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In this issue:

The true costs of decarbonisation

Sustaining multinational nuclear fuel and materials testing capacities for safety, industry and science

Knowledge management and the sustainability of the nuclear sector

and more...

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Contents

OECD Boulogne building.

Senate Committee on Environment and Public Works Subcommittee on Clean Air and Nuclear Safety a subcommittee hearing, “Advanced Nuclear Technology: Protecting US Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies”, 4 June 2019.

www.epw.senate.gov/public/index.cfm/hearings/

Statement of

William D. Magwood, IV, Director-General of the OECD Nuclear Energy Agency

United States Senate Environment and Public Works Subcommittee on Clean Air and Nuclear Safety

4 June 2019

Good morning Chairman Braun and members of the Subcommittee. I am Bill Magwood, Director-General of the Nuclear Energy Agency. Thank you for the opportunity to appear before you today to provide my perspectives on the future outlook for nuclear energy.

As I engage with leaders around the world, I find that in essentially every country with which we work, the level of uncertainty regarding the future of energy is currently at a very high level – perhaps the highest it has been since the oil shocks of the 1970s. In some ways, the uncertainty is even higher than that tumultuous period because we are today faced with radical shifts in technology, policy and politics that make the picture of the future murky and unreliable.

This is particularly true in the case of nuclear energy. Just as many countries around the world seek to reduce emissions into the environment, nuclear energy in the developed countries of the OECD – including the United States – is on a declining path. Existing plants are faced with premature closure and few new plants are being built.

At the NEA we have analysed the reasons for these trends and they are varied and complex. Some countries have made political decisions to eschew nuclear or to emphasise other energy options at the expense of nuclear energy. Some countries face public resistance and concern about nuclear power plants in the aftermath of the Fukushima Daiichi accident. But the most important drivers for the declining prospects for nuclear energy in the United States and in many other OECD countries are economic.

First and foremost, the electricity markets have become dysfunctional in many markets around the world. It is not unusual to see market prices for electricity at zero or even negative during parts of the day. In many countries, the power companies that have provided reliable supplies of electricity face shrinking revenues just as the need for new investment is at its highest. I have had the leaders of power companies in several countries indicate to me that the only capacity they can afford to build is that which is subsidised by governments. These are no longer "markets" in any real sense.

Governmental interventions – including out-of-market subsidies and required shares for variable renewable energy – have contributed to these developments. However these conditions developed, they make the economics of operating a nuclear power plant very challenging. With zero marginal cost, variable renewables remove the floor in market prices, requiring baseload plants to either idle or operate at a loss during critical periods. Add historically low prices for natural gas in many places and the top of the market is compressed as well. As a result, nuclear plants are closing.

Overall, we believe that the electricity markets require significant reform. Around the world, whatever goals countries have for the future, today's markets are not serving their objectives. Markets should be balanced to provide for year-round reliability and stability and to enable electricity suppliers to make the investments needed to meet society's energy security and environmental goals. For those who are concerned about the emissions of carbon, the trends are particularly alarming. In the face of heavy investment in renewable energy sources, emissions are rising steeply and reached an all-time high in 2018.

We all certainly recognise the important and growing role of variable renewable energy in the world's long-term energy mix, and expect that wind, solar, geothermal and other technologies will be essential in the transformation of the electricity sector over the next few decades. But the results thus far highlight the need for strategies that more accurately reflect the costs and attributes of renewables.

A report released by the NEA in January entitled "The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables" demonstrates the vital role that variable renewables can play in the future energy supply – but as part of a well-balanced portfolio.

The NEA participated in the Tenth Clean Energy Ministerial (CEM10), which was hosted by the Government of Canada on 27-29 May 2019.

The contribution of renewables should reflect the realities of the electricity system in which they are to be deployed and the cost of the renewable resources available. Each country should assess the full costs of all its potential sources of supply and develop the balance of renewable and baseload supplies that best fits its particular circumstances. The balance is likely to be different from country to country. As it becomes clear that the amount of baseload supply needed in the future is not zero, each country will need to decide how it will meet its future electricity supply needs.

This would certainly appear to create an important opportunity for nuclear energy. Nuclear energy is the only expandable, dispatchable source of large-scale electricity that does not generate air emissions. Countries around the world have benefitted from the reliability and price stability provided by nuclear power plants for more than 50 years. Yet, nuclear energy is on path to decline in North America, Europe and OECD Asia.

Today, few plants are under construction in OECD countries. As reflected by the projects underway in Finland, France, the Slovak Republic and the United States, the nuclear industry in most OECD countries has a damaged reputation as a reliable supplier of plants and equipment. Eye-watering cost overruns, schedules for completion missed by a decade, failed projects and stratospheric cost estimates for new builds do not build confidence.

The fact is that the capacity to build nuclear power plants in the countries that led nuclear development in decades past has deteriorated. The skilled project leadership, supply chains for critical nuclear-quality components, and trained workforce needed for the effective construction of new nuclear plants simply have not been available to support nuclear projects in most OECD countries. After not building nuclear plants for decades, they are like the overweight man who never exercises but decides to clear his driveway of two feet of snow in a Washington winter. It's not a pretty sight.

Among OECD countries, only Korea has maintained a long-term building programme that enables it to supply nuclear plants to cost and schedule requirements. In contrast, China and Russia are quite proficient in building plants and are currently the most aggressive countries in the international market for new plants. Both countries have benefitted from continuous build programmes and have developed world-class construction expertise and robust supply chains. Organisations from these countries are winning contracts in both developing countries and in highly developed countries. Russia has proven its capabilities in Bangladesh and Iran and is now developing projects in Finland, Turkey and other countries. China has signed agreements to build in Argentina and is likely to construct a plant in the United Kingdom. In addition to their construction capabilities, both countries are offering financing for projects that can make the difference between an aspiration to build and a project to build.

The success of suppliers from China, Korea, and Russia demonstrates that the difficulties faced by projects in Finland, France, the United States and elsewhere have less to do with the nature of nuclear projects and much more to do with the lack of proficient, experienced construction capacities in countries that haven't hosted continuous nuclear build programmes since the 1980s.

Many government and industry leaders hope to leapfrog these difficulties by shifting from light water-based Generation III nuclear designs to new technologies – small modular reactors that can be largely built in factories and Generation IV technologies that seek to shift old paradigms. In May 2019, at the Clean Energy Ministerial held in Vancouver, governments and industry came together to discuss and pave the way for these new technologies. Most of the nuclear discussions were held in the context of the Nuclear Innovation: Clean Energy Future initiative – NICE Future – which was launched last year by Canada, Japan and the United States.

Gas-cooled reactors, liquid metal reactors, molten salt systems and others are being pursued. These are exciting technologies that offer many bright hopes. If successful, the potential exists for the introduction of technologies that have economic, flexibility and safety characteristics that could entirely change the global discussion about energy.

The NEA delegation visiting the Shanghai Institute of Applied Physics (SINAP), which is leading China's development and demonstration of molten salt reactor technology, February 2019.

Beyond even the shift in technology, discussions in Vancouver highlighted a shift in leadership in nuclear technology development from the government sector to the private sector. It is estimated that more than 30 companies are today developing advanced nuclear energy technologies – most of them Generation IV technologies. Many others are working on fusion energy as well.

This new, private sector-led approach to development is somewhat inspired by the success of NASA in encouraging innovation in space technology by supporting the private sector. Governments, particularly Canada, Japan, the United Kingdom and the United States, are emphasising this approach and have moved away from the traditional government-led development model that led to past nuclear technology innovations.

This new approach, however, faces important questions. As we watch this transition from government to private sector leadership, three primary areas of concern must be addressed if these initiatives are to be successful.

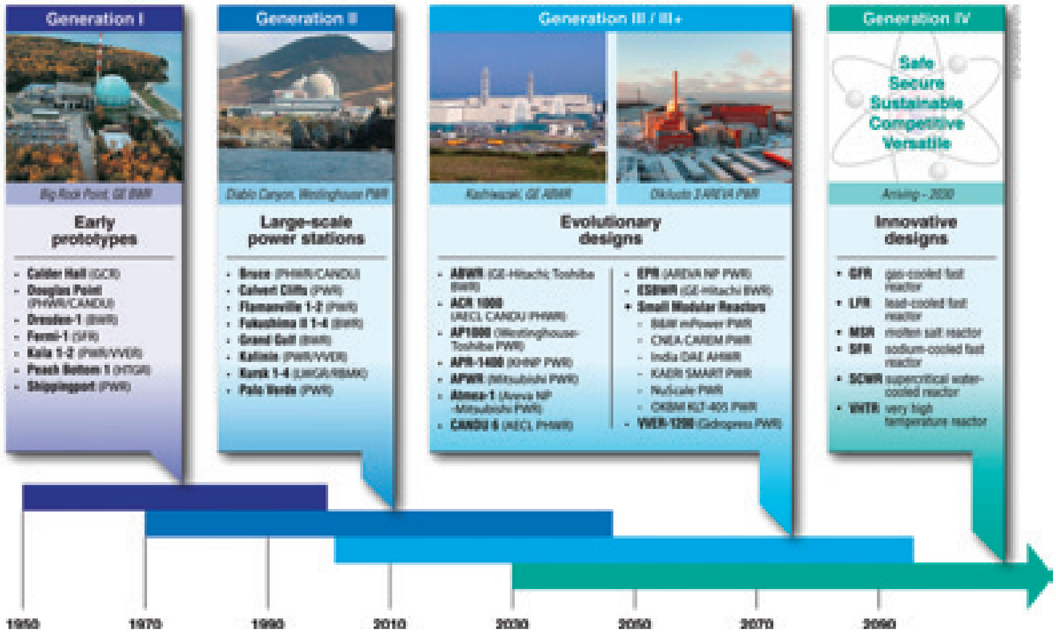
First, it is important to recognise the unique nature of nuclear technology development. The reason nuclear technology development has been led in the past by governmental organisations is because it is very technically challenging, expensive work that requires access to facilities that can safely and securely manage nuclear materials. As anticipated by the United States Department of Energy's (DOE's) Gateway for Accelerated Innovation in Nuclear (GAIN), national laboratories can support some of these needs.

This requires an approach to enable companies to benefit from the broad expertise and capabilities in national laboratories. This matter was discussed last week in a unique meeting sponsored by the Canadian government that brought together a dozen or so leaders from companies developing new nuclear technologies for market and the Generation IV International Forum (GIF). The GIF, for which the NEA provides the Technical Secretariat, has been active for nearly 20 years as a global framework for advanced reactor research co-operation between the world's leading countries in advanced research. It is led by government and national laboratory experts who have always worked in long-term government-sponsored research and development activities. The meeting demonstrated that the needs of the private sector are driven by investor impatience and the need to support regulatory processes. These imperatives contrasted with the long-term research approach of the government sector.

These discussions also highlighted that developing a new light water technology and shepherding it through regulatory approval is likely to cost at least USD 1.5 billion. Generation IV technologies are likely to cost substantially more. The typical company participating in the Vancouver meetings has perhaps a dozen engineers and scientists devoted to its technology development efforts and access to a few tens of millions.

In comparison, the Shanghai Institute of Applied Physics, is developing a molten salt reactor technology. Molten salt reactors are an area of high interest to several private sector companies because they represent a path to extraordinarily safe and efficient nuclear reactors that consume nuclear waste rather than generate it. The project at SINAP currently has over 400 scientists and engineers at work developing the technology with plans to build a demonstration reactor within the next decade. In terms of resources, this project is larger than the resources of all the companies that participated in the Vancouver meetings combined.

This highlights that the private companies upon which OECD countries are largely relying will need access to more resources than they currently have in order to be successful. Investors will look for early indications of success and a clear opportunity to enter the market in the foreseeable future. How some of the 30-odd companies aspiring to bring Generation IV technologies to reality will acquire the resources and expertise necessary for success is not clear. Government-sponsored technology projects in China and Russia appear to have a clearer path to market.



The second challenge is related to the dysfunction in today's energy markets. Prices for electricity in the United States are very low, which is good for consumers, but it provides limited incentive to private investors to support new nuclear energy technologies. Fortunately, there are visionary investors who are willing – for the sake of future generations – to launch the exploration of new technologies. But billions will be needed. In contrast to NASA, which provided the market to incentivise private space efforts, the markets for energy today cannot sustain fully depreciated existing nuclear power plants. It is therefore challenging to make an economic case for massive private investment in unproven technologies.

A possible exception might be the case of "microreactors", which could be deployed for specific niche purposes – such as providing energy for remote communities, to support military deployments or mining operations – but these face interesting regulatory questions regarding their deployment that remain to be resolved.

This brings us to the last major challenge: regulation.

There is no cause for concern at the ability of regulators, given sufficient lead time, to react to new technologies. Many observers call for more "streamlined" licensing to ease the introduction of advanced technologies, but I believe that the current frameworks in the United States and most other nuclear safety regulatory agencies can be adapted to license new technologies.

Clearly, more can be done to make the process simpler, but radical changes are not necessary to move technologies forward. The United States Nuclear Regulatory Commission (NRC) is considering how to modernise its framework and adapt it to non-light water reactor technologies. But even without these analyses, work conducted in the course of the DOE's effort to develop the Next Generation Nuclear Plant a decade ago demonstrated that the existing regulatory tools available to the NRC would allow for the licensing of an advanced technology.

Rather than a matter of framework and regulation, the most significant challenge for regulators will be to adjust the mindset of their staff towards new concepts and technologies. They must be more willing to become partners in innovation, though without violating their independence as nuclear safety regulators. Each regulator will need to manage its way to the appropriate balance.

The private sector has also expressed interest in having the NRC develop a stepwise approach to licensing new technologies along the lines of the pre-licensing vendor design reviews (VDRs) that can be conducted by the Canadian Nuclear Safety Commission (CNSC). This type of approach is helpful to small companies looking for ways of communicating progress to potential investors.

Nevertheless, at the end of the day, there is no shortcut to licensing advanced nuclear reactor technologies; nor should there be. The process will be expensive, time-consuming and likely require testing that can best be completed in established nuclear complexes such as national laboratories. No matter how regulators approach the licensing, the information they will need to make licensing decisions will be similar around the world.

This will require greater international co-ordination in the use and sharing of research facilities around the world. The NEA is today working with our members to address gaps in the global framework for the testing of new nuclear fuels and materials. This experience will be invaluable as regulators seek technical information regarding advanced reactor systems.

The bigger challenge for regulators will be to find ways to avoid forcing companies to resolve technical and regulatory questions about new technologies multiple times as they seek to introduce their technologies in multiple countries. Today, obtaining regulatory approval for a technology in France or Korea means very little for a construction project in the United States. For light water technologies, it requires about four years and the order of half a billion dollars to navigate approval processes. It is extraordinarily costly and inefficient if this must be done in each country for each technology.

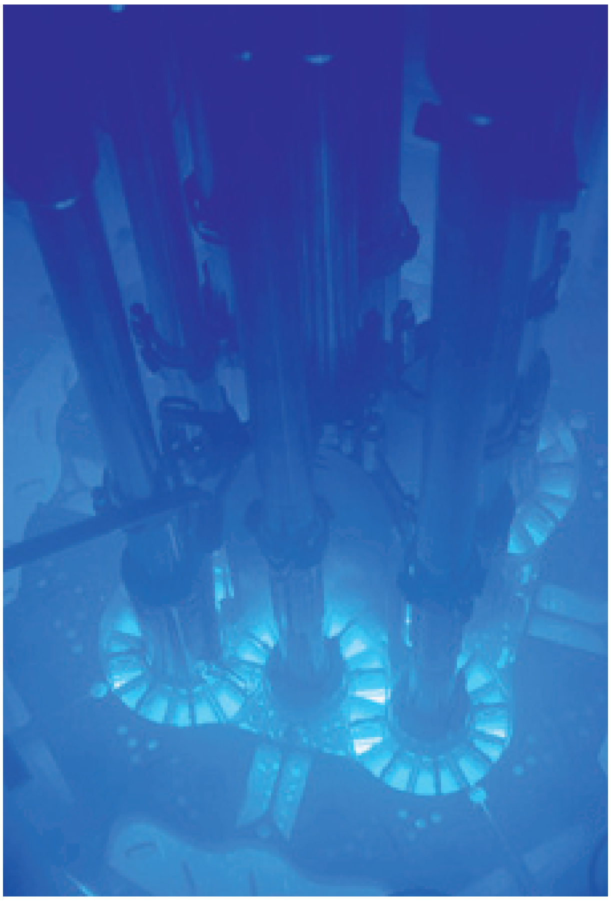
Moreover, if regulators can reach common positions on key aspects of technologies – such as requirements for autonomous operation and the nature of emergency preparedness requirements – companies can provide their products around the world applying the same rules. For small reactors in particular, which would benefit most from access to the largest practical market, this is a vital issue. The NEA is exploring how this issue might be resolved.

The need for nuclear energy technology is clear, but the path in the United States and other OECD countries to develop and deploy these technologies is not. The only major Generation IV nuclear technology demonstration projects underway today are in China, India and Russia. These countries have implemented and continue to implement advanced reactor demonstrations across a broad front. Russia's BN-800 sodium-cooled fast reactor and floating nuclear power plant and China's high temperature gas-cooled pebble-bed modular reactor are examples of successful projects. More are on the way.

The traditional nuclear development countries have not implemented a successful Generation IV reactor technology programme since the 1980s and the expertise and infrastructure these countries built over the decades have eroded dramatically.

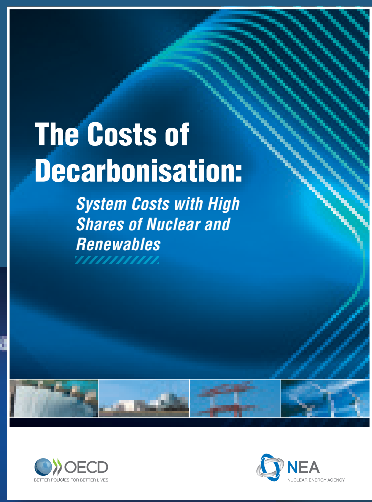
The United States and many other OECD countries rest their hopes on a large number of mostly small innovation companies that aspire to develop game-changing technologies for the future. But to be successful, these companies will need a supportive market, access to significant expertise and resources, and regulators who are prepared to support innovation and the development of a global market.

The text has been lightly edited for clarity. A transcript of the entire hearing is available on the United States Senate website at www.epw.senate.gov/public/index.cfm/hearings.



The core of the Advanced Test Reactor (ATR).

Courtesy of Idaho National Engineering and Environmental Laboratory (INEEL)



www.oecd-nea.org/ndd/webinars/2019/system-costs/

Launch of NEA study:

"The costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables"

Video Message by Angel Gurría,
Secretary-General, OECD

15 January 2019

Dear William D. Magwood, IV, Dear Colleagues, Ladies and Gentlemen,

Welcome to this webinar on the true costs of decarbonisation.

We cannot say it enough: climate change is one of the greatest challenges that we continue to face. Containing global warming to below 2 degrees and protecting our planet and future generations requires bold and decisive action. A key part of this effort is the creation of a robust and resilient low-carbon energy sector.

Moreover, for countries to reach Sustainable Development Goal number 7 and "ensure access to affordable, reliable, sustainable and modern energy for all", they must weigh the full benefits and costs of their policy decisions. As such, particular focus should be given to the benefits and costs of clean energy generation technologies.

With the increasing electrification of industry, transport and buildings, electricity generation will be at the heart of our efforts to reduce carbon emissions. In fact, the new study highlights that holding the increase of global temperatures to below 2 degrees Celsius will require a massive effort to decarbonise electricity generation. CO_2 emissions from the electric power sectors of OECD countries would need to be reduced by almost 90% by mid-century.

A key question, which is at the heart of the NEA's new study, is: What is the electricity system of the future that will enable countries to meet carbon reduction goals in the most cost-effective manner?

We are fortunate enough to have a number of technically mature low carbon alternatives at our disposal, including: solar and wind technology, hydroelectricity and nuclear power. Let's make the most out of them!

The study shows that in the electricity systems of the future, all these available, low carbon, options will need to work together in a reliable and cost-efficient manner. It also highlights the need to implement electricity market designs that are economically and environmentally sustainable.

Such important transformation requires strong action from policymakers. What does this mean?

First, that governments must foster vigorous investment in low-carbon technologies. It is of paramount importance to provide long-term stability and boost investor confidence in these technologies, which are typically capital intensive.

And Second, we need proactive policies to facilitate a "fair transition" for the affected businesses and households, and particularly those in vulnerable regions and communities. No one can be left behind.

Dear Friends, Ladies and Gentlemen,

Governments have committed to both an ambitious global temperature goal and national actions to limit emissions. Yet today we are neither on track to achieve our environmental goals, nor executing existing policies in a cost effective way. It is time to accelerate and scale up our efforts.

In this respect, the study that we are launching today provides an extensive set of information and recommendations to help us shape better, cost-effective climate futures, for better lives.

Thank you.

The true costs of decarbonisation

by J.H. Keppler and M. Cometto

Dr Jan Horst Keppler (jan-horst-keppler@oecd-nea.org) is Senior Economic Advisor in the NEA Division of Nuclear Technology Development and Economics and Dr Marco Cometto, formerly at the NEA (m.cometto@iaea.org) is an Energy Economist at the International Atomic Energy Agency (IAEA).

Hydroelectric power station (Shutterstock/Gary Saxe); Brokdorf nuclear power plant, Germany (Alois Staudacher); Electricity pylon; Wind turbines (Shutterstock/Carlos Castilla).

Comparing the costs of decarbonisation scenarios

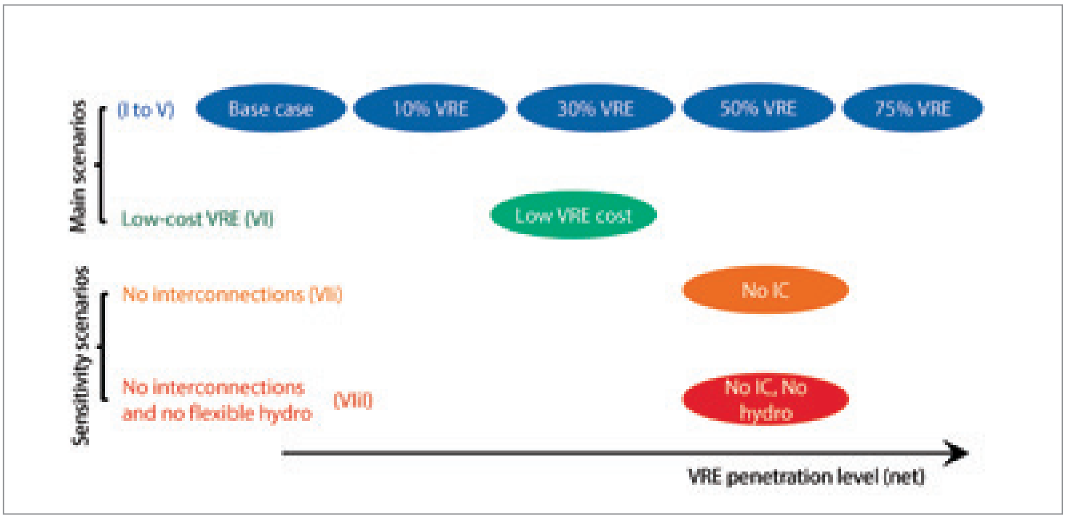
How do OECD countries decarbonise their electricity systems in the most cost-effective manner? The NEA study *The Costs of Decarbonisation: System Costs with Large Shares of Nuclear and Renewables* (NEA, 2019) finds that the answer depends on finding the right mix of dispatchable low carbon technologies, such as nuclear and hydro, and variable renewable energies (VRE) such as wind and solar PV.

The deployment of renewable energy technologies such as wind and solar PV can result in costs to the energy system rather than the plant. Such *system costs* are primarily due to the variability and unpredictability of their output and their comparatively small unit size. The former demands costly structural changes in the generation system to ensure the flexibility needed to accommodate variable renewable energies production, the latter requires additional investment in transmission and distribution infrastructure.

System costs were virtually unheard of before significant amounts of VRE capacity were added to electricity systems. In the space of only a few years they have become an integral part of electricity system analysis. The new study sets out to answer two questions: 1) Which combination of nuclear and renewables will minimise the costs of achieving a strict carbon constraint of 50 gCO_2 per kWh?; 2) Which policy instruments will ensure that this least cost mix is attained in the most efficient manner?

The NEA study compares different scenarios of the electric power sector in a representative OECD country, all of which are consistent with a low carbon constraint of only 50 gCO_2 per kWh but contain different shares of nuclear

Figure 1: Eight Scenarios to study the cost of low-carbon electricity systems with 50 gCO_2 per kWh



energy and of VRE such as wind and solar PV (Figure 1). In half of the scenarios the shares of VRE are exogenously imposed as if they were official targets of between 10% and 75% of total electricity consumption. In addition, there are two least-cost scenarios, in which all technologies compete on their own economic merit. One uses current costs (Base case) and the other assumes significant future cost reductions for VRE (Low VRE cost). Finally, two sensitivity analyses are built around different levels of available flexible resources (availability of interconnection and flexible hydroelectric resources).

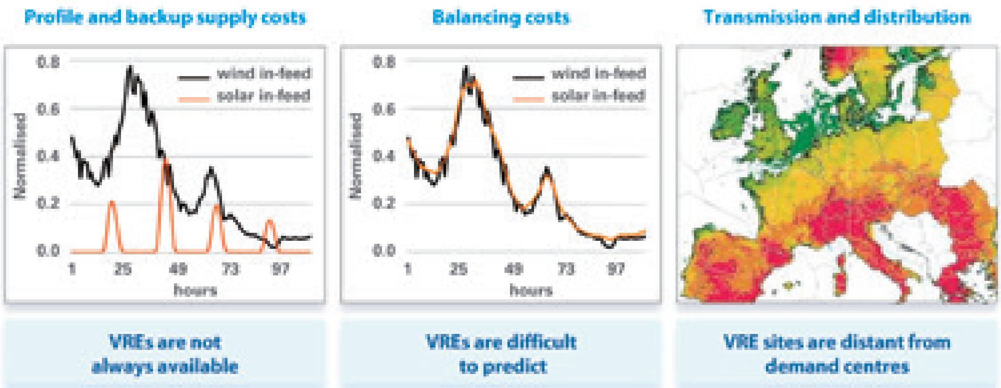
To study the system costs of these different scenarios, the NEA worked with a team of power system modellers at the Massachusetts Institute of Technology and their comprehensive GenX model. The model optimises over the 8 760 hours of the year and includes ramping constraints and reserve requirements. While system costs are highly dependent on natural conditions and the characteristics of the national energy system, the NEA has chosen a system that fairly represents the boundary conditions of an average OECD country.

System effects are often divided into four categories: profile costs, balancing costs, grid costs and connection costs. Profile costs are the increase in the generation cost of the overall electricity system in response to the *variability* of VRE output. They are at the heart of the notion of system effects. They capture the fact that in most of the cases it is more expensive to provide the residual load in a system with VRE than in an equivalent system where VRE are replaced by dispatchable plants.

Balancing costs are the increasing investments necessary to ensure system stability due to the *uncertainty* in the power generation.

Grid costs include building new infrastructure and strengthening the capacity of the existing infrastructure. Finallly, connection costs refer to the costs of linking a power plant to the distribution or transmission grid.

Figure 2: System costs arise from characteristics intrinsic to variable generation



Source: Hirth, 2015.

Figure 3: **Required capacity mix at different shares of VRE**

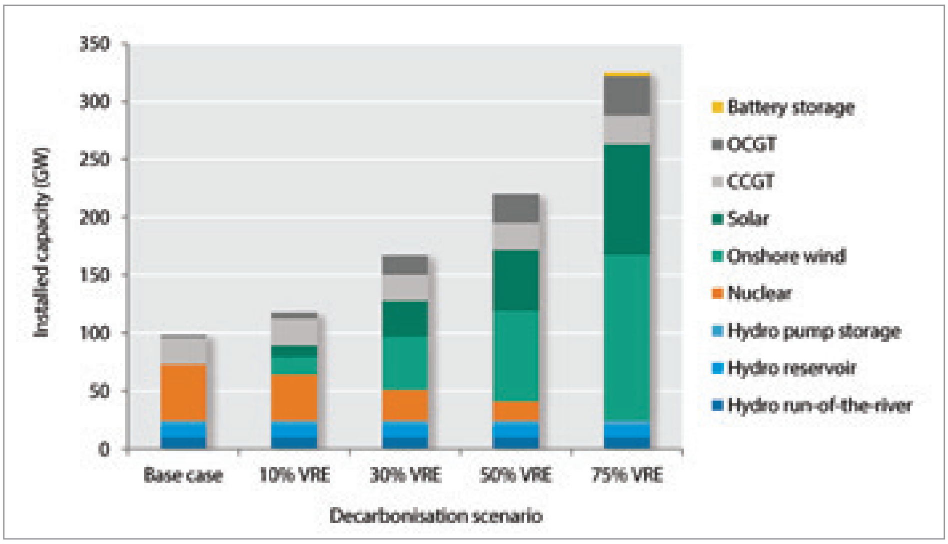


Figure 4: **Total cost of electricity provision including all system costs**

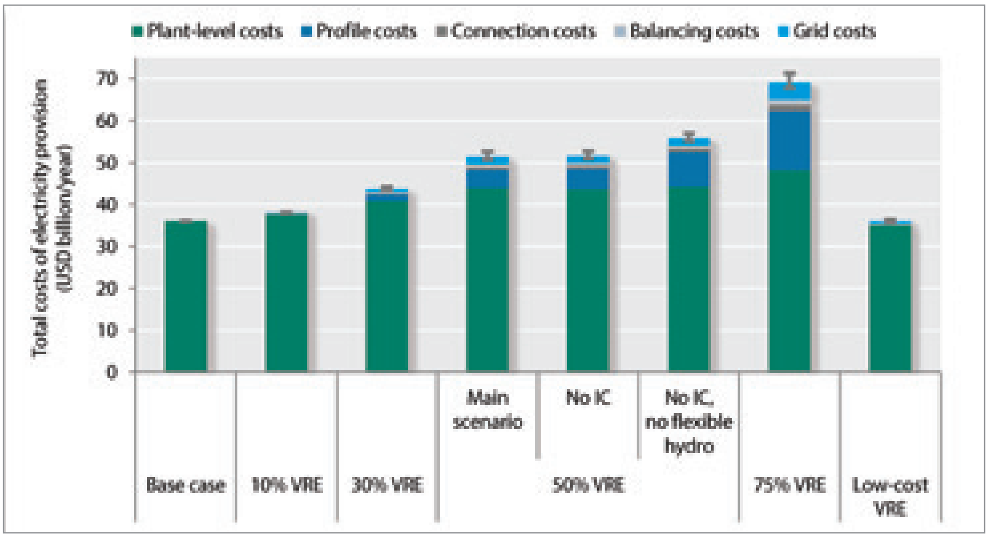
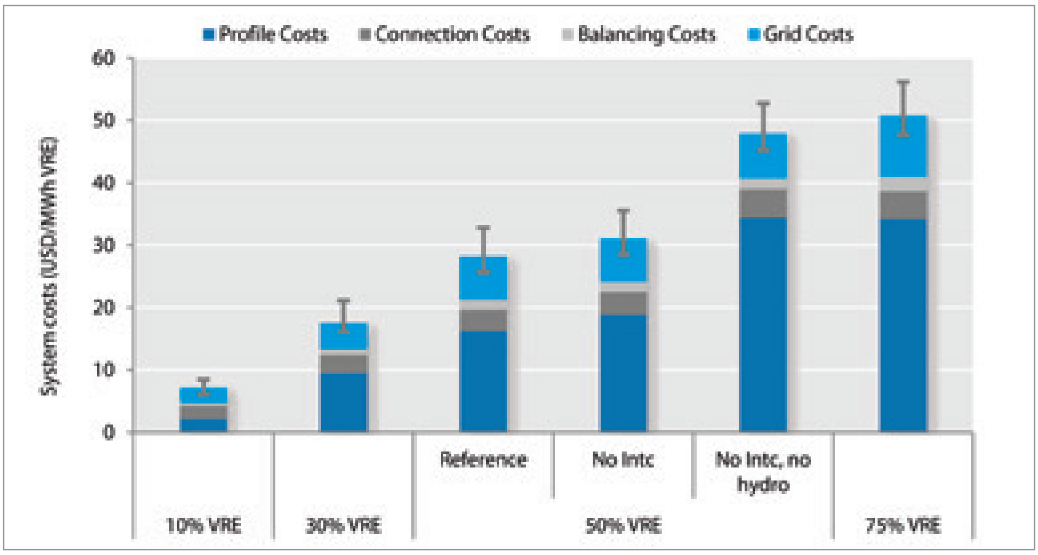


Figure 5: **System costs per MWh of VRE**



Variable renewables.
Shutterstock, Diyana Dimitrova

Main findings

The NEA study shows that combining explicit targets for VRE technologies and a limit on carbon emissions has important impacts on the generation mix and its cost. In particular, total generation capacity increases significantly with increased shares of VRE resources, even as demand and total electricity production stay the same (Figure 3). Since VRE load factors are lower than conventional thermal power plants, a higher capacity is needed to produce the same amount of electricity. While about 98 GW are installed in the base case scenario without VRE, the total installed capacity would need to more than double to 220 GW if a VRE penetration level of 50% is imposed. More than 325 GW, i.e. more than three times the peak demand, are needed if VRE generate 75% of the total electricity demand.

VRE change the long-term structure of the thermal generation mix. The share of fossil-fuelled generation – open cycle gas turbines (OCGTs) and combined cycle gas turbines (CCGTs) remains almost constant in all scenarios as it is limited by the carbon cap. However, the structure of the capacity installed of gas plants and the relative share of generation from OCGT and CCGT changes significantly with the presence of VRE. VRE displaces nuclear power generation on an almost one-to-one basis, which results from the fixed carbon constraint in combination with a fixed amount of hydroelectric resources.

As a result, the overall costs of the system as well as the different components of system costs increase strongly with the share of VRE production. Figure 4 shows the total system costs. An error bar indicates the uncertainty range from a range of possible assumptions on grid, connection and balancing costs. Total costs increase by more than USD 15 billion or 42% if half of all electric energy generation is assured by VRE and reaching a 75% VRE target means almost doubling the costs of electricity provision to nearly USD 70 billion per year.

Attributing the system costs to the VRE that cause them adds between USD 5 and USD 50 to the cost of a MWh produced by VRE (Figure 5). To meaningfully compare the full costs of different technologies at the system level, these unit system costs need to be added to the plant-level generation costs of VRE or the levelised cost of electricity.

The impact of large-scale VRE deployment

High shares of variable renewables not only drive up overall costs but also change how the electricity system operates. Three particular impacts can be identified: increased flexibility requirements demanded of nuclear operators; rising number of hours with zero prices; and the declining energy value of VRE. While they are interrelated, each one of them affects the system in a particular way.

An increasing VRE share changes how thermal plants such as nuclear or gas operate as average load factors are reduced and ramping and load-following requirements rise. In Figure 6 the installed capacity and the projected hourly generation pattern of the nuclear fleet in four of the five main scenarios is considered (there is no nuclear generation with 75% VRE). Nuclear plant flexibility requirements strongly increase as the share of VRE rises.

Figure 6: Projected generation pattern from nuclear power plants

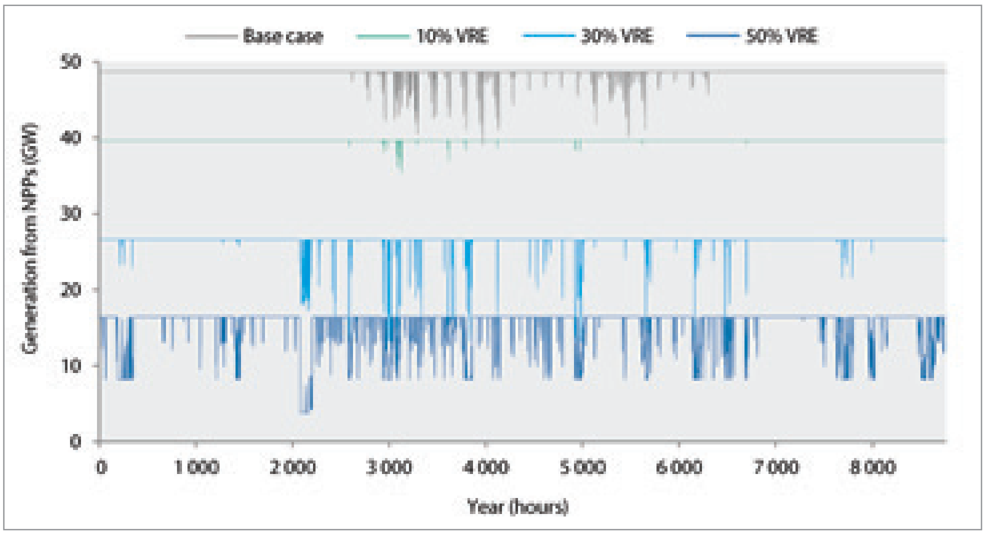
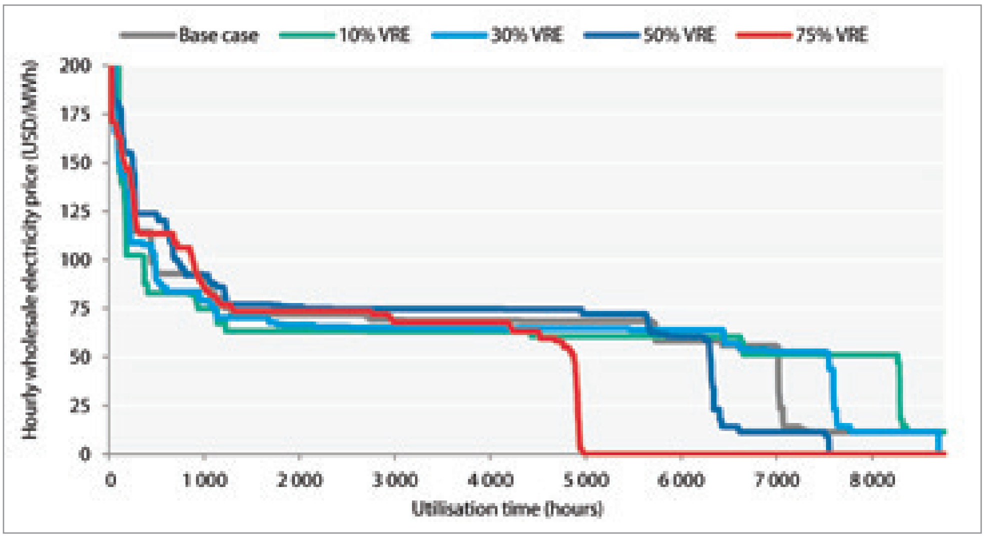


Figure 7: **Price duration curves of wholesale electricity prices in the five main scenarios**



A striking effect of the deployment of low marginal cost variable resources on the electricity market is the appearance of hours with zero prices and a substantial increase in the volatility of electricity prices. Zero price hours first start appearing when VRE reaches a penetration level of 30%. Their number then increases dramatically as VRE penetration level rises; at 50%, more than 1 200 zero price hours occur; at 75% this rises to 3 750 hours, i.e. more than 43% of the time (Figure 7). Since the model works under a financing constraint, zero price hours are compensated by hours with high electricity prices, which implies higher volatility and in a real-world setting, higher investment risk.

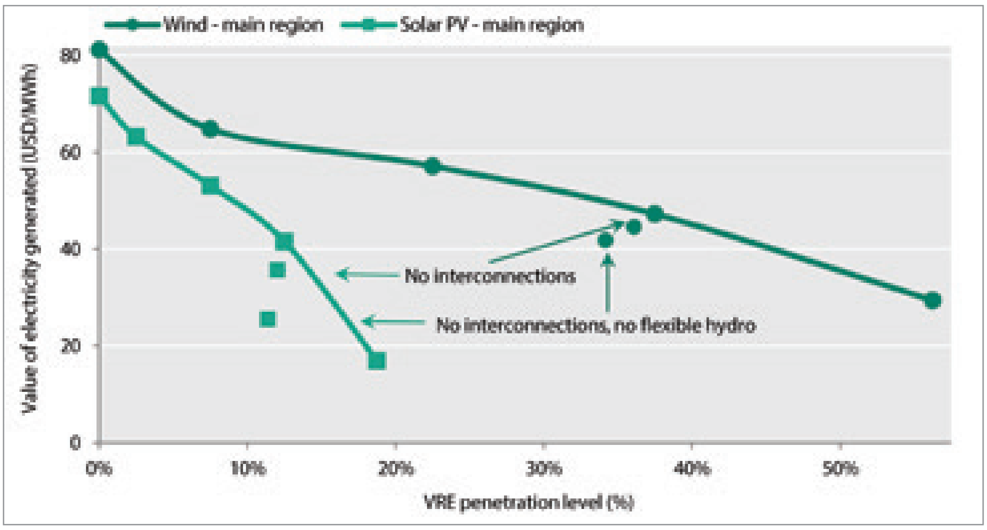
VRE generation, as a function of wind or solar radiation, is not only more variable than dispatchable plant generation, but also more concentrated during a limited number of hours. Periods with low or zero output are followed by periods with high output. Because VRE generation responds to the same meteorological conditions, they tend to auto-correlate, i.e. produce disproportionally more electricity when other plants of the same type are generating. In combination with the zero short-run marginal costs of VREs, this causes a decrease in the average price received by the electricity generated by VRE as their penetration level increases, a phenomenon often referred to as self-cannibalisation (Figure 8). The effect is stronger for solar PV than for wind and increases if flexibility options such as interconnections or hydroelectricity are lacking.

What should policy makers do?

Decarbonising the electricity sector to 50 gCO_2 per kWh in a cost-effective manner while maintaining security of supply requires five complementary policy measures:

- Implement carbon pricing, as the most efficient approach for decarbonising the electricity supply: Increase the cost of high-carbon generation technologies, reduce greenhouse gas emissions and enhance the competitiveness of low-carbon technologies such as nuclear and VRE.

Figure 8: **Market remuneration from wind and solar PV as a function of their share in the electricity mix**



- Recognise and fairly allocate the system costs to the technologies that cause them: For countries to make the best decisions regarding their future electricity supply, they must achieve a full understanding of each option's costs.
- Encourage new investment in all low-carbon technologies by providing stability for investors: The high capital intensity of low-carbon technologies requires specific financing solutions. Feed-in tariffs, long-term power purchase agreements, contracts for difference, regulated electricity tariffs, feed-in premiums or even direct capital subsidies can all help achieve long-term security of supply with low-carbon technologies.
- Use competitive short-term markets for the cost-efficient dispatch of resources: Marginal cost pricing based on short-term variable costs is the best available mechanism to ensure the optimal utilisation of existing resources. On its own it is, however, not sufficient to bring forward adequate levels of investment in low-carbon generation technologies.
- Ensure adequate levels of capacity and flexibility, as well as transmission and distribution infrastructure: Generation is at the heart of any electricity system, but the electricity system requires frameworks for the provision of capacity, flexibility, system services and an adequate physical infrastructure for transmission, distribution and interconnections.

These five key measures form the basic framework for a low-carbon electricity system enabling an optimal mix between VREs and clean, dispatchable sources, such as hydroelectricity and nuclear energy.

The NEA study shows that a mix relying primarily on nuclear energy is currently the most cost-effective option to achieve the decarbonisation target of 50 gCO_2 per kWh. A further decline in the costs of VRE would lead to integrated systems with sizeable shares of nuclear and VRE. With overnight costs for wind and solar PV between one third and two thirds lower than in the base case scenarios, Scenario VI demonstrates a future electricity mix that is realistic for a broad range of OECD countries. Such a mix integrating both VRE and nuclear would be composed of four main pillars:

- Some 30-40% wind and solar PV;
- Between 40% and 60%, provided by dispatchable low-carbon technologies such as nuclear and hydro;
- The maximum possible amount of low-carbon flexibility resources, including storage, demand response and grid interconnection;
- A decreasing share of gas-fired power generation for residual flexibility.

Between now and 2050, the implicit horizon of this study, much will change. However, as the only dispatchable low carbon technology that is not constrained by natural endowments nuclear energy will continue to play a major role. Today, nuclear power remains the most competitive option on the basis of plant-level costs. This may change. However, the reason for nuclear power's enduring cost advantage is not in its plant-level costs but in its low overall costs to the electricity system. Variable renewables are likely to further reduce their plant-level costs, even as their overall costs to the system rises with their level of deployment.

For a cost-effective electricity system, OECD countries should implement the five key policy measures mentioned above, and then let the market decide. Even with further changes in technologies and consumer behaviour, these measures will remain the reference for the design of low-carbon electricity systems in the future.

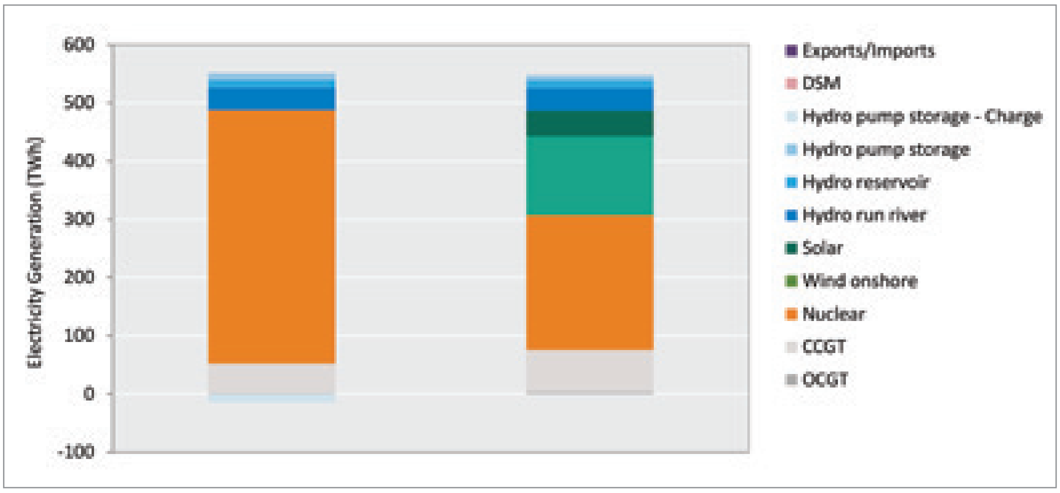
References

NEA (2019), *The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables,* OECD, Paris.

NEA (2018), *The Full Costs of Electricity Provision,* OECD, Paris.

NEA (2012), *Nuclear Energy and Renewables: System Costs in Low-carbon Electricity Systems,* OECD, Paris.

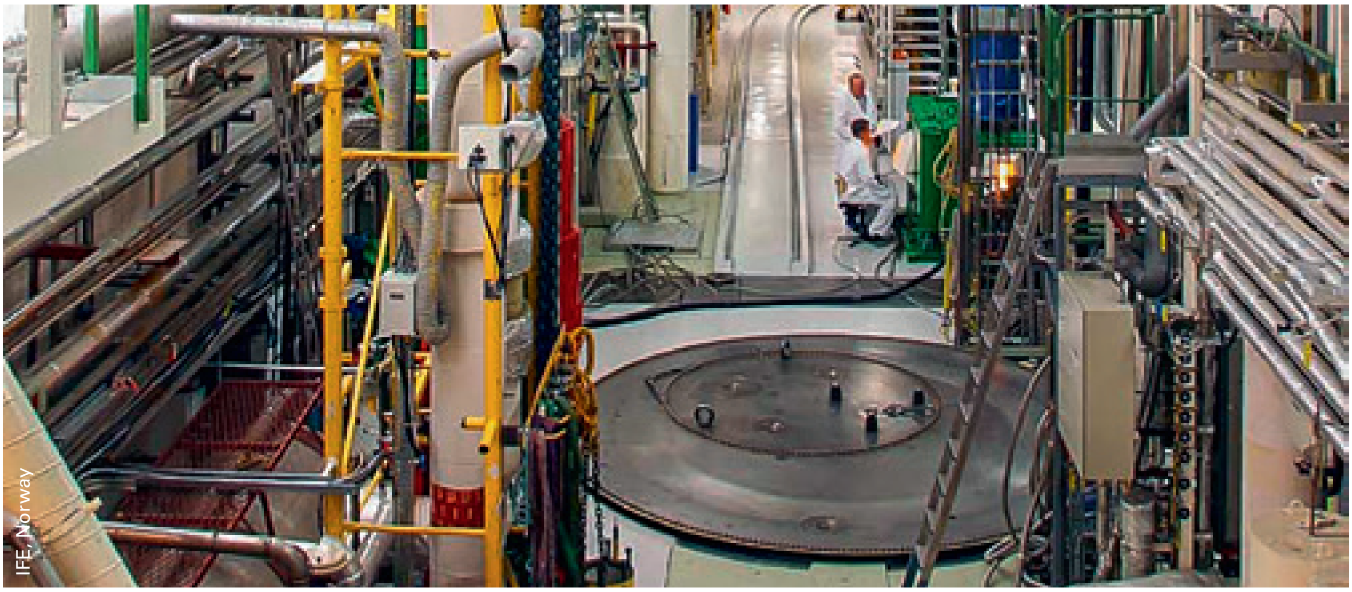
Figure 8: Least-cost mixes with current cost and future lower-cost renewables



Sustaining multinational nuclear fuel and materials testing capacities for safety, industry and science

by D. Iracane and T. Ivanova

Dr Daniel Iracane (daniel.iracane@oecd-nea.org) is Deputy Director-General and Chief Nuclear Officer of the NEA and Dr Tatiana Ivanova (tatiana.ivanova@oecd-nea.org) is Head of the NEA Division of Nuclear Science.



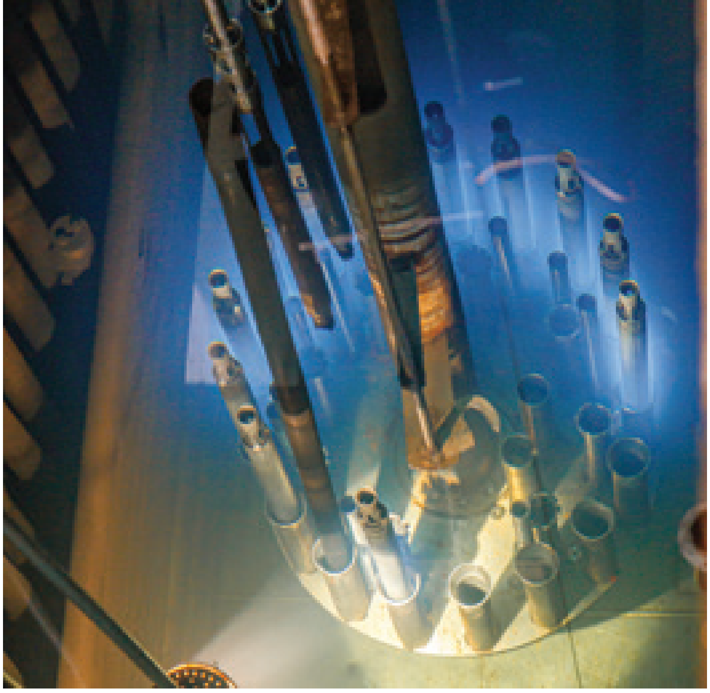
View of the Halden reactor hall.

In order for nuclear fuel and materials (F&M) technology to evolve and for their performances to be optimised, experimental evidence obtained from tests performed in fuel and materials test facilities, with the ability to perform neutron irradiation under representative steady-state or transient conditions, is essential. Following the implementation of more aggressive irradiation conditions in most commercial Nuclear Power Plants (NPP), new safety related requirements, and the evolution of modelling and simulation capabilities, these F&M test facilities are a key piece of infrastructure for the demonstration of safe, reliable and efficient operation of NPPs. This is particularly true for the category of tests near to, or beyond, normal operation conditions where failure may occur, including reactivity-initiated accidents, loss-of-coolant accidents, and power ramps, all of which can only be addressed in dedicated test facilities. The same applies to other studies on operational limits.

However, the worldwide network of experimental facilities is in significant decline, especially the research reactors used to test fuel and material behaviour under irradiation. In the past five years, major testing reactors providing services for the nuclear community have been shut-down: the Halden reactor in Norway, OSIRIS in France, JMTR in Japan, NRU in Canada. These reactors were built more than fifty years ago to support potential nuclear energy developments in a number of countries. Most of these reactors were originally intended to support national goals and their utilisation diminished over time as nuclear power reached maturity at both the national and international level.

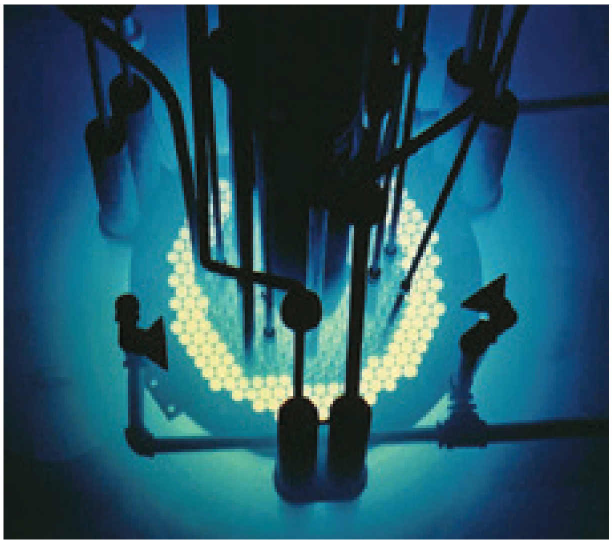
In this context, the NEA has recently launched a multilateral initiative to strengthen fuel- and material-related experimental capabilities for the benefit of a broad community of users. A core aspect of this initiative is to develop a co-ordinated approach for the performance of key experiments using facilities around the world. This undertaking became necessary in mid-2018 following the closure of the widely-used Halden test reactor in Norway after decades of service to the international community.

The Halden reactor was an important testing facility throughout its 60 years of operation. In addition to providing a predictable source of financing, the NEA Halden Reactor Project (HRP) facilitated the creation of a stable and trustworthy relationship between the reactor and its users. The success of the HRP and other NEA international projects proved that significant synergetic effects can be achieved and



MIR.M1 reactor of RIAR.

RIAR, Russia



Flash during a simulated reactivity-initiated accident at the NSRR.

JAEA, Japan

strong interaction and co-ordination between partners can be sustained for decades at a time. International joint research projects created and managed under the auspices of the NEA offer efficient and flexible platforms for multinational, mutually beneficial collaboration.

In recent months, the NEA has organised a series of workshops, bringing together participants representing utilities, fuel vendors, regulatory bodies and their technical support organisations (TSOs), research institutes and experimentalists. The discussions among the participants of the events were focused on developing a collective strategy to provide the experimental support necessary for advances in fuels and materials. It has been confirmed that the establishment of a multinational framework is required to open access to a diverse range of experimental facilities, and to ensure that they are used in a co-ordinated, efficient and cost-effective manner to address long-term needs.

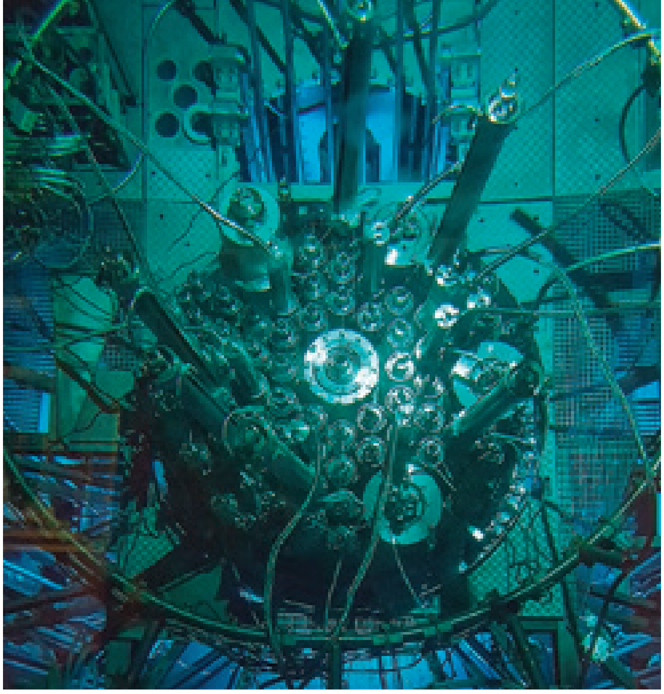
In order to address these needs, the NEA is launching a new Multinational Framework for In-pile Fuels and Material Testing: Framework for IrraDiation ExperimentS (FIDES) as a new NEA joint research project. The main objectives of FIDES will be to:

- Identify and prioritise the needs of the nuclear energy community, including the regulators and their technical support organisations, the industry and the research organisations;
- Consolidate the related resources;
- Identify, open access to, and obtain the best value from research facilities, which have adopted service-oriented policies and a user facility approach;
- Co-ordinate the available capacity in order to fully address the needs of the international community, with cross-border access to facilities;
- Create the conditions that enable efficient bilateral arrangements between facilities and end-users;
- Ease the transport of irradiated fuels and material between the involved research facilities;
- Facilitate the creation and transfer of prototypical samples from industry partners;
- Identify the gaps between the needs and the currently available experimental capacity;
- Trigger governmental investments and decisions by developing evidence-based proposals to fix the gaps and providing the necessary arguments in the associated value;
- Maximise the value of the experimental data gained from programmes implemented within FIDES. This includes the systematic consolidation and preservation of experimental data obtained across the FIDES programmes in order to build consensus and share knowledge on the safe and efficient use of the nuclear technology;
- Enable use of state-of-the-art modelling and simulation techniques and instrumentation;
- Provide training and education based on the FIDES programmes within the NEA Nuclear Education, Skills, Technology Framework (NEST)[1].

The workshops' participants have highlighted that F&M test facilities will continue to be essential to:

- Validate safety margins and test beyond failure to explore source terms in severe accident scenarios;
- Demonstrate safety and operational performance of existing nuclear fuel technologies, both within normal and abnormal operation ranges, including plant life extension;
- Perform fuel cycle optimisation and fuel performance optimisation;
- Assess the behaviour of NPPs material in the context of the long term operation programmes;
- Fully explore the performance of F&M up to and surpassing operational limits;
- Develop advanced F&M, and determine their performance;

TREAT subpile room, Idaho, United States.



BR2 reactor of SCK•CEN.

- Collect data required for the development and validation of simulation tools and development of new tools tailored to more complex F&M structures;
- Expand fundamental understanding of fuels and other materials;
- Provide on-line measurement capabilities unavailable at commercial power plants;
- Provide testing capacity to respond to evolving data needs triggered by requirements from utilities and/or safety institutions.

Regulators and their technical support organisations, research organisations, as well as the industry require F&M testing capacities on an ongoing basis. In particular, they have urged that the availability of test facilities, particularly for loss-of-coolant accidents, reactivity-initiated accidents and power ramps, is crucial.

The NEA has engaged in discussions with research organisations operating testing facilities and requested them to elaborate technical proposals to meet those needs. In the past year, several proposals for Joint ExpErimental Programmes (JEEP) were collected. Currently, six JEEPs at different stages of maturity have been proposed and were discussed at a workshop held in March 2019:

- Programme for quantifying thermomechanical clad load mechanisms during LWR slow transient (P2M) that will be conducted at the BR2 reactor in Belgium and at the CEA hot cells in France.
- Programme for studying fuel rod behaviour under LOCA conditions at the MIR.M1 reactor in Russia.
- In-pile Creep Studies of ATF Claddings (INCA) at the LVR-15 material test reactor in the Czech Republic.
- Programme for studying PWR fuel rods behaviour under LOCA conditions at the CABRI reactor in France.
- International NSRR Test Programme for LWR fuels (INSTEP), which considers possible RIA tests on additive fuels in the newly restarted NSRR facility in Japan.
- Missing Pellet Surface (MPS) experimental programme using conventional LWR fuel to support 3D modelling and simulation.

Discussions are ongoing about involving the TREAT and ATR reactors in the United States in the new joint project.

Of the JEEP proposals above, the most mature are intended to be started within two years after their kick-off. The first three proposals are being finalised and will be discussed at the meeting "Preparing the Kick-off of FIDES Joint Experimental Programmes" scheduled for 3-5 September 2019 in Paris.

In addition, March 2019 workshop participants highlighted that FIDES must address continuous needs, complement domestic research and connect data users with the facilities that produce the data. The community should avoid discontinuities in fuel and materials testing and maintain momentum with the prompt conclusion of a framework agreement, developed in parallel with JEEPs based on the most mature proposals presented at the workshop. The NEA is engaging on both fronts, developing agreements to connect the interested parties with the current experimental programme proposals, while further developing the new Framework concept.

The Framework will create a co-operative dynamic among governments and interested organisations, paving the way for future investments in the worldwide experimental capacity, such as new experimental devices in existing facilities or new research reactors.

This long-term endeavour has received a strong support from relevant NEA standing committees and from the NEA Steering Committee that underlined the importance of the topic for the safety and industry.

Note

1. The NEA NEST Framework was launched to help address important gaps in nuclear skills capacity building, knowledge transfer and technical innovation (see facing page).

Knowledge management and the sustainability of the nuclear sector

by D. Iracane and A. Di Trapani

Dr Daniel Iracane (daniel.iracane@oecd-nea.org) is Deputy Director-General and Chief Nuclear Officer of the NEA and Dr Antonella Di Trapani (antonella.ditrapani@oecd-nea.org) is an expert on multilateral and multidisciplinary project development and implementation, leading the NEST Framework in the NEA Division of Nuclear Science.

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Knowledge is an essential asset for any organisation. Without knowledge the organisation's success, even its very existence, are at risk. And while globalisation may have accelerated knowledge and information sharing, organisations still need to preserve their knowledge, their *savoir-faire*. Organisations with a high turnover of personnel and experts coming to the end of their careers are facing the potential loss of accrued knowledge. The flip side of this coin is that these organisations also need to transfer their accumulated knowledge to newly arrived skilled graduates in order to assure both its continuity and for the continued survival of the organisation that generated the knowledge in the first place.

Organisations have multiplied their efforts to preserve and codify their information and knowledge via databases information technology, reports and books, and to transfer them via training and development courses (such as workshops and summer schools). However, not all knowledge can be captured, preserved or shared.

It is important to distinguish between explicit knowledge that can be easily captured and transferred through records, databases and documents, or summer schools, and the tacit (or implicit) knowledge held by an individual or a team that is neither codified nor formalised. In general, tacit knowledge is acquired through practical and hands-on experience and, by its own intrinsic nature, resides only in the minds of practitioners. Tacit knowledge causes the most concern in the nuclear sector.

NEA member countries need scientists, engineers and technologists to ensure the safe and efficient use of nuclear energy to meet global energy demands and environmental challenges. Knowledge management in the nuclear sector therefore has to map accurately the origins of tacit knowledge. The tacit knowledge nowadays most at risk was generated during the pioneering years of nuclear power. During this period, R&D projects and innovative construction projects were ramping up and many nuclear power plants were being built. As a result, personnel in the industry were confronted with challenging and groundbreaking projects as well as the risk of failure. It is this knowledge that is most difficult to harvest and is generally transferred via hands-on experience. In the current nuclear power landscape, where R&D spending is decreasing and innovation slows down as a general trend in OECD countries, this knowledge risks being lost if there are fewer opportunities to acquire hands-on experience work on challenging projects. More than ever, it is imperative to preserve the continuity of tacit knowledge, to develop such competences and knowledge, and to seek such opportunities at the international level where they are not available domestically. Building a critical mass of activities and having access to state-of-the-art infrastructure are necessary if these competencies are to be developed.

The NEA, as a knowledge-based organisation, is helping its member states to address their knowledge management concerns and needs.

In the field of explicit knowledge, NEA committees and expert working groups are continuously contributing to the codification and preservation of data, information, know-how, research results, procedures and best practices. The transfer of this knowledge occurs through training courses, publications, broad databases, workshops, summer schools, webinars, video recordings and virtual reality tools.

To address challenges related to tacit knowledge, the NEA launched the Nuclear Education, Skills and Technology (NEST) Framework. The NEST Framework has been designed to expose younger researchers, NEST Fellows, to challenging projects and real-world problems. As a result, they will acquire competencies, learn critical thinking and absorb tacit knowledge by working alongside leading experts in the field. Some 15 organisations in 10 countries have already signed on to the NEST Framework (Belgium, Canada, France, Germany, Italy, Japan, Korea, Russia, Switzerland and the United States). Their young researchers will work alongside recognised international experts on projects with a clear application to real-world problems. Currently four projects have been developed:

- The NEST hydrogen mitigation experiments for reactor safety (HYMERES) project is addressing safety-relevant phenomena in a containment during an accident. It offers a hands-on training opportunity during the experimental test campaigns to be carried at the Paul Scherrer Institute (PSI) PANDA facility in Switzerland, one of the most advanced containment test facilities in the world. Besides Switzerland, six countries (France, Germany, Korea, Spain, Sweden and the United States) are currently participating in this project.
- The NEST small modular reactor (SMR) project will include elements of technology assessment and development, regulatory frameworks, societal issues, spent fuel management and SMR economics. This project is led by McMaster University, Canada, and four additional countries (Belgium, France, Switzerland and the United States) in connexion with a European research programme.
- The NEST project lead by the Collaborative Laboratories for Advanced Decommissioning Science (JAEA/CLADS) in Japan is dedicated to advanced remote technology for decommissioning under intense gamma-ray radiation environments (e.g. robotics, virtual reality). In parallel to seminars, site tours and practical exercises, NEST Fellows will use virtual reality to understand the circumstances inside a reactor building, conducting virtual operations by simulated remotely-operated robot.
- The NEST project led by ROSATOM in Russia, addresses the issues of irradiated graphite management, including characterisation, decontamination and disposal. Hands-on training for NEST fellows will consist of using the fully-fledged infrastructure, pilot and experimental facilities present at the ROSATOM site: specially-manufactured equipment for graphite remote sampling, graphite incineration facility and RW repository mock-up models for investigation of geological barriers.

In addition to the above projects, two projects are currently being developed. Medical Applications, Nuclear Technologies, Radioprotection and Safety (MANTRAS), led by Italy, will focus on the development of new technologies for application in medicine and dosimetry, including the experimental production of radioisotopes and radiotherapy techniques. The last project under development aims to provide the necessary education and hands-on training component to the new multilateral initiative currently developed by the NEA to strengthen fuel and material-related experiments, making use of a variety of research reactors available worldwide.

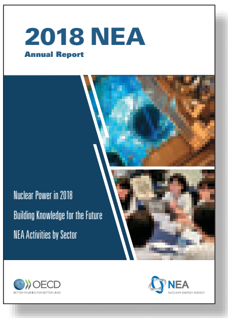
PANDA, a large-scale thermal-hydraulics test facility.
Paul Scherrer Institute, Switzerland

In a nutshell, NEST projects address key technical issues in order to sustain the educational and experimental programmes of the type needed to provide a fertile and sustainable environment for innovative R&D.

Assuring the continuity of knowledge and encouraging talented individuals is a long-term critical investment for every country and organisation. Overall, the NEST Framework complements a number of existing initiatives managed by national and international organisations in the field of Knowledge Management. This investment requires strategic vision and involvement and, in the current context, reinforced international co-operation of the sort provided by the NEA NEST Framework.

All NEA publications are available free of charge on the NEA website.

General Interest



Annual Report 2018

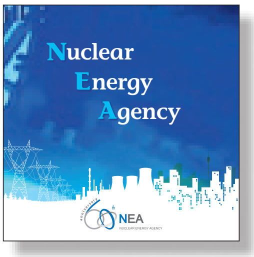
NEA No. 7462. 76 pages.

http://oe.cd/nea-2018-en

Rapport annuel 2018

AEN n° 7463. 80 pages.

http://oe.cd/nea-2018-fr



Nuclear Energy Agency

28 pages.

Also available in French, Chinese and Russian.

Available online at:
http://oe.cd/neabrochure

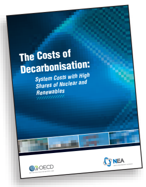
Nuclear technology development and economics

Nuclear Energy Data 2018/ *Données sur l'énergie nucléaire 2018*

NEA No. 7416. 102 pages.

Available online at:
http://oe.cd/nuclear-data-2018

Nuclear Energy Data is the NEA's annual compilation of statistics and country reports documenting nuclear power status in NEA member countries and in the OECD area. Information provided by governments includes statistics on total electricity produced by all sources and by nuclear power, fuel cycle capacities and requirements, and projections to 2035, where available. Country reports summarise energy policies, updates of the status in nuclear energy programmes and fuel cycle developments. In 2017, nuclear power continued to supply significant amounts of low-carbon baseload electricity, in a context of strong competition from low-cost fossil fuels and renewable energy sources. Governments committed to having nuclear power in the energy mix advanced plans for developing or increasing nuclear generating capacity, with the preparation of new build projects making progress in Finland, Hungary, Turkey and the United Kingdom. Further details on these and other developments are provided in the publication's numerous tables, graphs and country reports.



The Costs of Decarbonisation:

System Costs with High Shares of Nuclear and Renewables

NEA No. 7299. 220 pages.

Available online at:
http://oe.cd/nea-system-costs-2019

Executive Summary

NEA No. 7335. 16 pages.

Available online at: https://oe.cd/2uj

Under the Paris Agreement, OECD countries agreed to aim for a reduction of their greenhouse gas emissions sufficient to hold the increase in the global average temperature to well below 2°C above pre-industrial levels. This commitment requires a massive effort to decarbonise energy and electricity generation, a radical restructuring of the electric power sector and the rapid deployment of large amounts of low-carbon generation technologies, in particular nuclear energy and renewable energies such as wind and solar PV.

This study assesses the costs of alternative low-carbon electricity systems capable of achieving strict carbon emission reductions consistent with the aims of the Paris Agreement. It analyses several deep decarbonisation scenarios to reach the same stringent carbon emission target but characterised by different shares of variable renewable technologies, hydroelectric power and nuclear energy.

Uranium 2018: Resources, Production and Demand

NEA No. 7413. 458 pages.

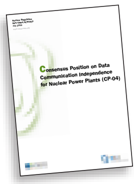
Available online at:
http://oe.cd/nea-red-book-27

Uranium is the raw material used to produce fuel for long-lived nuclear power facilities, necessary for the generation of significant amounts of baseload low-carbon electricity for decades to come. Although a valuable commodity, declining market prices for uranium in recent years, driven by uncertainties concerning the evolution in the use of nuclear power, have led to significant production cutbacks and the postponement of mine development plans in a number of countries and to some questions being raised about future uranium supply.

This 27th edition of the "Red Book", a recognised world reference on uranium jointly prepared by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), provides analyses and information from 41 producing and consuming countries in order to address these and other questions.

The present edition provides the most recent review of world uranium market fundamentals and presents data on global uranium exploration, resources, production and reactor-related requirements. It offers updated information on established uranium production centres and mine development plans, as well as projections of nuclear generating capacity and reactor-related requirements through 2035, in order to address long-term uranium supply and demand issues.

Nuclear safety and regulation

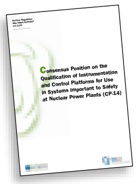


Consensus Position on Data Communication Independence for Nuclear Power Plants (CP-04)

NEA/CNRA/R(2018)2

14 pages.

This consensus position (CP) provides agreed-upon principles on data communication independence for digital instrumentation and control (I&C) systems. Digital I&C architectures may employ data communications between safety systems, between redundant portions of a safety system, and between systems of different safety classes. One of the more significant regulatory implications is maintaining data communication independence, thereby ensuring that faults from data communications do not propagate and adversely affect safety functions. Therefore, a consolidated set of design principles is necessary to maintain communication independence between safety systems, between redundant divisions of a safety system, and between systems of different safety classes. Although the focus of this consensus position is on data communication independence, the agreed-upon principles discussed herein may also apply to other forms of communications.

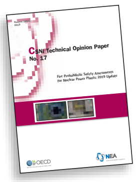


Consensus Position on the Qualification of Instrumentation and Control Platforms for Use in Systems Important to Safety at Nuclear Power Plants (CP-14)

NEA/CNRA/R(2018)3

19 pages.

Instrumentation and control (I&C) platforms are used for systems important to safety in nuclear power plants. Some of these platforms were developed specifically for nuclear power applications, but many were developed for a wide range of industrial applications. The qualification of I&C platforms for use in systems important to safety at nuclear power plants is needed in order to demonstrate that these I&C platforms are suitable for their intended applications. This consensus position provides evaluation guidance for the qualification of platforms developed for general industrial use, as well as those developed specifically for nuclear applications important to safety. In some cases, an I&C platform may be qualified with a specific application in mind; in others, a generic qualification may be undertaken. This consensus position provides evaluation guidance for the qualification of platforms for both generic and specific applications.



CSNI Technical Opinion Paper No. 17

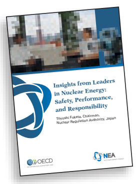
Fire Probabilistic Safety Assessments for Nuclear Power Plants: 2019 Update

NEA No. 7417. 40 pages.

Available online at: https://oe.cd/2C4

CSNI Technical Opinion Paper No. 17: Fire Probabilistic Safety Assessments for Nuclear Power Plants: 2019 Update provides an authoritative review of the current status and use of the fire PSA in nuclear power plants. The report demonstrates that while fires at a particular plant site are highly dependent on plant and site specific factors, they are nonetheless an important contributor to overall risk. Insights from fire PSAs are generally found to be aligned with operating experience and to be representative of the expected plant response, making them valuable in addressing risk. This report should be useful for regulators overseeing the use of fire PSAs in nuclear installations, practitioners in understanding the considerations for performing or reviewing fire PSAs, and researchers in identifying areas requiring further study.

Radiological Protection and Human Aspects of Nuclear Safety



Insights from Leaders in Nuclear Energy: Safety, Performance, and Responsibility

12 pages.

Available online at: https://oe.cd/2C5

Insights from Leaders in Nuclear Energy shares personal insights through a series of in-depth conversations between the OECD Nuclear Energy Agency Director-General and leading figures in the sector. Each conversation explores the current issues and offers new ways to address challenges and aim for excellence.

In August 2018, NEA Director-General William D. Magwood, IV sat down with Toyoshi Fuketa, Chairman of the Japanese Nuclear Regulation Authority (NRA), for a wide-ranging discussion regarding nuclear safety issues in Japan. The conversation touches on the Tokyo Electronic Power Company (TEPCO) Fukushima Daiichi Nuclear Power Station accident, as well as ongoing challenges, Chairman Fuketa's perspective and insights and new directions for the NRA.

Occupational Exposures at Nuclear Power Plants

Twenty-Sixth Annual Report of the ISOE Programme, 2016

NEA No. 7453. 126 pages.

Available online at: https://oe.cd/2C6

This 26th Annual Report of the International System on Occupational Exposure (ISOE) Programme presents the status of the Programme in 2016.

As of 31 December 2016, the ISOE programme included 74 participating utilities in 28 countries (343 operating units; 53 shutdown units; 7 units under construction), as well as the regulatory authorities in 26 countries. The ISOE database includes occupational exposure information for over 400 units, covering over 85% of the world's operating commercial power reactors.

This report includes a global occupational exposure data and analysis collected and accomplished in 2016, information on the programme events and achievements as well as principal events in participating countries.

Radioactive waste management

Metadata for Radioactive Waste Management

NEA No. 7378. 68 pages.

Available online at: https://oe.cd/2uk

National programmes for radioactive waste management require very large amounts of data and information across multiple and disparate disciplines. These programmes tend to run over a period of many decades resulting in a serious risk of data and information loss, which in turn can threaten the production and maintenance of robust safety cases.

Metadata and associated tools and techniques play a crucial role in modern data and information management. The Radioactive Waste Repository Metadata Management (RepMet) initiative has prepared the first international study on the application of metadata to the field of radioactive waste management. This report introduces the concept of metadata, explains how metadata can help to facilitate data management, and gives advice on the issues arising when developing metadata within radioactive waste management programmes. It is aimed at readers looking to obtain a high-level overview of metadata, and associated tools and techniques, and the strategic importance they can play in Radioactive Waste Management Organisations (RWMOs).

Preservation of Records, Knowledge and Memory across Generations: Developing a Key Information File for a Radioactive Waste Repository

NEA No. 7377. 62 pages.

Available online at: https://oe.cd/2C7

Radioactive waste repositories are designed to be intrinsically safe in that they are not dependent on the presence or intervention of humans. In response to this challenge, the Nuclear Energy Agency initiated the Preservation of Records, Knowledge and Memory (RK&M) Across Generations Initiative, calling on the international community to help create specific means to preserve RK&M.

The concept of a key information file (KIF) emerged in response to the challenge presented by the large volumes of RK&M material generated by national disposal programmes. This concept has been developed into an important component of a RK&M preservation strategy. The KIF is designed to be a single, short document, produced in a standard format, with the aim of allowing society to understand the nature and intent of a repository, and thus to reduce the likelihood of unnecessary human intrusion. It should be made openly available and ultimately be widely distributed.

This report describes the KIF concept in detail, in a manner that should enable those concerned with any particular repository to create their own versions. Three draft key information files, currently under development to support RK&M preservation in France, Sweden and the United States, are provided as examples.

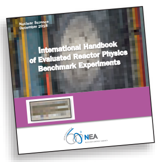
Nuclear science and the Data Bank

International Handbook of Evaluated Criticality Safety Benchmark Experiments

NEA No. 7360. DVD.

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook contains criticality safety benchmark specifications that have been derived from experiments that were performed at various critical facilities around the world. The benchmark specifications are intended for use by criticality and safety analysts as well as nuclear data evaluators to validate calculational techniques and data. The handbook is produced by the ICSBEP working group, under the aegis of the NEA. While co-ordination and administration of the ICSBEP is undertaken by the NEA, each participating country is responsible for the administration, technical direction, and priorities of the project within their respective countries. Access to some of the information and data included in this handbook may be restricted; full conditions for access are available online.

The 2018 edition contains data evaluated criticality safety benchmark data in nine volumes that span over 70 000 pages. The handbook contains 567 evaluations with benchmark specifications for 4 913 critical, near-critical or subcritical configurations, 45 criticality alarm placement/shielding configurations with multiple dose points for each, and 215 configurations that have been categorised as fundamental physics measurements that are relevant to criticality safety applications.



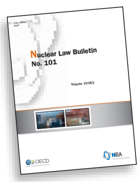
International Handbook of Evaluated Reactor Physics Benchmark Experiments

NEA No. 7361. DVD.

The International Handbook of Evaluated Reactor Physics Experiments contains reactor physics benchmark specifications that have been derived from experiments that were performed at various nuclear facilities around the world. The benchmark specifications are intended for use by reactor designers, safety analysts and nuclear data evaluators to validate calculational techniques and data. The handbook is a product of the International Reactor Physics Evaluation (IRPhE) project, conducted by the OECD Nuclear Energy Agency (NEA). While co ordination and administration of the IRPhE project is undertaken by the NEA, each participating country is responsible for the administration, technical direction, and priorities of the project within their respective countries. Access to some of the information and data included in this handbook may be restricted; full conditions for access are available online.

The 2018 edition contains data from 159 different experimental series that were performed at 54 different nuclear facilities. Some 156 of the 159 evaluations are published as approved benchmarks. The remaining five evaluations are published as draft documents only. All draft documents were reviewed by the International Reactor Physics Evaluation (IRPhE) Technical Review Group (TRG). Example calculations are presented; however, these calculations do not constitute validation or endorsement of the codes or cross section data. The IRPhE project is patterned after the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and is closely co-ordinated with the ICSBEP. Some benchmark data are applicable to both nuclear criticality safety and reactor physics technology. Some have already been evaluated and published by the ICSBEP, but have been extended to include other types of measurements besides the critical configuration.

Nuclear law



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All correspondence should be addressed to:
The Editor, NEA News – OECD/NEA – 2, rue André-Pascal – 75775 Paris Cedex 16, France
Tel.: +33 (0)1 73 21 28 19 – Fax: +33 (0)1 45 24 11 10

For more information about the NEA, see: **www.oecd-nea.org**
Editor: Andrew Macintyre
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Editorial assistant: Rhiann Pask
Production assistant: Laurie Moore

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Nuclear Energy Agency (NEA)
46, quai Alphonse Le Gallo
92100 Boulogne-Billancourt, France
Tel.: +33 (0)1 73 21 28 19
nea@oecd-nea.org **www.oecd-nea.org**

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