A Comparative Perspective on Reactor Decommissioning[1]

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ABSTRACT

A comparative perspective on decommissioning, based on facts and figures as well as the national policies, is useful in identifying mutually beneficial "lessons learned" from various decommissioning programs. In this paper we provide such a perspective on the US and European approaches based on a review of the programmatic experience and the decommissioning projects. The European countries selected for comparison, UK, France, and Germany, have nuclear power programs comparable in size and vintage to the US program but have distinctly different policies at the federal level.

The national decommissioning scene has a lot to do with how national nuclear energy policies are shaped. Substantial experience exists in all decommissioning programs and the technology is in a mature state. Substantial cost savings can result from sharing of decommissioning information, technologies and approaches among various programs. However, the Achilles' heel for the decommissioning industry remains the lack of appropriate disposal facilities for the nuclear wastes.

INTRODUCTION

Safe and cost-effective decommissioning of reactors when they are retired is necessary not only from the public health and safety perspective, but also from the fact that successful decommissioning is imperative for nuclear to remain a viable energy option.

With a large number of reactor decommissioning projects in advanced stages in the United States, and several European and other countries, substantial experience now exists on the technical and non-technical aspects of decommissioning. Yet, there is no unique or preferred approach to decontamination & decommissioning (D&D) of reactors because the D&D inherently depends on national policies, approaches, circumstances, and standards. While in principle, the US and European approaches are similar in the sense that they involve immediate decontamination and dismantlement or safe storage (or some combination of both), there are significant differences in actual application of these decommissioning approaches.

This paper provides a comparative perspective on the US and European (UK, France, and Germany) approaches based on a review of the programmatic experience and the decommissioning projects that are currently underway. A complete comparative evaluation would include the areas: decommissioning policies, approaches, regulatory requirements, and industry trends; economic aspects; disposition of bulk

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[1] The views expressed in this paper are those of the authors and do not necessarily reflect the views of their employers, customers or funding agencies.

materials; spent fuel disposition and disposition of radioactive waste; site release criteria and license termination; and Public acceptance. However, given the extensive nature of such an evaluation and the space limitations of this paper, the discussion in this paper is limited to the impact of decommissioning policies and approaches and the economic aspects.

A comparative perspective based on facts and figures as well as the government policies in this regard is useful in identifying the mutually beneficial "lessons learned" from various decommissioning programs.

NATIONAL POLICIES AND APPROACHES

U.S. Perspective

US Decommissioning Scene

The U.S. commercial nuclear reactors fleet is the largest national fleet in the world with a generation capacity greater than the combined capacity of three of the largest nuclear producers in Europe (France, Germany, and UK). With 103 operating reactors, over 780 billion kWh generated annually, and an estimated investment of over 700 billion dollars, nuclear industry is also a very significant part of the energy industry. It accounts for about 20 percent of the nation's total electricity production.

On average the reactors in the United States are a quarter of a century old but no new reactor construction has occurred in three decades. Even though recent federal energy policies have provided economic incentives for new build, it is uncertain whether any new nuclear generation will come on line in the near future. Rather, a significant current trend in the industry is to extend the licensed operating period of the reactors that are close to the end of their current license. About two thirds of the operating reactors have either received license extensions, formally applied for it, or have informed the regulatory authorities that they are considering it. Up until a decade ago this was not the norm and a few if any reactors were considering license extensions. Nevertheless, with an expected energy demand to increase by at least 50% in the next two decades, it is clear that additional nuclear capacity through new build will be necessary. However, the utilities have found that it is much more cost-effective and convenient from regulatory perspective and from public's acceptance perspective to re-license the existing reactors for another 20 years. Even though the political climate in the country has been not been in favor of nuclear in the decades past, the current government energy policies are pro-nuclear and provide incentives for new build.

A significant cause of the anti-nuclear public sentiment in the country may be the lack of public trust in the industry's and government's abilities to deal with the decommissioning waste and the spent nuclear fuel. The storage facilities for spent fuel alone (such as the Independent Spent Fuel Storage Facilities, ISFSIs) cost 70 to 100 million dollars each, which many utilities have opted to construct on site..

Considering that the public ultimately pays for the reactor decommissioning through the accumulation of decommissioning funds through a levy on the electricity rates, the public expects a cost-effective and safe decommissioning of the reactors when they are retired. The reality is that for nuclear to remain a viable energy option, the decommissioning costs need to be carefully controlled, the decommissioning funds need to be carefully managed and utilized, and above all, the U.S. Department of Energy (DOE) must find a way to ensure the cost-efficient management of spent fuel from the utilities on an interim basis until Yucca Mountain repository is opened.

The decommissioning framework in the United States is governed by the regulations in the Code of Federal Regulations (CFRs); primarily by the provisions of 10 CFR 20 and 10 CFR 50. However, some provisions of 10 CFR 30, 40 and 70 also apply. The U.S. Nuclear Regulatory Commission (NRC) is the regulating agency and the relevant NRC guidance is provided in several documents including NUREG-1757 (Consolidated NMSS Decommissioning Guidance), NUREG-1700 (Standard Review Plan for Evaluating Nuclear Power Reactor License Termination), and Regulatory Guide 1.184 (Decommissioning of Nuclear Power Reactors).

Three alternatives are defined by the NRC as acceptable methods for decommissioning: DECON (immediate dismantlement of the plant, beginning as soon as it closes), SAFSTOR (a delayed DECON option) and ENTOMB (entombment of the reactor in concrete).

The decommissioning process requires notifying the NRC of the intent to decommission 2 years in advance of the anticipated shutdown, eventually preparing and submitting a decommissioning plan and receiving approval from NRC prior to start of decommissioning activities. It should be noted that a number of activities can proceed under the Post-Shutdown Decommissioning Activities Reports (PSDAR) and in fact, many of the decommissioning activities have occurred during this stag at the current decommissioning projects.

When the licensee removes the fuel from the reactor they must notify the NRC, which then rescinds the authority to operate the plant and issues a possession only license (POL) which allows the utility to own the plant and it's fuel, but not to operate the plant. Within two years a written decommissioning plan must be submitted which includes the proposed schedule for accomplishing the steps outlined in the plan. The decommissioning plan is made available to the public and a public meeting is held 90 days after submission of the formal plan and 30 days after the public meeting the utility can begin implementing the plan.

Ultimately, the license termination and release of the site is governed by the License Termination Rule (LTR), 10 CFR 20 Subpart E (10 CFR 20.1401-1406), which was published by the NRC in 1997. The LTR sets a total effective dose equivalent (TEDE) limit of 25 mrem/y (0.25 mSv/y) to an average member of the critical group for an unrestricted release of a decommissioned site. It also requires the application of ALARA. It should be noted that the NRC regulations also require reactor licensees to submit and License Termination Plans before the site to the license is actually terminated. Differences in site release criteria between various agencies, especially the NRC and the U.S. Environmental Protection Agency have been subject of much debate. A Memorandum of Agreement between the two agencies was reached on this issue in 2002 [1].

Nineteen reactors are currently undergoing various stages of decommissioning; in addition, licenses of four reactors have been terminated after successful decommissioning. It is worth noting that of the three alternatives defined earlier, the shut down power plants have opted for either the SAFSTOR or the DECON alternative; none have opted for the ENTOMB alternative. A lot has changed since the alternatives were defined in the 1988 GEIS (NUREG -0586). While in principle all alternatives are feasible, political realities of today and the economic considerations set these alternatives considerably apart.

European Perspective

European Decommissioning Scene

Article 37 of Euratom Treaty provides the general guidance on decommissioning and it requires the preparation and submission of the decommissioning plans. Actual regulatory requirements are national requirements in the specific countries. In the three countries selected for comparison (UK, France and Germany), the national policies, approaches, and the regulatory requirements are summarized below from the perspective of this paper.

The UK has the oldest nuclear program in Europe with the first commercial nuclear power coming on line in 1956. The type of reactors include the Magnox (gas cooled, graphite moderated), AGR (Advanced Gas Cooled Reactor), SGHWR (Steam Generating Heavy Water Reactor), PWR, and FBR (Fast Breeder Reactor). Currently operating 23 reactors supply approximately 74 billion kWh annually, about 20% of the nation's electricity. The government policy favored nuclear energy up until the 1980s. Starting in 1988, uncertainties about the future of nuclear power have emerged, mostly related to cost. As the electricity industry privatized starting in 1989, the nuclear power remained in the public sector and by 1995 the government had stated that no public sector support for building new nuclear plants was warranted.

The power reactor decommissioning scene is summarized by 21 reactors at 10 sites that are undergoing decommissioning. They are primarily Magnox type, with one each of AGR, FBR, and SGHWR type. The diversity of the reactor concepts and the various design types in some concepts create challenges in decommissioning. One specific issue in decommissioning in contrast to the US program is the management of graphite from the gas cooled reactors.

The principal regulating provisions are from the Nuclear Installations Act of 1965, which governs the construction and operations of the nuclear plants. The UK Nuclear Installations Inspectorate (NII) controls the regulatory aspects of reactors including decommissioning and compliance with license conditions. NIREX formed in 1982 is responsible for developing an ILW facility. The Nuclear Decommissioning Authority (NDA) was created under the 2004 Energy Act and became operational in April 2005. It is the agency responsible for cleaning up UK's nuclear legacy including the reactors.

The primary decommissioning strategy in UK is to leave the reactors in the SAFSTOR condition for periods ranging up to 100 years. The underlying reason for this option is clearly the lack of disposal facilities in the UK for various types of waste. This strategy is however, currently undergoing change with the NDA trying to reduce the time period to 25 years for decommissioning the legacy sites.

The UK regulatory system is based on broad environmental goals in contrast to the US standards that are very prescriptive in nature. While there are merits to both approaches, it would appear that the regulatory system must function such that the appropriate standards are always met. Otherwise, the result may be inconsistent decommissioning standards and different levels of cleanup. For releasing sites for unrestricted use, appropriate standards need to be applied in each case to avoid revisiting the sites for further clean up. If sites are released with restrictions, the life cycle costs for the project must be taken into account with respect to maintaining restrictions and surveillance on the site

France has the strongest nuclear energy program in Europe with over 75% of its electricity derived from nuclear power reactors resulting from a long-standing policy favoring nuclear energy based on the national desire to maintain energy security. The 59 reactors operated by Electricite de France (EdF) supply over 420 billion kWh annually. Eight early reactors were gas cooled, but all currently operating units are PWRs of different capacity designs. In addition, the fast breeder reactor Phoenix is being used for research and development only. The breeder power reactor Super-Phoenix was closed down in 1998 and is being decommissioned. Eleven experimental and power reactors are being decommissioned, eight of them the gas cooled, graphite moderated type, six of which are similar to the UK's Magnox reactors. The other three are the Super-Phoenix mentioned above, a 1966 prototype PWR at Chooz, and an experimental GCHWR at Brennilis. As far the currently operating reactors are concerned, the uniformity of design (all PWRs) will clearly translate into standardization of decommissioning techniques, disposal criteria, and cleanup methodologies, leading to more cost effective decommissioning.

In France, the Nuclear Safety Authority (Autorite de Surete Nucleaire, ASN) is the regulatory body and it reports to the Minister of Environment, Industry & Health. The DGSNR (General Directorate for Nuclear Safety and Radiation Protection) was set up in 2002 to integrate functions of two other bodies and to implement government policy. The high level waste management is pursued under the 1991 Waste Management Act and it is in the research stages at sites located in clays and granite. Low level radioactive waste management in France is managed by ANDRA (Agence nationale pour la gestion des dechets radioactifs), the waste management agency set up under the above act.

Since 1998, the German nuclear power program has been in the process of being phased out under the government directions. The operating 17 reactors generate approximately 158 billion kWh annually, about 33% of the nation's electricity supply. Phasing out the nuclear energy was the policy of the government after the 1998 federal election; however, since 2001, a compromise has been not to implement immediate shutdowns but to limit the operational lives of the nuclear reactors to an average of 32 years. The power reactors are of two types, PWRs and BWRs. The decommissioning program involves 18 reactors; two of the reactors have been completely dismantled and the sites released from regulatory control.

In Germany, the decommissioning is covered under Article 7 of the German Atomic Energy Act. The approval and licensing power rests with the Federal Ministry of the Interior and the State government. Most states in Germany impose very stringent conditions on all nuclear operations. The system allows for various stages; storage with surveillance, partial decommissioning and restricted release; and decommissioning and unrestricted release. The government agency, BfS (German Federal Office for Radiation Protection) is responsible for construction, operation, and disposal of repositories for radioactive waste.

ECONOMIC FACTORS AND INDUSTRY TRENDS

U.S. Perspective

Industry Trends

In the U.S., it appears that the nuclear industry is now poised for a resurgence. A combination of factors, energy demand and oil prices among others, have led to a climate where nuclear energy is likely to come out of the slump. There is even talk of new build nuclear capacity at the national level. The government has recently provided political support and incentives for the nuclear industry in the Energy Bill of 2005. This continues from the Energy Policy Act of 2003 that provide financial incentives for up to the first 6,000 MW of new nuclear power generation.

The projections of electricity demand show a continued growth in the decades ahead. Total electricity demand is expected to grow to 5500 billion KWh by the year 2025 from the 2005 demand of slightly below the 4000 billion kWh. Building of perhaps five new reactors by 2015, a dozen by 2020 are possible based on some estimates.

This potential resurgence in the fortunes of the operating nuclear industry means, that more and more industry is doing everything to extract as much power from the reactors as possible and less and less the utilities are thinking of decommissioning the reactors. The current industry statistics bear that out.

The capacity added through improved performance (higher capacity factors) and power uprates during the past decade (1994 to 2004) has amounted to an equivalence of adding 18 reactors of 1000 MW each.

Nineteen reactors have implemented power uprates with NRC approval, typically in the 4 to 5 % range. A number of the plants are running at 100 % capacity or very close to it.

The production costs of nuclear have been coming down to reach a level of 1.69 cents per kWh in 2004, a level that is competitive with coal and is actually lower than the kWh costs of oil and gas plants. And the industry’s safety record has also remained excellent as compared to other industrial sectors.

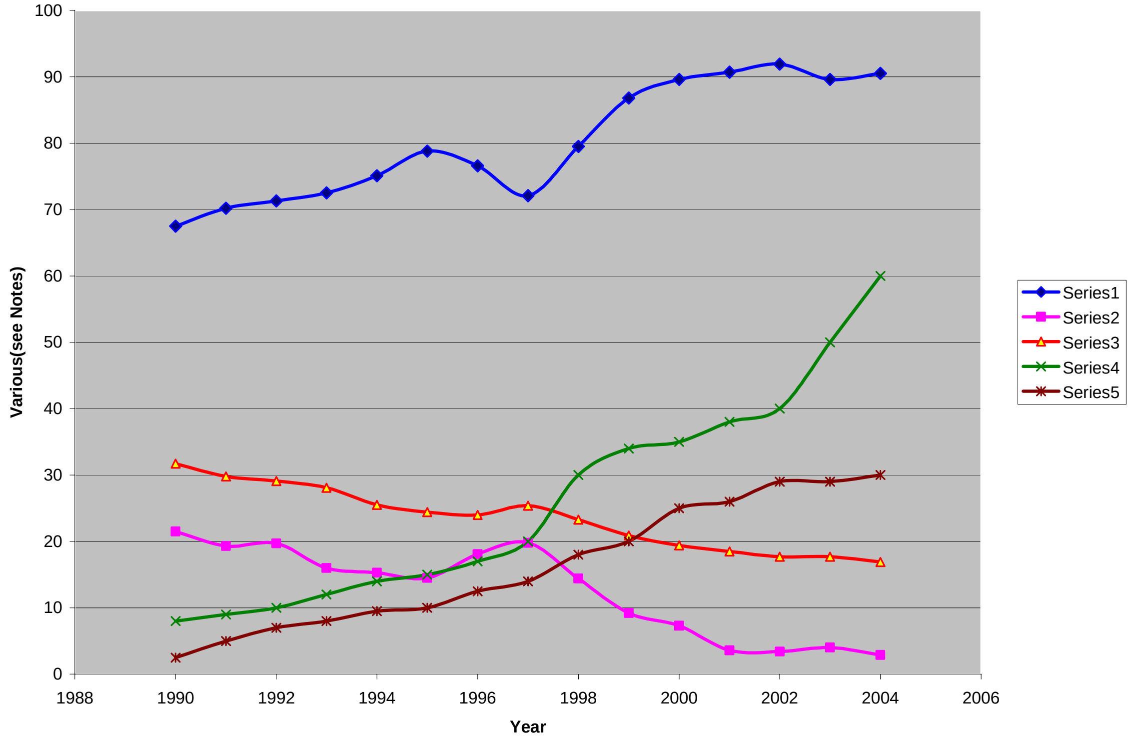
Fig. 1 shows the leading indicators for the nuclear industry. The data has been compiled from the industry data bases and from the information gleaned from NEI, NRC and INPO. The performance of the operating reactors has achieved excellent ratings. The capacity factors are at all time high approaching an industry average of over 90%. The License Event Reports (LERs) which are issued by the NRC for violations are events, have gone down to low numbers over the past decade. (Note that LERs given here are totals of all categories and the serious category events a tiny fraction of these). Economic performance of the industry is excellent to appoint where it is directly competitive with coal. Current costs of nuclear energy production including fuel costs are at 1.7 cents per kWh.

Two issues that are important to decommissioning (also to operating reactors), we see that the storage capacity for spent fuel is lacking. By 2004, 60% of the spent fuel pool capacity was filled and projections show that in the next five years, the filled spent fuel pool capacity will reach 95%. This has major implications for the operating reactors as well as the decommissioning reactors and the utilities have no choice but to build on-site dry fuel storage facilities at a large expense. Disposal costs of low level radioactive wastes (LLRW) have increased dramatically to a level of \$300 per ft^3 in 2004 for Class A waste at the nation’s primary commercial LLW disposal facility in Barnwell, South Carolina. This, combined with a regulatory void for a reasonable and cost-effective disposal of bulk materials, creates a major obstacle for the decommissioning projects.

The Spent Nuclear Fuel (SNF) in the United States is a federal responsibility and the Department of Energy (DOE) has been conducting extensive site characterization studies during the past two decades at the Yucca Mountain site. A licensing application is expected to be submitted to NRC under the 10 CFR Part 63. The current DOE schedule shows the repository to be open for operations in 2010.

Relicensing of the reactors that are approaching the end of their licensed operating period is the main trend in the Us nuclear industry. March 2000 became a historic date for this sharp turning point when the NRC renewed the operating licenses of the two units of Calvert Cliffs nuclear power plant located at Lusby, Maryland, for an additional 20 years. As of December 2005, 35 license renewal applications had been granted, and 14 were under review; in addition 27 new applications have been announced (intent to renew). That is 74% of the operating reactors going for license applications and more may soon follow. In fact, relicensing is now expected for virtually all the operating nuclear power reactors in the United States.

Another significant trend has been the recent consolidation in the nuclear power plant ownership. The U.S. electrical industry is in the midst of an overhaul. Whether deregulation will lead to renewed private investment in nuclear projects is uncertain. However, since 1998, more than a dozen old plants were sold, some fetching impressive sums. Large energy companies like Exelon, Entergy, and Dominion have recently made such acquisitions.



Series 1: Capacity Factors; Y scale in %
Series 2: LERs; Y scale: x (times) 100
Series 3: Nuclear Energy Cost in Cents per kWh; Y scale: x 0.1
Series 4: Cumulative Filled Spent Fuel Pool Capacity; Y scale in %
Series 5: LLRW Disposal Cost in $ per ft3; Y scale: x 10

Fig. 1. Leading indicators for the US nuclear industry

The NRC has also implemented a new oversight and assessment process for nuclear plants. A summary of this topic can be found in the Nuclear Energy Institute (NEI) Status Report) on Nuclear Power Plant Regulation [2]. Among others, the improvements are in the areas of developing and implementing a new process to assess the nuclear plant performance, developing a new enforcement process focusing on safety-significant issues, and launching a comprehensive, multi-year initiative to revise the regulations where necessary. The regulatory process is also more open with enhanced participation from stakeholders and public.

Decommissioning Funds

Current estimates for decommissioning a full size reactor in the U.S. are generally in the $500 million - $650 million range. The NRC requirements for decommissioning funds are generally the minimum regulatory based requirements under 10 CFR 50.75 (b) and (c) and are much lower. However, the minimum requirements for decommissioning funds do not cover all the decommissioning costs – for example, the restoration of the site. The operators collect decommissioning funds through a levy on the electricity rates during the operational life of the reactor. In the past several years the US Congress has allowed some flexibility as to how these funds are invested. Of the estimated total (minimum) cost of approximately $40 billion for the nation's fleet of nuclear power plants, about $30 billion had been collected into the decommissioning funds.

It should be noted that the total cost of decommissioning can be significantly affected by the decommissioning option chosen, the sequence and timing of the various stages of the decommissioning program, and the availability of disposal sites for the radioactive waste and the storage options for the SNF. An evaluation of the cost-benefit analysis of whether to delay or not delay decommissioning is discussed in a recent paper presented at International Conference on Environmental Remediation and Radioactive Waste Management [3].

Disposition of Bulk Materials

Decommissioning of a commercial nuclear power plant generates large quantities of solid bulk materials such as concrete, metal, and demolition debris. Disposition of such materials has a large impact on the overall decommissioning cost. Yet, there are no clear and cost-effective alternatives for the disposal of these materials from a regulatory perspective in the United States.

Even though the NRC has been in the rule making status on this issue for the past several years it is no closer to a final rule. In the meanwhile, because of a lack of specific guidance and consistent free release standards, application must be made to NRC on a case-by-case basis under either a Technical Specification amendment or a 10 CFR 20.2002 submission, which still would classify these materials as radioactive waste.

Based on the estimates in a 2002 report by the National Academies [4], disposition of bulk materials (concrete and metal) from decommissioning of the nation's nuclear power plants could range from $4.5 billion to $11.7 billion based on the current costs and depending on the LLW disposal site chosen. If regulatory mechanism were in place and slightly radioactive material could be sent to local landfills (Subtitle D or RCRA Subtitle C), the disposal cost for the above would range from $0.3 billion to $ 1 billion. Clearly, the cost of the regulatory void is substantial. Disposition of materials has been the subject of rulemaking efforts by the NRC for several years. A more detailed discussion of the issue is available in a paper presented previously [5].

European Perspective

The data for the countries selected for comparative perspective and the information on European programs in general has been gleaned from published literature and the web information centers; specifically, References [8 – 13 and 14,15]. In addition, relevant international decommissioning experience is documented by the International Atomic Energy Agency in two TEC-DOC reports [6,7].

Industry Trends

Under the present UK situation, according to the literature reviewed, no uprates are expected at the currently operating reactors and no relicensing plans have been announced. It should be noted that most Magnox plants are licensed for 40 year lifetime. The UK government policy supported the increased share of nuclear power in the nation's energy mix up until the 1980s. In 1989 the deregulation and privatization of the energy sector began but all nuclear power generation remained in the public sector. In 1995, a review of the nuclear power was published in white paper, confirming the government's commitment to it but stating that no public sector support for new nuclear plants was warranted [14]. In a white paper on keeping the nuclear option open which was issued in 2003, the government acknowledges that it should not rule out the possibility that new nuclear build might be necessary at some point in the future [15]. It also adds that any future decision to proceed with the building of new nuclear power stations will need to be based on the fullest public consultation.

Even though the operating power reactors in UK have performed well with on average over 70% capacity factors (even 90% in 2004), the nuclear share of the nations total energy mix has steadily decreased in the past decade. Economic competitiveness issues and technical problems with old Magnox reactors have led to the shutdown of several reactors.

Programs in the 1970s and 1980s explored the geological disposal concepts but the programs were eventually shelved. While UK NIREX has developed a concept for the ILW/LLW, the repository concept for HLW/SNF is provisional at this time. UK has only one operational radioactive waste facility, the Drigg site, which takes only solid low level radioactive waste. The intermediate level waste and the high level waste are stored at the Seallafield site.

In France, the reactors have generally had available capacity factors higher than 80% (83% in 2004) even though due to load following, the actual capacity factors have varied in different years. Some license extensions have been granted for 10 years and EdF has also uprated some reactors, typically in the 3% range. However, the long-term plans are to replace the operating reactors when they are retired with European Pressurized water Reactors (EPRs) or other advanced designs. In fact EdF is planning to start construction on the first EPR in near future for a planned operation in 2012. Recent energy legislation passed in July 2005 continues a strong commitment to nuclear power in the nation's energy mix. One outstanding feature of French energy policy has been the extensive public debate, which may be the one of the reasons why French public in general is supportive of the nuclear energy.

Since, the French national policy is to reprocess waste, the HLW from reprocessing is vitrified and stored in surface vaults until the development of a final repository. Research is being conducted at sites located in clays and granite. Low level radioactive waste management in France is managed by ANDRA. Centre de la Manche that received waste with short-lived radionuclides for 25 years is closed. Two disposal facilities that are open include the surface facility at Morvilliers for very large volume waste with very low radioactivity and the surface facility at Soulaines (Aube disposal center) for conditioned type A waste. Other wastes, such as ILW and HLW, are currently placed in interim storage at the nuclear sites.

In Germany, phasing out the nuclear energy has been the policy of the government after the 1998 federal election and the amendment of the German Atomic Energy Act in 2002 calls for an end to the commercial nuclear energy production in a structured manner. The federal election in September 2005 resulted in a coalition government and contrary to nuclear industry expectations, it is unlikely that the phase out legislation will be reversed in near future. Thus, under the current situation, no reactors are likely to be relicensed or uprated. In the long-term however, the fate of the nuclear industry may depend on German public's view towards the nuclear energy and the energy demands of the nation. The existing reactors have been performing at very high capacity factors, above 80% (89% in 2004). However, in 2005 another station (Obrigheim) closed leaving 17 operational units.

No disposal facility is currently available in Germany. Morsleben repository that was used for the disposal of low level waste has been closed. The Gorleben site which was being investigated for HLW is under moratorium. One the of the reasons given by the federal government was the uncertainty of the suitability of the rock slat for such disposal. However, the government's own agency BfS has confirmed recently (in 2005) the suitability of rock salt formations for such repository development. Konrad repository project (in the iron ore mine) was also terminated. Extensive research has been done on the deep geological repository concept in the past but the since the 2000 moratorium was issued, further research at the existing locations suspended and plans call for finding the most suitable site in Germany with a possible operation of the repository in 2030. The situation is clearly more political than technical and decisions in this regard remain in a flux at the present time.

In Europe, the nuclear power costs (per kWh) are comparable to those in the US and the nuclear energy costs are much lower than the fossil fuels. Overall track record of nuclear industry in terms of public safety and worker safety remains excellent when compared to other industries.

Decommissioning Funds

There are distinct differences among various European Union countries in the way the decommissioning funds are collected and managed and the European Commission has been promoting harmonization of decommissioning funds for some time.

In UK, the funds are managed internally but with special control under the government authority. The NDA was set up by the UK government under the Energy Act 2004 and came into being in April of 2005. The nuclear cleanup may cost £56 billion for decommissioning and cleaning up 20 sites. The NDA has moved the time frame of the cleanup from 125 years to 25 years.

In France and Germany, the nuclear operators manage the decommissioning funds and there appears to be more flexibility in their use.

In France the EDF sets aside EUR 0.15 cents/kWh and the fund at the end of 2004 had collected EUR 13.4 billion. It should be noted that the national policy in France is to reprocess the spent fuel. Thus, out of the above funds, EUR 9.6 billion are earmarked for reprocessing and EUR 3.8 billion for disposal of high level and long-lived waste.

The amendment of the German Atomic Energy Act in 2002 calls for an end to the commercial nuclear energy production in a structured manner. The expected costs for decommissioning nuclear power could range from 500 million Euros to 1 billion Euros. The decommissioning cost for all nuclear facilities could be as high as 25 billion Euros. The German industry has to cover the costs of decommissioning the nuclear facilities and the disposal of resulting radioactive waste. The operating plants accumulate decommissioning funds during their operation.

Under the present situation, the German industry lacks the availability of disposal even for the low level waste. The Morsleben repository (used for LLW and some ILW) was shutdown in 1998, the Konrad repository has not operated and is tied up in litigation and the Gorleben repository has also not yet operated and is also under moratorium.

Disposition of Bulk Materials

Of the three European countries considered, observations are made here only on the German experience where specific information is available which can be used for illustrative comparison of this issue in the United States. Some German estimates show that only about 2 to 4 percent of the total material generated from PWR and BWR decommissioning may require disposal as radioactive waste. The rest can be decontaminated and disposed of. A major portion will have very little radioactivity and can be released under the clearance criteria. The German Commission on Radiological Protection Recommendations (Strahlenschutz Commission) in the SSK 1988 report specified the 10 μSv/y criteria and provided specific radioactivity levels in materials for the clearance purpose. The criteria are consistent with the IAEA clearance guidelines which provide a criterion of 10 μSv/y for individual dose and 1 man Sv criteria for collective dose.

SUMMARY COMMENTS AND CONCLUSIONS

Based on the discussion above, some qualified comments can be made and some lessons learned can be listed.

1. The national policies and public opinion drive the future of nuclear power in various countries. This in turn affects the decommissioning scene. In the US, recent national energy policies have provided financial incentives for new nuclear build. The industry trend is to relicense the operating reactors for additional 20 years. Almost all of the reactors are expected to pursue this option and it is expected that no new commercial reactors will enter the decommissioning scene. In addition, at least two companies have already announced plans for submitting Construction/Operation License (COL) [16, 17] and three applications have been filed by various companies for the Early Site Permits (ESP) [17]. In UK the future of nuclear power is uncertain. The NDA that came into being in April of 2005 consolidates all the legacy nuclear sites and reactor decommissioning under one umbrella. In France where there is a strong national policy in support of nuclear power, it is expected that new reactor build will soon on the horizon. As opposed to US, the French program focuses on less (and shorter) license extensions; instead, the belief is that the reactors approaching retirement should be decommissioned and replaced with new reactors. In Germany, since 1998, the national policy calls for a phase out of the commercial nuclear power. As their current license period will run out, the reactors will enter the decommissioning phase, some without significant operational periods.

2. Substantial experience in decommissioning in the US and the European countries exists and many technologies for decommissioning have been developed that are of benefit to other decommissioning programs. Some programs have specific expertise because of the type of reactors in their fleet; for example, management of graphite from decommissioned AGRs (Advanced Gas-cooled Reactors) in UK and the German experience at Greifswald and Rheinsberg, where 6 WWER (Russian design pressurized light water reactors) are being dismantled is of benefit to such programs in rest of Europe and in Russia where such reactors are in use. The costs of decommissioning AGRs are also much higher than the costs for decommissioning PWRs.

3. Countries with standardized designs or limited number of designs have the cost advantage as far as decommissioning is concerned, because of the cost savings through standardized decommissioning plans, D&D technologies, project management and regulatory submissions. An example is the US

system with PWR and BWR designs and the entire operating commercial French fleet with PWR design.

4. Substantial savings can be achieved by designing decommissioning into the new reactor design from the start. With smarter design, such as modular concepts, it is possible to limit the extent of the decommissioning waste.

5. There are major differences in the regulatory system in various national programs as far as the decommissioning standards and their application are concerned . For example the regulatory system in UK is based on broad environmental goals where as the US system is highly prescriptive with fixed standards for cleanup. In the US system not only are the release standards more prescriptive but demonstration of compliance with it is also prescriptive such as the application of the MARSSIM (Multi-Agency Radiation Survey and Site Investigation Manual) methodology [18].

6. Waste disposal issues continue to hamstring the decommissioning industry. There are no facilities under development for SNF in the three European countries discussed in this paper. In the US, the Yucca Mountain site has been designated as repository for SNF and HLW. Extensive site characterization work and associated disposal technology development work has been done over the past two decades and it is now closer to becoming a reality. Again, national policies have a bearing on such facilities. For example, in France the national policy is to reprocess fuel, hence different conditioning and disposal technologies are necessary. The LLW disposal programs are also limited in the three European countries discussed in this paper and commercial waste disposal is a major issue for decommissioning projects. In US, the availability commercial disposal for LLW at the present and uncertainties in the future access to commercial disposal have provided incentives for the decommission sites to choose the immediate dismantlement option.

7. Disposal of bulk materials are a substantial cost to any decommissioning program because of their large quantity. There are no specific regulatory standards in US for material release or recycle in this regard and the US regulatory program could benefit from the IAEA and EC release criteria applied in the European countries.

In conclusion, the national decommissioning scene has a lot to do with how national nuclear policies are shaped. In countries with a favorable opinion of the nuclear energy, the perception is that to build new reactors we must be able to safely decommission the retired ones. In US, even though there is a recent shift in support of nuclear power at the federal level, the utilities find it much more attractive to obtain license extensions than plan on building new reactors in the immediate future. Substantial experience exists in decommissioning of power reactors and the technology is in a mature state. The Achilles’ heel for the decommissioning industry remains the lack of appropriate disposal facilities for the nuclear wastes.

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