Harmonization of Decommissioning Approaches and Design Features - 11092

Jas S. Devgun, Ph.D.
Manager
Nuclear Power Technologies
Sargent & Lundy LLC
55 E. Monroe St
Chicago, IL 60603 U.S.A.

ABSTRACT

This paper discusses the harmonization in decommissioning approaches in the areas of decommissioning strategies, regulatory framework, decommissioning cost estimating, implementation of decommissioning, site release criteria, and the materials release i.e., clearance.

Past decommissioning experience shows that varied approaches have been utilized by the reactor decommissioning projects. While some degree of harmonization in the field of decommissioning has taken place, further standardization, especially in the areas of site and material release criteria are desirable.

As far as the designs for the new reactors are concerned, many significant lessons learned from the past decommissioning projects are being incorporated into the design process. Harmonization of design features is discussed in the following areas: reduction in the system components, reduction in construction materials, modular designs of systems and structures, advanced construction techniques, better designs to avoid contamination during operations, waste minimization, and harmonization of international codes and standards for the design of new reactors.

INTRODUCTION

Decommissioning is a mature industry where large experience already exists. Worldwide 80 commercial power reactors, 45 experimental or prototype reactors, and over 250 research reactors have been shut down and many are undergoing decommissioning. Some of these have been fully decommissioned and dismantled and overall, substantial experience has been accumulated over the past 40 years.

Nuclear energy is experiencing a renaissance and in addition to 441 reactors in 30 countries (as of October 2010), 60 additional plants are under construction in 16 countries. The 375 GW capacity in operation provides about 14% of the world's electricity. This will be supplemented to the extent of the installed capacity of 59 GW with the reactors currently under construction. All reactors will eventually undergo a decommissioning phase at the end of their operating life, which for the new reactors being constructed may be at the end of their design life of 60 years or later if the license extensions are granted.

Decommissioning is the last phase in the lifecycle planning for a nuclear power plant. Decommissioning approaches and technologies continue to evolve and decommissioning features are being taken intro account for the design of new reactors.

To some degree, the reactor decommissioning approaches and the technologies applied are specific to the site and the type of reactor. The decommissioning approach is influenced by the location (e.g. multi-unit site), ownership, decommissioning fund status and the federal, state and local regulatory issues, as well as the public participation in the process. However, immediate decontamination and decommissioning has shown significant advantages and has lead to a timely and more economical closure of these projects. Some degree of harmonization in the decommissioning approaches, technologies applied, and release criteria are desirable.

On the regulatory side, significant advances have been made to provide a more uniform regulatory process and guidance but areas remain where the guidance is still evolving. For example, in the United States, the Nuclear Regulatory Commission (NRC) decommissioning process is well defined and the requirements are well understood by the decommissioning sites. The 10 CFR Part 20.1402 provides the criteria for release of a site without restrictions. The MARSSIM (Multi-Agency Radiological Survey and Site-Investigation Manual) methodology is a good example of the status survey approach for site release that has been developed and implemented with uniformity across a number of the Federal agencies in the United States. However, in many cases the states have applied their own and more restrictive release criteria to the sites.

There are no specific regulatory criteria for release of bulk materials from the decommissioning site where as at the international level the criteria advocated by International Atomic Energy Agency (IAEA) is being applied across many European and other countries. Such release and recycle criteria will become more important as the material is transported across national boundaries. In this case, application of the IAEA standards across Europe is a good example.

The treatment and disposal of radioactive waste remains another area where there is some degree of uniformity in categorization but the decommissioning sites have to find their own commercial disposal facilities. The spent nuclear fuel storage remains a major national issue in many countries. In US, because of the non acceptance of the spent nuclear fuel by the US Department of Energy (DOE), many decommissioning sites had to construct dry storage facilities at the site. Thus, while some harmonization has occurred in certain areas of decommissioning, there are many areas where this development needs to continue to evolve.

Past experience has provided significant lessons for the new reactors where harmonization of the design approaches with respect to decommissioning is already evident. The designs are optimized by reducing the structural concrete, piping, pumps and valves, cables and other materials, in some cases by as much as half of the current reactor designs. Almost all the designs use modular design approach that facilitates construction but will also facilitate dismantling at the decommissioning stage. This in turn translates into major capital cost savings for the project during construction as well during future decommissioning at the end of the life of the reactors.

This paper examines the past reactor decommissioning approaches and experience, explains how harmonization in decommissioning approaches and criteria can lead to more cost effective projects, and how the new reactor design features are moving the industry a step closer towards this harmonization.

HARMONIZATION OF DECOMMISSIONING APPROACHES

This paper discussed harmonization in the following areas of decommissioning approaches.

i) Decommissioning Strategies
ii) Harmonization of the Regulatory Framework
iii) Decommissioning Cost Estimating

iv) Implementation of Decommissioning
v) Harmonization of Site Release Criteria
vi) Harmonization in Materials Release – Clearance

Decommissioning Strategies

In general there is already a degree of harmonization in the decommissioning approaches of the regulatory system of the US NRC [1] and those advocated by IAEA [2] and applied by the European countries. In the US system, the three alternative decommissioning strategies include: DECON, SAFSTOR, or ENTOMB. These are similar to the international (IAEA) strategies of Immediate Dismantling, Deferred Dismantling, and Entombment. Under DECON (Immediate Dismantlement) the facility is decontaminated and decommissioned soon after the facility is permanently shut down (in the decommissioning time frame it may take about10 years or more). Note that the decommissioning process starts after the spent nuclear fuel has been transferred from facility to either national authorities or to an independent storage site for such materials. The radioactive waste from decommissioning is transferred to storage or disposal site. After verification that the site meets the release criteria, the license is terminated and (if certain criteria are met) the site is released without restrictions.

SAFSTOR,(Deferred dismantling) follows the process of allowing radioactive decay to occur before starting the decommissioning activities. The storage period may last several decades. This may facilitate final dismantling at a later date and may provide the benefit of reduced worker radiation doses when the dismantling work is eventually performed.

Under ENTOMB, radioactive contaminants are permanently encased onsite in materials such as concrete. In this option, the site becomes a waste disposal site. The site will need to be appropriately maintained. Entombment option’s use on the international scene has been only for special situation, specifically, the Chernobyl site.

In general there is a preference for immediate dismantlement. In the United Sates, the decommissioning plants have opted for DECON or SAFSTOR. None have opted for entombment. Several projects chose the DECON option and decommissioning was completed within a reasonable period. Examples in this category include Big Rock Point, Main Yankee, and Connecticut Yankee. Other projects have chosen SAFSOR option and /or SAFSOR followed by DECON within a decade or so. Examples include Dresden 1, Indian Point 1, Millstone 1, Zion 1&2, LACBWR, Humboldt Bay. Rancho Seco has taken the incremental decommissioning approach where the activities have spanned nearly two decades.

Note that in some countries, phased decommissioning may take place if there is a need for a break in the decommissioning process. This may be necessitated by specific technical issues but more likely may be due to availability of decommissioning funds. In US a similar process, the so called incremental decommissioning (mixture of SAFESTOR and DECON process) has been used at Rancho Seco plant as mentioned earlier.

Harmonization of the Regulatory Framework

There are differences in the national regulatory framework for decommissioning for various countries. However, the basic principles are the same with regards to the safety, licensing, and release criteria. The implementing regulations depend on a number of factors – such as the availability of waste disposal sites, funds for decommissioning, international/regional requirements (e.g. European Union), commercial vs. government projects, among others.

Even within the US while the regulatory framework of the US NRC is applicable to all commercial nuclear reactors, the nuclear facilities of the DOE including test, demonstration, and other reactors are not subject to NRC regulations. The DOE has its own regulations and guidance for decommissioning of facilities.

The US NRC decommissioning process begins with the decision by the licensee to permanently shut down the reactor operations. The licensee is required to notify the NRC and is required to submit a Post-Shutdown Decommissioning Activities Report (PSDSAR) before, or within 2 years after cessation of operations. The PSDAR includes description of the planned decommissioning activities, schedule, estimate of the expected costs, and a discussion of the environmental impacts associated with decommissioning activities. The NRC then posts a notice of receipt of the PSDAR in the Federal Register and make the PSDAR publicly available. The licensee can not perform any major decommissioning activities until 90 days after NRC has received the PSDAR. After this period, the licensee can perform decommissioning activities subject to certain conditions.

The licensee must submit an application for termination of its license which must be accompanied or preceded by a License Termination Plan (LTP). The LTP includes plans for site characterization, identification of any remaining dismantlement activities, plans for site remediation, detailed plans for the final radiation survey, and a description of the end use of the site (if restricted release). The licensee submits a final status survey report (FSSR) at the conclusion of decommissioning activities. This report identifies the final radiological conditions of the site and provides NRC a basis for terminating the license either without restrictions or with restrictions. Note that if there is a dry fuel storage at the site (such as Independent Spent Fuel Storage Installation (ISFSI)), the NRC may reduce the 10CFR Part 50 license to the boundary of the ISFSI or the ISFSI may be licensed under 10 CFR Part 72.

Some degree of harmonization within the regulatory framework of various organizations and countries is necessary. International cooperation and interaction is a step in that direction. IAEA's International Decommissioning Network (IDN) launched in 2007 is a good example of a forum for the sharing of decommissioning experience and lessons, and exchange of information on decommissioning technologies. The NRC maintains interaction with the international community in the area of decommissioning, and coordinates such activities through the US State Department missions at the IAEA and the Nuclear Energy Agency (NEA). The NRC also participates in several bilateral and multilateral exchanges with other nations in the area of decommissioning challenges.

Decommissioning Cost Estimating

Overall cost estimates of decommissioning a commercial nuclear power plant can range from about $350 million to $700 million. While decommissioning costs will vary for specific plants and in specific countries, and will also be significantly affected by the availability of disposal sites for radioactive waste, and the disposal costs, there are many parts of the cost estimating that can benefit from standardization.

Significant work has been undertaken in the area of cost estimation by the IAEA and NEA through the Working Groups on decommissioning costs. The movement towards standardization of parts of decommissioning cost estimation is facilitated by the fact that even across national boundaries, the phases and activities are same or similar. The technologies used for decontamination, segmentation, removal, and packaging are similar or the same. In many cases, international companies are bidding for decommissioning services and implementing decommissioning in different countries, thus leading to harmonization in cost estimating through this process itself.

Currently, it is possible to have standard cost models with unit based cost input, at least for the portions that are dependent on the decommissioning activities in the field e.g., removal of per unit pipe or other materials. The decontamination and demolition costs can also be standardized. If recycling of metals is chosen by the project, these costs can also be standardized as the recycle of metals from decommissioning is a mature industry, especially in Europe. Dedicated efforts have been made jointly by the EC, NEA/OECD, and the IAEA working groups for the creation of a common list of standardized decommissioning cost item definitions. Such work provides a single, uniform, and agreed upon reference list of decommissioning cost items. The approach has been discussed in references [3,4,5]. Thus, the cost models are getting harmonized in principle, even though the waste disposal costs and issues will remain specific to the country.

The decisions on application of technologies may be based on the decommissioning cost, maturity of technologies and facilities available in the country, or be driven by the national regulatory direction or policy. For example, intact (one piece) removal of reactor pressure vessel has many advantages in terms of dose reduction to workers, keeping radioactive materials contained, and a reduction in total waste produced. However in other cases, it may be necessary to segment the pressure vessel and other large components and technologies for both options are currently available.

It should be noted that the past cost estimates for decommissioning for nuclear power plants have varied greatly and have also differed significantly from the actual costs. Decommissioning is labor intensive and thus the cost of labor in different countries will have substantial effect on the overall costs and decision making by the project with respect to approach to the implementation of decommissioning. The way decommissioning is funded has also impact in this regard. In the United States for example, the decommissioning funds are accumulated during the operating life of the nuclear power station with a per kW levy on the electricity. These funds are held in trust for the purpose of decommissioning at the end of the reactors' operating life. The mechanisms for financing and the growth (or loss) of the decommissioning funds will have a substantial affect on the actual decommissioning costs and the implementation of decommissioning. Additionally, in the international projects, other factors such as currency exchange rates, update of the decommissioning costs on an annual basis to adjust for inflation will also have an impact.

Thus, while sophisticated cost estimating tools and software for projects are now available, their applicability based on standardized and unit based costs and tied to decommissioning activities and phases will lead to greater harmonization across projects and across national boundaries.

Implementation of Decommissioning

A phased approach is generally used in implementing the decommissioning because of the size, complexity, and the duration of such projects. Key activities in implementation of a decommissioning project include:

- Submission of the required regulatory documents
- Decontamination of major components
- Reactor Pressure Vessel removal or segmentation of the RPV
- Remote dismantling of other activated parts or contaminated components
- Dismantling of biological shield and activated structures

- Dismantling of non-radioactive components and buildings
- Decontamination and removal or release of structures or materials
- Release of the site or facility

Implementation of decommissioning may vary from project to project and from country to country. Decommissioning is a costly activity and decommissioning is a labor intensive activity. Depending on the availability of funds and the cost of labor, utilization of state of art technologies may differ from country to country. For example, the remote handling and remote cutting technologies may be preferred in one project and may not be preferred in another project. Similarly, decision on dismantling of structures may vary from removal on a part by part basis or total demolition and rubblization of the whole structure. Different types reactors (for example, Gas Cooled Reactor (GCR) as compared to Pressurized Water Reactor (PWR)) will require handling of different specific materials (e.g. graphite). This will necessitate the use of material specific technologies. Decommissioning technologies in general include thermal techniques (e.g. arc, plasma torch cutting) and mechanical techniques (sawing, cutting, grinding, shears, etc.) for metals and concrete. Other types of dismantling and removal techniques may be used for materials such as cables, insulation etc.

Note that the implementation of decommissioning may extend from less than a decade to several decades. Nevertheless as technologies develop and mature, a degree of harmonization in the implementation techniques will occur. Technology information is available from decommissioning programs of individual countries. On the international level, the IAEA has compiled a state of the art technology for decontamination and dismantling of nuclear [6]. However the continual improvements in technologies necessitate that the projects take into consideration the maturity level of the technologies and the newer, better, or more efficient technologies at the time of the decommissioning implementation planning.

Harmonization of Site Release Criteria

The release criteria across the countries may vary. In the United States, the criterion for release of any decommissioned site for unrestricted use is established by the NRC as a dose of 0.25 mSv (25 mrem) per year to an average member of the critical group. The dose limit includes the dose from drinking groundwater. In addition, it is required to demonstrate that the amounts of residual radioactivity have been reduced to levels that are "as low as reasonably achievable (ALARA).

The subject of release of the site is complicated by the issues such as - do the same release standards apply to soil as applied to the buildings, should the application of the standards be dose-based, or concentration-based, should the standards for groundwater be included, should the surface contamination criteria for walls and surfaces be sufficient or volume based standards need to be applied. In addition, public acceptance may have an impact on what standards and criteria are actually applied in the project. As an example of this, in the United States, some projects had to use lower criteria than the national regulatory criteria because of insistence by the state that the site be released only with those lower criteria.

Dose modeling to derive the concentration levels and the need to perform final status surveys are key to demonstrating that the site has been cleaned up to sufficiently low levels of contamination that it can be released without restrictions. In the US, a good example of harmonization among various organizations (Department of Defense (DOD), the DOE, Environmental Protection Agency (EPA), and the NRC) in the country is the development and application of MARSSIM methodology [7].

Clearance criteria for the restricted release option will vary in many countries and may be implemented on a case by case basis.

European Union documents such as RP 113 [8], RP 157 [9] and the NEA no. 6403 [10] provide guidance on the release criteria for materials and the sites for the European countries. The concentration values for radionuclides are derived are based on the concept of triviality of dose and an effective dose of less than 10 μSv/year and a collective dose less than 1 man Sv during one year. For the site release, a criterion of 100 μSv/year has been used in some projects. These are consistent with the IAEA guidance in this area [11, 12].

Another important aspect of decommissioning is the removal of radioactive waste from the site to a storage or a disposal facility. While the availability of disposal sites and the associated costs will remain a national issue, it is possible that in future some form of international waste disposal facilities may be developed. Even though such concepts have national, legal, and public issues and concerns associated with them, it could be an economical solution for some countries with limited nuclear activities and a limited potential for developing appropriate disposal facilities. It could also provide economic incentive for joint development of such facilities between multiple countries. In this regard, a harmonization of the radioactive waste classification is desirable as many countries have somewhat different classification schemes.

Harmonization in Materials Release - Clearance

Besides the large components that may have to be removed, transported and disposed of in a certain fashion, decommissioning generates large quantities of waste. However, only a portion of the overall material from decommissioning may need to be disposed of as radioactive waste. It may be possible to release large quantities of bulk materials (such as demolition debris - concrete and rebar materials, excavated soils etc) based on applicable national clearance policies or regulatory guidelines. Radiological characterization of the materials and the regulatory clearance criteria are the prerequisites for application of the process in this regard.

Clearance can be defined as the removal of materials from any further regulatory control and where such materials are confirmed to have residual radioactivity under the established standards. The dose or risk associated with the subsequent use or disposal of such materials should be low enough to be of no regulatory concern. The primary radiological basis for establishing values of activity concentration for the clearance of bulk materials is that the effective dose to an individual should be below 10 μSv (1mrem) per year.

International guidance has been provided by IAEA [12] Many countries have adopted the clearance procedures and clearance levels consistent with the IAEA methodology and clearance is an important option for the management of bulk materials. Measurement equipment and techniques are available for performing clearance of material (i.e. the release of materials that are either not contaminated or are below the clearance levels after decontamination).

In the United States, there is direct guidance on the clearance of materials [13]. Essentially, the termination of a reactor operating license under the provisions of 10 CFR 20, Subpart E is permitted with trace levels of licensed radioactive materials remaining providing that the residual radioactivity does not result in a calculated Total Effective Dose Equivalent (TEDE) exceeding 0.25 mSv (25 mrem) per year. However, there is no defined mechanism specifically for the clearance of materials. The requirement under 10 CFR 20 Subpart K to demonstrate the absence of licensed material necessitates that some mechanism be found for the release of such materials.

There are only two potential mechanisms under the existing regulatory circumstances: 10 CFR 20.2002 submission, or a license amendment submission. The 10 CFR 20, Subpart K, 20.2001, requires that licensed radioactive material be disposed of only through (1) transfer to an authorized recipient, (2) decay in storage, (3) release in effluents within the limits in 20.1301, or (4) as authorized under 20.2002, 20.2003, 20.2004, or 20.2005. Subpart K does not provide a regulatory basis for demonstrating the absence of licensed radioactive materials when they could potentially exist. Note that the 10CFR 20.2002 still labels the material as radioactive waste, which creates issues for acceptability of the release from a public perspective. The NRC application in regards to bulk materials release is on a case by case basis. However generally, the international clearance guideline of dose limit of 10 µSv (1mrem) per year or less is used by the projects.

Since clearance procedures and clearance levels have been introduced by a large number of countries and since recycling of materials is now practiced at least in Europe, harmonization of clearance criteria and the methodologies to demonstrate that compliance is necessary.

HARMONIZATION OF DESIGN FEATURES RELEVANT TO DECOMMISSIONING

As far as the designs for the new reactors are concerned, harmonization in the following areas is of interest.

i) Reduction in System Components
ii) Reduction in Construction Materials
iii) Modular Designs of Systems
iv) Modular Design of Structures
v) Advanced Construction techniques
vi) Better Designs to Avoid Contamination During Operational Phase
vii) Waste Minimization
viii) Harmonization of International Codes and Standards for Design

Reduction in System Components

Harmonization of design approaches for new reactors with respect to reduction in components is being achieved to a large degree. As an illustration of this progress, Table 1 below lists the reduction in components for three designs, ESBWR, USEPR, and AP1000. All three are designed for a 60- year design life and have refueling cycles ranging from 18 months to 24 months.

Table 1: Reduction in Components

ESBWR	US EPR	AP1000
Reduction in components • 11 systems eliminated • 25% of pumps, valves and motors eliminated	Reduction in components • 44% fewer heat exchangers • 50% fewer tanks • 47%fewer valves • 16% fewer pumps	Reduction in components • 87% less control cable • 80% less piping • 50% fewer valves • 35% fewer pumps

This reduction in components has cost benefits not only for the capital costs of building the plant but also eventually during the decommissioning phase when substantial cost savings can be achieved due to reduced dismantlement costs and reduced waste disposal costs.

The author has previously discussed in detail various decommissioning factors that should be included as a part of the new reactor design process [14].

Reduction in Construction Materials

One of biggest impacts of the new reactor designs on the decommissioning phase is the overall reduction in total amount of construction materials used. As shown by the data in Table 2, the new reactor designs use significantly less rebar and concrete than the past designs of the reactors that are currently operating. For example, on the basis of per MWe capacity installed, the current designs use less than half the concrete. For comparison, the AP 1000 design uses about one third the amount of concrete than a typical PWR in operation today in the US and about one fifth of the Sizewell B plant in the United Kingdom. Similar material reductions are in the rebar steel.

Table 2: Concrete and Rebar Comparison

Era	Concrete	Rebar
1970s	m^3/MWe installed 190+	t (metric)/MWe installed 40+
Current Designs	90	40
Comparisons Sizewell B (UK)	Total Concrete m^3 520,000	Total Steel t (metric) 65,000
US typical	300,000	46,000
ABWR	351,000	<12,000
AP1000	<100,000	Approx.10,000

Again, this harmonization towards reduced amount of construction materials and reduction in components have cost benefits not only for the capital costs of building the plant but also eventually during the decommissioning phase when substantial cost savings can be achieved due to reduced dismantlement and waste disposal costs.

Modular Designs of Systems

Past construction practices for nuclear power plants involved fabricating many of the mechanical and electrical systems on site and only after the structures have been constructed. Current reactor designs allow for modular construction of structures and systems. This allows many of the activities to proceed in parallel. Many large and small mechanical, electrical, and I&C system modules can be built off-site.

As an example of the modular design, the AP1000 design consists of approximately 350 structural and mechanical modules. Complete system modules or subsystem level modules can be fabricated off site, transported to the site, and assembled in place. This has significant cost and schedule advantages. The construction time for an AP-1000 plant is anticipated to be 48 months, much shorter than the standard PWR construction schedule. The design approach also reduces the number of components by approximately fifty percent from a standard 1000 MWe PWR as discussed earlier.

Modular construction of systems and structures for eventual deconstruction and decommissioning has been previously discussed by the author [15].

Modular Designs of Structures

Current reactor designs allow modular construction of the plant structures. For the AP1000 in China, Sanmen Unit 1 which is projected to go on-line in late 2013, the largest structural module measured 20 m long, 14 m wide and 20 m high and weighed 900 tonnes. More than 18 modules weighed more than 500 tonnes, while another 50 weighed in excess of 100 tonnes.

For modular design and construction, the key points are as follows:

- Modular construction involves bigger logistical challenges. This involves construction or fabrication at off-site facilities and transportation over long distances. Transportation by barge is the preferred route for large modules. The land route transportation restrictions may limit the design and the size of the construction modules.
- Some activities may involve first-of a- kind engineering activity.
- Modularization at nuclear power plant construction involves the use of very heavy lift cranes. The VHL cranes are a costly equipment to erect and operate at the site.
- Modularization and off-site fabrication may require setting up or expanding existing factories or manufacturing facilities to accommodate the module size and scope. This may involve additional expenses.
- Larger modules may need to be designed and fabricated as multiple sub-modules, which can then be assembled at the site.

Advanced Construction techniques

Advanced construction techniques such as slip forming and open top construction (in combination with the modularization approach) require considerable advance planning and detailed engineering to support the fabrication and assembly of large modules for the structures and systems. Open top construction methods will also require the use of a temporary weather covers during the construction period.

The advantages of the advanced construction techniques in conjunction with modular design are many as discussed below.

- Reduction in project schedule by allowing parallel construction activities on system and structural modules.
- Reduction in manpower needs at the project site.
- Uniformity in systems and structural modules for multiple units at the same site and/or of the same design at different sites.
- Better quality control through initial testing of the components at the fabrication facility.
- Reduction in facility footprint.
- Reduction in system components.
- Reduction of work congestion at the construction site.
- Mass production capability providing economies of scale.

- Significant cost savings.

Advanced construction techniques and modularization of systems and structures bring harmonization to the design and fabrication of new reactors with substantial cost savings.

Better Designs to Avoid Contamination During Operational Phase

The new reactor designs place emphasis on building robust systems where the systems could lead to potential failures which not only have implications for the operation of the reactor but also implications for contaminating systems, structures and soils. Such systems include: piping systems, HVAC systems, and sumps and drains. The designs also minimize embedded piping to the extent feasible.

For the reactors with a secondary side (in addition to the primary side), such as the PWR (and PHWR), there is a separation of the contaminants in the reactor coolant loops and the steam cycle side. The secondary systems are not expected to become contaminated even though this is dependent on the reliability of the steam generators and the ability to contain the radioactive material within the primary system boundary throughout the plant life.

Waste Minimization

The newer reactor designs are optimized towards generating lower operational waste as compared to the currently operating reactors. In addition, as discussed above, their system and structural design optimization with respect to decommissioning considerations reduces the eventual decommissioning waste as well. This is illustrated in Table 3, where low level radioactive waste volume from a typical 1000MWe PWR is compared with the AP1000 design.

The decommissioning waste in this category for AP1000 is nearly half that of the standard PWR.

Table 3: Comparison of Waste Volume

Waste Volume	Current PWR 1000 MWe	AP1000
Operational (Dry and Wet Wastes)	270 m^3/y (9540 ft^3/y)	163 m^3/y (5760 ft^3/y)
Decommissioning waste (low level)	18,340 m^3 (647,500 ft^3)	Approx. 10,000 m^3 (353,000 ft^3)
Comparison from an actual decommissioning of a full size reactor: Decommissioning waste (low level) from Main Yankee : 19,800 m^3 (700,000 ft^3)		

Harmonization of International Codes and Standards for Design

Most current plant designs are developed by international companies who plan to build these units in many different countries and in many cases one plant built in one country may be considered a reference plant for construction of that design in other countries. The plant features and the modular designs are also meant to allow fabrication of the systems and even structures at an off site location and then assembling the plant at the sit. This provides economies of scale and this is a key element in making nuclear power competitive. This is already a fact for the major components such as the RPV and the Steam Generators, where only a few manufacturers have the capability for production of these components. However for this to work, national variations in safety regulations need to be harmonized.

The success if the nuclear renaissance will depend on achieving economies of scale by building modular components and structures and by building plants in series. Variations in national safety regulations will need to be harmonized to fully realize the internationally standardized nuclear reactor designs and the cost benefits these will provide.

In Europe, the Western European Nuclear Regulator's Association (WENRA) [17] has working groups engaged on the task to harmonize safety approaches between countries in Europe on reactor safety and on decommissioning and nuclear waste safety. Among the purposes of these initiatives are to continuously improve safety and to reduce unnecessary regulatory differences between the countries.

A greater harmonization of national standards would allow for more uniform regulatory design review and licensing process and it will curtail the variation required for adaptation of the international reactor designs from one country to another. In addition to the safety standards in general, a greater degree of convergence is desirable at the international level for civil/structural design, mechanical design, and quality control.

CONCLUSIONS

Varied approaches have been utilized by the reactor decommissioning projects in the past. While some degree of harmonization in the field of decommissioning has taken place, further standardization, especially in the areas of site and material release criteria are desirable.

For the new reactor designs, system and component reduction, modularization, and advanced techniques applied during construction bring a degree of harmonization to the new build. This has cost advantages to construction as well as the eventual decommissioning of the reactors at the end of their design life. A greater harmonization of national standards would allow for more uniform regulatory design review and licensing process and international reactor designs can then be easily adapted from one country to another.

REFERENCES

1. USNRC, http://www.nrc.gov/
2. IAEA,Selection of Decommissioning Strategies: Issues and factors; IAEA-TECDOC-1478, Vienna, 2005
3. NEA 99a : Nuclear Decommissioning : A Proposed Standardised List of Items for Costing Purposes ; an Interim Technical Document, OECD/NEA, 1999.
4. Towards Greater Harmonisation of Decommissioning Cost Estimates. OECD 2010, NEA No. 6867.
5. Lucien Teunckens, Kurt Pflugrad, Candace Chan-Sands, Ted Lazo, Proposal for Internationally Standardized Cost Item Definitions for the Decommissioning of Nuclear Installations, IDS 2000 June 13-16, 2000, Knoxville, TN

6. IAEA, State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities, Technical reports series, no. 395,Vienna, 1999.
7. NRC, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) NUREG-1575, Rev. 1 EPA 402-R-97-016, Rev. 1 DOE/EH-0624, Rev. 1, August 2000.
8. European Commission, Radiation Protection No. 113, Recommended Radiological Protection Criteria for the Clearance of Buildings and Building Rubble from the Dismantling of Nuclear Installations, 2000.
9. European Commission, Radiation Protection No. 157, Comparative Study of EC and IAEA Guidance on Exemption and Clearance Levels, 2010.
10. OECD/NEA, Release of Radioactive Materials and Buildings from Regulatory Control - A Status Report, OECD 2008, NEA No. 6403
11. IAEA, Release of Sites from Regulatory Control on Termination of Practices, IAEA Safety Standards, Safety Guide, No.WS-G-5.1, IAEA 2006.
12. IAEA, Application of the Concepts of Exclusion, Exemption and Clearance; Safety Guide, Safety Standards Series No. RS-G-1.7, Vienna, 2004
13. Jas Devgun, Free Release Standards for Decommissioning projects- Building Consensus, *Radwaste Solutions* article published January/February 2003. p 9-15.
14. Jas S. Devgun, Designing Decommissioning into New Reactor Designs, American Nuclear Society, *Radwaste Solutions*, Vol. 14, No. 5, p. 40-46, September/October 2007.
15. Jas S. Devgun , Modular Construction for Eventual Deconstruction and Decommissioning WM2010 Conference, March 7-11, 2010, Phoenix, AZ
16. IAEA Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning of Nuclear Facilities; Technical Reports Series No. 401, Vienna, 2001.
17. WENRA policy and activities, See web site: www.wenra.org