A REVIEW OF DECOMMISSIONING CONSIDERATIONS FOR NEW REACTORS[1] - 8398

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ABSTRACT

At a time of "nuclear renaissance" when the focus is on advanced reactor designs and construction, it is easy to overlook the decommissioning considerations because such a stage in the life of the new reactors will be some sixty years down the road. Yet, one of the lessons learned from major decommissioning projects has been that decommissioning was not given much thought when these reactors were designed three or four decades ago. Hence, the time to examine what decommissioning considerations should be taken into account is right from the design stage with regular updates of the decommissioning strategy and plans throughout the life cycle of the reactor.

Designing D&D into the new reactor designs is necessary to ensure that the tail end costs of the nuclear power are manageable. Such considerations during the design stage will facilitate a more cost-effective, safe and timely decommissioning of the facility when a reactor is eventually retired.

This paper examines the current regulatory and industry design guidance for the new reactors with respect to the decommissioning issues and provides a review of the design considerations that can help optimize the reactor designs for the eventual decommissioning.

INTRODUCTION

World's growing energy demand and concerns about global warming have lead to a "nuclear renaissance", which is now clearly established. By the year 2030, the energy demand is expected to be over fifty percent higher than what it is today. Interestingly, according to the International Energy Agency, two countries, China and India, will account for about forty five percent of the increase in this energy demand because of the rapid economic growth in these countries [1]. Nuclear energy is expected to contribute significantly towards this future energy demand as a source of cleaner energy. Industry estimates show that anywhere from 60 to 130 new reactors may be added during the next twenty years adding a sizeable capacity to the nuclear power generated by the current 442 nuclear units that are operating today on a worldwide basis.

Several countries are now considering building nuclear power plants or expanding their existing nuclear fleet. In Asia, India and China have ambitious plans for new nuclear stations and have in fact begun building them. In Japan and South Korea, nuclear has always been a significant part of

[1] The views expressed in this paper are those of the author and do not necessarily reflect the views of his employer or the clients.

the energy mix and these countries are expanding their nuclear reactor fleet. In Europe and in North America the “nuclear renaissance” in the past several years was limited to programs of life extension for the existing nuclear plants. However, the pace has picked up in the past five or so years for the actual plans for new construction. Advanced reactors are now planned both in Europe and in North America. In Europe, the first new EPR plant is under construction in Finland and in France, EDF has announced the decision to launch the construction of an EPR.

In the United States, a sharp reversal in the nuclear industry has occurred as compared to the situation only a few years ago and the plants that were originally destined for decommissioning are now being re-licensed for continued operation. In addition, several utilities and consortiums have accelerated plans for new reactor construction. From the latest figures available, applications for 32 new nuclear power reactors at 21 sites may be filed by 2009 in the Unites States. This is a dramatic upturn in the nuclear industry which until only a few years ago was in a state of stalemate.

At this time of “nuclear renaissance” with the focus on advanced reactor designs and construction, it is easy to overlook the decommissioning considerations because such a stage in the life of the new reactors will be some sixty years down the road. Yet, one of the lessons learned from most major decommissioning projects has been that decommissioning was not given much thought when these reactors were designed three or four decades ago. Hence, the time to examine what decommissioning considerations should be taken into account is right from the design stage with regular updates of the decommissioning strategy and plans throughout the life cycle of the reactor.

The focus of this paper is on what design considerations should be a part of the design process for the new reactors to optimize the designs for eventual decommissioning. It also examines the current regulatory and industry design guidance for the new reactors with respect to the decommissioning issues.

SIGNIFICANCE OF THE DECOMMISSIONING STAGE

There are some variations in the total decommissioning cost estimates for the existing nuclear fleet of 104 reactors in the United States and the reactors that are already shutdown. As of the end of 2004, an estimated cost of approximately $40.7 billion had been reported and $30.9 billion of that (i.e., about 76%) had been collected [2]**.** The decommissioning funds are accumulated over the operating life of the reactor (as a levy on a per kWh basis) and held in a decommissioning fund. The decommissioning cost for an individual reactor can range from approximately $300 million to over $600 million depending on the reactor and the site specific factors. The average decontamination & decommissioning (D&D) cost for a full size reactor s is closer to $600 million per reactor. This is a significant portion of the overall life cycle costs of the reactor.

Several prototype/demonstration reactors and commercial reactors have been decommissioned in the United States or are in the various stages of decommissioning. In some cases the site has been decommissioned to “greenfield” and sites have been released for unrestricted use, for example, Fort St Vrain, Shoreham, Big Rock Point and Trojan. Currently, fifteen power reactor sites and eleven research and test reactor sites are undergoing decommissioning. .

Worldwide, some 115 power and research reactors have been retired from operation and are either undergoing decommissioning or are in planning stages. Thus, substantial experience already exists in decommissioning of nuclear reactors in the United States and many other countries. Nevertheless, a common misconception at reactor sites is that decommissioning is an extension of the operating phase. During the decommissioning stage, the focus must shift from reactor systems to decommissioning areas and decommissioning strategy must be in place well in advance of the reactor's permanent shutdown. The actions taken during the decommissioning stage are irreversible actions with a goal of removing the systems, materials, structures and contamination from the site and releasing the site for other uses.

Extensive guidance on decommissioning is available in regulatory documents and in literature. In the United States, decommissioning regulations are covered in Title 10 of the Code of Federal Regulations, Part 20 (10 CFR Part 20), Subpart E. The regulations for release of a site for unrestricted use are contained in the provisions of 10 CFR 20.1406. Several NRC guidance documents are available related to decommissioning. These include NUREG-1757 that consolidates the decommissioning guidance, NUREG-1700 that provides a standard review plan for license termination plans, NUREG 1577 on financial qualifications and decommissioning funding assurance, NUREG-1574 on MARSSIM, and Regulatory Guide 1.184 on decommissioning of nuclear power reactors. Information on these documents and relevant links are available on the NRC website [3]. Internationally, the International Atomic Energy Agency document IAEA-TECDOC-1394 provides guidance on planning and managing the decommissioning of nuclear facilities and the lessons learned [4].

REGULATORY AND INDUSTRY GUIDANCE FOR NEW REACTORS

The discussion of the regulatory and industry guidance in this paper is limited in scope to the examination of the process and requirements, if any, with respect to decommissioning. It is also only in the context of the United States.

Currently operating reactors in the United States have been licensed by the Nuclear Regulatory Commission (NRC) under 10 CFR Part 50. This process has required a two-part licensing with the licensee obtaining both a construction permit and an operating license. To improve the regulatory efficiency, the NRC established an alternate licensing process in 10 CFR Part 52 which defines the Combined Construction/Operating License Applications (COLA) process. Design certification rules are already appended to this CFR for several of the designs - Appendix A for ABWR, Appendix B for System 80+, Appendix C for AP600, and Appendix D for AP1000. Appendix N covers the standardization of nuclear power plant designs: combined licenses to construct and operate nuclear power reactors of identical design at multiple sites; (Appendices E through M are currently reserved).

The new reactor licensing applications in the United States are being submitted using the COLA process. To date three sites have filed COLAs with the NRC. These sites are the South Texas Project (ABWR Unit 3 and 4), Calvert Cliffs (EPR Unit 3) and Bellefonte (AP1000 Units 3 and 4). Several other companies are planning to file the applications in near future. A variety of advanced reactor designs have been selected by the applicants, including AP1000, ESBWR, ABWR, EPR, and USAPWR.

As mentioned earlier, the regulatory basis for COLAs is contained in 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," which was recently updated (final rule published in the Federal Register on August 28, 2007, 72 FR 49351). This updated rule revises the provisions applicable to the licensing and approval processes for nuclear power plants. Another recently published final rule supplements the final rule on 10 CFR Part 52 to clarify regulations that allow certain construction activities (on production and utilization facilities) to commence before a construction permit or combined license is issued. This rule, "Limited Work Authorizations for Nuclear Power Plants," (published in the Federal Register on October 9, 2007, 72 FR 57415), modifies the scope of activities that are considered construction for which a construction permit, combined license, or Limited Work Authorization is necessary. These recent changes are expected to further enhance the efficiency of the licensing and approval process for the new nuclear power reactors.

Primary guidance for COLA is contained in Regulatory Guide 1.206. However, while detailed information is available on various design aspects, discussion of decommissioning is very limited. The design basis section of this guide on the solid waste management system states that in accordance with the requirements of 10 CFR Part 20.1406, the applicant should describe how the above design features and operational procedures minimize, to the extent practicable, contamination of the facility and the environment, facilitate decommissioning, and minimize, to the extent practicable, the generation of radioactive waste.

Similarly, the industry guidance document (NEI 04-01, Revision E, Draft, October 2005) for applications under 10 CFR Part 52 talks about decommissioning very briefly and only in the context of decommissioning funding that is discussed in section 4.2.3 of the guide. Each applicant for a combined license for a power reactor is required to describe in its application how it will provide reasonable assurance that funds will be available to decommission the plant, when required. This is to comply with the NRC requirements in 10 CFR 50.75 for the decommissioning funding assurance. Section 50.75 also requires holders of a combined license to perform an annual update of decommissioning assurance funding estimates.

The regulatory guidance and the industry guidance are detailed and extensive on reactor systems, safety systems, and submissions of COLAs. However, the discussion on decommissioning is limited and is focused primarily on the topic of decommissioning funding.

RATIONALE FOR DECOMMISSIONING CONSIDERATIONS DURING DESIGN

Once the reactor has started operation, the core is irradiated, and the primary system components have become radioactive, the cost of decommissioning a nuclear reactor is basically fixed and is permanent. Other factors may change the overall costs somewhat but the general level of decommissioning cost would remain similar. Factors during the operation phase that could lead to an increase in the eventual decommissioning cost could be, for example, potential degradation in operational performance or a major contamination event. On the other hand, innovations and developments in decontamination technologies could reduce the decommissioning cost. One important factor that has the potential to substantially change the decommissioning cost is the availability of facilities and cost of the radioactive waste disposal as well as the facilities for management and storage of spent nuclear fuel. Note that the spent nuclear fuel and high level waste disposal are government projects in most countries including the United States. However, Yucca Mountain facility for such wastes will not open for accepting such wastes in near future. Thus, the reactor sites must manage the spent nuclear fuel in the interim as a part of the decommissioning process, even though technically, the federal government (Department of Energy) is responsible for accepting the spent nuclear fuel from the reactor operators. Many of the sites have opted to install Independent Spent Fuel Storage Facilities (ISFSI).

From the discussion above, it can be concluded that while several factors could affect the overall decommissioning strategy and decommissioning cost, one way to reduce the decommissioning cost would be to optimize the design of the systems and structures for eventual decommissioning.

DECOMMISSIONING CONSIDERATIONS DURING DESIGN

By and large, the main factors driving the design of the new reactors are the enhanced safety features, safeguards considerations, and the economic factors. Optimization of the facility and system design for decommissioning is generally not a high priority. This means that decommissioning considerations are not be fully represented as a design item in the new reactor design process.

Eventually all reactors, including the ones under construction or planned, will need to be decommissioned at the end of their lifecycle. The fact that decommissioning for the new reactors may be sixty or more years into their life cycle has clearly led to decommissioning considerations being seen as a low priority in the design and the regulatory process. However, the benefits of such considerations early in the design stage are many. Incorporating decommissioning considerations into the designs of the new reactors can ensure that the eventual decommissioning can be completed in shorter time frames, with minimum generation of radioactive waste, and with better radiological safety.

Some of the reactor designs have been successfully optimized in this regard. An example is the AP1000 which is discussed later in this paper.

Decommissioning Seven and Two factors of Specific Interest

The author has previously published a list of seven areas (called Decommissioning Seven), which should be considered as important factors during the design development stage for the new reactors [5]. Two of these are of specific interest to the design phase of the new reactors.

System Design:

In this case, an emphasis on the following considerations will optimize the project from the very beginning towards eventual decommissioning. These include:

- Reduction in the system components
- Modular designs of systems
- More reliance on passive safety systems
- Use of contained systems (thus, minimizing the potential for cross contamination)
- Better designs of piping systems, HVAC systems, and sumps and drains.

The experience with decommissioning projects so far shows that approximately 65 to 75 percent of the costs are related to removal activities (systems and structures – decontamination, demolition, removal), disposal of components and low level waste, dry spent fuel storage facility construction, and staffing. The remaining costs account for the other items such as security services, radiological surveys, taxes, NRC and other fees, and other miscellaneous items.

System design optimization with respect to decommissioning considerations can reduce the eventual decommissioning cost of both the removal activities and the disposal costs. Both of these are a major portion of the overall decommissioning cost. A reduction in the system components and a modular design that will facilitate dismantlement activities will clearly reduce the costs of decommissioning. An additional benefit of an optimized design will be the reduction in the overall radiation exposure to the decommissioning workers.

Facility Design:

In this case, an emphasis on the structural design and the architectural design considerations will optimize the project from the very beginning towards eventual decommissioning. These include:

- Minimizing the foot print of structures
- Modular designs of structures
- Designing for large component removal.

Similar to the discussion above, the disposal cost of the structural debris is substantial, especially if it has to be treated as low level radioactive waste. Even though it may be possible to segregate the radioactive and non-radioactive debris, the licensing issues, the release criteria and other factors may influence the disposal of such materials. Thus, minimizing the structures that will be eventually demolished reduces the overall volume of the material that will need to be disposed. A discussion of issues related to the release of bulk materials is available in reference [6].

The issue of designing for major component removal is significant because from the industry experience so far, the preference has been to avoid segmenting the reactor vessel. This reduces costs and reduces the radiation dose to decommissioning workers. Thus, a design optimized during construction that will allow for major component removal will facilitate decommissioning.

AP1000 Design and Decommissioning Features

Detailed design information on the various advanced reactors is proprietary. However, based on the published data, an example of AP1000 is discussed below to illustrate optimization that will facilitate eventual decommissioning.

Westinghouse's AP-1000 standard design is a two-loop PWR with an output of approximately 1100 MWe. It is an evolution of the company's AP-600 design that was the first passive, advanced light water reactor design certified by the NRC in December 1999. The AP-1000 final safety evaluation report and final design certification were issued by the NRC in September 2004; and a revised final design certification was issued by the NRC in March 2006.

The design life for AP1000 is 60 years without a planned replacement of the reactor vessel. The design does provide for the replacement of other major components, such as the steam generator. Relevant to our decommissioning review, the AP-1000 design minimizes the components and hence, facilitates future decommissioning. It comprises two heat transfer loops, each containing a steam generator, two reactor coolant pumps, one hot leg, and two cold legs as compared to a standard four-loop PWR comprising four steam generators, four hot legs, and four cold legs. The reduction of two steam generators and associated piping alone is a major reduction in the eventual component volumes and disposal cost (at the time of decommissioning). The reduction in equipment and structures is estimated as: 35% fewer pumps, 50% fewer safety valves, 83% less piping, 87% less control cable, and 50% less seismic building volume [7].

Design similarities between the AP-600 and AP-1000 also promote standardization, where medium and large reactors are of the same design family. This has advantages in reduced construction costs, operational system efficiencies, and levels of safety.

Thus, in the case of AP-1000, the modular construction and a substantial reduction in components is expected to lead to significantly simpler and cheaper decommissioning.

SUMMARY KEY FACTORS AND SUGGESTIONS

Based on the extensive decommissioning experience that is now available, it is possible to summarize key factors that are relevant to the new reactors and that would facilitate their future decommissioning. These along with a few suggestions are listed below.

- Incorporation of modular concepts in structural design
- Innovations in equipment, materials, and system layout
- Lessons from decommissioning projects, especially in terms of major component removal
- Access to highly contaminated components for decontamination
- Consideration of the total life cycle including decommissioning while designing equipment and structures and while implementing modifications during the operating life of the reactor
- Minimization of underground drains and buried piping as much as possible
- Designs that will prevent or minimize the potential for leaks and spills and that will allow for their early detection
- Minimization of future waste volume generation during the decommissioning phase of the reactor
- Good Historical Site Assessment with records of any spills, radiological contamination, soil excavations, and disposals during the plant operation
- Design assessment in terms of estimated decommissioning cost per MWe effectiveness
- Design concepts incorporating early selection of the decommissioning option - DECON or SAFSTOR
- Decommissioning engineers embedded on the reactor design team with a specific mission to optimize the reactor systems and structures for eventual decontamination and decommissioning
- Developments in release criteria for the decommissioned sites and materials.

CONCLUSIONS

At a time of a worldwide “nuclear renaissance” when new reactor designs are being developed and construction is planned or happening, it is easy to overlook decommissioning considerations because such a stage in the life cycle of the plant is some sixty years away. With respect to decommissioning, the focus of the current regulatory and industry guidance for the new reactors is on the decommissioning funding considerations. Defense-in-depth and the generation cost economics primarily drive the reactor design process and generally the decommissioning considerations are not a priority. However, one of the lessons learned from the past reactor decommissioning projects has been that decommissioning was not given much thought when these reactors were designed three or four decades ago. Hence, the time to examine what decommissioning considerations should be taken into account is right at the design stage.

Designing D&D into the new reactor designs is necessary to ensure that the tail end costs of the nuclear power are manageable. Such considerations during the design stage will facilitate a more cost-effective, safe and timely decommissioning of the facility when a reactor is eventually retired.

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