and remote vs. manual activities.

Spent Fuel Management

The pressing problem of the management of spent fuel is a common theme for most research reactors. The problem has been alleviated in recent years by return contracts negotiated with the original suppliers of the fuel. However, the negotiation and finalisation of such arrangements requires commitment, time and resources and should be started early. In the general case of wet stored fuel, cladding deterioration risks the loss of fission products to the environment. Early removal of the fuel to dry storage prior to start of decommissioning has the double advantage of reducing the decommissioning schedule saving costs and preventing the onset of corrosion. Spent fuel removal is normally a pre-requisite to implementation of decommissioning, and no further discussion to spent fuel will be given in this paper.

Radioactive Waste Management

These form typically the major part of the costs of decommissioning so it is important that radioactive waste arisings are consciously minimised both during operations and during decommissioning. Volume reduction by mechanical size reduction/compaction is identified as a method to control costs. Additionally, decontamination of wastes for re-categorisation purposes should be considered. Simple optimisation techniques such as Cost Benefit Analysis should be used to select the optimum technique noting that the capital costs of additional plant required and any secondary wastes generated must be taken into account. Clearly, as waste storage and disposal charges increase, pre-processing of wastes for volume reduction and/or re-categorisation becomes increasingly advantageous on a cost/benefit basis.

Assuming that waste categorisation bands are defined then care must be taken not to over-categorise waste (since this adds cost to waste), conversely, under-categorisation will lead to regulatory and environmental issues. Process requirements such as sampling and measurement regimes should be defined and agreed with the regulators (e.g. for site clearance purposes). Definition of the national categories for wastes and, in particular, criteria for release of materials has an important bearing on project costs e.g. if it can be demonstrated that increasing levels of site remediation will not generate meaningful health benefits then resources can be saved.

Wherever possible and practicable, waste containers should be sourced from existing suppliers such that advantages can be gained from the experiences of others. However, it should be noted that licensing of such containers for waste transportation, storage and/or disposal will be required within the national regulatory regime concerned.

When implementing the decommissioning plan of the SCK•CEN (BR-3 reactor) in the period 1995-1996, the decommissioning management team observed a yearly increase of the waste costs [3]. To keep the decommissioning costs under control, it was decided to invest in decontamination facilities and to find alternatives routes for decommissioning scrap metals. The routes used at SCK•CEN were:

- radioactive waste;
- unrestricted release after chemical or mechanical decontamination followed by free release by measurement;
- melting for recycling in the nuclear industry;
- melting for unrestricted release.

From the early beginning of the decommissioning programme at SCK•CEN, it was found important to establish alternative waste routes and assess their cost effectiveness**.** It was also important to create some redundancy in alternative waste management routes because each of the routes had it’s own constraints e.g.:

- Unrestricted release of material by decontamination or by melting depends on public acceptance;
- Recycling/reuse in the nuclear industry depends on the demands of the industry. [3]

Remote, Semi-Remote or ‘Hands-on’ Working

While much emphasis has been placed on the development of remote technology for decommissioning purposes, which is often seen as the method of choice, such equipment is only advantageous where radiation levels preclude either manual techniques being contemplated or there is sequence of repetitive tasks where economies of scale are evident. Such situations are rarely the case in the decommissioning of research reactors where most jobs are of a ‘one-off’ nature and many have been tackled before in a refurbishment context. In a situation of constrained resources the merits of ‘semi-remote’ working requiring minimal capital outlay are evident – this is facilitated in many instances by the radiation shielding effected by water in pool-based systems. Additionally, specialist handling and size reduction tools can be produced by the modification of existing commercially available and proven tools. Such modifications are generally well within the capability of standard engineering enterprises.

Clearly, ALARA criteria must be met. Dose budget estimations based on predicted/measured radiation fields, worker number and occupancy periods provide a rationale for choice of the appropriate technology i.e. manual, semi-remote or fully remote working.

Management and Organizational Issues

Organization and management of decommissioning projects is another area requiring attention. Hindrances to smooth progress of decommissioning may include poor record keeping and lack of information on technologies/experience available in a given country. These aspects may require considerable organizational efforts prior to commencement of decommissioning. Also, there is often a poor understanding that decommissioning, unlike R&D, has a beginning and an end. The perception that the objective is “to work yourself out of a job” has to be dealt with carefully in a well-planned decommissioning project. The above-mentioned aspects are further detailed in the following sections.

Structured Approach to Management

Both the transition from operations and the decommissioning phases of a project requires a disciplined approach to management. In the interests of improved efficiency it is necessary to invoke the techniques of modern project management to plan operations, monitor performance, control costs and feedback lessons learned. Decommissioning requires a different ‘mindset’ from operations – the transition from R&D or process type operations will not be easy for the workforce. While it may be appropriate to release some of the older staff, it is essential to maintain some key skills to support the early phases of decommissioning – particularly those involved in engineering and health physics support services. These skills will be required during the initial phases of decommissioning enabling economies to be gained. It was found at SCK-CEN, Mol, Belgium [3] that the sound management of a decommissioning programme implied the following:

- clear definition of the roles and responsibilities of all the parties involved;
- close co-operation between the services concerned;
- good description of the work to be done including the preparation work (e.g. provision of electricity, instrumentation and circuits);
- records of the progress made (e.g. update of the inventory, traceability of the decommissioning work streams);
- debriefing of the work done to improve the decommissioning studies in terms of management, safety and performance.

Cultural and Social Aspects

These factors need careful consideration. The transition from operations to permanent shutdown is a particularly problematic time for the staff of older facilities. It will not be easy to re-focus R&D staff to the task of decommissioning as this is often seen as a less intellectually challenging occupation than previous work and, as such, workforce morale is likely to suffer. A positive ‘slant’ has to be fostered by management in these situations and a ‘completion culture’ needs to be fostered. Staff may see themselves as working out of a job leading to lethargy and reduced motivation to meet project objectives. Reference 6 provides a number of examples – including research reactors- of factors impacting on the timely, safe and cost-effective transition from operation to decommissioning.

Use of Contractors

Contractors have an important role to play in the decommissioning process. If an experienced contractor infrastructure is not available on a national basis then there are a number of contractor organisations which operate on an international basis who are able to provide services from consultancy through to ‘turn key’ decommissioning services. However, it is unclear as to whether such services can be fully utilised effectively in a developing country context since they are expensive and a clear funding route is necessary to support such contractor activities.

Funding may be unavailable. Cultural considerations are also evident – in centralised structures there may be resistance - third party involvement being considered as a threat to both jobs and working practices.

Training and Re-training

To exemplify the importance of this topic and its impact on cost-effectiveness, the following experience from SCK-CEN, Mol Centre, Belgium is quoted [3]. People involved in decommissioning activities are faced not only with radiation hazards (direct radiation and airborne contamination) but also with industrial safety problems (fire, toxic substances, dust, noise, load handling and work with scaffolding). They often use new techniques or proven techniques in a new environment. There is however a trend, when performing work, to minimize the implementation of the safety rules in order to make the work easier and quicker.
At Mol, information and training sessions were organized to emphasise that the decommissioning procedures that were approved by the Health Physics Department, specifically mentioned the safety measures to be taken before, during and after performing the dismantling work. Non-radioactive testing on mock-ups was also organized for the BR3 reactor for the dismantling of the highly activated internals and pressure vessel. Testing was also used in laboratory buildings where glove boxes and hot cells have to be dismantled or decontaminated.

SUMMARY AND CONCLUSIONS

Decommissioning of research reactors and other small nuclear facilities with constrained resources requires an ability to select applicable experiences gained in the wider decommissioning context and apply them in a pragmatic way to enable ‘fit-for-purpose’ and cost-effective solutions. Such experiences must be used selectively and optimised for the project in hand – there is no universal panacea. Key to the process is getting the existing messages over to those in nuclear environments which do not have the benefit of access to a developed nuclear infrastructure. Fortunately, the decommissioning community is ‘close-knit’ and benefits from the sharing of experiences via international collaborations and the conference scene. Additionally, organisations such as IAEA have recognised the requirement for support to these areas by developing assistance programmes where the wider experiences of others can be shared effectively.

REFERENCES

1. INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning Techniques for Research Reactors, IAEA-TECDOC-1273, IAEA, Vienna (2002).
2. LARAIA, M., Pending Issues in Decommissioning of Nuclear Installations in Developing Countries, proceedings of the Fourth USDOE International Decommissioning Symposium, Knoxville, TN, USA, 12-16 June 2000 (CD).
3. INTERNATIONAL ATOMIC ENERGY AGENCY, Planning, Managing and Organizing the Decommissioning of Nuclear Facilities: Lessons Learned, IAEA-TECDOC-1394, IAEA, Vienna (2004).

4. LARAIA, M., GORDELIER, S., Transition from a Nuclear to an Industrial Site- Managing Change in the Re-Use of Sites Including a UK Example, NEA Int. Workshop on Safe, Efficient and Cost-Effective Decommissioning, Rome, 6-10 September 2004.
5. INTERNATIONAL ATOMIC ENERGY AGENCY, Record Keeping for the Decommissioning of Nuclear Facilities: Guidelines and Experience, Technical Reports Series No. 411, IAEA, Vienna (2002).
6. INTERNATIONAL ATOMIC ENERGY AGENCY, The Transition from Operation to Decommissioning of Nuclear Installations, Technical Reports Series No. 420, IAEA, Vienna (2004).