Strål
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Swedish Radiation Safety Authority

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Research

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On Decommissioning Cost for Nuclear Power Plants

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SSM perspective

A task for the present generation is to assure that Nuclear Waste Liabilities are assessed with a high degree of precision. The allocation of adequate financial provisions to the Swedish Nuclear Waste Fund is required to ensure that future generations will have available the necessary resources to undertake efficient measures in the decommissioning and dismantling (D&D) of nuclear power plants and other nuclear facilities that have been shut down permanently.

SSM is engaged in an on-going review to secure the quality of estimated future D&D costs, inter alia for the entire fleet of Swedish commercial nuclear power plants. Some of these reviews utilise the assessments prepared by external and independent experts, which enhances the transparency of the process and contributes to a higher level of confidence in the conclusions, for all stakeholders.

Objectives

The main objective of this study has been to investigate the extent to which changes and developments have occurred concerning the financial resources required for the D&D of nuclear power plants in Sweden, Germany, the U.K. and the U.S.A., as a basis for guiding the SSM process of reviewing financial accruals to cover this part of the Swedish 'nuclear legacy'.

Results

This research report summarizes what has changed over the latest 15 years concerning actual and estimated costs for the D&D of nuclear power plants that have been shut down permanently. It also reports on the availability of detailed information for actual nuclear power plant D&D cost breakdowns.

The results will be one supporting document in the review of the estimates submitted for the decommissioning cost of the Swedish Nuclear Power Plants under the Nuclear Liability Act. An additional benefit will be that the findings of the study also can contribute in the validation of the appropriate fees that is charged according to the so-called Studsvik Act in respect of the future cost for decommissioning of the permanently shut down central heating reactor in Ågesta.

Need for further research

It is evident that it has been some important changes in the last 15 years, including modified waste management and disposal routes, more prescriptive regulatory requirements and improvements in the availability and cost of equipment. In addition, some significant actual power plant D&D projects have been completed, or are well under way, which provides new references for benchmarking Swedish cost estimates against actual international experience. These factors make it worthwhile to undertake a more comprehensive review, based on contemporary data, of the reasonableness of the decommissioning cost estimates for Swedish NPPs; in a first step addressing PWRs, followed by a study of BWRs in a second step.

Project information

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1. Introduction

A detailed inter-comparison of NPP decommissioning costs was performed by NAC and reported to SKI in September 1995. This study compared decommissioning plans and cost estimates for selected PWRs and BWRs in Sweden, Germany and the United States.

The nominal estimates indicated that the Swedish cost estimates were about two times the estimated cost in the U.S. for the same size and type of reactor but only about half of the cost estimated in Germany. The NAC comparison study investigated these differences and succeeded in explaining the rational reasons for virtually all of the apparent discrepancies.

That study was completed around 15 years ago and the decommissioning sector has experienced substantial developments and progress over the intervening period.

At the time of the study a cost estimate for decommissioning the Trojan PWR in the U.S. was selected for comparison with the sister reactor at Ringhals 2. Since then Trojan has actually been decommissioned, so there is information on actual project execution and related costs, rather than just cost estimates. Other reactors have been shut down and decommissioning programs begun. Financial arrangements related to decommissioning also have evolved.

Other things have changed, including benefits from the feedback of experience, modified waste management/disposal routes, possible changes in regulations and advances in technology for dry storage of spent fuel. Also the Swedish decommissioning cost estimates have been revised, the latest versions having been prepared in the early years of the 2000s. New, individual cost estimates for the Swedish NPPs are in the pipeline and will be submitted to the authorities in the near future.

In light of these changes, an updated inter-comparison of Swedish NPP decommissioning cost estimates (PWR and BWR) versus relevant international benchmarks is under consideration. This report summarises the results from an exploratory investigation of what has changed over the last 15 years, including evolution of methods for calculating NPP decommissioning costs and the related funding of those liabilities, as well as what sources of information are available in sufficient detail to support a subsequent comprehensive review of the reasonableness of Swedish NPP decommissioning cost estimates.

2. Germany

2.1 Important Developments 1995-2010

2.1.1 Overall Strategy and Approach

During the 15 years between 1995 and 2010, a number of things have changed related to NPP operations in Germany that will impact NPP D&D activities and associated costs. These include:

- A ban on spent fuel transports to the reprocessing plants in La Hague and Sellafield from mid-2005 onwards and the corresponding development of long-term, AFR, interim dry storage of spent fuel at the NPP sites.
- In 2002, granting of the permit to operate the repository KONRAD for low and intermediate level wastes, with a scheduled start-up in 2014/15.
- In 2010, prolongation of the lifetime of 17 NPPs by between 8 and 14 years.

In 1995 two general approaches were considered as candidates for D&D:

- Safestore, to allow time for the decay of heavy component radioactivity over a period of about 30 years, with deferred final D&D (including decontamination and segmentation of the heavy components)
- Immediate dismantling.

In both cases the final objective was to achieve green field status. Since 1995 the NPP operators have increased their understanding of the issues, through feedback from NPP D&D projects in Germany and elsewhere in Europe. Working Groups of the NPP operators have provided a forum for the exchange of relevant know-how and experiences. Based on this feedback, the German NPP operators now have decided in favour of the immediate dismantling method and against the safestore approach. This decision was made in order to have a greenfield site available for other use approximately 10 years after final shutdown of power generation. Some reactors that were being prepared for the Safestore option now are expected to change approach and switch to the near-term dismantling strategy.

The advantages of immediate dismantlement method are considered to be as follows.

- Existing technical support systems can be used for pre-dismantlement work, such as radioactive mapping and other characterization of different areas of the NPP, measurements on plant and equipment items.
- The knowhow of experienced operational staff can be utilized and the risk of losing important records and related understanding, can be minimized. This contrasts with the safestore approach where reliable records and plant experience would need to be available perhaps 30 years after shutdown.

The dismantling of installations in the NPP radiation control area will take place in four to five phases, followed by conventional demolition of residual buildings and structures. An example for the Stade reactor involves four phases, as follows:

PHASE I :

- Material air lock and air recirculation unit;
- Flood tanks
- Control rod drive assemblies
- Pressurized water tanks

PHASE II:

- Steam generator
- Primary Coolant
- Pipe systems including pumps

PHASE III:

- Controlled are concrete structure
- Fuel racks
- Reactor Pressure Vessel
- Concrete Shielding

PHASE IV:

- Polar crane
- Fuel Transfer Platform
- Ventilation Plant
- Water Purification Plant

This phasing of work programs is considered to be decisive in order to perform the D&D activities in a well understood, efficient and cost-effective way.

D&D activities begin directly after shutdown of the NPP. In the first transition phase, which typically will last for about five years, spent fuel and core components are removed from the reactor pool and transferred into away from reactor (AFR) on-site storage facilities, currently using dual-purpose (transport & storage) metal casks. Prior to dismantling, auxiliary systems that are not needed in support of D&D are shutdown and separated from the operating systems, emptied (if necessary), cleaned and permanently isolated. The interfaces are controlled and documented. This measure leads to significant cost savings.

In order to comply with the rules and radiation exposure limit values specified in Germany's Radiation Protection Regulations (STSV), it is necessary that the characterisation exercise achieves:

- Thorough and careful cataloguing/registration of relevant parameters for all facilities, buildings and areas
- Classification of equipment and building materials into clearance categories .

These steps provide a basis on which the project management team can develop a detailed D&D plan. The plan must include details on the necessary facilities and capacities for dismantling and treatment of residual material and a time plan for storage. This includes the planning of interim storage facilities for spent fuel and wastes, as well as for conditioning and storage of the materials on-site until the relevant repositories are available to accept them for final disposal.

The status of nuclear power plant (NPP) decommissioning (D&D) projects in Germany, some completed and some on-going.

Table 2.1 Status of Recent Completed and Active German NPP D&D Projects

VAK Versuchsatomkraftwerk (BWR) [2]	Status: completed in 2010
KRB-A Gundremmingen (BWR) [3]	Status: work in progress, since 2006 usage of the buildings- except the reactor building-as a technology centre for the development of processes for cutting and cleaning of radioactive contaminated materials prior to clearance by the radiation protection staff, and to accumulate know-how for subsequent decommissioning NPP projects
KWW Würgassen (BWR) [4]	Status: work in progress, completion scheduled in 2014
KWL Lingen (BWR) [11]	Status: Work in progress and originally designed to achieve safestore status. In 2008 RWE decided to change strategy and applied for a permit to allow immediate dismantlement.
KWO Obrigheim (PWR) [11]	Status: since the D&D permit was granted, on schedule, the transfer of spent fuel and core components from the reactor wet pool to the away from reactor (AFR) onsite dry storage facility (using dual purpose metal transport & storage casks) has been started, after which the actual NPP D&D activities can begin.
KKS Stade (PWR) [5]	Status: work in progress, completion scheduled in 2014/15
KMK Mülheim- Kärlich (PWR [6]	Status: work in progress, completion scheduled after the acceptance of the reactor vessel and other heavy components by the repository KONRAD. RWE does not have any on-site interim storage capacity for such wastes.
KGR Greifswald (WWER- 440) [7]	Status: work in progress, completion scheduled in 2012, safe enclosure and decay storage of radioactive components are ongoing. This project is managed by EWN, a daughter company of the Federal Ministry of Financial Affairs.

Specifically concerning physical D&D activities, significant improvements and changes have occurred over the last 15 years. These include:

- Improved techniques and technologies for decontamination and dismantling
- Changes in the regulatory requirements for waste conditioning and packaging, prior to interim storage and ultimately final disposal in the KONRAD LLW and ILW repository
- Changes to other licensing procedures and regulations. The ongoing D&D programs have been a learning process for the operators and also for the regulators. As techniques and tools have evolved, it has been necessary for the operators to apply to the state authorities for supplementary authorizations related to, for example, methods, processes and material recycle proposals.

- Changes to the estimated costs and related financial provisions for NPP D&D. Some components of the overall cost have decreased and others have increased.

These are discussed in the following sections.

2.1.2 Technologies and Techniques

Techniques and technologies have evolved over the last 15 years, with some D&D activities now performed by means of specialised, tailored tools and machines. The advances made have contributed to reducing dose uptakes, simplifying processes, improving efficiency, minimizing wastes and reducing costs.

2.1.2.1 Decontamination

In the initial stages of decontamination the main driver is the lowering of does uptake by the D&D workforce. German experience shows that even relatively low decontamination factors make a significant contribution to savings in dose uptake.

Afterwards, the avoidance of costly waste disposal solutions provides a strong economic incentive to assess the potential for reducing the level of contamination to the point where free release of materials is possible. Accordingly, decontamination methods used are specifically tailored taking into account the method of disposal.

In many cases it continues to be the case that surface contaminated components can be decontaminated by thorough washing or abrasion. A range of other techniques, some more sophisticated, have been improved and developed to deal with the more difficult decontamination tasks where radioactive contamination has penetrated significantly the materials surfaces.

Deep penetrated contamination can be removed by mechanical, chemical and electrical techniques. Examples, including experimental approaches, are:

- Steel grit lasting
- Water blasting with/without abrasive
- Chemical flushing
- Microwaves for the removal of concrete surfaces
- Laser ablation
- Electro-polishing technique that is particularly useful with complex surfaces.

2.1.2.2 *Dismantling*

The range of tools and techniques available now is extensive and includes, in no particular order of priority or degree of importance:

- large blade saws
- hydraulic shears
- cutting torches
- metal shredders
- oxyacetylene cutting
- plasma cutting
- laser cutting
- underwater contact-arc electro-thermal cutting
- elektro-discharge machining
- disc milling and grinding
- jackhammers and nibblers.

It is important that the available techniques include ones that are suitable for application under water. The further development of tools continues, with the aim of improving efficiency and cost effectiveness.

2.1.3 *Waste Disposal Alternatives*

In the 1990s the reactor operators received preliminary guidelines for waste packaging. Then in 2002 the permit for operation of the KONRAD low and intermediate level waste disposal facility was granted. This permit specified more restrictive requirements, to the extent that, to meet the KONRAD acceptance criteria, most of the already existing residues resulting from ongoing NPP D&D programs will have to be re-conditioned and re-packaged into standard containers and casks. This represents an extensive task, comprising:

- Qualification of casks and containers
- Qualification and approval of the products, after re-conditioning and re-packaging the wastes, by the competent authorities and their devolved administrations
- The preparation of the associated documentation

Completion of these tasks will add to the costs of D&D at ongoing projects. For NPP D&D projects yet to start there also will be a cost impact because part of the new requirements relates to more extensive measurement of radionuclide content in the wastes.

The cost implications of using the KONRAD facility for D&D wastes in the LLW and ILW categories provides a motivation to consider if a cheaper solution, albeit acceptable on safety and environmental grounds, might be developed in Germany. For example the disposal of LLW in a near-surface engineered repository instead of a deep geological formation like KONRAD. Such facilities are used elsewhere in Europe, including in France and the United Kingdom. Currently there is no process in place to facilitate such a change of strategy. However, with operating lifetime extensions having been granted to all of the reactors in Germany, there is a longer period before decommissioning starts. The intervening period, in principle, provides time for the nuclear industry in Germany to take up this challenge. Whether or not there will be sufficient will and motivation to do so in the complex (nuclear) political environment of Germany remains to be seen.

2.1.4 Regulations and Guidelines

As stated, restrictive Guidelines including; requirements for conditioning, packaging, transports in containers and casks, extensive documentation and witnessing of processes and products, as well as the disposal of radioactive and non-radioactive material to KONRAD and other repositories, were set up earlier by the competent federal ministry (BMU – Ministry of Environment) at the time of a Green-Red governing alliance and under the Authority of the Bundesanstalt für Strahlenschutz (BFS – Ministry for Radioprotection), which at the time was led by a president of Green political orientation. The provisional requirements for conditioning and packaging and disposal of wastes and residues were replaced in 2002 by the acceptance and operations specifications embedded in the permit for the repository KONRAD in 2002. This has had a strong impact on the tasks that have to be performed during NPP D&D and has resulted in a substantial increase in costs.

In contrast, at the individual state level, where the permits for D&D at the NPP sites are reviewed and granted by the competent authorities e.g. TÜV, the ongoing NPP D&D programs appear to be running in a smooth way. This generally productive environment has encouraged a positive attitude that has focused on minimising dose-uptakes, simplifying processes, improving efficiency, minimizing wastes and reducing costs by using better developed tools and machines.

Regarding safety clearance for unrestricted conventional recycling or re-use, materials must meet extremely stringent standards in order to qualify. This involves initial radiological characterization, control measurements and final clearance testing after decontamination.

There is a feeling that the current requirements are cumbersome and that more optimal arrangements could be achieved, through a combination of approved techniques and safety clearance procedures, that would generate significant cost savings.

2.2 Available Detailed D&D Cost Information

A considerable amount of decommissioning cost estimate information has been generated in Germany and it is updated annually. In addition ongoing D&D projects provide a basis for actual information to be gathered to compare with estimates. The extent to which this can be accessed for the use in a study that would become publicly available currently is not clear. NAC has been in contact with the service companies who support the development of utility D&D cost estimates and this preliminary contact indicates that some meaningful information could be released but the specific, applicable terms and conditions attaching to such information release via this potential route have not yet been determined.

NAC also has been in contact with one of the major German utilities that is engaged in an ongoing highly relevant NPP D&D project. Initial contact has indicated a general willingness to cooperate in the provision of meaningful information that could be used in a D&D cost benchmarking inter-comparison. Arrangements have been made to pursue the collection of such information in the event that a future requirement emerges.

Other German utilities remain as candidates to pursue the collection of cost estimate information but currently there is nothing clear that can be reported regarding the access to such information via this route.

2.3 Funding of NPP D&D Liabilities

2.3.1 Responsibilities

Each individual NPP operator is fully responsible for setting aside sufficient funds to cover future D&D liabilities for the reactors that they own.

2.3.2 Calculation Methods

The estimated costs for D&D must be updated annually as a basis for defining the required financial provisions. This is a legal obligation on the NPP Operators. Working Groups of the NPP Operators provide the necessary information and data to enable service companies to calculate and define the financing costs for the financial provisions, using approved computer models. GNS is responsible for waste packaging, segregation and disposal aspects. NIS is responsible for all other items, in coordination with the individual operators who are responsible for the specific characteristics of their own NPPs.

A reference D&D study was performed in 2000. This study was approved by the Federal ministry of Finance and accepted as basis for future annual updates. Auditors and Finance Offices at the individual state level review on an annual basis the recommended financial provisions generated by the model.

According to sources in Germany who are involved in the development of cost estimates, the estimated costs for D&D of a LWR technology NPP in Germany at present are in the order of €440 M, with a range of about ±30 percent, dependent on the specific design, size, age and other specific characteristics of the NPP. This indicative cost *includes* all planning, licensing and demolition costs up to the point of achieving Greenfield status, including the treatment, conditioning and packaging of the radioactive wastes. It *excludes* the costs for the so called transition phase when the reactor is being de-fuelled.

As experience in this field accumulates, it is likely that future NPP projects could achieve cost savings relative to the above indicative cost level, in particular by using the following measures:

- Optimization of the planning, licensing and actual D&D phases
- Optimization of the techniques and technologies for decontamination, mechanical dismantling and safety clearances
- Improved knowledge transfer using a database approach

In addition, if it were possible to develop a near-surface repository approach for the disposal of LLW, rather than the expensive KONRAD solution, this also could contribute further to saving on D&D costs.

3. United States

3.1 Important Developments 1995-2010

NAC has researched the extent of changes in the U.S. over the last 15 years regarding the main factors that direct and determine the cost of NPP decommissioning costs that include general approach, technologies, waste management and disposal costs, regulatory framework, worker efficiencies and benefits of experience.

3.1.1 General approach

The general approach involves major decisions about the type of decommissioning that will be selected included storage (Safestor), immediate Decommissioning (DECON) or entombment. It also involves the organizational aspects for performing D&D activities and the selection of methods. Some examples of key changes over the past 15 years are listed below.

TROJAN EXPERIENCE

The Trojan PWR in the U.S. was used as one of the refercne plants for comparison with Swedish NPP D&D cost estmates. The Trojan information used in analyses performed by NAC and reported to SKI in 1996 was based on the Trojan Decommissioning Plan (TDP), which was submitted to the U.S. Nucelar Regulatory Commission (NRC) in January 1995 and subsequently approved in April 1996. The NRC's review of the plan occurred at the same time that NAC was preparing an analysis and report for SKI.

Since April 1996 Trojan has been completely decommissioned, including the demolition of the power block (control, reactor, fuel & turbine) buildings. Actual D&D information for this reference plant will be a valuable source for use in any future detailed intercomparisona analyses.

Several of the individual D&D activities performed at Trojan used a completely different approach compared to that originally contemplated in the TDP. These activities include removal and disposal of the reactor pressure vessel (RPV), spent fuel management and the approach to groundwater contamination.Importantly these changes impact the project cost.

Reactor Pressure Vessel:

The most significant change between actual D&D activities and the TDP was the burial of the RPV and associated internals, instead of segmentation and on-site storage of the segmented equipment pieces. The TDP assumed the segmentation approach, having received NRC guidance as follows:

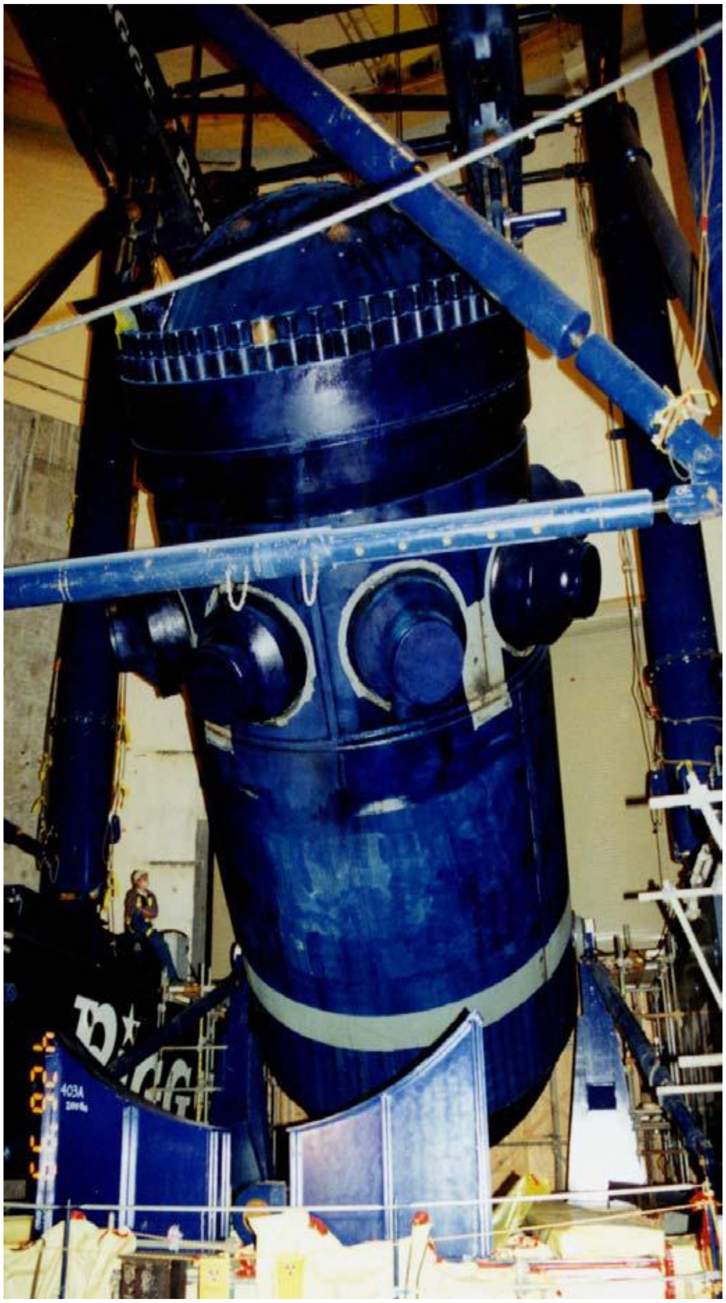
"A reactor vessel cannot be disposed of at a LLW site unless it meets waste classification requirements specified in the regulations and any site-specific requirements specified in the disposal facility's license."

The Trojan D&D staff subsequently performed an analysis to determine if the reactor internals and RPV could meet the burial requirements of the Hanford LLW site. The analysis was positive and a license application was submitted to permit burial. The analysis took credit for volumetric averaging of the radioactivity of the RPV and associated internals. Averaging the radioactivity over the entire volume of the RPV was conditional on inserting the internals into the RPV and then filling the RPV with concrete. Figure 3.1 shows the Trojan RPV ready for transport and being lowered onto a transportation rack. This was a significant licensing success because the NRC has noted that:

"In most cases where disposal of the reactor vessel has occurred, the reactor vessel internals have been removed before any parts of the reactor vessel were shipped to an LLW disposal site. In two cases, the Trojan Nuclear Plant and the Saxton Facility, the reactor vessel was removed from the building and shipped intact to a LLW disposal site. Licensees are required to demonstrate that the shipment meets the regulations for package integrity and that the package meets the acceptance criteria for the LLW disposal site, such as criteria for radionuclide concentration and waste form."

The burial approach saved $15 million compared to segmentation and was achieved at a cost that was $4 million lower than the revised project budget estimate for this activity.

Figure 3.1 Preparation of the Trojan RPV for Transport to a LLW Disposal Site



Spent Fuel Management:

Spent fuel management usually is separated from the D&D of a nucelar plant because the associated costs are treated as a separate project. Of course complete D&D cannot take place until the ancillary systems associated with a spent fuel pool are no longer required and that can only be accomplished once the spent fuel pool has been emptied.

In the case of Trojan, a unique dry cask canister design lead to a 3.5 year delay in the project to move the spent fuel to a dry storage faclity. Some D&D work was accomplished in parallel with the dry storage project but the net result was a 2.5 year delay in the Trojan D&D schedule.

The first contractor for the provison of an independent spent fuel storage installation at Trojan was Sierra Nucelar. They had submitted a bid based on a dry storage canister design using carbon steel with a zinc-based coating. At Point Beach, the same zinc coating produced hydrogen when it came into contact with borated water and the hydrogen burned. The NRC accordingly was not contetn with the proposed appraich and informed the owenr of Trojan, Portlan General Electric (PGE) not to apply to the NRC with that type of design.

A revisd design using a chromium-based coating was adopted. When the canister internals with the chromium-based coating were introduced into the Trojan spent fuel pool, the coating did not perform as expected. The net result was that PGE stopped the contract with Sierra Nuclear but was able to salvage the vertical concrete canisters (VCC) that had already been constructed on-site. PGE then contracted Holtec to design canisters to fit inside the Sierra Nuclear VCCs. Holtec designed a canister that would hold 24 PWR assemblies and eventually the fuel was removed from the Trojan spent fuel pool and put into dry storage.

Ground Water Contamination:

In the TDP, PGE reported that:

"Background surveys were taken at a variety of locations off-site to account for the differences in natural radiation from the different types of rock and soil in the area. The background measurements had a sample mean of 7μR/hr with a standard deviation of 1μR/hr. However, the measured soil radionuclide concentrations had unacceptably high variances. NUREG/CR-5849 specifies that surveys be performed to a 95% confidence level. For background surveys, OAR 345-01-010 (3)(b) also requires a 95% confidence level. In order to meet these confidence level requirements, PGE must take additional samples."

PGE sampled and analyzed groundwater from 17 monitoring wells at various site locations. At one well located east of the fuel building, tritium levels were found to be above background levels but were well below the EPA drinking water standard. As a result, Trojan did not have to deal with ground water contamination (e.g. Tritium) as has been the case at a number of other U.S. sites.

LLW Disposal Charges:

The LLW burial site at the Hanford reservation operated by U.S. Ecology is regulated and the rates have fluctuated. PGE was able to take advantage of periods when the rates were lower for the disposal of their LLW.

RANCHO SECO EXPERIENCE

During 1974-1989, the Sacramento Municipal Utility District (SMUD) operated the Rancho Seco nuclear plant (B&W designed PWR). In 1995, the NRC-approved the original Rancho Seco Decommissioning Plan (RSDP) which included Safestor as the general approach. The D&D program was scheduled to begin in 2008.

The SMUD Board of Directors in January 1997 approved an "incremental decommissioning" project for Rancho Seco. This incremental decommissioning involved performing some decommissioning activities earlier than 2008. The main reason for this change of plans concerned labour costs (for underutilised labour) that would be incurred due to delays in completing the transfer of SNF to an away from reactor (AFR) storage facility. In July 1999 the SMUD Board of Directors voted to continue the decommissioning process at Rancho Seco until termination of the license. The decision process leading to this transition from Safestor to immediate decommissioning activities occurred at about the same time that NAC’s 1996 report for SKI was being prepared.

With the termination of the NRC license, decommissioning of the Rancho Seco nuclear plant was completed in May 2009. The advantages of immediate decommissioning as assessed by PGE include all or some of the following items.

1. A reduction in overall uncertainty for a significant portion of D&D costs.
2. Availability of the plant operational staff experience-base.
3. Resources for radiological dismantling activities would be readily available as well as for conventional demolition.
4. Avoids annual costs for inspections and maintenance over a long period.
5. It is consistent with environmental stewardship and communicates a positive message to the public in this regard.
6. Sustains jobs in the near-term
7. The risk of possible cost increases if D&D is delayed, resulting from:

- Retention of the 10CFR50 nuclear license for longer
- Possible changes in regulations
- The need for ongoing inspections of remaining structures
- The need for ongoing maintenance of remaining structures

Even if immediate dismantling is adopted, the demolition of less costly and risky buildings can be delayed if necessary.

Even though the Rancho Seco nuclear plant was not specifically referenced in NAC's 1996 report for SKI , certain aspects about its decommissioning activities are of interest for any future benchmarking comparison exercise. In particular, unlike the case of Trojan, the major activity of segmenting the RPV and associated internals was performed at Rancho Seco. SMUD did not have access to a LLW facility that could accept burial of an RPV and associated internals.

ZION SITE LICENSE

In October 2010, one of the most significant changes in general D&D approach was approved by the NRC. The Zion site license was transferred from Exelon Nuclear to Energy Solutions, which is an expert organization in the D&D field. In general utilities have not demonstrated a good track record for nuclear plant D&D so the expectation is that this will be a benefit. Any funds left over from the $900 million in the decommissioning fund will be returned to the Exelon customers but Energy Solutions. It is not yet known if there are incentive payments built into the financial agreement with Energy Solutions. It is understood that Energy Solutions can receive up to $200 million more than is in the fund, if needed, but the conditions associated with this arrangement are not yet known.

Because Energy Solutions is the operator of a major low level waste disposal facility, the approach to D&D can be modified, making the process faster and simpler and with projected cost savings of about 25 percent. The main reason for this cost reduction is a decision not to engage in the degree of segregation of radioactive materials from nonradioactive materials that typically has been done in the past i.e. segregation of waste that must go to a licensed disposal facility versus waste that can go to an unrestricted public disposal/landfill site. The cost of separating waste was considered to be a costly mistake in the D&D of the Maine Yankee and Yankee Rowe nuclear plants.

It appears that Energy Solutions is prepared to use up a larger part of its (very large) available disposal site capacity at an effectively lower (internal) unit cost on grounds that, if the extra D&D work instead were done by the utility, the volume of waste coming to Energy Solutions for disposal would be lower, because the full commercial fee for radioactive waste disposal would preclude the utility from foregoing the radioactive waste separation process.

The transfer of the Zion license to Energy Solutions could be a model that other commercial nuclear plant operators in the U.S. may decide to follow.

3.1.2 Technologies

Technological changes have been discussed with experts involved in nuclear D&D who are located at the Argonne National Laboratory (ANL). The following aspects of D&D technology were highlighted to illustrate evolution over the last 15 years.

- Application of technology has changed more than technological changes *per se* associated with D&D equipment. D&D work has become simpler. For example, in 1970, $500,000 was spent for development of underwater plasm-arc cutting equipment. Now, such equipment can be procured off-the-shelf.
- For nuclear D&D, some equipment has been adpated from other industries. For, example, diamond wire cutting was adapted from the quarry industry. The D&D of the Tokamak fusion vacuum vessel provides an example of the new focus with diamond wire cutting .

  In 2002, plans were made to D&D, the vacuum vessel of the Tokamak Fusion Test Reactor located at the Princeton Plasma Physics Laboratory. The original D&D approach was based on disassembling / segmenting the vacuum vessel and decontaminating multiple pieces and segregating radioactive and non-radioactive pieces. This effort was going to be costly in time and radiation exposure.

  The approach was changed to fill the vacuum vessel with low-density grout (concrete) thus fixing the radioactivity and provideng some radiation shielding, followed by cutting the vacuum vessel into large sections with a diamond wire saw. Each section would be disposed of as a stabilized section of the vacuum vessel.

  In addition, the 327 Hot Cell Building at the Hanford reservation was demolished in large blocks instead of removing contaminated concrete from the hot cell surfaces and spending the time on a significant surface decontamination / concrete layer removal processes.

The D&D of Zion will use the appraoch of cutting buildings into large blocks and disposing the blocks without decontaminating the blocks by removing surface and near-surface contamination. This approach already seems to have been assigned the colloquial description of "rip and ship".

- Explosive demolition is another technology that has been adapted to nuclear D&D. It was used in demolition of the rocket motor program in Nevada and also at the Fernald, Hanford and Savannah River sites. Explosives also have been used in the demolition of nuclear plant containment buildings, gas discharge stacks and cooling towers.
- An area in which an approach has and will continue to drive a change in equipment is the characterization of on-site conditions. The approach is that the charactierisation of equipment and/or facilities can be perfomed on-the job as necessary, rather than taking samples that must be transported to an off-site laboratory analysis. Instrumentation has been developed to perform on-site measurements of the levels of lead, PCBs, or radioactive contamination present. Robotics can be used to take measurements in highly contaiminated or restricted areas. This approach saves time and money in that D&D crews are not waiting for laboratory results.

In conclusion, simplification appears to be a significant trend. Removal of pieces of equipment and building structures that have been stabilized from spreading contamination is replacing the concept of detailed decontamination and segregation of radioactive materials from non-radioactive materials.

3.1.3 Waste management and disposal costs

The cost of waste disposal in any given country is what it is. At the stage of developing a D&D approach and detailed plan, the costs of more decontamination can be balanced against the projected savings in waste disposal costs and the result used to guide the ultimate approach. Changes in the available capacity and/or type of LLW disposal facilities available can impact the cost of waste disposal.

The following outlines events and situations that could impact the U.S. capacity for disposing LLW from D&D but does not evaluate the associated cost structure of the facilities.

WASTE CONTROL SERVICES FACILITY IN TEXAS

In 1998, the states of Texas and Vermont formed a 'compact' to establish a permanent repository for LLW generated by nuclear power plants and medical and research facilities in Vermont and Texas. The compact was set up for exclusive use of these two states. In 2009 Waste Control Specialists (WCS) received a license to open a LLW facility in West Texas for the compact and this is under construction.

In December 2010, the Low Level Radioactive Waste Disposal Compact Commission (LLW Commission) conducted public hearings regarding a proposal to open the Texas facility to 36 other states that do not have access to a facility that would be able to accept all classes of LLW. On 4 January 2011 the Texas LLW commission voted to open the new LLW facility in Texas to the 36 states that do not have access to a LLW facility that can take ***all*** classes of LLW. The 36 states currently have access to the Clive LLW facility in Utah but that facility can only take Class A LLW. The latest change will bring significant benefits to generators of LLW in the 36 other states. For example, since D&D activities were completed at the San Onofre 1 site, the reactor vessel has been stored on-site. Class B and C LLW from D&D activities at the Rancho Seco site are stored on the site.

In conclusion, opening the WCS facility in Texas to 36 states will have a direct impact on the future D&D costs of nuclear plants. It offers an alternative to Energy Solutions Clive Utah facility for Class A LLW and also provides capacity currently not available for the disposal of Class B and Class C LLW.

PROCESSING AND DISPOSAL OF IMPORTED LLW

In most countries the disposal of radioactive waste is based on the concept that the waste will be disposed of in facilities located in the country where the waste is generated. However, in 2007, Energy Solutions proposed importing 1,600 tons of LLW from D&D activities at nuclear plants in Italy, processing it at its facilities in Oak Ridge, Tennessee and then burying the processed waste in its facility in Clive, Utah. The proposal met with significant public opposition and the project was successfully challenged in the courts.

In November 2010, Energy Solutions applied to the NRC to import 1,000 tons of LLW from German hospitals and universities, to process the waste at its incinerators in Oak Ridge, Tennessee and then return the waste residue to Germany. The waste residue would not remain in the U.S. The proposal is very new and so the application process has just begun. Ultimately disposing the waste in the country of origin may improve the likelihood of approval.

Regardless of the outcome of this specific application, processing waste across country boarders is a relatively new concept and companies like Energy Solutions that operate in multiple countries may be able to take advantage of processing waste in facilities in different countries. That could reduce the need to build the same facilities in every country, thereby providing the potential to reduce the cost of LLW processing and disposal.

The possibility of Russia importing LLW for storage at the facilities in Zheleznogorsk has been openly discussed as a result of ratification of the U.S.-Russian 123 agreement on nuclear cooperation. Whether such activity becomes reality is speculative. But it could provide yet one more option for LLW disposal, which could cause disposal rates to decline at other LLW disposal facilities in the face of competition. The agreement was ratified by the U.S. Congress on December 9, 2010.

BLENDING WASTE TO SATISFY RADIOACTIVE CONTENT RESTRICTIONS

The Energy Solutions facility in Clive, Utah is licensed to dispose of only Class A LLW, the lowest level of radioactive waste defined by the NRC. In order to provide utilities with the option to dispose of Class B and C LLW waste, Energy Solutions has proposed diluting the Class B and C to reduce its relative concentration and thereby changing the waste to Class A LLW.

Diluting waste is not a new concept; the disposal of the Trojan RPV discussed in section 3.1.1 is a case in point. If dilution were to become a more common practice, the net effect will be to increase the number of facility options for disposal of LLW, which in turn may have an impact on cost.

CANCELLATION OF YUCCA MOUNTAIN AND IMPACT ON GREATER-THAN CLASS C LLW

The cancellation of the Yucca Mountain repository has resulted in the loss of a permanent disposal site mainly for spent nuclear (SNF) fuel from commercial, research and naval propulsion reactors. However, a secondary result is that it is no longer a potential disposal option for greater-than-Class-C (GTCC) LLW that consists mainly of reactor internals components. The reactors that have completed or are in the process of completing D&D have stored or will store GTCC in the same type of containers that are used for SNF. The containers will be located at the site AFR facility that eventually becomes the only remaining facility at a reactor that has been completely decommissioned.

Delay in the eventual disposal of GTCC will increase the cost of monitoring and storing GTCC at reactor sites.

3.1.4 Regulatory framework

Prior to May 1988, when the Commission approved publication of new regulations on decommissioning, NRC's regulations did not fully address the costs or methods to decommission nuclear power plants and fuel cycle facilities. In late 1987 NRC staff submitted a proposed final rule to the Commission providing more specific requirements on the types and costs of actions to be taken. The rule was approved by the Commission and became effective on July 27, 1988.

Just after NAC's initial report was delivered to SKI in 1995, the regulations were updated to include the three major options for D&D of nuclear plants:

1. DECON (Immediate decommissioning)
2. Safestor (nuclear plant placed in a storage status and D&D accomplished in the future)
3. Entombment (radioactive materials and equipment are entombed on-site and non-radioactive equipment and facilities are decommissioned and removed)

DECOMMISSIONING PLANNING RULE

As the NRC's Decommissioning Program continues to mature and fewer sites remain in the Decommissioning Program, the program is evolving to focus on methods to expedite the timely and effective decommissioning of sites with difficult issues (e.g., those with ground water contamination) and the prevention of sites becoming legacy sites after completion of facility decommissioning. To help prevent this, the NRC submitted to the Commission SECY-09-0042, dated March 13, 2009, requesting approval to publish a final rule on decommissioning planning.

The rule will require licensees to minimize the introduction of residual radioactivity at the respective site during operations. It also will require licensees to keep survey records of residual radioactivity, including in the subsurface soil and groundwater. The NRC said the high costs of disposing radioactive material offsite may lead licensees to store more waste onsite, which could increase the potential for subsurface radioactive contamination and higher decommissioning costs.

Licensees currently are required to perform surveys to verify that radioactive effluent releases are below regulatory requirements. However, the new rule was required because the NRC found that existing regulations were not clear enough regarding subsurface contamination and required interpretation to apply to long-term environmental conditions. The regulatory body said that surveys rarely have been performed to assess the radiological hazard of chronic releases and subsurface contamination, because these are not considered effluent releases and do not cause immediate exposure to workers. Nor do they approach regulatory limits in relation to exposure of the general public.

Additionally, licensees may have new recordkeeping requirements for documenting spills, leaks, and unplanned releases.

In November 2010, the Commission approved the rule, which becomes effective 18 months after it is published in the Federal Register.

3.1.5 Worker efficiencies and benefits of experience

Since 1995, considerable D&D experience has been accumulated in the course of completing actual D&D activities at seven nuclear plants, including Big Rock Point, Connecticut Yankee, Maine Yankee, Rancho Seco, San Onofre 1, Trojan and Yankee Rowe. Through this benefit of experience, the achievable worker efficiencies in completing numerous D&D tasks now should be better understood.

3.2 Available Detailed D&D Cost Information

Considerable detailed information from a number of sources is available in order to perform an updated comparison of internationjal benchmark D&D costs versus updated D&D cost estimates for Swedish nuclear plants.

TROJAN INFORMATION

The information available to date from the actual Trojan D&D project includes the following categories:

1. Annual costs of radiological decommissioning, non-radiological decommissioning, waste disposal and final survey.

2. Final total costs of radiological decommissioning, non-radiological decommissioning, waste disposal and final survey. These costs are further divided in to a number of categories including reactor vessel and internals removal; other large component removal; auxiliary, fuel and other building equipment removal; containment building equipment removal; total cost of utility and contractor staff; non-radiological decommissioning; and building demolition.
3. Total labor cost of reactor vessel and internals removal for utility supervision, utility labor and contractor labor.
4. Total cost of LLW reduction, packaging, shipping and burial.
5. Cost of ISFSI construction and loading and projected ISFSI operation and decommissioning.
6. Man-hours incurred and area surveyed during final survey.
7. Numerous pictures of large component removal, shipment and burial including a complete gallery of pictures showing the removal, transport and burial of the RPV.
8. RPV dimensions, dry weight, weight after being filled with reactor internals and low density concrete.
9. Projected waste volumes from detailed Trojan nuclear plant assessments performed by Pacific Northwest National Laboratories.

RANCHO SECO INFORMATION

The segmentation of the Rancho Seco RPV and reactor internals is particularly important because a number of D&D plans indicate segmentation. Rancho Seco performed segmentation and so information is available about the segmentation experience including project description, engineering & design, full scale testing project, equipment description and pictures, and final report.

Additional detailed information has been sought and it hoped to gain access to it in due course.

LLW BURIAL COST INFORMATION

In November 2010 the NRC published the “Report on Waste Burial Charges - Changes in Decommissioning Waste Disposal Costs at Low-Level Waste Burial Facilities” (NUREG1307, Rev. 14). This report provides the current rates for disposal at the LLW facilities in South Carolina and Washington. The information is provided for use by utilities to “adjust the estimate of the cost of decommissioning their plants, in dollars of the current year, as part of the process to provide reasonable assurance that adequate funds for decommissioning will be available when needed.” This adjustment to D&D cost estimates is required annually.

3.3 Funding of NPP D&D Liabilities

Licensees of nuclear plants are required to submit estimates of decommissioning costs on an annual basis. NRC regulation 10 CFR 50.75 has been changed over the years and specifies the minimum amount, in January 1986 dollars, required to demonstrate reasonable assurance of funds for decommissioning nuclear plants, as follows:

- BWR greater than or equal to 3400 MWth - $135 million
- BWR between 1200 MWth and 3,400 MWth - $104 million + 0.009(MWth)
- BWR less than 1200 MWth - $104 million + 0.009(1200)
- PWR greater than or equal to 3400 MWth - $105 million
- PWR between 1200 MWth and 3400 MWth - $75 million + 0.0088(MWth)
- PWR less than 1200 MWth - $75 million + 0.0088(1200)

The same regulation requires nuclear plant licensees to annually adjust this minimum amount to current year dollars. The equation for making the annual adjustment is as follows:

$$\textit{Estimated D\&D Cost (Current Year)} = [\textit{1986 minimum amount}]\ x\ [A\ L_x + B\ E_x + C\ B_x]$$

where A, B, and C are the fractions of the total 1986 dollar costs that are attributable respectively to labour (0.65), energy (0.13), and burial (0.22). The factors L_x, E_x, and B_x are defined as follows:

L_x, = labour cost adjustment, January of 1986 to January of Year X (Source: NRC report NUREG-1307(as revised), "Report on Waste Burial Charges." based on regional data from the U.S. Department of Labour – Bureau of Labour Statistics)

E_x, = energy cost adjustment, January of 1986 to January of Year X, (Source: NRC report NUREG-1307(as revised), "Report on Waste Burial Charges." Based on regional data from the U.S. Department of Labour – Bureau of Labour Statistics)

B_x = LLW burial/disposition cost adjustment, January of 1986 to January of Year X (Source: NRC report NUREG-1307(as revised), "Report on Waste Burial Charges.")

The LLW burial/disposition cost adjustment factor (B_x) is a function of the LLW compact associated with nuclear plant sites. An explanation of LLW compacts is provided in Section 8.3.1.2. If a nuclear plant site is located in a state that belongs to a

LLW compact, NUREG-1307, Rev.13 assumes the cost for disposal is the same as that provided for the Atlantic Compact.

The following example summarises how an annual adjustment calculation is performed:

- Assume a 3,400 MWth PWR located in South Carolina (state in the Atlantic LLW compact)
- Base D&D cost in January 1986$ = $105 million
- L_x, = 2.33; E_x, = 2.746 and B_x = 25.23 (Source: NRC report NUREG-1307 Rev. 13, "Report on Waste Burial Charges.")
- D&D Costs (2008 $) = ($105 million) *[(0.65)*(2.33)+(0.13)*(2.746)+(0.22)*(25.231)] = $779.3 million

A nuclear plant licensee must either set aside the estimated cost in full (effectively prepay), or else create an external sinking fund to build up over time the necessary funds to cover the ultimate D&D cost liability.

In response to the worldwide financial downturn that began in 2008 and the decline in the value of decommissioning funds that were dependent on bond and stock values, the changes to financial assurance requirements in 10 CFR Parts 30, 40, 70, and 72 provide additional assurance that:

1. licensees have accurate information during operations on which to base their future decommissioning work scope, and have provided the NRC a decommissioning cost estimate consistent with the work scope at regular intervals, and
2. the licensee’s decommissioning financial assurance will be available when needed, even if the licensee or its guarantor enter bankruptcy.

The surveys of significant subsurface contamination at the site are to be used in preparing the cost basis of the decommissioning cost estimate. To better ensure that funds are available when needed, the rulemaking eliminates use of a line of credit for all NRC licensees and eliminates the use of and escrow account by materials licensees. The NRC view is that both of these financial instruments are more appropriate for short-term transactions, not the longer time frames that may be required for decommissioning financial assurance. Amendments in 10 CFR Part 30 Appendices A, C, D, and E, for the parent guarantee and self guarantee financial assurance mechanisms assure that funds will be available from the guarantor at time of decommissioning.

The changes to 10 CFR Part 50 reporting requirements involve licensees that have a power reactor that is being decommissioned. Such licensees must file an annual report detailing the amount of funds spent on decommissioning, the amount required to complete decommissioning, and the remaining balance of decommissioning funds. This report is due annually until the licensee has completed the final radiation survey at the site.

Power reactor licensees are allowed to use a 2 percent real rate of return on invested funds in their determination of adequate decommissioning funding. If the balance of funds, plus earnings, in conjunction with the other financial assurance methods do not cover the amount needed, then the licensee must provide in a status report additional financial assurance to cover the estimated cost to complete decommissioning. The licensee must file an annual report detailing projected costs and funding for spent fuel management until title to the spent fuel and possession of the fuel is transferred to the Secretary of Energy. The content of the financial status reports differs from the content of other decommissioning financial assurance reports required of power reactor licensees that do not have reactors in the process of being decommissioned.

4. United Kingdom

4.1 General Remarks

The U.K. is somewhat diffuse in terms of its three different types of operating reactor technology (MAGNOX, AGR and PWR). The responsibilities for decommissioning also vary. For the MAGNOX reactors the Nuclear Decommissioning Authority is fully responsible i.e. these reactors come under the umbrella of a large, national liabilities program. The responsibility for the AGRs and for the Sizewell B PWR also formally lies with the NDA but British Energy would perform the actual D&D work. However, relatively recently British Energy was acquired by EDF. The overall management of NPP decommissioning for the AGRs and Sizewell B therefore now ultimately comes under the central EDF organisation in France responsible for NPP D&D. Concerning new build in the U.K., an applicant for a construction and operating license must include as part of the submittal a so-called funded decommissioning and waste plan. EDF is the lead organisation applying for such a license in respect of an EPR to be constructed at Hinkley Point C.

The MAGNOX and AGR designs are very different to those of a PWR or BWR reactor. MANOX reactors have large, low power density cores that include a large volume of graphite moderator (some 58,000 tons across the whole MAGNOX fleet). The AGRs are constructed using pre-stressed concrete for the core containment arrangement and including embedded heat exchangers. Accordingly neither of these reactor designs represents a convenient and obviously meaningful reference to use in a benchmarking inter-comparison against LWR D&D programs and costs. The only relevant references that might be extracted from the U.K. would relate to the Sizewell B PWR and/or applications for future new reactors to be constructed. Today the only one sufficiently advanced in this regard is the EDF application for an EPR at Hinkley Point C.

4.2 Available Detailed D&D Cost Information

Detailed cost estimates have been prepared in respect of D&D for the Sizewell PWR. The release of such estimates at the current time is considered to be confidential however. D&D cost estimate data related to the EPR application by EDF is understood to be in sufficient breakdown detail to be helpful in a D&D benchmarking inter-comparison but this also cannot be released at the current time. Based on enquiries made, other sources of information relevant to LWR D&D date from 1996 and accordingly do not have contemporary relevance.

In summary the U.K. appears to be not a good prospect for the collection and analysis of meaningful LWR related D&D cost estimate information.

4.3 Funding of NPP D&D Liabilities

The funding of D&D for all currently operating U.K. reactors, including MAGNOX reactors, AGRs and the Sizewell B PWR is the responsibility of the NDA. However, the funding of D&D for the BE AGR fleet and for the Sizewell B PWR is provided by British Energy, a subsidiary of EDF, through contributions to the Nuclear Liabilities Fund, which is managed by the NDA. The amounts contributed annually are adjusted depending on issues like operating lifetime. Recently the lifetime for some AGRs was increased, giving more time for the collection of the necessary D&D funds. The funding of new NPPs yet to be built will be the exclusive responsibility of the owners of each NPP project.

5. Summary

The two biggest changes in NPP D&D over the last 15 years that are applicable across all countries are:

a. Equipment and tools used in NPP D&D have evolved to be available on a more industrial basis, although concerning D&D of the main NPP components, such activity typically is very individual and requires one-of equipment to be developed.

b. Regulation of D&D has increased. Earlier regulations were adapting to what emerged from evolving D&D projects. Today regulatory requirements have caught up and have been framed based on the feedback of experience over the last 15 years. In general they impose prescriptive requirements on D&D approaches and execution.

In the U.S. access to LLW disposal has been opened up to a majority of states, which will ease the development and timely execution of D&D projects. A newly emerging trend in the U.S. is that segregation of some categories of waste, to facilitate the disposal of some volumes in general landfill rather than in radioactive waste disposal facilities, is being sacrificed, on cost grounds, in favour of mixing waste volumes with the consequence of having to dispose of a larger volume of waste in a LLW facility.

Regarding access to information that can be meaningful and sufficiently detailed to support an international benchmarking inter-comparison of NPP D&D cost information:

- NAC has established good access to detailed information on actual D&D projects at one U.S. PWR (Trojan) and one U.S. BWR (Rancho Seco). Additional information sources probably can be accessed with additional investigation.
- Germany has highly relevant cost estimate and actual NPP D&D experience. Accessibility of the information is not yet fully determined. This will need more extensive, face-to-face interaction with the relevant stakeholders. Utilities and cost estimate service providers offer the opportunity to access relevant information. Specific terms and conditions that would apply and the extent of detail that would be released requires further investigation.
- The U.K. does not offer a good prospect for relevant LWR D&D information.

In general nothing major has occurred in terms of the ultimate responsibility for funding NPP D&D liabilities. However, the provisions to be accrued may have changed, and may change further, *inter alia* in accordance with changes including technologies available and approved waste disposal options. The extent of changes that might happen in the future may be bigger in the U.S. than in Europe.

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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