End of Lifecycle Issues for Reactors Yet to be Built[1] - 9041

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ABSTRACT

By and large, the new reactor designs are optimized for cost economics and defense-in-depth issues. Because such reactors are being designed for an operating period of 60 years, the end of the lifecycle of a new nuclear power plant is so far into the future that it is easy to overlook the significance of the issues relevant to that phase. The limited decommissioning focus that current regulatory and industry guidance does have is on ensuring that decommissioning funding mechanisms will be in place (typically required to be collected over the operational lifecycle). Yet, one of the most important lessons learned from past and current reactor decommissioning projects has been that decommissioning was not given much thought when these reactors were in the design phase over thirty years ago or later during their operations phase.

Considering that a significant expansion of nuclear power's role in the world electricity production is on the horizon with a planned addition of anywhere from 60 to 130 new reactors worldwide over the next twenty years, the time to examine the end-of-lifecycle issues is now, right from the start. This paper will provide a comprehensive overview of the end-of-lifecycle issues for reactors yet to be built including issues that are under the industry control and those that are not. It will also discuss how designs can be optimized with a perspective of end-of-lifecycle issues in mind.

INTRODUCTION

Energy Demand and Role of Nuclear Power

According to the 2008 International Energy Outlook by the Energy Information Administration of U.S. government, the projected total world consumption of energy is projected to increase by 50 percent by the year 2030 from the energy data in 2005 [1]. The largest projected increase in energy demand is for non-OECD countries, with economies in Asia, Middle East, Africa, and Central and South America accounting for a major portion of the increase. Specifically, China and India, whose economies have been growing at a much faster rate than other countries, are projected to become key players in the world energy consumption in the future. The net electricity generation worldwide, as a part of the world energy mix, is projected to total 33.3 trillion kilowatt-hours in 2030, nearly double the 2005 total. Even though natural gas and coal are projected to remain the main fuel sources for electricity with projections at 25% and 46%, respectively, the electricity generation from nuclear reactors is projected to account for approximately 11% of the total.

The data comparison from 2005 to the projections for 2030, translates to a 46% increase in the nuclear electricity production (to 3.8 trillion kilowatt-hours in 2030) [1].

Concerns about rising fossil fuel prices, energy security, and greenhouse gas emissions have accelerated the pace of nuclear generation development in many countries. This has led to a "nuclear renaissance" in many western countries including the United States. The estimates are changing more rapidly in the case

[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.

of nuclear power and it is not inconceivable that the share of nuclear power may get larger in the future. For example, the 2008 estimate for the projected world nuclear electricity generation in 2025 is 31 percent higher than the projection made in the 2003 outlook report, just 5 years before.

Expansion of nuclear power's role in the world electricity production is more optimistic from the industry estimates that project anywhere from 60 to 130 new reactors being added during the next twenty years to the world's current nuclear fleet of 442 reactors. Both India and China have ambitious plans for new nuclear stations and several new construction projects are underway. In the Far East, in Japan and South Korea, nuclear has always been a significant part of the energy mix and these countries are also expanding their nuclear reactor fleet. In Europe, especially in France, nuclear has been a strong component of the energy mix. In North America, the "nuclear renaissance" in the past several years was limited to programs of power uprates and life extension for the existing nuclear plants. However, the pace has picked up in the past few years and actual planning for the new construction has begun.

In the United States, a sharp reversal in the nuclear industry has taken place as compared to the situation only a few years ago and the plants that were originally destined for decommissioning are now being relicensed for continued operation. The U.S. fleet of civilian reactors currently stands at 104. Several utilities and consortiums have accelerated plans for new reactor construction. From the latest figures available [2], at the end of October 2008, COL (combined license- construction and operation) applications for 26 reactors at 17 sites have been filed with the U.S. Nuclear Regulatory Commission (NRC). The current NRC projections also show that by the end of calendar year 2010, licensing applications will total 34 for the new nuclear power reactors at 21 sites. This is a dramatic upturn in the nuclear industry which until only a few years ago was in a state of stalemate.

Issues That May Impact Nuclear Renaissance

There are considerable issues that could slow the development of new nuclear power plants worldwide. These include state of national economies, high capital costs, safety and safeguard concerns, non-proliferation issues, spent nuclear fuel disposition, radioactive waste disposal, and the public acceptance. It is worth noting that under the U.S. Department of Energy's (DOE) Nuclear Power 2010 program, the cost of the COL applications so far has been shared by the industry and the DOE.

So, at this time of "nuclear renaissance" when major focus from the industry and the government is on new build, it is easy to overlook the end-of-lifecycle issues for these reactors that are yet to be built. This is partly due to the fact that such a stage in the life of the new reactors will be some sixty years down the road after they become operational. Yet, an important lesson learned from the past and current reactor decommissioning projects has been that decommissioning was not given much thought when these reactors were designed over thirty years ago or later during their operational phase.
This paper focuses on the end-of-lifecycle issues for the new reactors and provides a detailed discussion of the issues that should be considered throughout the lifecycle of the reactors with the end stage in mind.

SIGNIFICANCE OF THE END OF LIFECYCLE ISSUES

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 lifecycle has clearly led to decommissioning considerations being seen as a low priority in the design process and the regulatory process. Nevertheless, the benefits of such considerations during the earlier stages, specifically in the design, construction and operational stages are many. Life-cycle considerations for a nuclear power plant should consider a single period covering all stages from conceptual design, construction, and operation through to decommissioning and release of the site.

The average decontamination & decommissioning cost for a full size reactor is over $600 million in current dollars. This is a significant portion of the overall life-cycle costs of the reactor. By the time the reactors that are yet to be built are decommissioned some sixty years down the road after they are built, the costs adjusted only for inflation alone (for example, assuming at 5%) could mean approximately 2 billion dollars at that time. Of course, there are many uncertain variables over such a long period of time, some that may increase the cost dramatically, and some that may lower the cost dramatically. For the existing fleet of 104 operating reactors and the reactors that are already shutdown, there are some variations in the cost estimates as to what it would take to decommission all these reactors. The NRC has reported [3] that at the end of 2006, approximately $35.8 billion dollars had been collected into the decommissioning funds. This represents about 84% of the minimum decommissioning costs (as defined by the NRC) that will be required for these reactors. It should be noted that the minimum decommissioning costs as defined by the NRC are actually much less than the actual decommissioning cost. It should also be noted that the decommissioning funds in the U.S. are accumulated over the operating life of the reactor (as a levy on a per kWh basis) and held in a decommissioning fund. However, as some of the funds are invested in financial markets, there is some uncertainty as to the changes in the value of their portfolio. Some discussion of the adequacy assessments of the decommissioning funds is available in the literature, for example, in references [4] and [5].

Incorporating end-of-lifecycle factors, including decommissioning considerations into the designs of the new reactors can ensure that the eventual end-of-lifecycle activities including decommissioning can be completed in shorter time frames, with minimum generation of radioactive waste, and with better radiological safety.

DISCUSSION OF END OF LIFECYCLE ISSUES AND CONSIDERATIONS

A broader range of end-of-lifecycle issues needs to be captured in the lifecycle planning for the reactors yet to be built. These issues generically include:

- Strategies for decommissioning
- Spent fuel storage/disposition
- Low level radioactive waste disposal and bulk materials disposal
- Site cleanup and release/reuse.

Because there are many issues that are under the industry control and many that are not, all relevant issues can be better grouped as follows.

I. At the Reactor Level
   a. Reactor design
   b. Capital cost and lifecycle economics
   c. Stakeholder issues
   d. Operations
   e. Site plan for future use
   f. Decommissioning plan
   g. Regulatory criteria for site release

II. At the National Level
   a. SNF policies (reprocessing or not)
   b. SNF/HLW storage and disposal facilities
   c. Public participation in national nuclear policies
   d. Decommissioning funding policies

e. Regulatory framework
f. LLW storage, disposal, and cost
g. Compacts role (in the U.S.)
h. ILW storage and disposal (other countries); Greater than Class C (U.S.).

III. At the International Level
a. International standards
b. International programs, cooperation and coordination
c. International experiences and lessons learned related to end-of-lifecycle issues

Reactor Level Issues

Rationale for Considering Decommissioning During Design Stage

The opportunity to optimize the reactor with respect to eventual decommissioning during the design stage can not be overstated. Once the reactor has started operation and the core gets irradiated and the primary system components become radioactive, decommissioning costs of the reactor are already a permanent reality. Other factors may change the overall costs but the basic decommissioning costs can not be avoided.

The new generation of reactors (Generation III, and Generation III+) that are being built or are under consideration are evolutionary designs that are generally based on the currently operating reactors. Many of the lessons learned from the past four decades of operation are being applied to the design of the new reactors. Many of the improved designs for safety systems, control rooms, instrumentation, and support systems are based on the lessons from this past experience.

The author has previously published a comprehensive list of factors which should be considered during the design development stage for the new reactors [6]. Two of these, the system design and the facility design, are of specific interest to the design phase of the new reactors.

System 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. The capital cost in terms of “overnight costs” is a primary consideration for the nuclear industry for nuclear energy to be competitive with other sources of energy. The industry estimates put the capital costs between $1,600 and $2,000 per kWe installed depending on the reactor design [7]. An additional issue for the industry is the “first of a kind engineering” issue for the new reactors that pushes up the capital cost of a new plant that will be built first. Once the design of such systems is established, the design engineering costs for subsequent reactors of the same design will be lower, by some estimates as much as 30% lower.

Even though optimization of the facility and system design for eventual decommissioning is generally not a high priority at the front end, the long-term consequences of the end of lifecycle can not be overlooked. Decommissioning considerations need to be fully represented as a design item in the new reactor design process. In this case, an emphasis on system design will optimize the project from the very beginning towards eventual decommissioning. These considerations 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 decommissioning costs are related to removal activities (systems and structures – decontamination, demolition, and removal), disposal of components and low level waste, dry spent fuel storage facility construction, and staffing. The remaining costs account for 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 for the waste. Both of these are a major portion of the overall decommissioning cost. A reduction in the system components and a modular design will facilitate dismantlement activities and it will facilitate overall cost reduction. An additional benefit of an optimized design will be the reduction in the overall radiation exposure to the decommissioning workers.

Some of the reactor designs have been successfully optimized in this regard. The design features of AP-1000 (from the available information) are discussed below to illustrate optimization that will facilitate eventual decommissioning.

The AP-1000 standard design is a two-loop PWR with an output of approximately 1100 MWe. It is an evolution of the AP-600 design that was the first passive, advanced light water reactor design certified by the NRC in December 1999. The final safety evaluation report and final design certification for AP-1000 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 of AP-1000 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 generators. Relevant to our review, the AP-1000 design minimizes the components and thus 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 [8]. 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.

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 considerations include:

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

Similar to the discussion under the System Design, 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, other issues related to licensing, release criteria, and public acceptance 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 of. A discussion of the issues related to the release of bulk materials is available in reference [9].

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

Other issues

A brief discussion follows of the other relevant issues that include: stakeholder issues, operations, site plan for future use, decommissioning plan, and regulatory criteria for site release.

From new reactor perspective, the stakeholder issues involve the power plant owner and investors, the regulatory entities, the workforce, and the local public. During the construction phase, the plant brings large economic activity and a large number of jobs. Over the operating phase, the plant again provides large economic and job benefits to the local community. However, the planning for economic and workforce issues for the eventual end-of-lifecycle is just as important.

Detailed decommissioning planning needs to start several years ahead of the proposed decommissioning date. The new reactors are required to provide plans and assurances for decommissioning funding. However, decommissioning strategy can not be ignored during the earlier phases of the project including during the operations.

While the preferred strategy for decommissioning is “immediate dismantling” (termed DECON in U.S.), there may be situations where dismantling is deferred and storage over a longer term (SAFSTOR in U.S) may be employed. Such an option may be suitable when issues such as lack of funding, lack of waste management facilities, and other reasons dictate delaying the project. A potential reuse of the site for new nuclear power reactors may also affect such a decision. Note that the ENTOMB is another option which may be suitable but only under special circumstances.
Site cleanup under the preferred strategy of decontaminating and decommissioning would generally require a cleanup of the site for unrestricted use. The governing regulations for release of a site for unrestricted use in the U.S. are contained in the provisions of 10 CFR Part 20.1406. New reactor projects must also be cognizant of the fact that the release standards in future could get more restrictive and that in addition to the federal regulations, some states already have stricter site release criteria.

National Level Issues

SNF, HLW and LLW Issues

About 99% of the radioactivity in a nuclear reactor is associated with the spent nuclear fuel (SNF). The SNF needs to be removed before any decommissioning work as a part of the end-of-lifecycle phase can begin. The surface contamination of the plant structures and equipment and the activation products lead to the rest of the radioactivity. The activation (in steel components and concrete) occurs due to long exposure to neutron irradiation. Activation products found in reactor materials include Fe-55, Co-60, Ni-63, C-14, and Eu-152. Additional radioactivity may result from potential releases of fission products from fuel failures, most prominently from Sr-90 and Cs-137.

In the U.S., a reactor goes into a refueling outage typically every 18 months when a portion of the spent fuel is replaced with fresh fuel. The SNF has been stored in water pools at the site under at least 20 feet of water, which provides adequate shielding from the radiation. However, the wet storage capacity in the U.S. is nearly full and the reactor sites have no choice but to opt for above ground dry storage. The SNF issue is the single most difficult issue for the reactors yet to be built and nuclear industry has no control over this. This is an issue that is an Achilles heal for the nuclear energy in terms of the lifecycle costs and its full public acceptance.

Spent nuclear fuel is a national issue in every country with a nuclear power program. While some countries, such as France, have opted to reprocess the SNF (which extracts fissionable material but also creates high level radioactive waste (HLW), the U.S. national policy is not to reprocess the fuel. The DOE is developing the Yucca Mountain repository for the disposition of SNF and HLW. The spent nuclear fuel is a federal responsibility and the DOE was supposed to start accepting the SNF from commercial reactors in early 1990s. The progress on this issue has been limited. The Yucca Mountain site was initially planned to open for accepting spent nuclear fuel and other high level wastes in 1998, then in 2010, and is now scheduled to open in 2017. Approximately 13.5 billion dollars have already been spent to date. Based on the latest figures (2007 estimate) released by the DOE in August 2008 [10], the updated lifecycle costs of building and operating Yucca Mountain repository (for 150 years; from 1983 when research on the project started, through closure and decommissioning in 2133) now stands at $96.2 billion in 2007 dollars. The 2007 estimate for the commercial nuclear spent fuel has been revised to 109,300 metric tons of heavy metal. Also worth noting is a recent DOE initiative geared towards the availability of Yucca Mountain disposal contracts for new nuclear reactors [10].

In the current decommissioning projects, the on-site storage facilities that many of the plants have opted to construct in the interim (Independent Spent Fuel Storage Installations, (ISFSIs)) cost anywhere between 60 to 100 million dollars.
While the international classification includes intermediate level radioactive waste (ILW) and low level radioactive waste (LLW), the radioactive waste other than the HLW in the U.S. is classified as low level waste. The waste classification into Class A, Class B and Class C is based on the provisions of 10 CFR Part 61. Some LLW with higher activity is classified as greater than Class C waste (GTCC).

The commercial LLW disposal costs currently run about $600 per cubic foot in the U.S. A reactor generates significant quantities of LLW during its operational life time that needs to be managed via storage and disposal. At the end of the lifecycle, the reactor decommissioning will generate large quantities of debris, some with radioactive contamination, as well as the LLW. Thus, strategies for minimizing the eventual waste generated at the decommissioning stage are important. In addition, if the site is to be cleaned to a “greenfield site” status, minimization strategies throughout the lifecycle are important.

Considering that the decommissioning costs (dismantlement, LLW disposal, bulk materials disposition, and site cleanup) for an average reactor may be in excess of 600 million dollars in today’s dollars, there is good economic incentive to factor in these considerations from the early stages and throughout the lifecycle.

<u>Compacts Role in the U.S</u>.

Compacts for LLW disposal site development came into being with the 1980 Low-Level Radioactive Waste Policy Act and the subsequent Low-Level Radioactive Waste Policy Amendments Act of 1985. This legislation gives states the responsibility to provide for disposal of commercial low-level radioactive waste and encourages states to form interstate agreements, or compacts, to cooperatively implement the law. Even though the original Congressional intent was to provide for a more equitable system, after 25 years in existence, the compacts have been essentially spinning their wheels and no new disposal facilities have been developed. The original three sites that accept LLW remain the same: Barnwell, South Carolina; Richland, Washington; and Clive, Utah. The Richland site accepts waste only from the Northwest Compact and the Rocky Mountain Compact. The Barnwell site and the Clive site accept waste from all regions of the U.S. but the Clive Site's license is restricted to Class A waste only. Richland and Barnwell sites accept Class A, Class B, and Class C wastes.

Long term prospects on disposal site availability and disposal costs for the LLW will impact new reactors, not only during the operational phase but also during the end-of-lifecycle phase.

Regulatory Issues

The reactors that are operating in the United States were licensed by the NRC under 10 CFR Part 50. This process required a two-part licensing effort with the licensee obtaining a construction permit and then an operating license. To improve the regulatory efficiency, the NRC established an alternate licensing process in 10 CFR Part 52 which defines the Combined License (COL) applications process that allows for a single construction/operating license. 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 AP-600, and Appendix D for AP-1000. 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 U.S. are being submitted using the COL application process. As mentioned earlier, applications for 26 reactors at 17 sites have already been filed with the NRC. Note that it is expected that the NRC review period may last anywhere between 12 to 18 months. Once the combined license is granted, the company may start the construction of the reactor. There is some uncertainty as to how many companies will actually begin construction and how soon after a license is granted. Design certification applications for a number of reactor designs (in addition to the ones already licensed) are under review at the NRC. These designs include ESBWR, U.S.EPR, and the USAPWR.

Primary guidance for COL application process is contained in NRC 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.

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

Thus, the regulatory guidance and the industry guidance on new reactors are detailed and extensive as far as the reactor systems, safety systems, and the submission process are concerned. However, the discussion on decommissioning is very limited and it is focused primarily on the topic of decommissioning funding. It is clear that the regulatory emphasis and guidance on the end-of-lifecycle and decommissioning issues for the new reactors needs to be increased.

It should be noted that for the reactors currently being decommissioned, several relevant NRC guidance documents are available. 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. International guidance can be found in the International Atomic Energy Agency (IAEA) document IAEA-TECDOC-1394 that provides guidance on planning and managing the decommissioning of nuclear facilities and the lessons learned [11].

Other Issues

In addition to the discussion above, public participation in national nuclear policies is essential. Specific to new reactors, the NRC in the U.S. holds public scoping meetings that are required under the National Environmental Policy Act (NEPA) for each new COL application. Other public meetings (meetings open to public) on new reactors are held for each project and NRC maintains a record of the meeting agenda and the meeting summaries. Public is a stakeholder in the regulatory process for the new reactors, and in addition to the public meetings, opportunities are also provided to request a hearing.

International Level Issues

International Standards

International Atomic Energy Agency has published safety standards and guidance documents that are relevant to the decommissioning subject and disposal of wastes. In addition, organizations such as IAEA, OECD/NEA and WNA provide information on safety assessments, technology updates and mechanisms for sharing and exchanging information.

Because the application of new reactor designs will be multinational in scope, international standards will be necessary that can be accepted across the national boundaries. An example will be the EPR design that is already under construction in France and in Finland and is also the selected design in several of the COL applications filed in the U.S. Thus, international standards and planning for decommissioning will also help better streamline the eventual decommissioning process. Another area where international standards will be helpful is the material recycling area, specifically, for metals from the decommissioned plants and establishing acceptable standards for the clearance levels.

International Programs, Cooperation and Coordination

International programs related to nuclear reactors have been coordinated by the IAEA and significant lessons in design, decommissioning experience, and international cooperation have been disseminated to member states. One of the latest cooperation programs relevant to this subject is the International Decommissioning Network (IDN) program.

International Experiences and Lessons Learned Related to End of Lifecycle Issues

Considering that some 115 power and research reactors worldwide have been retired from operation and are either undergoing decommissioning or are in various planning stages, substantial experience already exists in the field of reactor decommissioning. Dissemination of experiences and lessons learned is available through organizations, such as IAEA, OECD/NEA, as well as national agencies such as NRC and DOE in the U.S.

SUMMARY AND CONCLUSIONS

A common past misconception at reactor sites has been to treat decommissioning as an extension of the operating phase. During the decommissioning stage, the focus must shift from reactor systems and operations to decommissioning details and the actual decommissioning plans must be in place several years prior to the actual shutdown. The actions taken during the decommissioning stage are irreversible actions with a goal of removing the systems, materials, and structures as well as the contamination from the site and releasing the site for other uses. Thus, in the context of lifecycle management, decommissioning should be planned for right from the start, from the design stage though the operational phase to the eventual shutdown of the reactor at the end of its lifecycle.

Many factors will impact the end-of-lifecycle issues for the reactors yet to be built. There are many issues that are not under the control of the nuclear industry. These issues are national issues such as the disposition of spent nuclear fuel and the disposal of high level radioactive waste. There are other factors that will require international cooperation. However, there are many issues that are actually under the industry's control. Significant among these are the designs of the systems and facilities which can be optimized with respect to the eventual end-of-lifecycle issues.

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.

Some factors during the operation phase that could lead to an increase in the eventual decommissioning costs include, for example, potential degradation in operational performance or a major contamination event or an accident. On the other hand, innovations and developments in decontamination technologies could reduce the general decommissioning costs. Two important factors that have the potential to substantially change the decommissioning costs are the availability of facilities for radioactive waste disposal and the facilities for the storage and disposition of spent nuclear fuel.

The time to examine what decommissioning considerations should be taken into account is right from the design stage. Designing new reactors with end-of-lifecycle issues in mind 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 new reactors when they are eventually retired.

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