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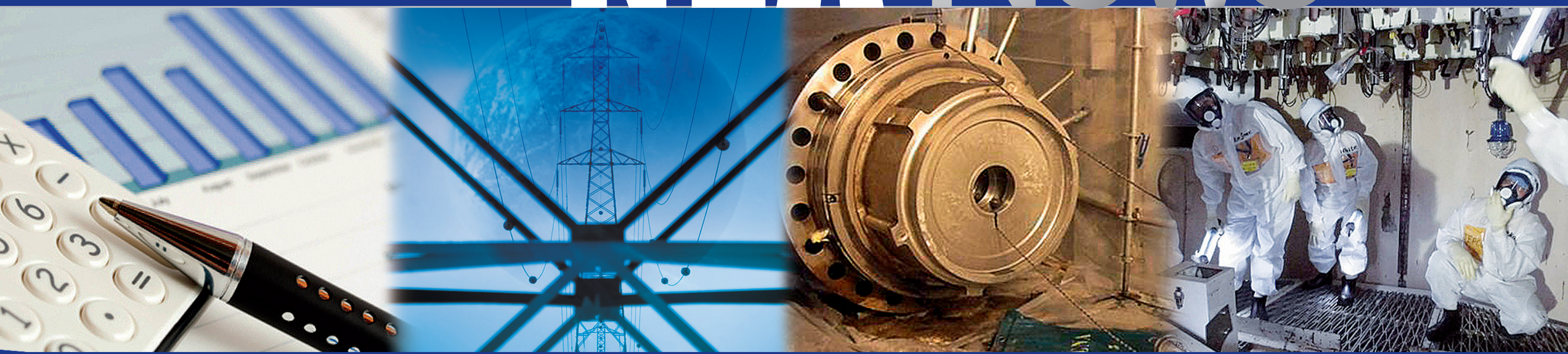

In this issue:

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The Nuclear Energy Agency (NEA) is an intergovernmental agency established in 1958. Its primary objective is to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. It is a non-partisan, unbiased source of information, data and analyses, drawing on one of the best international networks of technical experts. The NEA has 31 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The NEA co-operates with a range of multilateral organisations including the European Commission and the International Atomic Energy Agency.

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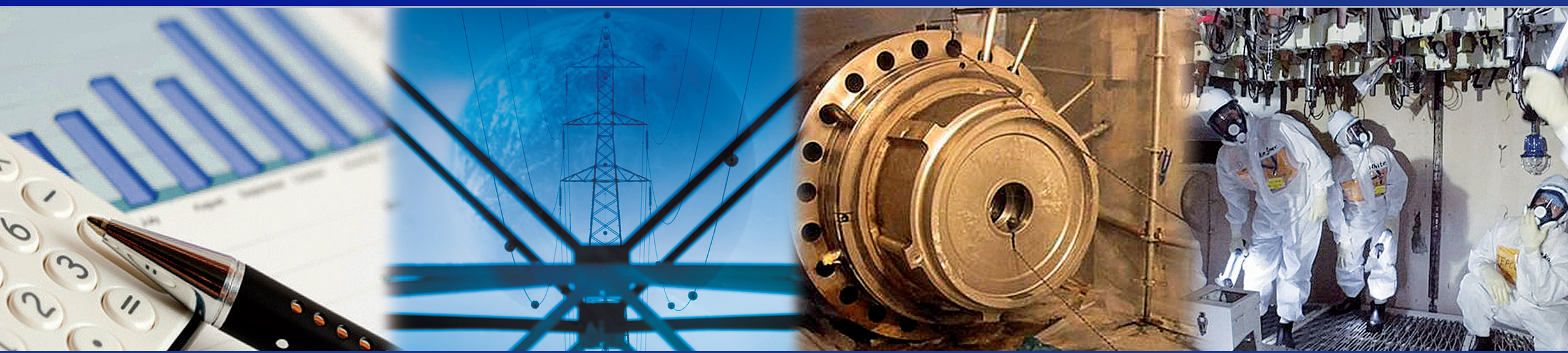
OECD Boulogne building.



An evolving electricity market

The transition from the use of fossil fuel to that of low-carbon energy will drive future energy systems towards a new paradigm with diversified and interacting technologies. Part of this new paradigm is related to the growing penetration rate of variable renewable energy. In many countries, this rate has reached a point where the overall balance in the electricity market in terms of key criteria of economics, stability and reliability needs to be reconsidered. Accordingly, the decarbonisation strategy, as promoted through the COP21 agreement, will require the deployment of carbon-free power systems through policies that clearly outline priorities and associated key criteria. The lead article in this edition of *NEA News*, on the full costs of electricity, provides sound insight into the profound and ongoing transition taking place in the electricity market.

Today, nuclear energy relies on mature technologies, offering effective products as a result of considerable industrial experience. Nevertheless, like any industrial activity, nuclear technology is subject to a continuous evolutionary process that is influenced by several drivers.

First, nuclear-related activities are continuously being optimised through an effective learning curve that is built upon both normal operating conditions and lessons learnt from past incidents and accidents. The recent NEA publication *Five Years after the Fukushima Daiichi Accident* is a good example of this process driven by a broad collaboration of relevant organisations and led by regulatory bodies.

A second important driver is the still open questions related to issues such as waste management and decommissioning as well as remediation. Despite a tremendous amount of available experience in the field, such questions continue to rouse extensive debate in the community and require active international co-operation, for which the NEA provides an effective framework.

A third driver is related to power market expectations that are linked to current technology optimisation and innovative developments. In the medium term, energy transition will create a growing need for flexibility in the market among all electricity generators, including nuclear power plants. This opens a path towards new designs (smaller units), new applications (beyond electricity) and optimised operation (load following and life-time extensions). Improved management of uranium resources will of course remain an important consideration.

This evolutionary process requires significant research and development investment and the availability of high-level skills. In the last century, a number of challenging projects at the national level were supporting the innovation process and the education of skilled generations of scientists and engineers. Today, international co-operation is a more effective pathway to reach this same result. To meet the expectations of its member countries in this area, the NEA is thus developing two complementary initiatives: “Nuclear Innovation 2050” to help set global R&D priorities and foster their implementation, and the “NEA Nuclear Education, Skills and Technology” initiative, which aims to support the creation of a new, highly skilled generation of professionals.

These projects are consistent with the longstanding NEA tradition of creating a positive environment and associating in-depth technical activities, along with the combined guidance of member countries, in order to enable significant scientific production while educating new generations of scientists through international co-operation.

Daniel Iracane
NEA Deputy Director-General
and Chief Nuclear Officer

Assessing the full costs of electricity

by J.H. Keppler*

For decades, economists, energy specialists and policymakers have been satisfied with assessing the comparative costs of electricity generation on the basis of discounted average costs over the lifetime and the total output of a generating plant. As a standardised form of cost-benefit accounting (CBA), these levelised costs of electricity (LCOE) indicate the required expenditures in terms of capital, fuel, and operations and management (O&M), adjusted for their incidence in time or the different technology options per unit of output (i.e. a MWh of electricity). This straightforward, transparent and comparatively simple metric worked well in a context of regulated markets where generators were centrally dispatched according to system requirements, tariffs were set by regulators and load factors could be predicted with confidence. In order to satisfy a given demand for electricity, the technology with the lowest LCOE was usually chosen, thus minimising the costs of the electricity system. Nuclear energy thus competed with hydro, where available, and coal and gas on the basis of their respective capital, labour and fuel costs at the level of the individual plant.

Environmental concerns and electricity market liberalisation: From LCOEs to "full costs"

Three major forces are compelling the move away from the methodological assumption that LCOEs alone can provide an adequate picture of the generating costs of electricity. First, as early as the late 1960s, concerns were growing about the environmental impacts of electricity generation. While such concerns were not confined to the electricity sector alone – with its large centralised production units, at the time still overwhelmingly run by public entities – declining air quality due to the firing of coal had coalesced into concrete efforts to identify, measure and monetise the "social", "full" or "external" costs of power generation. Such accounting of external effects would subsequently extend beyond air pollution and include the impacts of different generating technologies, both positive and negative, in areas such as resource depletion, risk management of major accidents, regional development or the security of energy supply. In recent years, two items have dominated discussions: CO_2 emissions resulting from the burning of fossil fuels and the costs of a nuclear accident. The use of the term "external costs" underlines the important role that costs beyond plant-level LCOEs have played in public discussion and policy decision making since the early days of the environmental movement.

The second major force has been the progressive liberalisation of electricity markets in OECD countries – a movement that commenced in the United States in the late 1970s and gathered steam in the United Kingdom and continental Europe during the 1980s and 1990s. This liberalisation was accompanied by an increased awareness that the financial cost considerations of private investors in markets with unstable prices differed from those of public entities operating under guaranteed tariffs set by a regulator. According to theory, in the absence of transaction costs and with freely available information, deregulated electricity markets with free entry and free price formation can replicate the outcomes of regulation aimed at social welfare maximisation. In practice, however, the exposure to both price and load factor risks, as well as the cost of capital of the private investor in a liberalised market, differ strongly from those of a regulated entity with public ownership. LCOE accounting can partly accommodate these changes in risk profiles by varying the cost of capital or the discount rate used. However, finance analysts have noted that LCOEs very inadequately capture issues such as solvency risk or portfolio effects that are at the heart of investor concerns. In the case of nuclear power and low-carbon technologies in general, their high up-front investment costs pose an added risk to investors facing uncertain prices, which is even less likely to be captured in the LCOEs. Credit constraints for very large units, over 1 000 MW generation III/III+ nuclear reactors for example, may also play a role.

In short, both concerns about social costs and the liberalisation of electricity markets have led to requests to complement the tried and trusted LCOE methodology. Despite its obvious limitations, the LCOE methodology has continued to enjoy broad use because of its intuitive appeal and its ability to provide a rough and ready comparison of the underlying social opportunity costs, i.e. the costs of production factors that might be gainfully employed elsewhere and of different generation technologies at normalised load factors.

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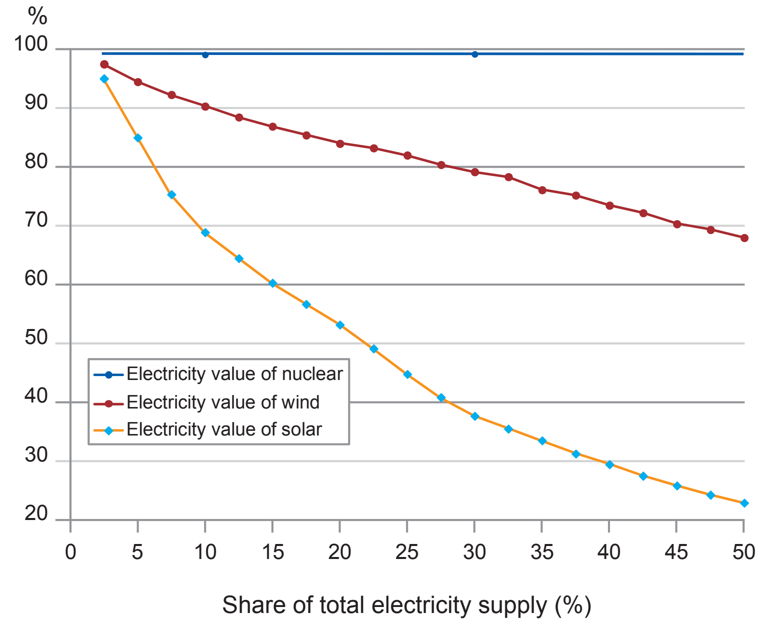
Variable renewables and the system cost challenge

The third of the three major forces mentioned above is the advent of important amounts of renewable energies, in particular wind and solar, with variable production profiles changing according to the weather. This third force will require a radical rethinking of cost and benefit accounting in the electricity sector. The most fundamentally challenging impact of electricity generation from wind and solar sources is that their production varies widely between zero and full capacity, but when they do produce they do so at zero marginal costs. Other dispatchable sources are thus pushed down the merit order of generation, seeing their load factors reduced in the process. They are nevertheless a necessary part of the system for the periods when wind and solar do not produce. Variable renewables thus drive a wedge between notions of capacity (i.e. the ability to stand by and produce when called upon) and energy (i.e. the actual delivery of electricity). LCOEs cannot capture the difference between capacity and energy since they work with load factors that are standardised over different technologies, are stable and, in the case of baseload power technologies such as nuclear at high levels, frequently reach 85%.

As variable renewables push into the electricity markets of OECD countries, supported by feed-in tariffs decided by governments and paid by electricity consumers, they are driving a restructuring of electricity systems that cannot be accounted for in terms of the levelised costs of production. The presence of these variable renewables will force a restructuring of the production mix that will lead to a shift towards technologies with low capital costs. The latter are comparatively less expensive given that conventional technologies will then run for a much smaller number of hours than in the past. However, building capacity as a back-up for only occasional use will clearly increase the cost of the overall system above and beyond the higher costs of the renewables themselves. In addition, a residual system geared towards technologies with low, fixed costs is inevitably a system with higher CO_2 emissions. The net magnitude of emission reductions resulting from variable renewables will thus invariably be of the second order. However, in the electricity markets of OECD countries, which are rapidly restructuring under the pressure of variable zero-cost production, incentives for investment are no longer unequivocally aligned with either the minimisation of the overall cost of the electricity system or the reduction of greenhouse gas emissions.

The shift towards a more expensive residual generating mix, also referred to as “profile costs”, is not the only mechanism by which the deployment of variable renewables increases the costs of the system as a whole. Since the uncertainty over the variable production of wind and solar sources is only resolved in real time, a certain amount of conventional production needs to *cycle*. In other words, it needs to work at less than capacity without injecting electricity into the grid so as to be

The value of variable renewables declines as their market share increases



available in the case that renewable production is less than predicted, or in the case that production and consumption need to be balanced at a moment's notice. The third mechanism by which renewables increase system costs is only partly related to their variability. It is primarily a result of their small unit size, decentralised nature and the fact that their location is usually chosen according to the availability of wind and solar resources rather than the proximity to centres of consumption. Electricity systems with significant shares of wind and solar production need both stronger and tighter meshed transport and distribution grids, which of course further contribute to cost.

These three factors are all contributing to very real increases in the total cost of electricity generation at the system level, in addition to the higher cost of renewable production in its own right. One final effect is perhaps the most striking one, although it is also the one that is conceptually the most difficult to explain. Variable renewables drive down the price of electricity in wholesale markets due to their zero short-run marginal costs. On the face of it, this is good news for the consumer, who is already paying for renewable support as well as higher grid and balancing costs. The substantial price falls observed with even modest shares of renewable production have meant, however, that operators who do not receive guaranteed out-of-market support are henceforth unable to recuperate their outlays. The first to be negatively affected by the decline of electricity prices when variable production increases is the renewable energies themselves. The more wind turbines are turning and the more PV panels are producing, the less each individual installation is gaining (see graph above). Thus far, feed-in tariffs have masked this effect, but it is increasingly evident that economically self-sustaining renewables production in unregulated electricity markets is unlikely to ever happen, even when allowing for significant cost declines.

To date, the burden has been solely on dispatchable producers. In OECD Europe, for instance, because renewable production prices and load factors are so low that gas plants are no longer capable of covering their fixed capital costs and their fixed operating costs, they tend to go out of business, causing not only a loss to their owners but also a loss in terms of urgently needed capacity services. As a result of a combination of renewable production and low gas prices, the situation is comparable for coal and nuclear power plants in certain parts of the United States. In some cases, for example, even nuclear power plants that received regulatory approval for life-time extensions and long-term operation (LTO) have closed because of a lack of profitability.

There are two solutions to such a situation. The first one would entail electricity markets working with declining margins of spare capacity and an increasing number of scarcity hours, for instance through rolling brown-outs during which not all demand would be satisfied, and where very high prices would allow operators to recuperate some of their fixed costs. The second solution is to anticipate the revenue shortfall of dispatchable operators and to install capacity remuneration mechanisms that offer compensation for plants with generation capacities that produce electricity only during a limited number of hours, but provide vital back-up services when demand peaks or renewable production falls short. This, of course, would imply a rise in the costs to consumers, but it would bring the benefit of increased security of supply. While experts argue over theoretical optimality, in a period of such massive structural change in the electricity sectors of OECD countries, emphasis must be placed on a pragmatic handling of a difficult transition.

CO_2 emission reductions or high shares of variable renewables?

The structural changes brought about by the extensive introduction of variable renewables in the space of just a few years were largely unanticipated. The situation has also forced both these groups to focus on two essential questions. First, electricity experts and economists need to concentrate on new methodologies to assess electricity generating technologies in order to replace the LCOE methodology. Average lifetime costs are a poor guide to profitability in a world that values the ability of a technology to provide low-carbon power in a predictable manner, the "capacity credit" of an installation, its cost of entry or its flexibility to ramp production up or down. The difficulty for cost estimates will be to develop common metrics that can be shared over technologies and systems with different characteristics so as to allow for meaningful comparisons.

Nuclear energy brings advantages and disadvantages to this new electricity world. Its primary strength is that it is the only large-scale source of low-carbon power that is both dispatchable and scalable. Its flexibility is middling and certainly better suited to follow changes in solar radiation during the day than to compensate the variability of wind profiles minute by minute. Its high fixed costs, however, make it unsuitable as only a provider of back-up capacity. Even in this new electricity world, nuclear energy is most conducive to providing reliably large bands of low-carbon power to centres of consumption.

For decision makers, the key issue is how to prioritise policy objectives in a coherent manner. Is the top priority to reduce greenhouse gas emissions at the lowest possible cost or is it to increase the deployment of renewables? The degree of convergence of these two objectives varies widely across contexts and countries. Except in niche markets, variable renewables today remain expensive in terms of LCOE. More importantly, variable renewables increase significantly the costs of electricity systems as a whole. If the reduction of greenhouse gas emissions is the objective, a significant share of nuclear baseload power is certainly part of the least-cost generating mix. However, this does not exclude the judicious use of wind and solar geared towards the resources and load profile of the country in which they are deployed. The idea that blanket coverage with windmills and solar panels will, by itself, lead to a low-cost, low-carbon future is unrealistic. Barring additional measures such as a robust carbon tax, current policies are likely to provide for a high-cost future with very uncertain emission results.

The role of the Nuclear Energy Agency

The NEA, and in particular its Division of Nuclear Development, is at the forefront of the development of new methodologies for electricity generating costs, including both full (environmental and social) costs as well as the grid-level system costs of decarbonising electricity systems. Recent or forthcoming publications include *Comparing Nuclear Accident Risks with Those from Other Energy Sources* (2010), *The Security of Energy Supply and the Contribution of Nuclear Energy* (2010), *Projected Costs of Generating Electricity* (2010 and 2015), *Nuclear Energy and Renewables: System Effects in Low-carbon Electricity Systems* (2012), *Costs of Decommissioning Nuclear Power Plants* (2016), *Social and Economic Impacts of Nuclear Power* (forthcoming), *Estimation of Potential Losses Due to Nuclear Accidents* (forthcoming).

Two major new studies by the NEA are attempting to further push the boundaries of research on these issues. The first, on full costs of electricity provision, aims to summarise the existing state of research concerning the value of different social and external costs, and to present them in a transparent and easily accessible format. This would include a definition of appropriate boundary conditions, the identification of orders of magnitude that are compatible with the large consensus existing among experts and suggestions of areas where these results would be most relevant for policymaking.

The second publication, on system effects in deep decarbonisation scenarios, will provide an overview of the wide and varied research that has been undertaken elsewhere on the issue of system costs since the publication of the NEA's first study on this subject in 2012. More specifically, it will compare quantitatively the cost of electricity systems that attempt to achieve a given CO_2 reduction target with different amounts of nuclear energy and variable renewables, taking full account of the impacts that variable renewables have on the full costs of an electricity system. Research will be based on a set of widely accepted assumptions and generally recognised modelling methodologies, in co-operation with well-known research institutes.

Neither study will put an end to the debate over the comparative costs of electricity generation. LCOE accounting will continue to be used, albeit in a less prominent manner. In this new and rapidly changing electricity world, the NEA will play an integral part in ensuring that the contribution of each technology, including that of nuclear energy, is adequately recognised so as to meet the demand for low-carbon electricity at the least cost to the overall system.

Nuclear power plant decommissioning costs in perspective

by G. Rothwell, M. Deffrennes and I. Weber*

At the international level, actual experience is limited in the completion of nuclear power plant decommissioning projects. Cost data for decommissioning projects are thus largely unavailable, with few examples of analyses or comparisons between estimates and actual costs at the project level. The Nuclear Energy Agency (NEA) initiated a project to address this knowledge gap and in early 2016 published the outcomes in the report on *Costs of Decommissioning Nuclear Power Plants*. The study reviews decommissioning costs and funding practices adopted by NEA member countries, based on the collection and analysis of survey data via a questionnaire. The work was carried out in co-operation with the International Atomic Energy Agency (IAEA) and the European Commission (EC).

One of the first issues addressed in the study is the definition of decommissioning, which is defined in the report's glossary as "administrative and technical actions taken to allow the removal of (some or all) regulatory controls from a facility." Another common definition is "...all the management and technical actions associated with ceasing operation of a nuclear installation and its subsequent dismantling to facilitate its removal from regulatory control (delicensing). These actions involve decontamination of structures and components, dismantling of components and demolition of buildings, remediation of any contaminated ground and removal of the resulting waste." It should be underlined, however, that the precise definition of decommissioning differs from country to country, as do the specific financing arrangements to meet the expected costs of such activities.

The NEA Expert Group on the Costs of Decommissioning (COSTSDEC) issued a questionnaire to member countries asking them to provide background on their understanding of decommissioning and on national regulatory frameworks, as well as details on the costs of decommissioning nuclear power plants (NPPs). In response to the question of whether there was a single national definition of decommissioning, most member country representatives responded in the affirmative, although a few indicated that there was no universal definition of "decommissioning". In the United States, for example, decommissioning refers to the termination of the operating licence and decontamination of the NPP following the US Nuclear Regulatory Commission (NRC) guidelines, thus relieving the owner-operator of paying fees to the NRC for the regulation of a radioactive facility. Environmental regulation issues could still prevail on site, and in this case it would be up to the state or federal regulators to determine the "end state" of the site.

In response to a question of whether there was a specific time frame to complete decommissioning, France and the United States both responded that there was defined guidance: in France it was "as soon as possible" and in the United States it was within 60 years of the termination of operations of an NPP. In most other countries, no mandatory time frame exists to reach the end point of decommissioning.

The limited information on actual experience in the completion of NPP decommissioning projects has meant that the COSTSDEC study has had to rely heavily on cost estimates, rather than on actual decommissioning project costs. Comparing these estimates internationally is not a straightforward exercise because of the considerable differences in decommissioning approaches across NEA member countries. Even at the level of specific activities, comparisons between cost estimates and specific cost items are not easy. For example, the main activity and objective of decommissioning is to remove radiological contamination. Using this objective as the lowest common denominator in all decommissioning projects, a simple approach could be to compare the cost estimates for decontamination. However, when considering cost estimates for this activity, some include pre-decommissioning activities (for example, preparations for maintaining the plant in a safe condition during an interim waiting period before the decommissioning work commences) and some do not. All cost estimates include waste material preparation for transport off-site to a waste management facility, but some estimates also include both the costs of transport and the full costs of off-site waste management, while some do not.

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Waste definitions and requirements for treatment and disposal of different waste categories vary as well. In some countries, such as France, all concrete from structures housing contaminated equipment will be considered low-level waste (because there is no clearance level), while in other countries, concrete that is not contaminated can be released from regulatory supervision (or "cleared") and reused, for instance in road beds.

Another example is spent nuclear fuel (SNF). SNF that is not destined for reprocessing is considered as a special type of high-level waste (i.e. waste that also generates heat). In some NEA member countries, deep geological repositories (DGRs) are being developed and will be operational within the next decade. In the United States, SNF is considered the property of the US government through the Department of Energy (DOE). Since major difficulties have been encountered in implementing the planned programme for a DGR in the United States, alternative interim arrangements for on-site spent fuel management are thus needed in the country. As reactors are closed down, NPP sites are being relicensed as independent spent fuel storage installations (ISFSI). Today, 34 out of 50 states in the United States have NRC-licensed ISFSIs. Some of the expenses for these facilities will be paid from the Nuclear Waste Trust Fund, although arrangements are still under negotiation. Outside of the United States, a range of financing is in place for interim spent fuel storage activities and investment.

Finally, there are differences from country to country regarding the end state of the site. In some countries, new NPPs can be built on the sites of currently operating plants. These sites may not require full site decontamination to allow unrestricted use. In other countries, the owner-operator must fully decontaminate the site so that it can be used by anyone for any activity (the so-called "greenfield" state).

These differences in decommissioning approaches have led to diverse interpretations of what is deemed to be a decommissioning project cost, and have had a major impact on the "bottom line" numbers for different cost estimates. To be able to compare cost estimates, boundary conditions – often referred to as "context" – must be specified. Differences in funding arrangements will influence both the amounts of financial resources required and how these resources are to be managed to meet future costs.

An awareness of the context in which a decommissioning cost estimate is produced is thus an important consideration in understanding and interpreting the estimate, mainly because the context both defines the purpose of the estimate and determines a number of key factors (assumptions, exclusions, boundary conditions, attitudes towards risk and uncertainty) on which the estimate is based. Key considerations include the overall policy framework governing nuclear energy, the regulatory framework for decommissioning and the integration of decommissioning planning in the overall system for management of waste arising from decommissioning. Decommissioning project-related elements such as the scope of work through to the end point of the site, the assumed duration of dismantling and clean-up activities, waste management, storage and the availability of final repositories need to be included in these considerations. Although it is difficult to weigh the impact of all these factors on cost estimates, their influence on the level of the cost estimate is fundamental.

There is no internationally accepted standard for a decommissioning cost estimation that would simplify the challenge of comparing cost estimates. In a long-term international effort, the NEA, the IAEA and the EC have developed the International Structure for Decommissioning Costing (ISDC),


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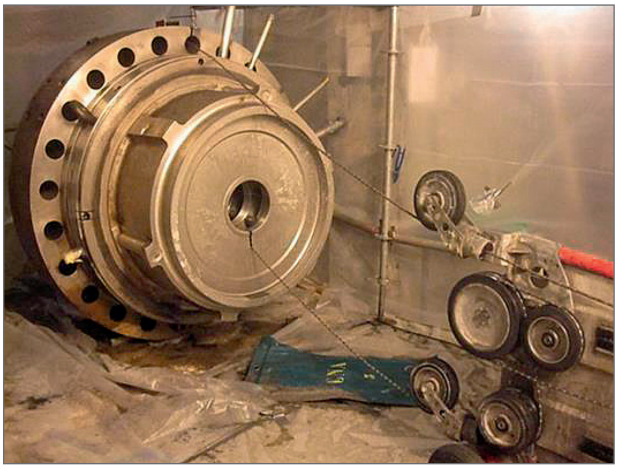

Enresa, Spain

Steam generator radiological characterisation (left) and dismantling of elements from the primary pump (right), José Cabrera nuclear power plant, Spain.

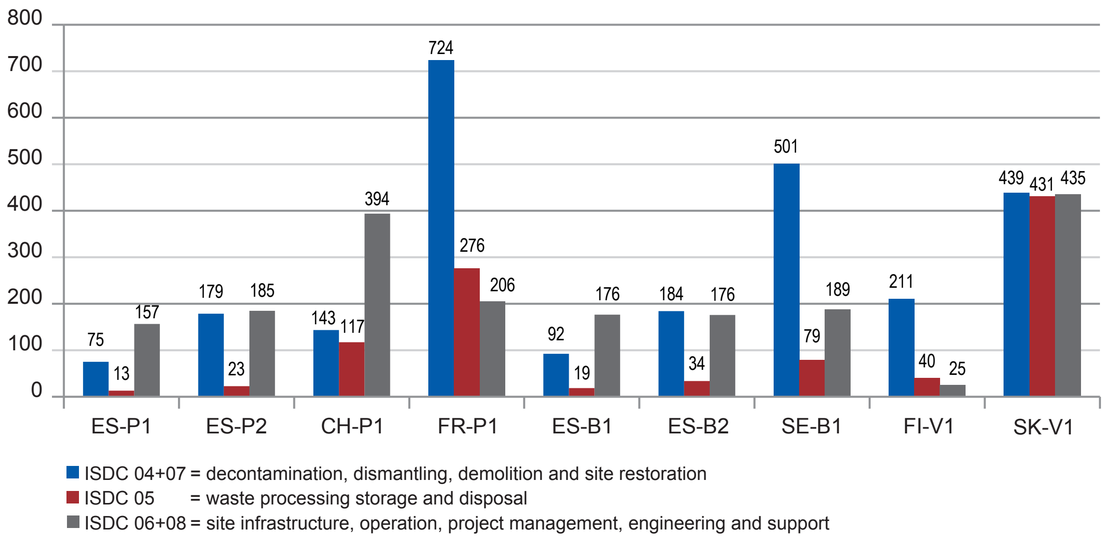
which sets out a standardised structure of cost items for decommissioning projects to ensure that all activities in the project scope are reflected in costs. This structure aims to serve as a platform for presenting cost estimates and to facilitate cost comparisons among these estimates of decommissioning activities or groups of activities.

Representatives of NEA member countries were asked via the questionnaire to provide specific costs for any fully decommissioned NPP, as well as cost estimates for specific plants or for generic plants using the ISDC format. This format was thought to be well understood by the survey participants and to provide a good basis for comparison. However, while the total estimates of costs of decommissioning were somewhat similar, the percentage allocations between the ISDC categories were dissimilar. Representatives confirmed that they had their own system of estimating decommissioning costs, which were then used to allocate expenses to the ISDC categories. Consequences such as these are not entirely unexpected given the limited experience to date in translating cost estimates to the ISDC presentation format.

Many of the earlier plants now being decommissioned were one-of-a-kind plants and the organisations concerned are using these decommissioning projects as opportunities to explore approaches and techniques for decommissioning. Therefore, many are first-of-a-kind decommissioning projects, which means that their cost data are only of limited use for comparison purposes. Further, there appears to be increasing competition among private firms now engaged in decommissioning, making the collection of quantified cost data even more difficult.

To complement the limited data made available through the questionnaire, the NEA thus made use of information contained in an NRC-funded study conducted by the Pacific Northwest National Laboratory (PNNL) entitled *Assessment of the Adequacy of the 10 CFR 50.75(c) Minimum Decommissioning Fund Formula*. The PNNL cost breakdown structure was translated into the ISDC format, allowing for a comparison between high-level aggregated cost categories from the PNNL study with responses to the NEA questionnaire: ISDC categories 04 and 07 (decontamination, dismantling, demolition and site restoration), ISDC category 05 (waste processing storage and disposal), and ISDC categories 06 and 08 (site infrastructure, operation, project management, engineering and support). The figures below provide decommissioning cost values for the primary decommissioning activities. The first figure presents the estimates in the questionnaire. The second figure provides the translation of the costs and cost estimates from the PNNL study into a comparable ISDC format.

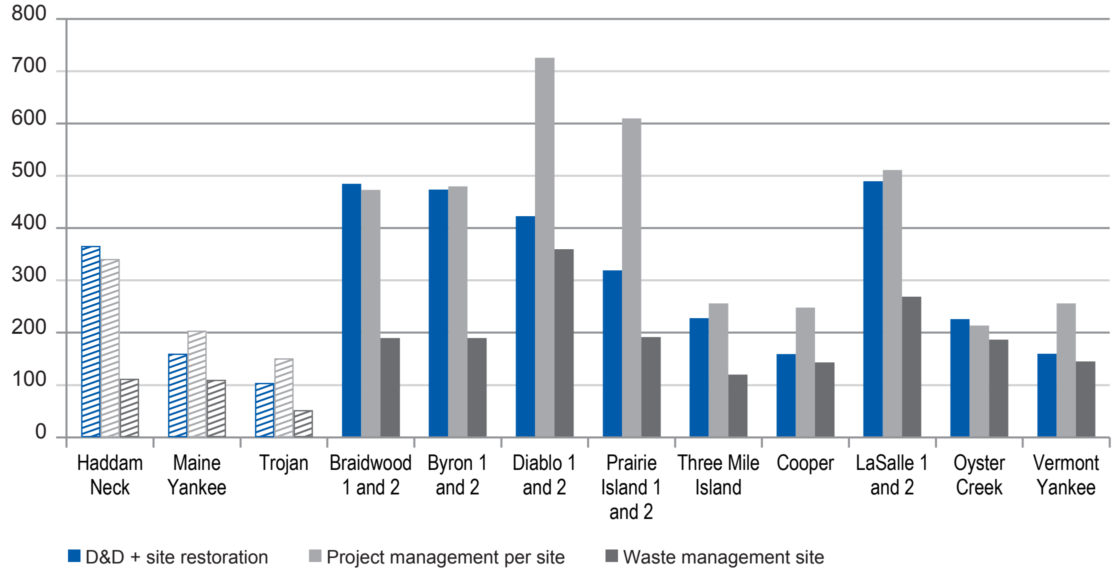
Figure 1: Costs related to aggregated categories in USD_{2013} million for the site
(collected through the questionnaire)



ES-P1: PWR José Cabrera (Spain) – 160 MWe; ES-P2: PWR Generic (Spain) – 1 066 MWe;
CH-P1: PWR Generic (Switzerland) – 1 000 MWe; FR-P1: PWR Generic (France) – 3 600 MWe;
ES-B1: BWR Santa Maria de Garoña (Spain) – 466 MWe; ES-B2: BWR Generic (Spain) – 1 092 MWe;
SE-B1: BWR Oskarshamn (Sweden) – 2 576 MWe; FI-V1: VVER Loviisa (Finland) – 976 MWe;
SK-V1: VVER Bohunice (Slovak Republic) – 880 MWe.

Source: Figure 3.A3.3 from NEA (2016), *Costs of Decommissioning Nuclear Power Plants*, OECD, Paris.

Figure 2: Costs related to aggregated categories per site in USD$_{2013}$ million, from the PNNL study, where the hatched blocks represent completed decommissioning projects



Source: Figure 3.A3.9 from NEA (2016), *Costs of Decommissioning Nuclear Power Plants*, OECD, Paris.

While findings related in the study on cost estimates for NPP decommissioning may seem uncertain because of limited experience, the text and case studies nevertheless highlight the main factors influencing these cost estimates. In the future, more opportunities will arise to learn from actual decommissioning projects, which should enable such experience to be applied to projects in other countries. The NEA will continue to develop methodologies to identify the main influencing costs and uncertainty drivers, while seeking to understand the reasons underpinning variability in decommissioning costs so as to facilitate learning among all interested parties at the international level.

Reference

NEA (2016), *Costs of Decommissioning Nuclear Power Plants*, OECD, Paris.

Nuclear safety: Five years after the Fukushima Daiichi accident

by H. Nieh, A. White and N. Salgado*

It is the nature of nuclear operations and regulation to learn from all experience. Many lessons have come to light as a result of the Fukushima Daiichi accident, and nuclear power plants in NEA member countries have become safer today thanks to a range of actions that have been taken in response to lessons learnt from the accident. The implementation of such actions and related research activities are, however, long-term initiatives that will continue to evolve as regulators and the nuclear industry examine their regulations and practices in light of the accident.

Since the Fukushima Daiichi accident, the Nuclear Energy Agency has been working closely with its member and partner countries to identify lessons learnt and follow-up actions at the national and international levels in order to maintain and enhance the level of safety at nuclear facilities. In 2013, the NEA published a report entitled, *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt*, which detailed the key immediate responses of the NEA and its member countries. The most important conclusion reached in the 2013 report was that, in the aftermath of the Fukushima accident, nuclear power plants in NEA member countries were safe to operate while additional actions and reviews were being conducted to enhance the level of safety.

The 2016 NEA report, *Five Years after the Fukushima Daiichi Accident: Nuclear Safety Improvements and Lessons Learnt*, focuses on what has been done by the NEA and its member countries to improve safety since 2011. It provides a high-level summary and an update on activities performed by member countries and by NEA committees, as well as further lessons learnt and challenges identified for future consideration, including:

- actions taken by regulatory authorities in NEA member countries to establish new requirements for specific nuclear power plant improvements in multiple areas, such as protective equipment for natural hazards, portable cooling water pumps and electrical power supplies;
- actions to underline the importance of using operating experience and risk insights, in particular through international co-operation;
- activities to improve regulatory frameworks in member countries, for example reinforcing the independence of the regulatory body;
- near- and long-term research activities undertaken to improve the knowledge and understanding of the accident itself;
- activities implemented to improve emergency preparedness and radiological protection, for instance improved co-ordination between on-site and off-site response organisations;
- efforts to understand and characterise the importance of strong nuclear safety cultures;
- actions taken to continue enhancing stakeholder involvement and public communication;
- legal improvements, such as those in the area of liability law.

The report was prepared with input from the NEA committees involved in nuclear and radiation safety issues – the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI), the Committee on Radiation Protection and Public Health (CRPPH) and the Nuclear Law Committee (NLC) – under the leadership of the CNRA. It is complementary to reports produced by other international organisations, including the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO).

Although enhancing safety is a common objective around the world, NEA member countries have nonetheless addressed this issue using different approaches. Since some national standards or safety requirements are country-specific and relate to the specific circumstances and external hazards in each country, member countries are not necessarily starting from the same point of departure. Some improvements have already been implemented, some are in the process of being completed, and still others are being planned and will be implemented in the coming years.

While all NEA countries have made significant progress since the accident and continue to make further progress towards enhancing safety, it is important to remember that ensuring safety is a process that evolves as we learn through operating

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experience and research. Much work remains to address new lessons, including how to effectively deal with more complex issues such as the human aspects of nuclear safety reflected in safety culture, training and organisational factors. The NEA will continue to play a key role in assisting and encouraging NEA member countries in the important work of ensuring safety for nuclear reactors today and in the future.

Summary of conclusions from the report

Continuing enhancement of safety

Ensuring safety is a continual process, which evolves as we learn through operating experience and research. Safety is the prime responsibility of the operator, with the regulator's goal to ensure that operators continuously improve and make nuclear power plants safer. The continued operation of nuclear power plants requires that their robustness under extreme situations be reinforced beyond-design-basis safety margins, and many of these improvements have been implemented or are in the process of being implemented. While an external event (an earthquake-induced tsunami) caused the Fukushima Daiichi accident, the actions that have been taken around the world to make nuclear power plants safer are applicable to any type of event, man-induced or naturally occurring.

Effective implementation of safety improvements

While NEA member countries have been able to discuss the same lessons learnt from the Fukushima Daiichi accident and the outcomes sought are very similar, there are nonetheless different avenues being taken to achieve the goal of enhancing safety, and preventing and mitigating potential accidents. Unique natural conditions exist in member countries, in particular with regard to potentially extreme natural events; different national regulatory requirements, for example, for the prevention and mitigation of severe accidents; various approaches to and applications of periodic safety reviews in order to continuously improve safety; and different types and generations of nuclear power plants. Differences in the priorities and implementation of schedules for safety improvements therefore exist among member countries.

Using operating experience and risk insights

Lessons learnt concerning operating experience have been disseminated internationally, particularly in relation to the main initiators and conditions that have been observed during the Fukushima Daiichi accident. The accident did not reveal any unknown initiators, sequences or consequences. However, the combination and the severity of initiating events had never occurred before, and the evolution of the accident in three units simultaneously was also new. The accident demonstrated that while existing operating experience feedback systems provide a good tool to identify lessons learnt and to help prevent the recurrence of events, operating experience combined with risk insights can provide an even greater source of potential improvement as demonstrated in the course of real events.

Strengthening regulatory frameworks

National safety frameworks have been and are being further strengthened to enhance governmental frameworks and update regulations, including through reinforcing the independence of regulatory bodies. The principle of regulatory independence, in particular the effective separation between the functions of the regulatory body and those of any other body or organisation concerned with the promotion or use of nuclear energy, is fundamental and requires vigilance to ensure it is maintained.

Some member countries have reviewed, and other member countries are in the process of reviewing, their regulatory frameworks and are making changes as appropriate to update their legislation so as to reflect lessons learnt from the Fukushima Daiichi accident. One example is the emphasis on ensuring that a clear and comprehensive legal framework exists to allow the operator of a nuclear installation – and its government, if necessary – to quickly react and adapt to the specific circumstances of an event in order to ensure timely and financially adequate compensation to victims.

A long-term learning process supported by safety research

While near-term, higher-priority lessons learnt are currently being addressed, overall knowledge will expand as the Fukushima Daiichi units are decommissioned. Efforts being undertaken through the NEA Senior Expert Group on Safety Research Opportunities Post-Fukushima (SAREF) and the NEA Benchmark Study of the Accident at

TEPCO, Japan

SAREF members at the Fukushima Daiichi site.

the Fukushima Daiichi Nuclear Power Plant (BSAF) have already provided invaluable insights concerning severe accident progression and the current status of the reactors in all three units that experienced core melt. Research continues into accident progression, recovery and the human factors involved in severe accident response. Important information is emerging from post-accident recovery efforts at the Fukushima Daiichi nuclear power plant.

The human element as an essential aspect of safety

Human and organisational factors and safety culture are essential to all aspects of nuclear safety, from design, construction and operation to the response to potential events or accidents. Both licensees and regulatory bodies identified these as relevant issues to be addressed in the post-Fukushima Daiichi accident assessment. The human element has a considerable impact on all levels of the defence-in-depth concept. Work carried out by the NEA and its member countries on both the characteristics of an effective nuclear regulator and on regulatory safety culture have been recommended for benchmarking, peer review, and for training and development of regulatory staff. Nuclear safety will benefit from continuing work in areas such as safety culture, and human and organisational factors.

Emergency management and the long-term commitment of resources

The accident at the Fukushima Daiichi site demonstrated the challenges involved when managing the consequences of a large-scale accident. As time progressed, radiological and social consequences became increasingly evident, while decisional responsibilities were shifting from central government to regional and local governments, and to affected individuals. Approaches to address the complexity generated by such long-lasting circumstances need to be considered and included in national planning. Moreover, the resources needed to manage an emergency on the scale of the accident at the Fukushima Daiichi nuclear power plant have proven to be considerable. Emergency management planning should thus take into account the Japanese experience in terms of the training and resources required to be appropriately prepared to manage the collection and flow of information.

Enhancing stakeholder involvement and public communication

Involvement of stakeholders (local authorities, industry, non-governmental organisations, government officials and the public) in decision making is appropriate and advisable to enhance the credibility, legitimacy, sustainability and final quality of regulatory and off-site emergency management decisions. In addition, proactive outreach to stakeholders in regular communications (i.e. in non-accident situations) is highly desirable to improve their understanding in times of crisis. Experience during the Fukushima Daiichi accident highlighted the need to reconsider approaches to information sharing and assessment, both domestically and internationally.

International co-operation as a key factor in continuous safety enhancement

International co-operation provides a forum for regulators to work together to share and analyse data and experiences, gain consensus and develop approaches that can be applied within each country's regulatory process. International co-operation also provides a platform for peer regulators to encourage vigilance in ensuring nuclear power plant safety and avoiding the complacency that contributed to the accident at Fukushima Daiichi. Regulatory authorities from NEA member countries are working together internationally to share information and actions taken in order to improve their regulatory frameworks and nuclear power plant safety. The NEA provides an effective forum for co-operation on both medium- and longer-term issues in its specific task groups, working parties and expert groups, as well as through joint international safety research projects.

Strengthening the scientific basis of radiological protection

by E. Lazo*

The overarching objective of the radiological protection system is to contribute to an appropriate level of protection against the harmful effects of radiation exposure, without unjustifiably limiting the desired results from the human activity causing exposure. Such a balance is achieved by understanding as best as possible the scientific characteristics of radiation exposure and the related health effects, and by taking this knowledge into consideration when judging which protection decisions will ensure the best balance between social and economic aspects and risks.

In general, the existing radiological protection system, on which national regulations are built in virtually every country in the world, works well and does not underestimate protection needs for either individuals or exposed populations as a whole. The latest International Commission on Radiological Protection (ICRP) recommendations, which define this protection system, were formed after a long and open dialogue with the public, where expert views were actively collected and discussed at national, regional and international levels.

Although the radiological protection system is very effective, and there is no current need for a prompt revision, it is important nonetheless to keep a watchful eye on the latest scientific results, and to work to ensure that the entire radiological protection community is kept up to date on evolving and emerging scientific issues. In this way, potential or actual scientific changes can be appropriately identified and in turn can stimulate reflection on changes that might be needed in the protection system, in policy, in regulation and in practice. Such reflection should benefit from the input of other scientific disciplines and interested stakeholders.

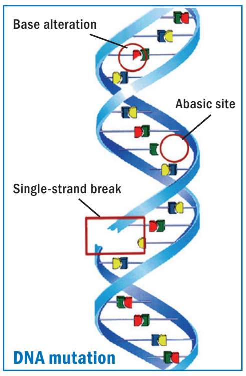
To contribute to this process, the NEA Committee on Radiological Protection and Public Health (CRPPH) has periodically reviewed and released reports on the state of the art in radiological protection science (see NEA, 1998 and 2007). With these analyses, the CRPPH has assessed the possible implications that emerging scientific results (e.g. recent findings on radiation effects on the lens of the eye), or that possible results (e.g. ongoing epidemiological studies that could show statistically significant cancer risks, or that could show no cancer risks at doses below 50 mSv) could have for the way that radiological protection is regulated and applied. The latest report in this series, *Radiological Protection Science and Application* (NEA, 2016), performs such an assessment for today's level of scientific understanding.

Report focus and findings

Cancer is the second leading cause of death in OECD countries, accounting for approximately one-third of all deaths (OECD, 2015). Although many factors can cause cancer (e.g. smoking, alcohol, exposure to certain chemicals, genetic predisposition), cancer development is a very complex process that is as not yet fully understood. Ionising radiation, which is classified as a weak carcinogen by the World Health Organization, is known to cause cancer at higher doses and is regulated as though any dose, no matter how small, can cause cancer, despite scientific uncertainties in this regard.

Since the discovery of radiation at the end of the 19th century, the health effects of exposure to radiation have been studied more than almost any other factor having a potential effect on overall health. While much more is known today, there is an enormous amount to learn, and radiation effects at low doses continue to be an important area of scientific study.

It is certain, for instance, that very high doses of radiation can cause serious damage to blood-forming organs, to the stomach, intestinal tract and to the central nervous system. These radiation-induced tissue injuries can lead to death, and at high enough doses can cause rapid death. Doses at this level will normally only occur as a result of very serious accidents, and only to those physically very close to the source of radiation. Lower doses of ionising radiation can cause leukaemia and solid cancer, appearing a few to many years after exposure, and such doses can potentially have effects on future generations. It has also been shown that high doses of radiation can cause health problems other than cancer, such as heart disease, strokes and cataracts.



At low doses, our scientific knowledge is much less complete, and it is not clear whether low doses can cause health problems such as cancer and leukaemia. Low doses of radiation include doses that are less than approximately 50 times the dose that people receive each year from natural sources, the earth, the cosmos and their own body.

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It is nevertheless important to understand the nature of any health effects that these doses might cause because almost all man-made doses to humans are in this low-dose range. Such doses may arise from accidents, from work and research activities involving radiation or nuclear energy, or from hospital and industrial releases of radioactive substances to the environment. Low doses can also emanate from medical examinations, which are given for the benefit of patients, but can also carry some risk. Higher doses to individuals can originate from medical treatments, areas of high radon concentration or large-scale nuclear accidents.

While scientific evidence suggests that high doses of radiation can cause cancer, there is no clear scientific proof that this is true at low doses. However, to be conservative, regulatory authorities around the world assume that any dose, no matter how small, is a potential risk. Most scientists believe that this assumption – and it is an assumption, not a fact – does not under or overestimate radiation risks. Thus, it is important to prevent unnecessary exposure, and exposure caused by activities bringing little or no benefit. Regulations require that allowed doses are kept as low as reasonably achievable (ALARA).

Although the effects from low doses of radiation are scientifically uncertain, many things are known about low doses. For example, some individuals can be more or less sensitive to radiation than others. Some people may be more sensitive because of their genetic background. Children are generally more sensitive to radiation than adults and women are more sensitive than men for certain health effects. Much more research is nevertheless needed to clearly understand these differences in sensitivity.

Radiation protection science can be complex, but should be understood by all those concerned so that protection choices and actions can at least attempt to meet everyone's needs. Decisions should therefore be made through dialogues with stakeholders, during which radiological protection professionals explain complex science in simple language. Social scientists may be of help as well when explaining such complex issues.

It has also been agreed that the environment must be protected from events or practices causing large-scale contamination. Although most scientists feel that nature is not at present threatened by artificially produced radiation, nature is very complex. As such, scientific approaches to radiological protection of the environment are still being refined, and further studies are needed on the potential effects of radiation on the environment.

Overall ways forward

Beyond the aforementioned assessment aspects, *Radiological Protection Science and Application* also examines areas where further knowledge would be of use for the support and evolution of the protection system in specific cases.

Clarity in the ethical basis of radiological protection

The system of radiological protection is based on three principles: justification of actions causing exposure; optimisation of protection; and limitation of exposure. Current studies are working to express these principles in terms of modern ethics, in an effort to enhance trust in the system.

A graded approach to protection of the environment

Focus has recently turned to radiological protection of the environment. Efforts should focus on a step-by-step approach to understanding ecosystem risks, and to developing protection indicators and strategies.

Strengthening the scientific basis of radiological protection

Ongoing scientific studies of radiological effects should focus on low-dose and dose-rate cancer risk and the linear non-threshold model; non-cancer effects at low doses; individual sensitivity; and a definition of the scope of "effective dose".

Tolerability of risk and dose limits

Dose limits have been defined as the boundary between risks that are "tolerable" and those that are "unacceptable". Further work, updating the ICRP Publication 60 rationale (from 1990) for the selection of numerical values for dose limits, is being encouraged.

Improving communication in the radiological protection system

Radiological protection concepts (e.g. effective dose, internal exposure) tend to be complex and difficult to explain to non-specialist stakeholders. Work on better approaches to dialogues with stakeholders should therefore be pursued.

International collaborative research

It is strongly recommended that research topics take advantage of collaborative approaches. Multi-organisation participation would help to optimise efforts and bring co-operative views together to more effectively advance science in areas such as mechanisms of radiation action at low doses and dose rates; joint research strategies, agendas and studies, and co-ordination of resources; research infrastructures; and training and education.

In general, the present radiological protection system works well and does not underestimate protection needs for either individuals or exposed populations as a whole. It is nonetheless important to continue reflecting in this area, to involve the entire radiological protection community in this reflection and to benefit from the input of other scientific disciplines and broader stakeholders.

References

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NEA (2007), *Scientific Issues and Emerging Challenges for Radiation Protection*, OECD, Paris.

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The NEA Nuclear Education, Skills and Technology (NEST) Framework

by L. Andreeva and J. Gulliford*

NEA member countries are, collectively, world leaders in the use of nuclear technology and materials for a wide range of industrial, scientific, medical and energy purposes. To ensure the safe, secure and sustainable use of nuclear energy, it is critical that these countries have the scientists, engineers and technologists needed to support the continued use of nuclear energy, and to meet global energy and environmental challenges.

The current talent base in nuclear technology and science has developed over a period of several decades in many countries. However, a large percentage of that generation of talent is now at or nearing retirement age. Some NEA countries are facing a situation in which key areas of expertise are at risk and may even be lost. It is thus imperative to create new approaches to retain, nurture and expand this knowledge base, and to build the new capabilities needed for innovative nuclear technologies.

Since the use of nuclear technology for a wide range of purposes is increasing, with many NEA member countries constructing or planning to construct new generation nuclear power plants, the NEA is developing the NEA Nuclear Education, Skills and Technology (NEST) Framework in partnership with its member countries. This initiative will help address important gaps in nuclear skills capacity building, knowledge transfer and technical innovation in an international context. It will also assist countries examining long-term options to manage high-level radioactive waste and spent nuclear fuel, as well as better ways to decommission old facilities. The majority of these countries are likewise facing challenging issues in other fields related to nuclear energy, ranging from medicine to the environment.

The need to develop and apply innovative technologies in order to meet these challenges is apparent in all these areas. At the same time, advances in fields such as materials science and instrumentation, linked with the availability of high-performance computing, have opened up new avenues ripe for exploitation, which makes for a combination of exciting new areas of innovation alongside longstanding challenges in the nuclear field.

The goal of NEST is to energise advanced students, post-doctoral appointees and young professionals to pursue careers in the nuclear field by:

- establishing a multinational framework among interested countries to maintain and build skills capabilities;
- establishing international links between universities, academia, research institutes and industry;

MEPHI, Russia

Education-Reseach Center “Nanocenter” training in the method of pulsed laser deposition.

- attracting technologists from other disciplines to examine nuclear technology issues;
- involving such actors in the resolution of real-world problems.

The NEST Framework can provide benefits for advanced students, post-doctoral appointees and young professionals, allowing them to:

- participate in NEA multinational projects jointly with experienced engineers and researchers, university professors and academia;
- work with their counterparts around the world as part of international teams pursuing research projects;
- acquire hands-on, practical experience and knowledge in nuclear science, advanced and innovative nuclear technologies and materials, experimental facilities and computer codes;
- expand professional connections;
- bring creativity to and enlarge the boundaries of current knowledge, while at the same time fostering innovation supportive of a low-carbon sustainable future.

The NEST Framework initiative was presented to the NEA Steering Committee for Nuclear Energy on 21 April 2016, at which time it was agreed that the topic of the next policy debate to be held in conjunction with its November 2016 session would be nuclear skills and education in NEA countries.

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OECD and NEA countries' national frameworks for nuclear activities

by K. Kuzeyli*

To assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, the NEA serves as a forum for sharing and analysing information and experience among its member countries in order to pool and maintain their technical expertise and human infrastructure and to support nuclear activities by providing them with nuclear policy analyses.

Comprehensive and effective legal regimes are necessary to help achieve confidence in the peaceful use of nuclear energy. These regimes, whose goals are to protect the public and the natural environment from the risks inherent in such activities, include regulation at a national level, co-operation at bilateral and multilateral levels and international harmonisation of national policies and legislation through adherence to international conventions. Regimes need to be strong enough to set and enforce limits, and flexible enough to keep pace with technological advances and changing public concerns.

The NEA collects, analyses and disseminates information on nuclear law in general and on topical nuclear legal issues in particular. Nuclear law is the body of special legal norms created to regulate the conduct of legal or natural persons engaged in activities related to fissionable materials, ionising radiation and exposure to natural sources of radiation.[1]

The "Grand Orange"

In 1995, the NEA began publishing country profiles entitled *Nuclear Legislation in OECD and NEA Countries – Regulatory and Institutional Frameworks for Nuclear Activities* or the "Grand Orange", a name which was adopted and became widely used because of the colour of the initial cover. Since 2006, these country profiles can be downloaded free online both in English and French from the NEA website.[2] The NEA endeavours to complement country profiles by publishing online an English, non-official translation of the primary legislation regulating nuclear activities in the country concerned.

The Grand Orange is prepared by the NEA in co-ordination with the relevant national authorities, and is revised periodically so as to ensure up-to-date information. The primary aim is to provide a brief outline of the regulatory and institutional framework for civil nuclear activities in these countries.

Each country profile consists of two main parts: the "General regulatory regime" and the "Institutional framework". The General regulatory regime is usually composed of ten sections, each of them detailing the national legal provisions that are implemented in accordance with the international instruments to which the country has acceded. It begins with an introduction laying down the basic legislative instruments governing nuclear energy and the status of the nuclear programme of the country.

The profiles then provide a detailed review of a full range of nuclear law topics that could include mining regimes; radioactive substances, nuclear items and equipment; nuclear installations; trade in nuclear materials and equipment; radiological protection; radioactive waste management; non-proliferation and physical protection; transport and nuclear third party liability.

The Institutional framework usually provides detailed information on the legal status, structure, responsibilities and financial arrangements of:

- regulatory and supervisory authorities, which are the competent ministries and nuclear regulatory commissions or committees that are mainly responsible for establishing the national nuclear programme of the country, drafting regulations for activities related to nuclear energy and issuing licences as such;
- advisory bodies that provide assistance to the regulatory and supervisory authorities on matters related to nuclear activities;
- public and semi-public agencies, which include public or semi-public associations, institutes, academies or centres mainly involved in research and development activities related to nuclear energy.

There are currently 31 country profiles. Since 2014, the NEA has managed to update the profiles (in English) of the Czech Republic, Denmark, Greece, Poland, the Slovak Republic, Slovenia and the United States. The profiles or updates for Austria, Finland, Mexico and the Russian Federation will be finalised in the coming months.

Notes

1. "Handbook of Nuclear Law", IAEA, STI/PUB/1160, IAEA, Austria, available at www-pub.iaea.org/mtcd/publications/pdf/pub1160_web.pdf.
2. www.oecd-nea.org/law/.

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Spotlight on Finland: The world's first deep geological repository

by O. Nevander*

Finland began planning and preparing radioactive waste management and disposal measures as early as the 1970s, during the procurement and construction phase of its first nuclear power plants. Four nuclear reactors were built at the time at two nuclear power plants located on the southern and western coasts of Finland at the Loviisa and Olkiluoto sites. The yearly electric energy output of these four nuclear units is about 22.5 terawatt hours (TWh), which was approximately 27% of electricity consumption (82.5 TWh) in Finland in 2015. Disposal facilities for low- and intermediate-level waste generated at Loviisa and Olkiluoto began to be used in the 1990s, and in 1995, power companies established the joint venture company, Posiva Ltd, to manage spent nuclear fuel.

It was in 1999 that Posiva applied for a decision-in-principle (DiP) for a final disposal facility that would be sited at a depth of 400-450 metres in the Olkiluoto bedrock. The DiP was ratified by Parliament in May 2001 with votes overwhelmingly in favour – remarkable evidence of the broad political support in Finland for a deep geological repository (DGR). This solution was chosen after the amendment in 1994 of the Nuclear Energy Act, which states that radioactive waste generated in Finland shall be managed and permanently disposed of in the country.

During the years 2004 to 2012, Posiva thus began construction of an underground laboratory (rock characterisation facility). The facility provides the basis for the final disposal facility for the spent nuclear fuel from the Loviisa and Olkiluoto plants that will be buried in Finnish bedrock. The permanent radioactive waste disposal facility, the first of its kind in the world, will stock 6 500 tonnes of uranium deep underground for more than 200 000 years. The construction licence for the final disposal facility and the encapsulation plant was submitted in 2012 and accepted by the government in November 2015. Repository construction is expected to start in 2016 and operation is planned to start around 2023. The sealing and closure of the repository is scheduled to take place around 2120.

Costs and funding

The entire construction and maintenance cost estimate for the project includes operational costs for approximately 100 years. This estimate serves as the long-term basis for depositing the necessary funds for future costs in the Finnish State Nuclear Waste Management Fund, which was established in 1988. Most of the funds to cover the estimated costs have already been collected in the state fund, through payments made by nuclear power utilities (TVO and Fortum). The costs of radioactive waste management and disposal account for about 10% of nuclear electricity production costs.

Technical solutions

The long-term safety of the disposal facility for spent nuclear fuel is based on the use of a multi-barrier disposal system originally developed by the Swedish Company SKB. The planned Swedish final disposal facility will use the same long-term disposal method: a combination of engineered barriers and a natural barrier provided by the host rock. The engineered barriers provide primary containment against the release of radionuclides, with the disposal system consisting of a tightly sealed iron-copper canister, a bentonite buffer enclosing the canister, a tunnel backfilling material made of expansive clay and sealing structures for the tunnels and premises, as well as the enclosing bedrock.

The host rock provides favourable and stable conditions for the long-term performance of the engineered barriers and also limits the transport of radionuclides. Many geological features have been taken into account for the long-term performance and safety of the repository, e.g. deformation and fractured zones, high salinity of groundwater at depth, effects of climatic cooling and glaciation leading to changes in rock stress, potential changes in groundwater and diluting of glacial melt waters into the host rock.

The main safety challenges of the repository are design-basis combinations of, for example, an extremely strong earthquake and glacial periods together with some very improbable events.

In addition to a disposal facility for spent fuel, two underground repositories for low- and medium-level radioactive waste are located at the Loviisa and Olkiluoto sites in Finland. At the end of the disposal period, all three repositories will be closed and sealed, and the responsibility for the radioactive waste will remain with the power companies until the final closure of the repositories.

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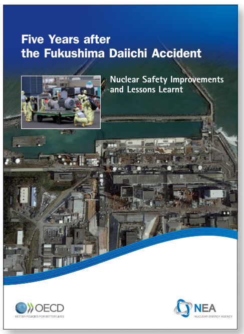
New publications

General interest

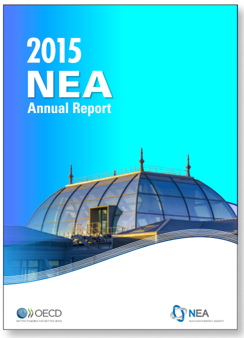


Five Years after the Fukushima Daiichi Accident: Nuclear Safety Improvements and Lessons Learnt

NEA No. 7284.

76 pages.

Executive summary available in English and Japanese.

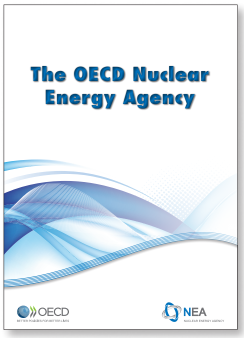


2015 NEA Annual Report

NEA No. 7293.

60 pages.

Also available in French.

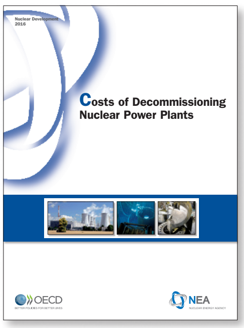


The OECD Nuclear Energy Agency

8 pages. Brochure.

Also available in French.

Nuclear development and the fuel cycle



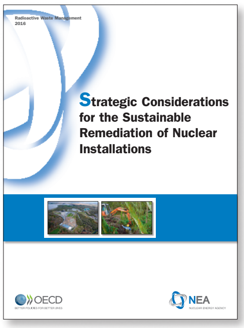
Costs of Decommissioning Nuclear Power Plants

NEA No. 7201. 256 pages.

While refurbishments for the long-term operation of nuclear power plants and for the lifetime extension of such plants have been widely pursued in recent years, the number of plants to be decommissioned is nonetheless expected to increase in future, particularly in the United States and Europe. It is thus important to understand the costs of decommissioning so as to develop coherent and cost-effective strategies, realistic cost estimates based on decommissioning plans from the outset of operations and mechanisms to ensure that future decommissioning expenses can be adequately covered.

This study presents the results of an NEA review of the costs of decommissioning nuclear power plants and of overall funding practices adopted across NEA member countries. The study is based on the results of this NEA questionnaire, on actual decommissioning costs or estimates, and on plans for the establishment and management of decommissioning funds. Case studies are included to provide insight into decommissioning practices in a number of countries.

Radioactive waste management

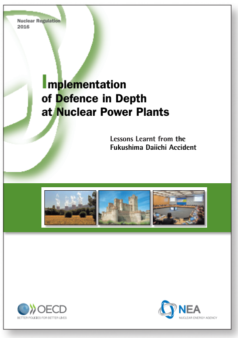


Strategic Considerations for the Sustainable Remediation of Nuclear Installations

NEA No. 7290. 110 pages.

Nuclear sites around the world are being decommissioned and remedial actions are being undertaken to enable sites, or parts of sites, to be reused. Although such activities are relatively straightforward for most sites, experience has suggested that preventative action is needed to minimise the impact of remediation activities on the environment and the potential burden to future generations. Removing all contamination in order to make a site suitable for any use generates waste and has associated environmental, social and economic drawbacks and benefits. Site remediation should thus be sustainable and result in an overall net benefit. This report draws on recent experience of NEA member countries in nuclear site remediation during decommissioning in order to identify strategic considerations for the sustainable remediation of subsurface contamination – predominantly contaminated soil and groundwater – to describe good practice, and to make recommendations for further research and development. It provides insights for the decision makers, regulators, implementers and stakeholders involved in nuclear site decommissioning so as to ensure the sustainable remediation of nuclear sites, now and in the future.

Nuclear safety and regulation



Implementation of Defence in Depth at Nuclear Power Plants

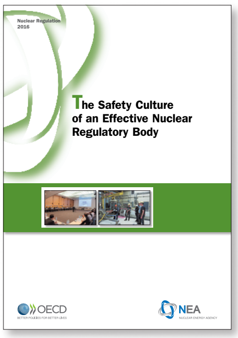
Lessons Learnt from the Fukushima Daiichi Accident

NEA No. 7248. 45 pages.

Defence in depth (DiD) is a concept that has been used for many years alongside tools to optimise nuclear safety in reactor design, assessment and regulation. The 2011 Fukushima Daiichi nuclear power plant accident provided unique insight into nuclear safety issues and raised questions about the tools used at nuclear power plants, including the effectiveness of the DiD concept, and whether DiD can be enhanced and its implementation improved.

This regulatory guidance booklet examines and provides advice on the implementation of DiD. A key observation is that the use of the DiD concept remains valid after the Fukushima Daiichi accident. Indeed, lessons learnt from the accident, and the accident's impact on the use of DiD, have reinforced the fundamental importance of DiD in ensuring adequate safety.

This report is intended primarily for nuclear regulatory bodies, although information included herein is expected to be of interest to licensees, nuclear industry organisations and the general public.



The Safety Culture of an Effective Nuclear Regulatory Body

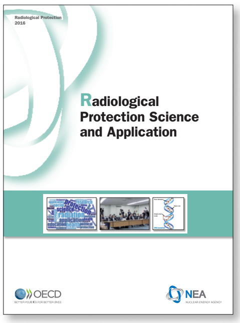
NEA No. 7247. 32 pages.

The fundamental objective of all nuclear safety regulatory bodies is to ensure that activities related to the peaceful use of nuclear energy are carried out in a safe manner within their respective countries. In order to effectively achieve this objective, the nuclear regulatory body requires specific characteristics, one of which is a healthy safety culture.

This regulatory guidance report describes five principles that support the safety culture of an effective nuclear regulatory body. These principles concern leadership for safety, individual responsibility and accountability, co-operation and open communication, a holistic approach, and continuous improvement, learning and self-assessment.

The report also addresses some of the challenges to a regulatory body's safety culture that must be recognised, understood and overcome. It provides a unique resource to countries with existing, mature regulators and can be used for benchmarking as well as for training and developing staff. It will also be useful for new entrant countries in the process of developing and maintaining an effective nuclear safety regulator.

Radiological protection



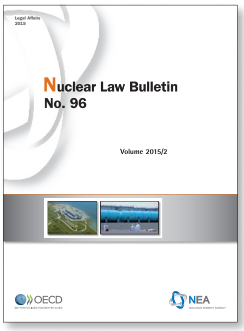
Radiological Protection Science and Application

NEA No. 7265. 111 pages.

Since the discovery of radiation at the end of the 19th century, the health effects of exposure to radiation have been studied more than almost any other factor with potential effects on human health. The NEA has long been involved in discussions on the effects of radiation exposure, releasing two reports in 1994 and 2007 on radiological protection science.

This report is the third in this state-of-the-art series, examining recent advances in the understanding of radiation risks and effects, particularly at low doses. It focuses on radiobiology and epidemiology, and also addresses the social science aspects of stakeholder involvement in radiological protection decision making. The report summarises the status of, and issues arising from, the application of the International System of Radiological Protection to different types of prevailing circumstances.

Nuclear law



Nuclear Law Bulletin No. 96

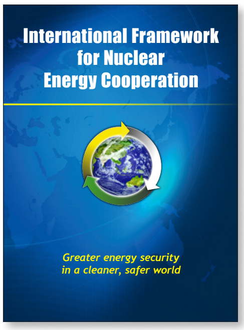
Volume 2015/2

NEA No. 7254. 116 pages.

The *Nuclear Law Bulletin* is a unique international publication for both professionals and academics in the field of nuclear law. It provides readers with authoritative and comprehensive information on nuclear law developments. Published free online twice a year in both English and French, it features topical articles written by renowned legal experts, covers legislative developments worldwide and reports on relevant case law, bilateral and international agreements as well as regulatory activities of international organisations.

Feature articles in this issue include "Treaty implementation applied to conventions on nuclear safety" and "Crisis, criticism, change: Regulatory reform in the wake of nuclear accidents".

NEA Secretariat-serviced bodies



International Framework for Nuclear Energy Cooperation (IFNEC)

8 pages. Brochure.

www.ifnec.org

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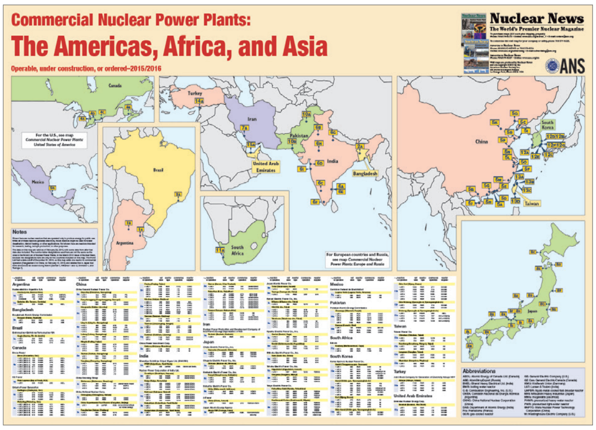

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