NEA News

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Contents

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The OECD Nuclear Energy Agency (NEA) is an intergovernmental organisation 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 28 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, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the NEA. A co-operation agreement is in force with the International Atomic Energy Agency.

For more information about the NEA, see:
www.nea.fr

Cover page: Speakers at the NEA 50th anniversary high-level session held on 16 October 2008 at the OECD Conference Center, in Paris (Gilles Bassignac, France).

NEA 50th anniversary high-level session

The NEA celebrated its 50th anniversary on 16 October 2008 with over 350 persons in attendance. A special section of the NEA website is devoted to the Agency's anniversary. It includes information about the speakers and complete footage of the high-level session. See www.nea.fr/html/general/50th.

Photos: Gilles Bassignac.

From left to right in order of participation:

Mr. Angel Gurría, *OECD Secretary-General;*
Dr. Mohamed ElBaradei, *Director-General, International Atomic Energy Agency;*
Mr. Luis E. Echávarri, *Director-General, OECD Nuclear Energy Agency*

Mr. Miguel Sebastián Gascón, *Minister for Industry, Tourism and Trade, Spain;*
Mr. Claudio Scajola, *Minister for Economic Development, Italy;*
Mr. Ľubomír Jahnátek, *Minister of Economy, Slovak Republic*

Mr. Pierre-Franck Chevet, *Director-General for Energy and Climate, Ministry for Ecology, Energy, Sustainable Development and Town and Country Planning (Regional Development), France;*
Mr. Dennis R. Spurgeon, *Assistant Secretary for Nuclear Energy, United States;*
Dr. Shunichi Tanaka, *Vice-Chairman, Atomic Energy Commission, Japan*

Mr. Tomáš Hüner, *Vice-Minister for Industry and Trade, Czech Republic;*
Dr. Dale E. Klein, *Chairman, US Nuclear Regulatory Commission, United States;*
Dr. Aris S. Candris, *President and CEO, Westinghouse Electric Company*

Mr. André-Claude Lacoste, *Chairman, French Nuclear Safety Authority;*
Mr. Hugh MacDiarmid, *President and CEO, Atomic Energy of Canada Limited;*
Mr. Nobuo Tanaka, *Executive Director, International Energy Agency (IEA)*

Mr. Luc Oursel, *President and CEO, AREVA NP;*
Mr. Pierre Gadonneix, *Chairman and CEO, Électricité de France (EDF); Chairman, World Energy Council;*
Mr. Richard J.K. Stratford, *Chair, OECD Steering Committee for Nuclear Energy*

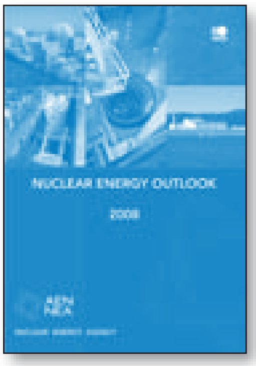
The NEA at 50

In 2008, the OECD Nuclear Energy Agency (NEA) celebrated its 50th anniversary. Over the years, it has played a key role in both strengthening and enhancing international co-operation in the nuclear energy field. It has made the most of the member countries' contributions, effectively leveraging the financial resources in support of cutting-edge international research projects and studies, but above all stimulating and uniting the synergies of its vast network of specialists coming from the most advanced nuclear energy programmes around the world.

At a time when nuclear energy is at a significant turning point of new development, the NEA is particularly well positioned to ensure that this development takes place safely and economically, with due respect for the environment. It will also continue to elaborate the scientific, technological and legal bases required to achieve such goals. The NEA has provided an important forum for international co-operation on the peaceful use of nuclear energy for the past five decades, and will do its utmost to continue providing the best added value for its member countries in the future.

Luis E. Echávarri
NEA Director-General

Nuclear Energy Outlook 2008



To celebrate its 50th anniversary, the OECD Nuclear Energy Agency launched its first *Nuclear Energy Outlook* (NEO). It responds to the changing dynamics and renewed interest in nuclear energy and arrives at a moment when energy security, climate change and the cost of energy have become priorities in both short-term and long-term energy policies.

Using the most current data and statistics available, the NEO provides projections up to 2050 to consider growth scenarios and potential implications on the future use of nuclear energy. It also offers unique analyses and recommendations on the possible challenges that lie ahead.

Topics covered by the NEO include:

- nuclear power's current status and projected trends;
- environmental impacts;
- uranium resources and security of supply;
- costs, safety and regulation;
- radioactive waste management and decommissioning;
- non-proliferation and security;
- legal frameworks;
- infrastructure;
- stakeholder engagement;
- advanced reactors and advanced fuel cycles.

The publication is available in English and French and can be purchased online at **www.oecdbookshop.org**. A Japanese translation will be available shortly.

NEO Executive Summaries can be downloaded free of charge from the NEA website (**www.nea.fr/neo**) in Chinese, English, French, German, Hungarian, Italian, Japanese, Korean, Russian and Spanish.

We are pleased to offer readers a copy of the Executive Summary in English in the pages that follow.

Nuclear Energy Outlook 2008

ISBN 978-92-64-05410-3. 460 pages. Price: € 105, US$ 161, £ 81, ¥ 16 800.

Key messages

Balancing growth of world energy demand with its resulting environmental, social and political impacts

Balancing energy requirements for continued social and economic progress against the potential resulting environmental and socio-political impacts is widely acknowledged to be a significant global challenge in the 21st century. By 2050, global electricity demand is expected to have increased by about a factor of 2.5.

Energy, and particularly electricity, is essential for economic and social development and for improved quality of life, but the last century's global trend in energy supply is generally recognised as being unsustainable. The world faces environmental threats from climate change caused by anthropogenic CO_2 emissions and socio-political threats from rising energy prices and the possible lack of secure energy supplies.

- Electricity generation accounts for about 27% of global anthropogenic CO_2 emissions and is by far the largest and fastest-growing source of greenhouse gases.
- Security of supply has become a major concern around the world, particularly for countries that have limited indigenous fossil fuel resources and are therefore dependent on imported energy.

In "business-as-usual" scenarios, strong economic growth in many developing countries, leading to a more energy-consuming lifestyle, and the projected 50% increase in the world population, primarily in the developing regions, are the drivers for growing energy demand. Fossil fuel use will continue its inexorable rise to meet this increase unless governments' energy policies change worldwide. Nuclear energy has a potentially strong role to play in alleviating these problems.

Current and likely future contributions to global energy supply from nuclear power

In 2006, nuclear energy supplied 2.6 billion MWh: 16% of the world's electricity and 23% of electricity in OECD countries.

- In June 2008, there were 439 nuclear reactors operating in 30 countries and one economy, with a total capacity of 372 GWe.
- France, Japan and the United States have 57% of the world's nuclear generating capacity; in 2007, sixteen countries relied on nuclear energy to generate over a quarter of their electricity.

In June 2008, 41 nuclear power reactors were under construction in 14 countries and one economy; average construction times of 62 months are consistently being achieved in Asia; of the 18 units connected to the grid between December 2001 and May 2007, three were constructed in 48 months or less.

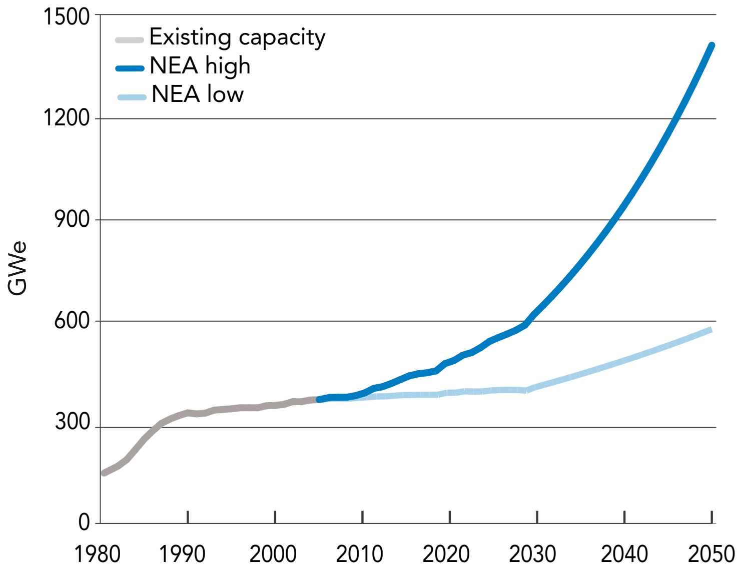
Current national plans and authoritative statements of intent suggest that the countries having the largest installed nuclear capacity in 2020 will be the United States, France, Japan, the Russian Federation, China and Korea. China and the United States plan the largest increases in capacity.

The NEA has projected global nuclear capacity to 2050 using low and high scenarios. The outcome is:

- By 2050, global nuclear capacity is projected to increase by a factor of between 1.5 and 3.8.
- Under the high scenario, the nuclear share of global electricity production would rise from 16% today to 22% in 2050.
- Under both scenarios, nuclear generation would continue to be heavily based in the OECD countries.
- Although a number of countries currently without nuclear power have plans to join the nuclear energy community, they are likely to add only about 5% to global installed nuclear capacity by 2020.

These projections are in broad agreement with those from other organisations. Historic evidence suggests that the world could construct nuclear power plants at a rate more than sufficient to meet the NEA high scenario projections during the period up to 2050.

Projected nuclear capacity in the NEA high and low scenarios



Nuclear energy's role in minimising the negative consequences of growing energy demand

Nuclear energy could play a significant role in avoiding CO_2 emissions, providing greater energy security and reducing the serious health effects that result from fossil fuel combustion.

Climate change

The United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) concludes that CO_2 emissions, including those from electricity generation, must be halved to contain the consequences of climate change at a tolerable level.

- On a whole life cycle basis, nuclear energy is virtually carbon-free.
- A combination of technologies is needed to meet this demanding target, but nuclear energy is the only carbon-mitigating technology with a proven track record on the scale required.
- Nuclear energy could make an increasing contribution to electricity generation, as well as to virtually carbon-free heat in the future; a potentially important development is global R&D aimed at producing hydrogen to fuel the transport sector, using nuclear heat.

Most potential external costs (i.e. those not represented in the price, including the consequences of climate change) have already been internalised for nuclear power, whereas for fossil fuels, external costs are around the same size as direct costs.

Energy security

Nuclear energy is more able than oil or gas to provide security of supply because the fuel – uranium – comes from diverse sources and the main suppliers are operating in politically stable countries.

- Identified uranium resources are sufficient to fuel an expansion of global nuclear generating capacity, without reprocessing, at least until 2050. Based on regional geological data, resources that are expected to exist could increase uranium supply to several hundreds of years.
- A significantly expanded global nuclear energy programme could potentially be fuelled for thousands of years using the currently defined uranium resource base; however, this would require fast breeder reactors, a technology that is well-developed but not yet in commercial operation.
- Uranium's high energy density (1 tonne of uranium produces the same energy as 10 000-16 000 tonnes of oil with current practices) means that transport is less vulnerable to disruption and storage of a large energy reserve is easier than for fossil fuels.

Health effects

Nuclear energy could contribute to reducing the significant health effects that arise from fossil fuel consumption.

- The health effects of operational emissions from nuclear power are negligible compared to those resulting from fossil fuel use.
- Loss of life from the health effects of emissions from burning fossil fuels far outweighs that from accidents involving all sources of energy.
- Comparison of full energy chain frequency/consequence data for real accidents shows that, contrary to popular belief, nuclear energy presents a far lower accident risk than fossil energy sources.

Meeting the challenges to nuclear energy growth

Nuclear energy offers the opportunity of meeting a significant part of the anticipated increase in electricity demand whilst reducing the potential environmental, political and economic concerns associated with fossil fuels. However, a significant fraction of public opinion perceives that the risks of nuclear energy outweigh its advantages. The nuclear industry and governments wishing to use nuclear power need to manage the real and/or perceived issues of safety, waste disposal and decommissioning, non-proliferation and security, and cost.

Safety

Nuclear safety is a global issue: a serious event in one country may have a significant impact on its neighbours; the nuclear industry has, and must keep, safety and environmental protection as its top priorities. Effective regulatory control will continue to be a key requirement.

- The safety performance of nuclear power plants and other nuclear facilities in OECD countries is excellent, as reflected in a number of safety performance indicators. This strong safety record reflects the maturity of the industry and the robustness of the regulatory system.
- The nuclear industry's safety performance has continued to improve over recent decades. Reactors of new designs have passive safety features that can maintain the plant in a safe state, in particular during an unexpected event, without the use of active control.
- The international community has initiatives in progress to increase regulatory effectiveness and efficiency, in view of the growing interest in new nuclear build and the next generation of designs.
- Countries with no previous experience must be helped to institute satisfactory industrial, regulatory and legal practices if they construct nuclear power plants.

Waste disposal and decommissioning

The delay and failure thus far of some major disposal programmes for high-level radioactive waste continue to have a significant negative impact on the image of nuclear energy; governments and the nuclear industry must work together to deliver safe disposal.

- Because disposal of spent nuclear fuel and high-level waste from reprocessing has not yet been implemented, it is thought by some to be technically difficult or even impossible.
- In practice, the volumes of radioactive waste produced are small, the technologies to manage them are available and there is an international consensus that geological disposal of high-level waste is technically feasible and safe.
- A variety of nuclear facilities has been successfully decommissioned, including several US power plants with capacities larger than 100 MWe that have been fully dismantled.
- Waste management and decommissioning costs for nuclear power plants represent only some 3% of overall nuclear electricity generation costs. Funding schemes exist to finance waste and decommissioning liabilities.

Non-proliferation and security

The global nuclear community must work together to prevent the spread of nuclear weapons by states and the malevolent use of radioactive materials by criminal or terrorist groups.

- For nearly four decades the Treaty on the Non-Proliferation of Nuclear Weapons has been the successful legal and political foundation of the international regime for restraining the spread of nuclear weapons.
- Multilateral approaches to the nuclear fuel cycle currently under discussion have the potential to

provide enhanced assurance to the international community that proliferation-sensitive nuclear technologies are kept contained.

- The technical characteristics of advanced nuclear technologies are designed to enhance their resistance to proliferation threats and their robustness against sabotage and terrorism threats.

Cost

On a levelised cost basis, building and operating new nuclear plants is economically viable in most circumstances; however, governments wishing to encourage investment in nuclear plants may need to mitigate the financial risks associated with licensing and planning, and those perceived by the financial community for radioactive waste management and decommissioning.

- A 2005 international comparison of the levelised costs for nuclear, coal and gas power plants showed nuclear to be competitive with coal and gas, with some dependence on local circumstances; since then, oil prices have quadrupled (as of June 2008) with other fossil energy prices following them upwards.
- The cost of uranium amounts to only about 5% of the cost of generating nuclear electricity.
- The economic challenges of nuclear power relate to investment funding rather than the levelised cost of generation.
- Returns from existing nuclear energy investments have in many cases been increased through improved availability, power uprates and licence renewal; world average availability has increased by 10 percentage points in the last 15 years, now reaching 83%. Many plants have been uprated, some by as much as 20%; a significant number of reactors have had lifetimes extended from 40 to 60 years.

Nuclear energy and society

If nuclear energy is to expand, an ongoing relationship between policy makers, the nuclear industry and society that develops knowledge building and public involvement will become increasingly important.

- Surveys show that over half of European Union citizens think that the risks of nuclear power outweigh its advantages.
- However, people are more concerned about some aspects surrounding nuclear energy (radioactive waste, terrorism and proliferation) than about the actual operation of nuclear power plants.
- Increased knowledge of nuclear energy leads to increased levels of support – but most people feel that they have inadequate levels of knowledge.
- Scientists and non-governmental organisations (NGOs) are the most trusted groups to provide information.
- Processes for stakeholder engagement and building public trust are likely to become increasingly important if nuclear energy is to be an accepted part of a country's energy policy.

Developing the technology

The present generation of reactor designs is capable of excellent performance. They will provide the basis for nuclear energy growth for the next two or three decades. International co-operation on both reactor designs and fuel cycles promises even further advances for the future.

Advanced reactors

Future light water reactors – the likely main reactor types until the middle of the century – will be Generation III+ designs with improved safety characteristics and better economics; four Generation III+ reactors are operating now and more are being constructed.

- Future high-temperature gas-cooled reactors – likely to be commercially available around 2020 – can operate at temperatures sufficiently high to produce hydrogen fuel for the transport sector and for other process heat applications.
- Small reactors being designed for developing economies have inherent and passive approaches to safety, especially advantageous in countries with limited nuclear experience; however, the technologies are not yet commercially established.
- Generation IV energy system concepts, for commercial operation after 2030, offer improved proliferation resistance and physical protection; global initiatives aim to support safe, sustainable expansion of competitively priced and reliable nuclear energy that minimises waste production.

- Fusion energy is still at the experimental stage and is not likely to be deployed for commercial electricity production until at least the second half of the century.

Current and advanced fuel cycles

Current practice divides between those countries which reprocess nuclear fuel and those that do not. Of the three countries with the largest nuclear fleets, France and Japan currently reprocess spent fuel and the United States currently does not. Advanced reprocessing cycles are under consideration and development in many countries, including the United States.

- The reprocessing of the spent fuel existing today could provide fuel for about 700 reactor-years in light water reactors. Additional existing potential fuel sources could provide fuel for over another 3 000 reactor-years.
- Fast reactors with closed fuel cycles, such as those considered by the Generation IV International Forum, can be designed to burn existing stocks of plutonium, or to breed plutonium from non-fissile uranium isotopes. In the latter case, the energy extraction from a given quantity of uranium can be multiplied by up to a factor of 60, enabling uranium resources to last for thousands of years.
- Reprocessing also has an advantage for spent fuel management, allowing a significant reduction in the volume of high-level waste requiring geological disposal.
- Advanced fuel cycles hold the promise of commercial scale separation of long-lived isotopes and their re-irradiation to eliminate them. The radioactivity of waste materials arising from spent nuclear fuel would then naturally decay to below that of the uranium from which the fuel was produced within a few hundred years.

Extended summary

Social, political and environmental consequences of the world's energy demand in the 21st century

Energy, and particularly electricity, is essential for economic and social development and for improved quality of life, but the last century's global trend in energy supply is widely recognised as being unsustainable. The world faces environmental threats from climate change caused by anthropogenic CO_2 emissions and socio-political threats from rising energy prices and the possible lack of secure energy supplies.

Balancing energy requirements for continued social and economic progress against potential environmental and socio-political impacts is acknowledged to be a significant global challenge in the 21st century.

Strong economic growth in many developing countries, leading to a more energy-consuming lifestyle, and the projected 50% increase of the world population, primarily in the developing regions, are expected to drive energy demand in the 21st century. Current annual per capita energy consumption differs markedly by country and region; today's developing countries, with some three-quarters of the world's inhabitants, consume only one-quarter of global energy. By 2050, with current government policies, both total primary energy supply and global electricity demand are expected to have increased by about a factor of 2.5.

By 2050, global electricity demand is expected to have increased by about a factor of 2.5.

If current government policies in most countries remain unchanged, fossil fuel use will continue its inexorable rise to meet this increasing demand for energy, whilst nuclear power is not likely to make a significant contribution. This increase in fossil fuel usage will lead to increased CO_2 emissions, which science and recent history show will have consequent impacts on our climate, and lead to political and economic instability resulting from reduced security of supply and increased energy prices.

The United Nations Intergovernmental Panel on Climate Change, in its most recent major report published in 2007, showed that environmentally sound sources of energy are imperative to control atmospheric emissions of greenhouse gases, particularly CO_2. Electricity generation accounts for 27% of global anthropogenic CO_2 emissions and is by far the largest and fastest-growing source of greenhouse gases.

If projections hold true, by 2050 the average CO_2 emissions per unit of energy consumption must be reduced by a factor of 4.

In 2005, most of the world's population used significantly less than 4 000 kWh of electricity per capita, the threshold below which life expectancy and educational attainment are observed to fall rapidly. Over the period to 2030, the biggest growth in electricity demand is expected to occur in India and in China. Electricity demand in the United States has grown continuously over the past 55 years, with no obvious sign of slowing. As other countries aspire to the level of economic development in OECD countries, it is likely that their energy demands will eventually follow the same pattern – electricity demand is unlikely to level out.

If UN population and IPCC gross domestic product (GDP) per capita and energy intensity projections hold true, the carbon intensity of the world's energy system must be reduced by a factor of four to achieve the 50% reduction in CO_2 emissions by 2050 that the IPCC considers necessary to stabilise climate change. This is tremendously challenging; IPCC data show that carbon intensity has improved by less than 10% in the last 35 years.

Security of supply has also become a major concern around the world, particularly for countries that have limited indigenous fossil fuel resources and are therefore dependent on imported energy. Most of the world's readily recoverable oil and gas reserves are concentrated in a few countries in the Middle East and in the Russian Federation. Over the past few decades, this has proved to be a significant source of tension, both economic and political.

Current and likely future contributions to global energy supply from nuclear power

In principle, nuclear energy could meet much of the anticipated increase in electricity demand.

Nuclear energy offers the opportunity of meeting a significant part of the anticipated increase in electricity demand whilst reducing the potential global environmental, political and economic concerns associated with fossil fuels.

The current contribution to global energy from nuclear power

The first civil nuclear power plants were built in the 1950s and this led to a major expansion in the nuclear industry in the 1970s and 1980s. Rapid growth ended following the accidents at Three Mile Island (1979) and Chernobyl (1986), and the collapse in fossil fuel prices in the mid-1980s.

In 2006, nuclear energy provided 16% of the world's electricity and 23% of electricity in OECD countries, from 439 reactors.

There were 439 nuclear reactors operating in 30 countries and one economy as of June 2008, with a total capacity of 372 GWe. Nuclear energy supplied 2.6 billion MWh in 2006: 16% of the world's electricity and 23% of electricity in OECD countries. Global operating experience of nuclear power reactors now exceeds 12 700 reactor-years. France, Japan and the United States have 57% of the world's nuclear generating capacity; in 2007, sixteen countries relied on nuclear energy to generate over a quarter of their electricity.

In June 2008, 41 power reactors were under construction in 14 countries and one economy: these units will increase global nuclear capacity by 9.4%. Average construction times of about 62 months are consistently being achieved in Asia; of the 18 units connected to the grid between December 2001 and May 2007, three were constructed in 48 months or less.

The energy output from existing nuclear energy investments has been increased through improved availability, power uprates and licence renewals. Energy availability factors for nuclear plants worldwide increased significantly over the past decade; although generating capacity rose by only 1% per year, nuclear electricity production increased by 2.5% per year. Power uprates to existing plants have increased global nuclear generating capacity by around 7 GWe, and in the United States, as of May 2008, 48 reactors had been granted licence renewals, extending their operating lives from 40 to 60 years, the longest out to 2046.

Although most nuclear fuel cycle services are concentrated in France, the Russian Federation, the United Kingdom and the United States, 18 countries have the capability to fabricate fuel, importing enriched uranium as necessary.

The likely future contribution of nuclear energy

There are plans for significant further nuclear power plant construction, particularly in China, India, the Russian Federation, the Ukraine and the United States. There are currently no firm plans to build additional capacity in Western Europe, other than the units currently under construction in Finland and France. Nuclear build is being encouraged by the UK government, but without firm orders to date. More recently the newly elected Italian government has also expressed an interest in new nuclear build. Several European countries – Belgium, Germany, Spain and Sweden – project significant reductions in their dependence on nuclear energy because they have adopted phase-out policies. However, in several of these countries political opinion is divided and nuclear power will still form a part of the energy mix for some considerable time: current final shutdown dates are 2022 in Germany and 2025 in Belgium and Sweden. Nuclear energy is regarded much more favourably in the countries of Eastern Europe, where some countries have firm intentions to add new nuclear capacity.

Current national plans and authoritative statements of intent suggest that the countries having the largest installed nuclear capacity in 2020 will be the United States, France, Japan, the Russian Federation, China and Korea. China and the United States have the largest planned increases in capacity. The countries that produce the largest amount of nuclear electricity in the world are not, with the exception of France, those that are most dependent on it. Among the probable top five producers in 2020, the United States and China are expected to have only 20% and 5% nuclear shares respectively. Although a number of currently non-nuclear countries have plans to join the nuclear energy community, they are likely to add only about 5% to global installed nuclear capacity by 2020.

The NEA has developed low and high scenario projections of nuclear electricity supply showing that global installed nuclear capacity could increase from 372 GWe in 2008 to between 580 and 1 400 GWe by 2050. Under the high scenario, nuclear energy's share of global electricity production would rise from 16% today to 22% in 2050. These projections are in broad agreement with those from other organisations.

The NEA projections suggest that nuclear electricity generation will continue to be dominated by the OECD countries out to 2050.

To achieve this increase, between 2030 and 2050 an average of between 23 (low scenario) and 54 (high scenario) reactors per year would need to be built both to replace plants to be decommissioned and to increase nuclear generation. Historic evidence suggests that the world could construct nuclear power plants at a rate more than sufficient to meet the NEA high scenario projections during the period up to 2050. History also suggests a global capability to construct nuclear plants at a rate that would allow 30% or more of global generating capacity to be nuclear by 2030, should that be what countries around the world were to require, compared with

NEA assumptions

Low scenario	High scenario
New plants are built only to replace retirements in the two decades to 2030. Capacity is maintained or slightly increased via life extension, uprating and higher power replacements. Between 2030 and 2050: • Carbon capture and storage are successful. • Energy from renewable sources is successful. • Experience of new nuclear technologies is poor. • Public and political acceptance of nuclear power is low.	Life extensions and plant upratings continue. Current national plans and authoritative statements of intent for additional capacity by 2030 are largely implemented. Between 2030 and 2050: • Carbon capture and storage is not very successful. • Energy from renewable sources is disappointing. • Experience of nuclear technologies is good. • Public concern about climate change and security of supply increases, significantly influencing governments. • Public and political acceptance of nuclear power is high. • Carbon trading schemes are widespread and successful.

the International Energy Agency (IEA) reference scenario projection of 10%.

The NEA low and high scenarios both project that nuclear electricity generation will continue to be dominated by the OECD countries. Despite the rapid economic growth expected in India and China, their projected share of global nuclear capacity is still relatively small by 2050.

Nuclear energy's potential role in minimising the negative consequences of the world's growing energy demand

Consequences for climate change

IPCC analysis concludes that annual CO_2 emissions must be halved from 2005 levels if the consequences of climate change are to be contained at a tolerable level. Emissions have to be cut to around 13 Gt/yr by 2050. Assessments suggest that emissions will be around 60 Gt/yr in 2050 unless serious ameliorative actions are taken. Electricity generation currently accounts for 27% of global anthropogenic CO_2 emissions and is by far the largest and fastest-growing source of greenhouse gases. On a total life cycle basis, nuclear energy is virtually CO_2 free.

Electricity generation is the largest and fastest-growing source of greenhouse gas emissions.

The IEA has suggested that a combination of technologies is needed to meet this very demanding target, including extremely high efficiency gains in both production and use of energy, a massive expansion of renewable energy, introduction of significant quantities of carbon capture and storage and a very significant expansion of nuclear energy.

Nuclear energy is the only virtually carbon-free technology with a proven track record on the scale required. In the NEA's low and high scenario projections, CO_2 emissions would be reduced by between 4 and 12 Gt/yr in 2050 if nuclear were used instead of coal, significant in terms of the 13 Gt/yr target level that the IPCC recommends.

Nuclear energy can provide electricity with almost no CO_2 emissions – it is the only nearly carbon-free technology with a proven track record on the scale required.

The concept of external costs applied to electricity generation accounts for consequences not represented in the price, including the consequences of climate change. Assessments that account for external costs in electricity production chains show that nuclear and hydroelectric power generation are the least expensive on a full life cycle basis.

However, the Kyoto Protocol did not recognise nuclear energy as an accepted technology under its Clean Development and Joint Implementation mechanisms, and the protocol's period of application was too short to have significant influence on investor decisions for power plants. The process of negotiation for a follow-on treaty has begun. Because electricity plants are the largest carbon dioxide emitting sector, with emissions growing faster than in any other, any new treaty must allow a much longer-term view and consider all available options.

Consequences for energy security

Nuclear energy is more able than fossil energy to provide security of supply because the fuel – uranium – comes from diverse sources, the main suppliers being in politically stable countries. Uranium's high energy density (one tonne of uranium produces the same energy as 10 000-16 000 tonnes of oil with current practices) also means that transport is less vulnerable to disruption. Furthermore, the high energy density and the low contribution of uranium to the cost of nuclear electricity production make the storage of a large energy reserve practical and affordable.

A significantly expanded global nuclear energy programme could potentially be fuelled for thousands of years using the currently defined uranium resource base – but this would require fast breeder reactors that are not yet commercially available.

Identified uranium resources are sufficient to fuel an expansion of global nuclear generating capacity employing a once-through fuel cycle (i.e. without reprocessing) at least until 2050, allowing decades for further discoveries. The current resource to consumption ratio of uranium is better than that for gas or oil. Based on regional geological data, resources that are expected to exist could increase uranium supply to several hundreds of years.

Reprocessing of existing irradiated nuclear fuel, which contains over half of the original energy content, could provide fuel for about 700 reactor-years, assuming 1 000 MWe light water reactors (LWRs) operating at an 80% availability factor. Additional existing resources, such as depleted uranium stocks and uranium and plutonium from ex-military applications, could provide nuclear fuel for about another 3 100 reactor-years.

Converting non-fissile uranium to fissile material in fast breeder reactors with closed fuel cycles can multiply the energy produced from uranium by up to 60 times. This technology could extend nuclear fuel supply for thousands of years, but fast breeder reactors are not yet in commercial operation. France, the Russian Federation, India and Japan have operable fast reactors (some of which are research reactors).

Consequences for health effects

The increasing use of energy carries with it significant health effects. The health impact of outdoor air pollution is uncertain, but has been estimated at currently almost one million premature deaths per year in the *OECD Environmental Outlook to 2030*. Nuclear energy could make a contribution to reducing the health effects of fossil fuel consumption.

A rational evaluation of the health effects of alternative electricity production technologies should consider both the long-term health effects of possible radioactivity releases from accidents and the far more dominant operational emissions from fossil sources. Gaseous and particulate emissions from fossil fuel use (SO_x, NO_x and fine particulates) are known to have significant deleterious health effects. Life cycle analyses of electrical energy production chains show that nuclear power (including the effect of radioactive emissions) is one of the best power production technologies for avoiding emission-related health effects. Loss of life from emission-related health effects far outweighs that from accidents in energy supply chains.

Comparison of frequency-consequence curves of real accident data for full energy chains in OECD countries for the period 1969-2000 shows nuclear to be very considerably safer than oil, coal and natural gas which are, in turn, notably safer than liquefied petroleum gas (LPG). However, public and political concern focuses on the very low probability of large accidents, which could lead to fatalities in the long term as a result of released radioactivity.

Meeting the challenges to nuclear energy growth

Despite nuclear energy's potential to reduce global environmental and socio-economic threats, a significant fraction of public opinion perceives that the risks of nuclear energy outweigh its advantages. If nuclear power is to achieve its full potential in the coming decades, the public and politicians will need to be convinced about a number of aspects of the technology, in particularly safety, waste disposal and decommissioning, physical security and non-proliferation, and cost.

If nuclear power is to achieve its full potential, the public must be convinced about safety, waste disposal, non-proliferation and costs.

Safety

The nuclear industry must keep safety and environmental protection as its top priorities. The rapid expansion of nuclear power in the 1970s and 1980s ended principally as a result of the Three Mile Island and Chernobyl accidents. At the same time, low fossil prices made new nuclear plants uneconomic in many countries. Despite current high fossil fuel prices, another serious accident, whether or not it released significant quantities of radioactivity to the environment, could have severe implications for the future of nuclear energy.

Nuclear safety is a global issue: a serious event in one country may have an impact on its neighbours. Although the responsibility for ensuring nuclear safety clearly resides within each country, the international nuclear community is seeking to increase harmonisation between national safety practices via the Multinational Design Evaluation Programme (MDEP) and other international initiatives.

The international community has initiatives in progress to increase regulatory effectiveness and efficiency, in view of the growing interest in new nuclear build and the next generation of designs.

The MDEP is an initiative undertaken by ten countries with the support of the NEA, to develop innovative approaches to make best use of the resources and knowledge of the national regulatory authorities that will be tasked with the review of new nuclear power plant designs. The main objective of the MDEP effort is to establish reference regulatory practices and regulations to enhance the safety of new reactor designs. The resulting convergence of regulatory practices and regulations should allow for enhanced co-operation among regulators, improving the effectiveness and efficiency of the regulatory design reviews that are part of each country's licensing process.

New designs of reactor have passive safety systems that are intended to maintain the plant in a safe state, in particular during an unexpected event, without the use of active control. Some advanced designs for smaller-sized reactors – not yet built – have an integral cooling system, with the steam generators, pressuriser and pumps all located within the reactor pressure vessel to reduce the probability and consequences of loss-of-coolant accidents.

Nuclear energy may be developed in countries where previous experience in nuclear power and its regulation is very limited. Ensuring that these "new" nuclear countries follow appropriate industrial and regulatory approaches and implement adequate legal procedures will be a duty of the international community and, in particular, of the vendor countries.

Waste disposal and decommissioning

Low-level and short-lived intermediate-level wastes account for the largest volumes of radioactive waste, but are only a small proportion of its total radioactivity. Technologies for disposal of such wastes are well developed and most countries with major nuclear programmes operate facilities for their disposal or are at an advanced stage in developing them.

Failure so far to build high-level waste disposal facilities is a significant factor in negative perceptions of nuclear energy – but there is now an international consensus for geological disposal.

The delay or failure thus far of some disposal facility programmes for high-level radioactive waste (HLW) continues to have a significant negative impact on the image of nuclear energy. Governments and the nuclear industry must work together to deliver safe disposal. Because HLW disposal has not yet been implemented, this has given the impression to some that it is technically very difficult or even impossible. In addition, waste management and decommissioning are sometimes believed to be prohibitively expensive.

The quantities of HLW arising are small and can be stored safely for extended periods of time. A 1 000 MWe light water reactor produces about 25 tonnes of spent nuclear fuel (SNF) per year which can be packed for disposal as HLW; alternatively, where spent fuel is reprocessed, about 3 m^3 of vitrified high-level waste is produced.

The consensus approach being pursued worldwide for ultimate management of SNF and HLW is geological disposal, for which the technological basis is well established. So far no facilities for disposal of SNF and HLW have been licensed, but progress is being made through participative national decision-making processes. In the United States a site has been selected and considerable investigation work conducted. In Finland the selected site has received political and local support, and it is possible that Sweden may be in that position soon. Numerous other countries, including France, Japan and the United Kingdom are currently engaged in the search for an acceptable HLW disposal site. If all countries investigating geological disposal succeed in operating a repository before 2050, only about one quarter of the SNF and HLW generated under the NEA high scenario would be without a defined disposal route at that time.

There is experience of successfully decommissioning a variety of nuclear facilities, including several US power plants with capacities larger than 100 MWe that were fully dismantled, with disposal of the resultant waste. An analysis by the United Kingdom Department of Trade and Industry showed that waste management and decommissioning costs for nuclear power plants represent only 3% of overall nuclear generation costs. Funding schemes exist to finance decommissioning liabilities.

It is estimated that 70% of today's worldwide nuclear decommissioning liabilities are associated with military activities from the Cold War rather than with civil nuclear power plants.

Non-proliferation and security

The possibility of materials or technologies developed for civil use in electricity production being diverted for military purposes is a concern to many people. The International Atomic Energy Agency (IAEA) safeguards system under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) has served the international community well in helping to prevent the diversion of civil nuclear materials and technologies into military uses. The NPT has 191 Parties and came into force in 1970; it was extended indefinitely in 1995. The safeguards arrangements are backed up by diplomatic, political and economic measures and complemented by controls on the export of sensitive technology.

The Treaty on the Non-Proliferation of Nuclear Weapons has successfully restrained the spread of nuclear weapons for four decades.

The NPT has been the legal foundation of the international regime for restraining the spread of nuclear weapons for nearly four decades. Yet its future effectiveness and support could be in jeopardy as a result of various political, legal and technical developments. To ensure its continued success, it needs to be enhanced.

Concerns about the spread of reprocessing and enrichment technologies have led the IAEA to propose multilateral nuclear approaches to increase non-proliferation assurances for nuclear fuel cycle facilities. These are aimed at reinforcing existing commercial arrangements for enrichment and reprocessing via a range of possible mechanisms: implementing international nuclear fuel supply guarantees; promoting voluntary conversion of existing nationally controlled facilities to multinational facilities; creating new multinational facilities based on joint ownership for enrichment and for disposal of spent fuel.

Several other proposals are also under discussion or development. These include the Global Nuclear Energy Partnership (GNEP) promoted by the United States, which has 21 participating member countries as of August 2008, and the Russian Federation's project to establish an International Uranium Enrichment Centre (IUEC). Proposals from Japan, Germany and a group of six countries with commercial enrichment facilities have also contributed to the international debate.

While the international safeguards regime is an important component of proliferation resistance, design measures may facilitate the implementation of safeguards controls. Advanced nuclear technologies are being designed with enhanced resistance to proliferation threats and robustness against sabotage and terrorism threats.

Cost and funding

A 2005 international comparison of the levelised costs for nuclear, coal and gas power plants, carried out by the NEA and the IEA, shows nuclear to be competitive with coal and gas, with some dependence on local circumstances. Since then, the price of oil has quadrupled (as at June 2008) with other fossil energy prices following it upwards. Building and operating new nuclear plants is clearly economically viable in the right circumstances. However, sensitivity analysis of nuclear electricity generation costs show that they are particularly dependent on overnight construction cost and on the cost of capital (financing charges). The large up-front cost is also a discouragement to investors. The economic challenges of nuclear power therefore relate more to investment funding than to levelised generation costs.

International comparison shows nuclear to be competitive with coal and gas – but governments may need to mitigate licensing and planning risks to encourage investment in nuclear energy.

The cost of generating nuclear electricity has three main components: capital investment, operation and maintenance (O&M) and fuel cycle. The capital investment required to construct a nuclear power plant contributes typically 60% to the total cost of nuclear electricity generation, while O&M and fuel cycle contribute about 25% and 15% respectively. The cost of the uranium itself amounts to only around 5% of the cost of generating nuclear electricity. This is markedly different from the cost structure of fossil electricity generation plants, particularly those operating on gas, where fuel costs dominate.

The introduction of competitive wholesale markets for electricity has generally been positive for existing nuclear plants. Competitive pressures have encouraged improvements in operating performance, allowing the full value of the assets to be realised. For both new and existing plants, improved economics can be achieved through uprating power levels, lifetime extensions and increased availabilities. Worldwide, average availability has increased by almost 10 percentage points in the last 15 years, now reaching 83%. Five countries exceeded 90% average availability in 2006 and in 2007 this increased to six countries; the best reactors in the world have availabilities around 95%. Many plants have been uprated to produce more power, some by as much as 20%. A significant number of reactors have had licensed lifetimes extended from 40 to 60 years.

The large initial capital cost of new nuclear plants and the length of time of licensing processes have caused investors to be very cautious of new build. Governments wishing to encourage investment in nuclear may need to remove or mitigate the real or perceived financial risks associated with licensing, planning and radioactive waste management and decommissioning. Achieving a broad national consensus on the nuclear programme would also be advantageous in reducing political risks for investors.

In addition, governments may need to put in place clear, long-term arrangements for carbon pricing or trading. Most potential external costs have already been internalised for nuclear power, whereas for fossil fuels, external costs are around the same size as direct costs. The manner in which a utility's income from electricity generation is taxed can also have the effect of influencing the relative competitiveness of generating technologies, discouraging the construction of capital-intensive facilities such as nuclear and renewables. Governments should ensure that their energy policy objectives and taxation regimes are in harmony.

Legal framework, infrastructure and resources

The current international legal framework consists of a suite of legally binding treaties, conventions, agreements and resolutions supplemented by numerous non-legally binding codes, guidelines and standards. It has undergone significant changes over the past five decades. Whether at national or international level, legal frameworks must be sufficiently flexible to adapt to future developments, including a significant increase in global nuclear energy production. One of the most important challenges will be to persuade countries with new nuclear power programmes to abide by the terms of the current international framework. The same challenge will apply to those countries that already have established nuclear programmes, but which have so far declined to harmonise their regimes with the existing international framework.

One of the most important challenges from an expansion of nuclear power will be to persuade countries with new nuclear programmes to abide by the terms of the international legal framework.

National regulatory bodies are important components of national legal frameworks for which it is essential to keep the following attributes:

- adequate legal authority, technical and managerial competence;
- adequate human and financial resources to fulfil their responsibilities;
- freedom from undue influence and pressure which could conflict with safety interests.

With the anticipated increase in demand for nuclear power, concerned stakeholders may press not only for more comprehensive and definitive national legislation, but for more effective international conventions on public participation. The further development and implementation of good governance is a necessary step towards educating, empowering and engaging society in the policy-making process of deciding and shaping the future of nuclear energy. For this to happen effectively, a legal framework that will support transparency of information and stakeholder involvement is required. Legislators are likely to ensure that stakeholders gain increasing rights to contribute to the nuclear decision-making process by established legal procedures; they are already convinced that increasing stakeholder involvement in nuclear decision making will lead to enforcement of nuclear and environmental policies that are more effective and will help to build public trust and confidence.

Many in the current nuclear workforce received their education and started their careers during the rapid buildup of nuclear programmes in the 1960s and 1970s. These people are now close to retirement, or indeed have already left the industry. The long life cycle of nuclear power plants, together with the requirement for technical competence, means that the nuclear industry in many countries now faces problems in retaining existing skills and competencies and in developing future skills to support any expansion of nuclear power. Availability of adequate human resources is affected by the increasing liberalisation of the electricity market, resulting in pressure to reduce costs as well as a decrease in government funding for nuclear research. Most countries have recognised the need to secure qualified human resources and recent international, regional and national initiatives have been aimed at encouraging and facilitating more students to enter the nuclear field. Although some progress has been achieved, more needs to be done.

An ageing nuclear workforce, the historic slowdown of new build and requirements for specialised competence, mean the nuclear sector now faces human-resource challenges.

Nuclear research is essential in a number of areas, including safety, radioactive waste management, and nuclear science and technology development. Throughout the 1990s, most OECD governments with nuclear programmes reduced the funding dedicated to nuclear fission R&D. This reduction in domestic resources increased the importance of international organisations, such as the NEA and the IAEA, as focal points to pool the expertise and resources of national laboratories, industry and universities. They also play an important role in activities related to the preservation of knowledge.

The reduced number of nuclear power plants built worldwide in recent years has led to a major consolidation of the nuclear construction industry, resulting in a currently limited capacity to construct new plants. If the demand is there, this can be rebuilt. There is some evidence that this is already happening.

Nuclear energy and society

Provided that the nuclear electricity produced is competitive, people are then more concerned about some aspects surrounding nuclear energy (radioactive waste, terrorism and proliferation) than about the actual operation of the power plants. It is likely that opposition to nuclear energy would reduce considerably if the matter of waste disposal sites were resolved.

However, over half of European Union citizens think that the risks of nuclear power outweigh

If nuclear energy is to expand, an ongoing relationship between policy makers, the nuclear industry and society that develops knowledge-building and public involvement will become increasingly important.

its advantages, particularly if they live in countries with no nuclear power and so have little personal experience of it, or if they do not feel well informed. Increased knowledge of nuclear energy leads to increased levels of support – but most people feel they have inadequate levels of knowledge. Scientists and NGOs are most trusted to provide information. National governments, energy companies and nuclear safety authorities are much less trusted. If nuclear energy is to expand, an ongoing relationship between policy makers, the nuclear industry and society that develops knowledge-building and public involvement will become increasingly important.

Providing citizens with a more in-depth understanding of nuclear issues through direct involvement has been demonstrated to be highly effective. While the provision of information is necessary in order to better educate society about nuclear risks, building public trust must be recognised as equally important. Communication must be open and straightforward, and must be balanced as a priority against conflicting demands such as security and financial pressures.

Developing the technology

Advanced reactors

Advanced reactors are those in Generations III, III+ and IV. Around 80% of today's nuclear power plants use Generation II light water reactors (LWRs), mostly built in the 1970s and 1980s, and LWRs are expected to continue to be the primary form of nuclear power generation until the middle of the century. However, most future nuclear power plants will be Generation III+ designs; four Generation III+ LWRs are operating now and several more are being constructed. These designs offer improved safety characteristics and better economics than the Generation II reactors currently in operation.

Nuclear power could make an increasing contribution to carbon-free heat as well as to electricity production; nuclear production of hydrogen as a transport fuel is an important potential development.

Nuclear power could make an increasing contribution to the supply of electricity as well as to the production of virtually carbon-free heat in the future. Two applications for nuclear heat using LWRs are in current use: district heating and desalination. Most other industrial processes require temperatures that can only be produced by high-temperature gas-cooled reactors (HTGRs). These HTGRs are designed to produce electricity using a gas turbine and to operate at temperatures sufficient for hydrogen production and other process heat applications. Globally, there is significant R&D investment in hydrogen production from nuclear energy, driven by a desire to reduce dependence on imported oil, with commercial exploitation expected around 2020. Hydrogen production could be a significant use of nuclear energy in the coming decades.

Much of the projected growth in world electricity demand will take place in developing economies, where the large nuclear power plants being developed and built in the advanced nuclear energy countries are not necessarily appropriate. Outside of baseload demand in the big and developing economies, such as China and India, large nuclear power plants will not always be well suited. The geographic isolation of some population centres makes them candidates for small or medium reactors (SMRs), particularly if the plants also produce heat and/or potable water. A number of Generation III/III+ SMR designs are under consideration, about half designed without the need for on-site refuelling in order to reduce capital costs and allow easier non-proliferation assurances. These are mostly LWRs with inherent and passive approaches to safety, such as integral primary coolant systems; such design features are especially advantageous in countries with limited nuclear experience. However, SMR technologies are not yet commercially established.

For the longer term, Generation IV energy systems involving advanced reactor designs are expected to be commercialised after 2030. Around the world, many advanced reactor designs are under consideration and it is clear that considerable international co-operation is required to maximise the outcome of scarce R&D funding. An important aspect of Generation IV energy systems is further-improved proliferation resistance and physical protection against terrorist threats.

Fusion energy is still at the experimental stage and is not likely to be deployed for commercial electricity production until at least the second half of the century.

Six energy systems, including their fuel cycles, have been chosen by the Generation IV International Forum (GIF) for detailed R&D, several of which are fast reactors with closed fuel cycles. At least three international initiatives are in progress that aim to support the safe, sustainable and proliferation-resistant expansion of competitively priced and reliable nuclear technology that minimises waste production:

- the GIF, for which the NEA provides the Technical Secretariat;
- the US-led Global Nuclear Energy Partnership;
- the IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles.

At a research and development level, controlled nuclear fusion has been realised, although only for a few seconds. Cadarache in France has been chosen as the location of the EUR 5 billion International Thermonuclear Experimental Reactor (ITER) project, the next major development step. The technology is inherently far more complex than fission and the economics of fusion are very uncertain; fusion is not likely to be deployed for commercial electricity production until at least the second half of the century.

Advanced fuel cycles

Current practice in dealing with spent nuclear fuel divides between those nations which reprocess and those that intend to directly dispose of spent fuel to a geological repository after appropriate packaging. Of the three nations with the largest nuclear fleets, France reprocesses fuel and provides reprocessing services to other nations on a commercial basis; Japan reprocesses fuel, buying services from others whilst developing its own domestic capability; and the United States does not reprocess, although it formerly had the capability to do so.

Advanced reprocessing technologies hold the promise of eliminating the long-lived radio-isotopes in nuclear waste.

Existing commercial reprocessing technology enables the recovery of unused uranium, the recovery of plutonium for use in mixed-oxide fuel for LWRs or future fast reactors and the reduction of waste volume for disposal in a deep geological repository. However, the very low price of uranium during the 1990s made reprocessing less attractive in economic terms and the separation of plutonium led to concerns about potential proliferation risks. The price of uranium has recovered in the last few years.

Advanced reprocessing technologies are under development in several countries, and are the subject of international co-operation as part of the Generation IV International Forum and the US-led Global Nuclear Energy Partnership. These hold the potential to provide a number of advantages. Proliferation risks can be reduced by avoiding the separation of plutonium from uranium. Separating the long-lived isotopes from spent fuel (partitioning) for subsequent re-irradiation can eliminate them (transmutation). The radiotoxicity of the waste resulting from the treatment of spent fuel would then reduce by natural radioactive decay to less than that of the natural uranium from which the fuel was originally produced in a matter of only a few hundred years. The volume and heat load burdens on geological repositories could be significantly reduced, allowing the capacity of a given repository to be greatly extended.

The use of thorium for energy production in nuclear reactors is also possible; thorium is believed to be considerably more abundant in the earth's crust than uranium. The naturally occurring isotope of thorium can be transmuted to a fissile uranium isotope. Research and development on thorium-based fuel cycles had been conducted in a number of countries but the technology has not been developed to the commercial scale. ■

Market competition in the nuclear industry

M. Taylor*

The nuclear industry provides a wide variety of specialised equipment and services to support the construction and operation of nuclear power plants (NPPs). This includes the supply of NPPs themselves, the range of materials and services required in the nuclear fuel cycle, and the services and equipment needed for maintenance and upgrading. The markets to provide these have changed substantially as they have evolved from the government-led early stages of the nuclear industry to predominantly competitive, commercial markets today.

Since the 1980s and until recently, the nuclear industry has undergone considerable consolidation and retrenchment in response to generally low demand, which have resulted in a small number of large, global players in certain sectors. This partly reflects special factors in the nuclear industry, but also the more general trend towards globalisation of major industrial activities. Meanwhile, the liberalisation of electricity markets in many OECD countries has changed the business environment for NPP owners/operators. Electricity utilities have been exposed to increased competition, requiring them to improve their business performance and making them more cost-conscious.

A recent NEA study on *Market Competition in the Nuclear Industry*[1] set out to examine how the industry's major sectors are performing in present market conditions and, with an expansion of nuclear power expected over the coming years, how these markets will likely evolve in response to the significant upturn in demand. The study also considered the potential implications for market competition of the multilateral, assured fuel supply arrangements being proposed by several governments.

The study notes that there are some areas of nuclear activity where competition is necessarily limited or even absent. This includes many research and development activities, especially those with long-term goals, and for which international co-operation and government support are necessary until new technologies are ready for commercialisation. Within existing commercial sectors, certain limitations also necessarily exist, notably non-proliferation controls on sensitive materials, equipment and technologies.

Furthermore, nuclear power involves very large investments in complex plant and equipment, and requires a high level of specialised expertise. This often results in long-term relationships between suppliers and customers, who work together to ensure that plants operate safely and efficiently, and that improvements and upgrades can be made effectively. The study notes that in nuclear energy markets, quality and reliability are often at least as important to customers as prices.

Assessing the competitiveness of markets

In the absence of detailed statistical information about each market sector, it was decided to consider a set of market characteristics which could act as indicators of competitiveness. Although the assessment of each indicator involved a degree of subjective judgement, taken together they provided a useful overall impression of the effectiveness of competition in each sector. These indicators were:

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- market shares of major participants,
- degree of vertical integration,
- proportion of long-term contracts,
- barriers to entry,
- transaction costs and market segmentation,
- product differentiation,
- balance of capacity and demand,
- market alliances and supplier co-operation,
- public goods aspects,
- trade barriers and restrictions.

Where possible, market shares were used to calculate the Herfindahl-Hirschman Index (HHI) for the market sector, defined as the sum of the squares of the percentage market shares of all market participants. If the value of the HHI is greater than 1 800, this is often taken as a sign that a market may be over-concentrated.

Main findings for each major market sector

Design, engineering and construction of NPPs

This sector appears poised for a major expansion in the coming decade and beyond. Despite the prolonged market depression since the 1980s and the consolidation which resulted, the remaining NPP vendors have continued to develop their designs and are now offering considerably improved products. At least in the major markets, where there is the potential for a series of orders, there is likely to be strong competition between four or five vendors. Despite some market distortions, a global market with several independent and competing vendors has emerged which provides a genuine choice of supplier to potential customers. However, different regulatory requirements for NPP designs between countries, which can lead to significant up-front costs for vendors, may effectively limit the choices available, particularly in smaller markets. In the longer term, there is the prospect of the emergence of additional important NPP vendors, notably in Korea and China.

Uranium supply

A significant number of new uranium production facilities is expected to enter operation over the coming years in response to rising demand. Many of these will be owned by new entrants or smaller producers with growing production. Although some consolidation is likely to occur, the trend is expected to be towards reduced market concentration. However, the possibility of a merger of two of the major producers could be a cause for concern if it led to the merged company controlling a very large share of global production. Trade restrictions on uranium imports into the United States and the European Union since the early 1990s have affected market competition. However, increased demand and the reduced availability of supplies from existing stockpiles is likely to limit the practical impact of these restrictions on the market, even if the measures themselves remain in force.

UF_6 conversion services

There are effectively only three major suppliers of UF_6 conversion services worldwide, with a fourth supplier which is mainly limited to providing uranium, conversion and enrichment as a package. From a market competition perspective, this indicates that the market is more concentrated than would be desirable. However, the role of conversion plants as the main storage locations and clearing houses of the uranium market may mean that it is more convenient for market participants if there is a relatively limited number of sites. Together with the fact that conversion represents only a small fraction (around 5%) of the total cost of nuclear fuel, this means that new conversion facilities on new sites may have difficulty in establishing themselves. Present expansion plans indicate that the existing major suppliers will expand their capacity as required and little change is expected in the degree of market concentration.

Uranium enrichment services

Enrichment technology is among the most sensitive in terms of non-proliferation, which means that it is possessed by a limited number of countries, and is entrusted by governments to only a small number of commercial operators; this inevitably limits market competition in this sector. However, the enrichment industry is undergoing major changes which will reshape it over the next ten years and beyond. The remaining older gas diffusion plants in France and the United States will be replaced by new centrifuge plants, while there is also the prospect of laser enrichment technology being commercialised. There will be at least two and possibly as many as four new enrichment plants in the United States by 2015, each operated independently by competing suppliers. The large enrichment capacity in the Russian Federation is also expected to play a growing role in the international market. These developments are likely to lead to shifts in the market shares of the existing suppliers.

Fuel fabrication services

Unlike other fuel cycle services, fuel fabrication is essentially a bespoke service to prepare fuel assemblies to the exact requirements of each NPP. For a new NPP, fuel is initially supplied by the NPP vendor. Only later in the NPP's operating life does the possibility of choosing between competing suppliers open up. Furthermore, some NPP operators may not consider that the commercial risk involved in changing suppliers is justified by the potential savings on fuel costs. Nevertheless, significant competition does exist in the fuel fabrication market, and for NPPs of more common designs there may be a choice of up to three fabricators. However, the fuel fabrication market has consolidated over recent years, as the main NPP vendors have consolidated. It now appears that the market for fuel fabrication is more concentrated than would be desirable. For some market sub-sectors there is effectively no competition.

Back-end of the nuclear fuel cycle

Much of the capacity of the limited number of spent fuel reprocessing plants is devoted to domestic arisings of spent fuel, but some also reprocess spent fuel from other countries under contracts with foreign utilities. Thus, a limited international market does exist. With the prospect of significant future expansion of nuclear power, the potential for spent fuel reprocessing and recycling is attracting renewed interest. However, reprocessing technology is highly sensitive from a non-proliferation perspective. Reprocessing is likely to be restricted to a small number of countries, or be subject to multilateral control. Its wider use is also likely to depend on the adoption of advanced reactor designs which allow full advantage to be taken of the recycled materials. The commercialisation of such designs is not expected to occur until well after 2020.

In general, utilities remain responsible for the management of radioactive waste arising in their plants, at least until it is transferred to a national authority or agency responsible for disposal. A similar situation exists for the decommissioning of disused facilities and the waste generated during such activities. Thus, commercial activity in these sectors is generally limited to the provision of services, technology and equipment. Many specialised companies are involved, as well as many of the main nuclear industry companies. Overall, there is considerable competition and innovation in the provision of services, technology and equipment for radioactive waste management and decommissioning.

Services for maintenance and upgrading of existing NPPs

With the lack of orders for new NPPs in recent years, reactor vendors and other nuclear engineering companies have been increasingly reliant on the business of maintaining, back-fitting and upgrading the existing reactor fleets. With life extensions now planned for a large number of existing NPPs, the demand for major upgrading projects is likely to remain high. At present, there appears to be a good balance between capacity and demand in this sector with a good degree of competition in most sub-sectors. However, if there is a significant increase in orders for new NPPs in the coming years this situation could change, as construction of new plants will often involve the same companies. It could potentially become more difficult to find competing suppliers able to undertake routine maintenance tasks and larger upgrading projects in a timely fashion.

Overall assessment and conclusions

The study's analysis shows that the most concentrated nuclear industry market sectors are enrichment and fuel fabrication, with in each case one supplier having over 30% of the market and others in the 20-30% range. Reprocessing is also concentrated, although this is a smaller and less well-developed market. Overall, however, no sector in the front-end of the fuel cycle has a single company with an overwhelming dominance, with each having at least four competing suppliers. There was no indication from presently available information that market shares of leading suppliers would increase significantly as the sectors expand over the next ten years. Indeed, in some sectors, notably uranium supply, it appears that the market may become less concentrated over the coming years.

As regards the market for new NPPs, it is difficult to assess future market shares as this will depend on the relative success of the vendors in winning orders. However, in most regions there is significant competition between at least three or four suppliers. In this, the NPP market compares favourably with certain other engineering-based industries with complex high-technology products, notably the aerospace industry. Early indications are that each major NPP vendor will win a significant share of new orders over the next decade. The future market for fuel fabrication services will to a large extent also be shaped by the market for new NPPs.

Several major nuclear companies have a significant share of more than one sector, meaning that there is a degree of vertical integration across several of the market sectors. Insofar as such companies supply nuclear equipment, services and materials as a package, this may lead to a reduction in competition in some sectors. Such comprehensive arrangements are so far rare, but in future some customers may prefer the perceived security

Summary of major suppliers in nuclear industry sectors by approximate market share

Market sector	Share > 30%	30% > Share > 20%	20% > Share > 10%
NPP construction*	—	AREVA Westinghouse	Atomenergoprom General Electric
Uranium supply	—	Cameco	AREVA Atomenergoprom Rio Tinto
UF_6 conversion	—	AREVA Atomenergoprom Cameco	ConverDyn
Enrichment	Atomenergoprom	AREVA United States Enrichment Corp. (USEC)	Urenco
Fuel fabrication	AREVA	Westinghouse	Global Nuclear Fuel (GNF)
Reprocessing	AREVA	Japan Nuclear Fuel Limited (JNFL) Nuclear Decommissioning Authority (NDA)	Atomenergoprom

* Including consolidated companies, based on all operating NPPs.

of receiving a complete package of services from a single, large supplier. If comprehensive provision is preferred by some customers, it is likely that an increasing number of companies will try to position themselves to meet this requirement.

In its conclusions, the study offers the following key findings and recommendations:

- Competitive markets for the supply of goods and services for the construction, operation and fuelling of nuclear power plants are an important factor in ensuring the overall competitiveness of nuclear power, thus helping its benefits to be more widely spread. Governments should encourage and support competition in these markets, and actively seek to prevent concentration of market power where it unduly limits competition.
- An important policy aim of some national nuclear programmes is the development of a domestic nuclear energy capability. This may necessarily involve some protection of infant industries, with national investment focused on a single supplier to avoid duplication. However, care should be taken not to permanently exclude competitive pressures, which should be allowed to strengthen as market and industrial sectors mature.
- While longer-term development and demonstration of new nuclear power technologies may require government support and funding, competition is a great spur to innovation and technological development, helping to improve the products and services available. As fledgling technologies mature and reach the stage of commercial deployment, they should be increasingly subject to the competitive pressures which will allow them to achieve their full potential.
- Strong non-proliferation controls on sensitive nuclear materials and technologies are vital to the existence of an open and competitive global market in the nuclear industry. Although such controls will necessarily involve some market restrictions and limitations, they are consistent with the development of new capacities by competing suppliers to meet the growing requirements of nuclear energy programmes around the world.
- Other restrictions and tariffs on international trade in goods and services for nuclear power plants can unnecessarily add to the costs of nuclear power. Governments should aim to eliminate or reduce them to the extent possible.
- The best assurance of supply of nuclear fuel and other essential goods and services to NPPs is the existence of a geographically diverse range of independent suppliers competing on commercial terms in all market sectors. Governments should seek to create the necessary legal and regulatory frameworks in which such a situation can develop. Furthermore, the harmonisation of such frameworks between countries, especially for the approval of new NPP designs, would increase customer choice and enhance competition in nuclear markets. ■

1. NEA (2008), *Market Competition in the Nuclear Industry*, OECD, Paris. Online ordering: www.oecd.org/bookshop.

Challenges in the field of materials science

M. Defranceschi*

The development of innovative thermonuclear fusion and nuclear fission reactors critically depends on the availability of not only nuclear fuels but also advanced structural and functional materials systems. These have to withstand extreme conditions: high temperatures, intense neutron irradiation, and strongly corrosive environments, in combination with complex loading states and cyclic loading histories. The challenges in the field of nuclear materials range from operation in critical conditions to compliance with the highest levels of safety and protection, while giving due regard to decommissioning, dismantling and waste processing issues.

Searching for new materials and tailoring them to the desired multifunctional properties is central to many industries but the nuclear sector must deal with the specific condition of radiation. Hardly any industry escapes having to investigate materials science; practically none must investigate to such an extent as does the nuclear industry. Beyond the sole scientific and technological questions are economic and societal issues: service life extension of nuclear power plants and more stringent safety requirements are increasing the demand for better control of the ageing of materials, components and structures.

Operating conditions offer further complexities. Very severe operational constraints and the extremely high requirements to be able to correctly forecast material behaviours on a long-term basis whereas radiation, thermo-mechanical loading and chemical attacks all combine to severely impair their states. In many respects the understanding gained remains empirical and cannot be easily extrapolated to new materials, new environments, or new operating conditions; basic underlying mechanisms governing manufacturing, behaviour and performance require greater understanding and call for in-depth investigation.

So-called "nuclear materials" are multiple and varied – metals and their alloys, polymers, glasses, ceramics – and can be used in various applications:

Fission: ferritic steel (RPV), austenitic stainless steel (internals), zirconium alloys (fuel cladding), oxide matrices (used fuels).

Fusion: ferritic/austenitic steels (wall and piping), ceramic composites.

Generation IV: iron-chromium alloys, silicon carbide, etc.

Waste conditioning: glasses, cementitous materials, mineral matrices.

Components of nuclear plants: polymers (cable and coatings).

Technological needs

Technological needs vary enormously: which type of materials, which property, which scale of length or time. Key differences between the science of condensed matter or solid state physics and materials science stem from its crucial technological drivers. These cover any assessment of the effectiveness of the design of the material properties, as for example: fitness for purpose (intrinsic property such as the capability to sustain high temperatures), whole life behaviour (e.g. the creeping of materials at high temperatures, the breakdown of polymers under electrical stress, the decomposition of glasses

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after disposal and the adaptability of materials to new nuclear fuel characteristics as fuel evolves), customer acceptability, economic, safety and environmental aspects (optimising materials for radioactive waste disposal, increasing lifetime).

The challenges faced by materials scientists in the nuclear field are multiple:

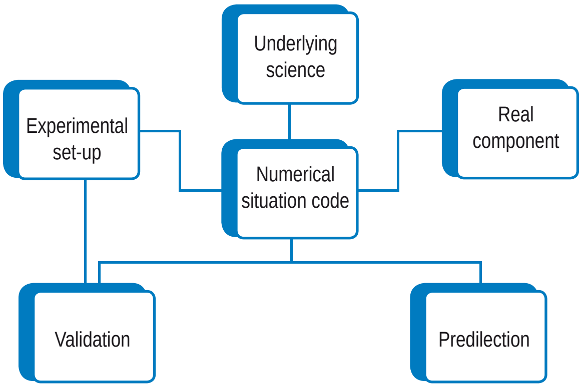
- Nuclear materials science examines multi-component, multi-phase problems, made more complex by variations in scale. The length scales range from atomic to mesoscopic (typically from a few nm to microns) to macroscopic, with these scales sometimes extensively mixed. The timescale ranges from femtoseconds to tenths of years for vessel lifetime to geological timescales for radioactive waste repositories.
- The basic phenomena controlling the behaviour of materials under irradiation are complex. A question still unanswered is: which scale is relevant for the phenomenon? Is it the atomistic scale of electronic structure or is a collective effect occurring at a larger scale? Physicochemical properties of nuclear fuel are important to evaluate too. However there is limited information on these properties due to the difficulties associated with observing high radiation fields.
- Many systems are prepared or used when neither in thermodynamic equilibrium, nor homogeneous; considering them in an equilibrium state is thus insufficient. For instance it is safely admitted that at high temperature most solids are in thermodynamic equilibrium state. At low temperature this is not always true since their relaxation time scales can be very long. A system can also be maintained in a non-equilibrium state exposing materials to irradiation by ion beams, or neutrons can also drive the system in a complex configuration. Sometimes the system is so perturbed that order-disorder phase transitions driven by irradiation occur in alloys. Phase transitions induced by irradiation can also be observed in simple oxides like zirconia where the solid transforms from one crystallographic structure to another. Irradiation-induced transitions have also been observed in more complex oxides. Mechanisms leading to such phase transitions under irradiation are not yet understood.
- Thermodynamic quantities are central to the assessment of the stability and/or the chemical reactivity of solid phases. These quantities have not all been established, whether upon experimental or theoretical grounds.
- Not only materials constraints (e.g. fatigue, corrosion, thermal creep, etc.) are central but also the interplay of all coupled systems, activated by a combination of the different forms of constraint; addressing this requires interdisciplinary research.

In such a context R&D is indispensable. Joint and comparative studies are most effective in supporting the development of various categories of innovative fuels (including clad materials). Interdisciplinary joint studies are useful in gaining multi-scale understanding of fuels and structural material for nuclear systems and in dealing with the scientific and engineering aspects of nuclear materials. In particular, they aim at establishing multi-scale models and simulations as validated predictive tools for the design of nuclear systems, fuel fabrication and performance. Collaborative R&D is a powerful tool to promote the exchange of information on models and simulations of nuclear materials, theoretical and computational methods, experimental validation and related topics. Up-to-date information, data, models and expertise are all shared. Combining experimental and theoretical knowledge from diverse fields of research can benefit each.

Research effort

Many bottlenecks still exist and call for particular research effort. Two examples will illustrate the specific and generic problems raised by nuclear materials. The example of developing numeric models highlights the important contribution to materials sciences of nuclear R&D, centred as it is on radiation phenomena, their modes of action and their impact on the utilisation properties of materials. The second example illustrates not only the specific features but also the general nature of the problems to be solved regarding lifecycle thermodynamic properties of materials.

The experimental study of irradiation effects in materials is very expensive because it requires rare, dedicated infrastructure (experimental nuclear plants, hot laboratories). Significant effort thus has been devoted to developing numeric tools to model irradiation effects in nuclear materials. To reduce the time and resources needed to develop new fuels and structural materials, researchers have concentrated on identifying fundamental problems amenable to analysis by modelling/simulation



and experiments. Modelling is typically used to describe the thermodynamics of point defects and the irradiation-induced phase. A major goal is to build a coherent set of tools operational for any physical model addressing multi-scale materials. Such a platform may include, but is not limited to the following:

- atomistically informed modelling and simulation of nuclear fuels and structural materials at progressively greater scales of time and size, with due attention to radiation damage effects and to the methodologies needed to achieve inter-scale integration;
- validation of simulations and model predictions by benchmarking exercises and identification of experimental data that would be most critical to this validation;
- creating and maintaining synergy of experimental and testing practices; establishment of reference experimental and simulation datasets and databases, aiming at improving the joint utilisation of modelling/simulation and experimental techniques;
- development of new applied mathematics and software tools such as new data storage and algorithmic methods, particularly those of common interest for fuels and structural materials;
- integration of results from multi-scale modelling and simulation into performance codes and materials qualification processes, as well as into multi-physics environments, such as the coupling of changes in materials' properties and neutronics.

For practical applications, the determination of accurate diagrams describing the equilibrium state of multi-component materials is an important issue. Specialised software is definitely of great use for both calculating acceptable diagrams and giving access to a complete thermodynamic database. Inputs (selected structures and values) must be chosen with care, and the critical analysis of the output results also presents challenges. Unfortunately, because of the above-mentioned difficulties quality-assured quantities are seldom available. Furthermore, the more severe operating conditions foreseen in Generation IV nuclear vessels create an even more stringent demand for thermodynamic data of quality. A detailed assessment of the thermodynamic quantities of all phases of the complex fuel systems is needed in order to predict the behaviour of materials (chemical compatibility for instance) in the temperature range of of 1000-2000°C. Such detailed assessment also aides the definition of the practical conditions for fuel material processing.

Fission products and minor actinide elements must also be taken into account to predict the physicochemical behaviour of irradiated fuels under both normal and accidental conditions. For severe accident conditions, a thermodynamic database constitutes a useful tool for interpreting future experiments on fission product release. It also allows prediction of the temperature at which liquid formation takes place. Databases on nuclear materials must contain all possible compositions of solid solutions and not only simple compounds.

Vast range of applications

The knowledge acquired and methods developed during nuclear materials investigations have a vast range of potential applications beyond the specific conditions of the nuclear domain. A great many physical phenomena and basic mechanisms which intervene in the nuclear field are just as pertinent in regard to the behaviour of these materials under less severe conditions, as well as in completely different utilisations and environments. ■

Geological disposal of radioactive waste: records, markers and people

An integration challenge to be met over millennia

C. Pescatore, C. Mays*

An issue that has long been on the radioactive waste management agenda is the means of marking a waste repository site, such that future generations will be able to comprehend its purpose and risks even if written records have been lost.

For years the main reason cited for needing such comprehension was to preclude unintentional future human intrusion into the repository and the ensuing exposure of the intruder to radiation. Such a future intruder could also cause damage to the repository system and endanger his own and subsequent generations.[1] More recently, other reasons have included the wish to maintain a certain degree of flexibility for future generations, in case the latter decide to retrieve the waste for motives that may go beyond safety, e.g., the economic exploitation of the energy potential that may remain in the waste.

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The conceptualisation and design of markers of records by technologists has typically focused on durability and has assumed that the repository is – and will be – something totally separate from its cultural environment. A new vision is emerging, however, that it may be worthwhile to consider the repository as part of a societal fabric. The task of maintaining memory would thus be facilitated by measures that would foster community involvement and would go as far as foreseeing that these communities will in time build their own new markers to replace old ones that have become obsolete or are fading away.

It must be understood that the timescales over which the hazard exists are much longer than just a few thousands of years, and it must be accepted that the current generation's capacity to assure continued integrity cannot be projected indefinitely into the future, but rather diminishes with time. Hence, there is perhaps the need to conceptualise a "rolling future" in which each generation takes responsibility to ensure continuity and safety for the succeeding several generations, including a need for flexibility and adaptability to circumstances as they change. The issue of archives and markers that last as long as possible (the technological approach) continues to be a topical one.[2] However physical markers and archives may also be complemented by – or integrated within – a cultural tradition that could be sustained over time starting with the planning of a repository and continuing through its implementation and beyond its closure.

Overarching observation

Traditional approaches to markers and institutional controls for geological disposal were based on the premise that safety was best assured by keeping the facility apart and isolated from people and the surrounding community. Active controls, for example, could be envisaged to include fences and guards that would restrict access to the site even after closure. It was acknowledged that one cannot rely unquestioningly on future generations to maintain, monitor and interact with the installation; eventually, the institutional structures supporting such controls could disintegrate. To address this contingency, geological disposal concepts are founded on the concept of "passive safety", which can function even without further intervention or maintenance. Furthermore, markers and records would be put in place with the goal to pass on knowledge of the site and its hazards. The tacit assumption, nevertheless, was nearly always that such an understanding was meant to help keep people away from the site, thereby best providing "safety".

Yet in everyday life, the concept of safety implies an element of control and familiarity. Even if continued active controls may fade away, familiarity and elements of indirect control continue to be important to safety. Because safety is related to our ability to function freely (unimpeded by fear), safety is also related to quality of life. Hence, there has been an evolution in the very concept of disposal. In addition to the traditional actions for oversight and monitoring, preservation of information in archives and passive markers, repository projects now typically also include the elements of reversibility/retrievability as well as active participation by local communities in decision making.

The extension of this trend for greater participation by local communities in making decisions implies that disposal facilities can be made part of the fabric of the community rather than operated in isolation from it – and there is a growing awareness that such integration can contribute to, rather than undermine, safety. Our understanding from stakeholder dialogue is that not only should we not hide the facility, but we should recognise that it will be a central part of a host community and its identity. Today's overarching message is very simply, "Do not hide these facilities; do not keep them apart, but make them A PART of the community."

The technological approach: preserving information

Past work on markers and records for geological disposal have focused on the durability and preservation of information as a prerequisite for preserving knowledge and understanding. Certainly, in order to be useable, information must first exist and must already be reasonably accessible.

Records that have to last thousands of years will need renewal from time to time. Paper lasts about 1 000 years. We have the record of ancient books because these were re-copied over timescales that are compatible with the shelf life of paper. Records such as microfilm, magnetic and optical tapes are not as durable in that recording and play-back technology constantly require new supports. Who is using floppy disks these days? Hence, another message: when dealing with large timescales, the recording technology should be as basic as possible. Stone, such as "The Rosetta Stone" is another, non-paper example of "basic" technology.

Besides the challenges associated with the physical limitations of the technological media and of the readability of the information, we need to face the challenge of weathering institutional and political changes. The best strategy here is to intentionally maintain duplicate records in several sites, including internationally. The Rosetta Stone is probably an example of duplicate records. National legislations typically require archiving of repository information in multiple venues.

To fully achieve the goal of knowledge transfer to future generations, however, we must ensure not only that information is available, but also that it is understandable. This is a significant challenge. In all cases, there will be the issue of the interpretation of the information that is being provided. For instance, it takes specialists to interpret medieval inscriptions, and it took Champollion to decrypt the Egyptian hieroglyphs starting with those on the Rosetta Stone. Once again, this re-interpretation would take place quite naturally if records were renewed intermittently, as was the case for the writings in the ancient books.

As a minimum, there ought to be a strategy to maintain awareness. Partial duplicate records will be derived from other institutional sources, such as land use control records, mining archives and regulatory archives. These will offer the opportunity to triangulate knowledge.

One simple way for ensuring that awareness of the repository is widely preserved is to have it included on maps. Maps are constantly renewed and updated and daily use is made of them. Another way is to foresee passive markers with minimum amount of information but constructed in such a way as to be evocative and to make people want to look for more information. For each repository, one may need more than just one marker as the principle of duplicate record still applies. Markers can be placed both on the surface – where people may constantly interact with them – and under the surface, to inform and/or warn off intruders in the case of excavation.[3]

Above and beyond such tangible actions as placing duplicate records in order to maintain awareness, there is a growing recognition that more cultural mechanisms – more informal but potentially self-propagating and highly persistent – could contribute substantially.

A new central actor?

Institutions, implementers and regulators have been discussed, but where does the greatest interest lie in keeping memory alive? Who is most likely to be willing to attend to and to renew and re-interpret the records? It must be the local communities for whom the facility is a constant presence. Ideally, the facilities should be seen by these communities not as a long-standing threat but as something that belongs to the local, social fabric and requires respect, as well as a source of added value (cultural, amenity or economic).

The report of the NEA Forum on Stakeholder Confidence (FSC) entitled *Fostering a Durable Relationship Between a Waste Management Facility and its Host Community*[4,5] explores the means by which a facility can respond to the requirement of providing added value and, with it, a basis for a continued relationship – which could extend over the centuries and millennia – with the facility and its site. Could one, for instance, memorialise the facility? If a monument could be made of it – or of its (symbolic) image – that had a distinctiveness and aesthetic quality, would this not be one reason for communities to proudly own the site and maintain it? A major question is, thus, whether the surface facility and its surroundings should become the ultimate marker of the existence of the underground repository.

In the 1st century BC, classical Roman architect Vitruvius outlined what good architecture should achieve. He stated that a structure must exhibit the three qualities of *firmitas, utilitas* and *venustas:* it must be strong or durable, useful and beautiful. These are qualities that can be sought for the radioactive waste management installation, for both the physical building structures, and for what the installation can bring to the community.

The FSC looked into designing and implementing facilities in ways that provide added cultural and amenity value to the local community and beyond. By cultural and amenity value we mean: agreeable additions to quality of life, through such features as distinctiveness, aesthetic quality, convenience and meaningfulness; through providing opportunities for residents and visitors to meet, learn, relax, enjoy; through fostering community improvements in areas like educational level, image definition or problem-solving capacity.

A number of basic design elements to foster a durable relationship between the facility and its host community were identified based on the analysis of input from 32 stakeholder contexts (interviews, questionnaires) and FSC experience. Such design elements include functional, cultural and physical features. These features tend to maximise the potential of a facility to be "adopted" by the members of the host community, by fitting in, adapting to and, moreover, contributing directly to their preferred way of life.

Adding value through functional, cultural and physical design features

Function concerns the uses to which an installation may be put. The radioactive waste management facility must serve the primary purpose of ensuring safe and secure long-term management of radioactive waste. Careful multi-functional design then can add value by allowing appropriate parallel uses that are of direct interest to residents and visitors. In the same vein, while in operation, parallel uses of radioactive waste management installations may add scientific value. Zero-gravity experiments are carried out at Japan's Tono Mine underground laboratory. Laboratory facilities at Spain's El Cabril and the US Waste Isolation Pilot Plant are available for regional environmental analysis or monitoring. Additionally, when creating a new facility, it is necessary to foresee the end of its useful life. If future needs are not anticipated, there is a risk that the facility will become a liability for the community. An adaptable, flexible facility can provide enjoyment during its operation and also make possible at reasonable cost the transition to a full community facility when its industrial use is no longer needed.[5] Along with careful planning for radiological safety on site, adaptability and flexibility will leave development pathways open.

The UNESCO Universal Declaration on Cultural Diversity defines culture as "the set of distinctive spiritual, material, intellectual and emotional features of society or a social group, encompassing, in addition to art and literature, lifestyles, ways of living together, value systems, traditions and beliefs". In this way, culture may be assimilated to shared meaning and practices. Cultural value is found in arrangements that reflect and strengthen a given society's knowledge, tastes, aspirations, ethical views or beliefs. It lies in all that is meant to help to transmit an honoured legacy, to communicate symbolic meaning or to advance ideals. Amongst the cultural design features, distinctiveness may be mentioned, indicating that the facility or site is attractive and like no other, and has the potential of becoming an icon, lending a positive reputation and drawing visitors. Other cultural features include aesthetic quality and understandability, whereby the installation can be tied in with existing knowledge and related to everyday life. Memorialisation is another cultural feature, meaning that both physical and cultural markers identify the site and tell its story, so that people will grasp and remember what is there.

Technical features will provide the agreed level of protection (the primary condition set by stakeholders consulted for the FSC study). Physical design elements will help create the feeling of security (another part of what community and regional stakeholders expect). Physical design features can be combined to create harmonious integration of the installation into its geographic setting, and increase overall amenity: enhancing attractiveness and overall satisfaction. Accessibility means that the site and facility are not barricaded, but are open and welcoming. Communities like Port Hope have pointed out that if a site that is licensed to operate can be freely visited, walked through or enjoyed for other uses, it clearly must be safe. It no longer seems to impose restraints on the user, nor shuts people out in an alarming way. It accomplishes its goal of protection without emphasizing danger.

Certainly, especially during operation, each and every area of a radioactive waste management facility cannot be made open to the public. Areas restricted for the necessities of safety and security need not benefit from the same degree of functional, cultural and physical design input. Still, the radioactive waste management facility and site should be considered in a holistic manner, in order to maximise the added value that it is possible to achieve with reasonable effort.

Adding value through the planning and implementation process

Local stakeholders who take an active role in site investigations, or who participate with implementers in formal partnerships, report that the very process of working out the desired features of a radioactive waste management facility and site can bring added value to the community. Social capital – networks, norms and trust – is built up, equipping the community to face other decisions and issues. Local stakeholders may also focus their work on community identity, image and profile. Even when not favourable to hosting a radioactive waste management facility, communities can use the opportunity to develop quality-of-life indicators and reflect on the direction they want to take in coming years. Other benefits that may be accrued are an enhanced educational level in the host community related to the influx of highly skilled workers. Not least important, when host communities demand training and participate in monitoring site development and operations, they are building their capacity to act as guardians and therefore ensure another layer of defence in depth.[6]

Early reflection is best

It takes time to work out new ideas, new possibilities and where the communities' own interests lie. Integrative reflection on technical and socio-economic aspects, and on cultural and amenity value that could be added by a radioactive waste management facility, is best started from the very first planning stages even before final siting agreement is reached. The information, concepts and ideas gained from this reflection will form a part of the basis on which a local community may agree to become a candidate and then actively engage in the final siting stages.

Institutions generally cannot commit to the final form of a radioactive waste management facility before a specific site is agreed, nor to the ultimate fate of the facility and site. Likewise, the relationship between a community and a facility or site will depend in part upon external events (for instance, safety performance in the nuclear or radioactive waste management realm; attitudes and statements by political actors, etc.). Still, feasibility studies and social science investigations early in the decision-making process can provide meaningful preparation. Such an approach is coherent with the UNECE Aarhus Convention, which has given many European citizens formal rights to participate in decision making about their environment.

A presentation by Janet Kotra (US NRC) at the June 2007 meeting of the FSC indicated that the mandated need to install "permanent" markers can only be fulfilled if one acknowledges that the markers themselves will evolve over time. Namely, they will become part of the local, subsequent cultures, and they will (or ideally should) be renewed as their materials are degraded, or as their significance evolves. This emphasizes again the importance of integrating the disposal system into the community: renewal (as compared to "durability") depends on future people to take action. The awareness of future people of such markers and their understanding of the meaning of the markers is more likely to persist if it is part of daily community life than if it is something kept apart, isolated and forgotten.

Conclusions

The timescales over which the hazard exists are much longer than just a few thousands of years, and it must be accepted that the current generation's capacity to ensure continued integrity cannot be projected indefinitely into the future, but rather diminishes with time. At the same time there is a common understanding that we should not "walk away" from these facilities or conceal them, even when we think they will be safe. In fact, the sense of safety will come from continuing, over time, some element of familiarity and control – hence the need to conceptualise a "rolling future" in which each generation takes responsibility to ensure continuity and safety for the succeeding several generations, including a need for flexibility and adaptability to circumstances as they change.

The issue of archives and markers that last as long as possible (the technological approach) continues to be a topical one. However, physical markers and archives may be complemented by – or integrated within – a cultural tradition that could be sustained over time starting with the planning of a repository and continuing through its implementation and beyond its closure. The mandated need to install "permanent" records and markers can only be fulfilled if one acknowledges that these will evolve over time. Namely, they will become part of the local, subsequent cultures, and they will (or ideally should) be renewed as their materials are degraded, or as their significance evolves.

Because a radioactive waste management repository and site will be a permanent presence in a host community for a very long time, a fruitful, positive relationship must be established with those residing there, now and in the future. Simply put, designers have to make the radioactive waste management facility and site to suit people's present needs, ambitions and likings, and to provide for evolution to match at reasonable cost the needs and desires of future generations. The challenge is to design and implement a facility (with its surroundings) that is not only accepted, but in fact becomes a part of the fabric of local life and even something of which the community can be proud. Parts of the facility and its surroundings may thus become themselves welcome markers of the existence of a waste repository underground. ■

Notes

1. This would also be the case for a large class of chemically hazardous wastes, but the issue does not seem to be a prominent one in that field.
2. See the proceedings of the workshop on "Record Management and Long-term Preservation and Retrieval of Information Regarding Radioactive Waste" held in Rome, 27-28 January 2003 (available from SKB, Sweden and the NEA).
3. See for example: T.L. Tolan, "The Use of Protective Barriers to Deter Inadvertent Human Intrusion into a Mined Geologic Facility for the Disposal of Radioactive Waste", Sand91-7097, Sandial National Labs, June 1993.
4. NEA (2007), *Fostering a Durable Relationship Between a Waste Management Facility and its Host Community: Adding Value through Design and Process*, OECD/NEA, Paris.
5. See also www.nea.fr/html/pub/newsletter/2007/NEA_News-25-1-fostering.pdf.
6. See www.nea.fr/html/pub/newsletter/2007/NEA_News-25-1-regional-development.pdf.

International operating experience

B. Kaufer, K. McDonald*

Some 30 years ago in October 1978, the Steering Committee for Nuclear Energy began discussing the exchange of information on operating experience gained from light water reactors. It is worth noting that this discussion took place prior to the Three Mile Island accident, showing that the Steering Committee had foreseen the importance of this issue. Two immediate benefits could be drawn from using operating experience feedback: 1) improved safety, and 2) improved plant availability and reliability. A Committee on the Safety of Nuclear Installations (CSNI) was set up and created a tool to collect such feedback. This tool is now known as the Incident Reporting System (IRS).

In 1983, the International Atomic Energy Agency (IAEA) joined with the NEA to jointly operate the IRS. Over the past three decades, the collection and analysis of operating experience has expanded and become more highly developed. Lessons learnt about organising such a system have been extended to other nuclear installations including fuel cycle facilities (the Fuel Incident Notification and Analysis System – FINAS) and research reactors and laboratories (the International IRSRR). In addition, through the World Association of Nuclear Operators (WANO) the nuclear industry has set up an independent database to collect and analyse operating experience.

In response to safety concerns over the last decade, additional NEA project databases have been established to look in greater depth at specific areas such as piping, fires and computer-based systems. In parallel with the establishment of these databases for operating experience, the NEA and the IAEA have set up a number of international information systems beginning with the International Nuclear Events Scale (INES) in the early 1990s. As an indication of the success of these systems, today over 30 countries provide input to the IRS and over 3 000 events have been recorded.

Developments in operating experience feedback have led to improved safety performance. However, in recent years questions have been raised as to whether the information is being used proportionately to its importance. In a series of international conferences and discussions in the NEA Committee on Nuclear Regulatory Activities (CNRA), the CSNI, the NEA Working Group on Operating Experience (WGOE) and among IRS co-ordinators at their annual information exchanges, participants have asked if the lessons learnt in the past have subsequently been forgotten, and whether countries actually consider foreign operating experience as relevant to their own situation.

In order to obtain a better understanding of the issues, in 2004 the CNRA formed a senior-level expert group which produced a "Green Booklet" identifying the *Regulatory Challenges in Using Nuclear Operating Experience* (OECD/NEA, 2006). This report, along with other high-level discussions taking place around the world, resulted in the CNRA tasking the WGOE to review existing international operating experience feedback (IOEF) processes and networks, and their connections with national operating experience feedback systems, as well as to provide recommendations for more effective use of IOEF to improve nuclear safety.

The results of the WGOE review have been published in a CNRA report on "The Use of International Operating Experience Feedback

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for Improving Nuclear Safety" (NEA/CNRA/R(2008)3). This report considers all existing international systems (e.g., IRS, FINAS and IRSRR) which together cover all nuclear facilities. The report states that development of an IOEF process and a network for implementing this process is meaningful only when there is a link to risk reduction and the enhancement of operational safety. A general goal of the IOEF process is to help prevent recurrence of events involving potentially serious hazards. There is evidence to show that lessons have been learnt from many events, both within and outside the nuclear industry, and from corrective actions implemented to improve nuclear safety. Nevertheless, the report acknowledges a need for continuous improvement.

In discussing the role of the regulator, the report emphasizes that the responsibility for safely operating the nuclear facilities lies with the operator. Nothing the regulator does should ever diminish or interfere with that basic responsibility for safety. Likewise, the collection of information on operating experience is the responsibility of the operator, and national OEF is the basis for IOEF. Accordingly, without high-quality national OEF it is not possible to ensure IOEF.

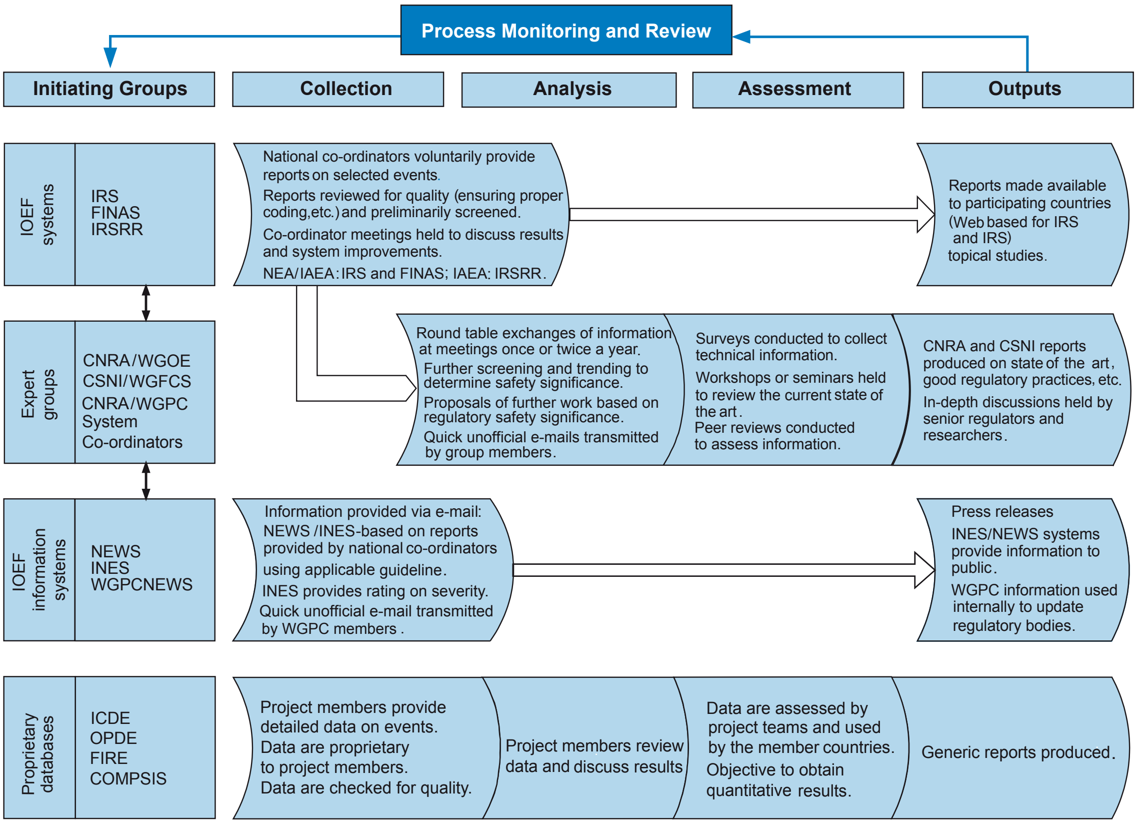
Operating experience of general interest is not limited to events, incidents and accidents, but also covers conditions, observations and new information that could affect nuclear safety. An effective IOEF process must capture any experiences that have led to significant corrective actions in human performance, hardware or safety management practices. Likewise, it must provide information on safety research programmes that were started to resolve a new safety concern, even if the concern was raised for reasons other than an incident at a nuclear facility. In addition, information should be exchanged on good practices that have the potential to assist others with their safety-based programmes.

Using the main elements outlined in the IAEA Safety Guide NS-G-2.1, which are adapted for international use, the CNRA report reviews the current state of national and international operating experience systems. It identifies positive and negative aspects of existing international systems, assesses the regulatory objectives and makes 21 recommendations for IOEF enhancements to meet these objectives.

The report identifies some notable strengths of existing IOEF systems: availability of web-based event reporting systems for the IRS and the IRSRR and supporting infrastructures and exchanges in the context of international networks, conferences and workshops to provide guidance and analysis of specific issues. The report did, however, find several areas to be particularly weak at the international level in regard to identified regulatory objectives; these include lack of overall strategic oversight of IOEF, lack of a web-based system for FINAS, inability of some current systems to capture lessons learnt, and inadequate screening and trending of events for determining priorities and programmes of work.

The recommendations are divided into categories including strategic issues, reporting practices, screening of events for safety significance, regulatory investigations and responses, and dissemination and exchange of information. Some of the key recommendations are as follows:

- In light of the necessary interfaces between national and international systems, NEA members should, as soon as possible, develop national OEF systems to meet international standards of best practice.
- The chairs of the various IOEF groups along with the chairs of the NEA working groups should form a Management Board to provide strategic oversight for clarifying the roles of the various IOEF organisations, improving co-ordination of their work and ensuring the implementation of changes.
- The IOEF operating systems should concentrate on collecting high-quality information on events.
- The working groups should focus on analysing events and determining their safety significance from a regulatory viewpoint.
- IOEF systems should be capable of receiving reports on good practices as well as reportable events and should be extended over the entire plant life cycle.
- NEA working groups should annually screen events for safety significance, lessons learnt and applicability of regulatory follow-up.
- IOEF organisations should provide technical experience and assistance (resources) to enable better quality reporting and to assist countries in starting or increasing their reporting of events.
- NEA working groups should establish methodology such that meaningful international trending can be performed (either through existing systems or other means) and will be available as a good knowledge base for lessons learnt.
- Information (including topical studies, generic reports, etc.) derived from national OEF systems, IOEF systems, and IOEF expert groups should be disseminated as broadly as possible (without releasing proprietary data).



The WGOE also notes that a unique opportunity exists today in relation to the new build being considered by many NEA member countries. The establishment of an IOEF system that can meet the regulatory needs as stated within the report would in effect provide a new, reliable, effective and efficient knowledge base to capture lessons learnt in the context of constructing and operating new generation III+ nuclear power plants. Undertaking system development at this time would provide regulators with a baseline departure for monitoring the next generation of plants, incorporating the advantages of experience gained from the past use of OEF.

In view of this opportunity and the high priority assigned to such work by the CNRA, the new NEA Working Group on the Regulation of New Reactors is developing a database to compile feedback from construction experience, which can be used in both the short term and long term for improving nuclear safety.

Over the past few years NEA experts have noted that almost all of the recent, significant events reported at international meetings have occurred earlier in one form or another. Counteractions are usually well known, but it would appear that the relevant information does not always reach end users or that corrective action programmes are not always rigorously applied. Thus, conditions for maintaining the recent good operational safety performance are to ensure that operating experience is promptly reported to established international reporting systems and that the lessons from operating experience are actually accessed and used to promote safety.

The 2008 CNRA report provides the impetus for advancing towards improved international operating experience feedback. The WGOE has established an implementation plan, including responsibilities and timescales, for the report recommendations. This plan received general support from the CNRA at its summer 2008 meeting. The CNRA has tasked the WGOE with reviewing progress against report recommendations biannually to ensure that momentum on IOEF improvement is maintained, with resulting benefits for nuclear safety on a global scale. ■

Nuclear regulatory communication with the public: 10 years of progress

J. Gauvain, A. Jörle, L. Chanial*

The NEA has an acknowledged role to assist its member countries in maintaining and developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy. In this context, the NEA Committee on Nuclear Regulatory Activities (CNRA) provides a forum for senior representatives from nuclear regulatory bodies to exchange information and experience on nuclear regulatory policies and practices in NEA member countries and to review developments which could affect regulatory requirements.

Public confidence in government and in risk management structures is important to all developed countries with an open society. The use of nuclear power in a democracy is built upon a certain trust in the political system and the national authorities. To foster and maintain such trust in a period of greater public scrutiny of nuclear activities, a number of nuclear regulatory organisations (NROs) initiated various processes to proactively inform the public about their supervision and control of nuclear activities, or when appropriate to involve the public in decision making.

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In 1998 the question was raised within the CNRA of whether public trust in the regulator might be very different from one country to another, and an activity was started among member countries to exchange experience and best practices and to learn lessons about NRO communication with their publics. Three workshops were organised by the NEA, and a Working Group on Public Communication of Nuclear Regulatory Organisations was set up in 2001. The activities and findings are summarised below.

Current societal expectations regarding information and nuclear energy

Public concern about the use of nuclear energy has long been present, probably due to its first application in military contexts. However, the 1979 Three Mile Island 2 accident is seen as a turning point in public opinion in many countries. Public demand for information about nuclear activities and assurance of their proper management grew from that time.

In modern societies, the public is inclined to request justification of the decisions taken by governments, but most nations' constitutions do not provide strong guarantees for such transparency. This is why in many countries specific laws have emerged related to the freedom of information (FOI). Such laws ensure public access to any official information or records held by government bodies, with only limited restrictions that are variable from one country to another. If the oldest such law was enacted as far back as 1766 (Sweden's Freedom of the Press Act), the second one appeared only in 1966 (United States) and only five other OECD countries had passed an

FOI law before the Chernobyl accident occurred in 1986. This issue of every citizen's access to government documents gave rise to lengthy discussions in many countries and it was only in 2006 (with legislation in Germany and Switzerland) that specific FOI acts came into force.

Furthermore, in some countries, specific acts or regulations give the public the right of access to all types of recorded information without restriction due to nationality or geographical location of the claimant, or to the age of the information. As a public body, a nuclear regulatory organisation must tell applicants whether the information sought is held by the NRO. If information is held it must be provided to the applicant unless it is subject to one of the exemptions or exceptions provided for in the legal texts.

Main findings from the CNRA workshops on nuclear regulatory communication

Three international workshops have been organised by the CNRA since 2000 to support the exchange of reflection and best practice as NROs turn their attention to activities which inform and engage the public:

- Investing in Trust: Nuclear Regulators and the Public, Paris, December 2000;
- Building, Measuring and Improving Public Confidence, Ottawa, May 2004;
- Transparency of Nuclear Regulatory Activities, Tokyo, May 2007.

The high degree of interest in the topics was demonstrated by the extensive participation of top regulators and of members of their staff as of the very first workshop. One of the key findings was that the participating countries had different approaches to public communication but could benefit from exchange of experience and feedback. The CNRA responded with the creation in 2001 of the Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC) which discussed a number of communication topics, set up a rapid information exchange system and published commendable communication practices.

A first general observation stemming from the workshops is that freedom of information acts in force in OECD countries have direct or indirect impacts on regulatory activity, and in some countries they have been supplemented by specific acts highlighting the importance of nuclear regulatory transparency and providing for its implementation.

A related observation is that public expectations regarding communication by the NRO have significantly increased in every country during the last 20 years and in turn most NROs have tremendously developed their activities with the goal of informing the public.

Conclusions of workshops and WGPC discussions have identified stakeholder involvement in nuclear safety as a necessary practice which helps enhance safety and support public confidence. It requires the establishment of communication mechanisms and tools for discussions between the interested parties and those responsible for decision making. It has been highlighted that stakeholder involvement policy needs dedicated resources to be efficiently implemented.

The internet, in allowing the public to gain direct access to documentation, has dramatically changed the audience of original written materials held by NROs. Nuclear regulators' websites have dramatically improved in the past decade, such that the mass media are no longer the major vector for the interpretation and transfer of decisions and technical documents to the public. This is a radical change in the possibility for direct communication with the public and for confidence building.

The workshops and ongoing activities of the working group have gradually disproved the formerly prevailing opinion that NRO communication was highly dependent on cultural context and that very little feedback could be exchanged amongst countries. CNRA/WGPC exchanges and studies show that more and more principles and practices for public communication about nuclear regulatory activities are now shared across OECD countries. Indeed, the NEA working group has directly contributed to this movement. Public communication of NROs is clearly an area where the experience of the more advanced has been used to help the less advanced.

Influence of CNRA activities upon convergence in communication practices

It is difficult to quantify the impact of WGPC activities in the various countries and among the participating regulators. However, the working group has proven itself to be a useful forum for discussing mutual difficulties and challenges, as well as for comparing the different solutions found. Initiatives like the "Flashnews" platform mentioned below make a direct contribution to communication readiness.

The WGPC observes that most OECD NROs now have a communication department or at least press officers, reflecting the fact that public communication is identified as an integral part of the NRO's mission. To this end formal communication plans have been developed by NROs in many countries, defining the mission statement of the organisations, their communication strategy, objectives and targets.

While communication practices are driven by the cultural context of a country, NROs recognise that many lessons can be taken from abroad. In today's global village the public is interested in and has access to information about what is happening in other countries. Divergent messages, or delay in information from any national authority, could affect confidence in regulators everywhere. It is paramount that NRO communicators maintain close contact to ensure that they are fully aware of any safety events, and can properly act in their own context as the primary source of information about nuclear safety. Thus, the CNRA communicators' network, supported by the electronic "Flashnews" platform, has become an essential instrument for consistently informing the public. In case of an event in one country, NRO professionals in other countries are now informed in advance of the media with the result that they can provide a consistent, reliable message to the public.

Remaining challenges for public communication

Some challenges nevertheless remain for the NRO, such as how to develop efficient and timely communication with the public in case of crisis, for instance when an event occurs in a nuclear facility. Another challenge is to set a proper balance between the need to strive for transparency and the need to cope with restrictions in disclosure of information which may arise for security reasons. A last challenge is how to measure public confidence in NROs and satisfaction with their performance as information providers, so that they can continue improving their public communication.

In summary, as a consequence of increasing convergence among OECD countries on communication principles and practices, new areas of practical interest are emerging for nuclear regulators. Continuous attention must be given to informing and educating the public about how NROs carry out their responsibility for the supervision of nuclear safety and for the protection of public health and the environment. Demonstrating good performance and dialoguing with the public are key to building confidence.

The WGPC has covered much ground and come a long way since its inception. However, there is still work left for the group to help improve the efficiency and effectiveness of public communication and to contribute to gaining a high level of public confidence in the nuclear regulators across OECD countries. The WGPC has stressed the fact that the existing exchanges between countries are useful and should be made as visible as possible within nuclear regulatory organisations, to foster continued sharing of good practices and practical advice on implementation. In addition to maintaining networking on events of media interest, the WGPC has identified local public information, surveying public perceptions, transparency in NRO activities and emergency communication as topics of primary interest for regulatory communication and is now structuring its work in an integrated plan to further assist in the improvement of nuclear regulatory organisations' public communication. ■

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2. NEA (2006), *Building, Measuring and Improving Public Confidence in the Nuclear Regulator*, Workshop Proceedings, Ottawa, Canada, 18-20 May 2004, OECD, Paris.
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News briefs

Legislative update: Turkey

Turkish law on construction and operation of nuclear power plants and energy sale

A law on construction and operation of nuclear power plants and energy sale[1] was adopted in Turkey on 9 November 2007. The law paves the way for the construction of the country's first nuclear power plant, which has been the aim for more than 30 years.

The law has a rather procedural nature, listing steps to be taken by a number of institutions involved in its implementation. The Turkish Atomic Energy Authority (TAEK) must define criteria for companies that plan to build and operate a nuclear power plant. These criteria concern nuclear safety, licensing, reactor type, plant lifespan, proven technology, fuel technology, localisation, operational record and electrical power, and have already been published by TAEK.[2]

The Ministry of Energy and Natural Resources has published a regulation on requirements to be met by the bidding companies, the selection process, land allocation, the licence fee, infrastructure incentives, fuel supply, production capacity, the volume of electricity to be purchased by the Turkish Electricity Trading and Contracting Company (TETAŞ) and the energy unit price.[3] Following the adoption of this regulation, TETAŞ launched the tender process on 24 March 2008, inviting local and foreign companies to bid until 24 September 2008.

The law stipulates that TETAŞ will buy the electricity produced at the nuclear power plant pursuant to a contract to be signed between the selected company and TETAŞ for a period not exceeding 15 years after the power plant has started its operation.[4]

With respect to third party liability, the law states that in case of an accident at a nuclear power plant or during transport of nuclear fuel, radioactive materials or radioactive waste, the 1960 Paris Convention on Nuclear Third Party Liability, its amendments and other national and international liability provisions shall apply.[5] Turkey is a contracting party to the 1960 Paris Convention on Nuclear Third Party Liability and its Amending Protocols of 1964 and 1982, and has signed the 2004 Amending Protocol.

A remarkable provision of the new law is that the company constructing the nuclear power plant shall be obliged to allocate 1% of its annual revenue to research and development activities.[6]

As an *ultima ratio,* the new law foresees that public companies may be established by the Council of Ministers and assigned to build and operate the plant and sell the electricity produced. This might be interpreted as Turkey's determination to turn this new attempt at nuclear energy into a success.

Background

Turkey has a long history of abandoned attempts at nuclear energy. Studies to build a nuclear power plant in Turkey started in 1965. Between 1967 and 1970, a feasibility study was undertaken to build a nuclear power plant and have it operational by 1977, but due to difficulties relating to site selection and other issues, the project was not realised. In a second attempt in 1974-1975, site selection studies were carried out and the Akkuyu location was found suitable for the construction of the first nuclear power plant for which the Atomic Energy Commission granted a site license in 1976. The next year, a bid was prepared and the ASEA-ATOM and STAL-LAVAL companies were awarded the contract. However, in September 1980, due to the Swedish government's decision to withdraw a loan guarantee, the project was cancelled. A third attempt was made in 1980 and three companies were awarded the contract to build four nuclear power plants, yet the project once again fell through as a consequence of financial difficulties. In 1993, the High Council of Science and Technology identified nuclear electricity generation as the third highest priority project for the country. In view of this decision, the Turkish

Electricity Generation and Transmission Company (TEAŞ) included a nuclear power plant project in its 1993 investment programme. After starting the bidding process in 1997, a series of delays lead to the government's decision to postpone the project in July 2000.[7]

Turkey lacks significant domestic energy resources and highly depends on foreign gas imports.[8] In 2004, Turkey had a total installed electricity generating capacity of 35.6 GWe which constitutes a 36% increase since 2000. Conventional thermal sources (coal, gas, oil and geothermal) composed 68% of Turkey's electricity supply in 2004; hydroelectricity generation makes up almost all of the remainder. Taking into consideration diversity and energy supply security, nuclear energy is seen as an important alternative to fossil resources. ■

Notes:

1. Law No. 5710 – an unofficial translation of the text has been reproduced in the *Nuclear Law Bulletin,* No. 80, page 105.
2. Available in English at www.taek.gov.tr/olcutler/taekcriteria_final_211207.pdf.
3. Published in the Turkish Official Gazette No. 26821 on 19 March 2008.
4. Articles 4(1)(a) and 3(5) of the law.
5. Article (5)(5) of the law.
6. Article (5)(6) of the law.
7. www.nea.fr/html/general/profiles/turkey.html.
8. Two-thirds of gas is imported from the Russian Federation and the rest mainly from Iran.

Phase IV of the TDB project

The NEA Thermochemical Database (TDB) project is a long-standing co-operative effort to assemble a comprehensive, internally consistent and quality-assured chemical thermodynamic database of selected chemical elements to meet the predictive modelling requirements for the performance assessments of radioactive waste disposal systems. The data are used, for example, to calculate the migration of radioelements across engineered barriers and the geosphere.

The TDB project combines a scientifically sound review methodology and a stable organisational framework in line with its long-term objectives. The main products of the review exercises are the books published in the Chemical Thermodynamics Series, providing in the open literature:

- access to critical judgement of existing literature and data, reviewed by world experts in the field;
- knowledge transfer between TDB review teams and the performance assessment community;
- identification of areas needing further research.

The project was established in the 1980s following the realisation that existing databases at that time lacked internal consistency or were not sufficiently documented to allow the tracing of the original data sources. The chemical thermodynamics of uranium, americium, technetium, neptunium and plutonium were the first elements to be reviewed and published. The data for these elements were updated during the second phase of the project (1998-2003), and new reviews were undertaken for inorganic species and compounds of fission and activation products, such as selenium, nickel and zirconium. In addition, reviews of organic compounds and complexes (oxalate, citrate, EDTA and iso-saccharinic acid) of all of the previously cited elements (U, Np, Pu, Am, Tc, Se, Ni and Zr) were completed and published in 2005.

In the third phase of the TDB project (2003-2008), it was decided to review:

- thorium (Th), chosen for reasons of chemical consistency within the database for actinides;
- tin (Sn), present as a fission product in nuclear waste and whose thermochemical properties present substantial gaps and inconsistencies for solubility limiting species;
- iron (Fe), a key element in determining the redox (oxidation-reduction) conditions in repositories for which a consistent chemical thermodynamic database is lacking.

Participants also agreed to prepare guidelines for the evaluation of thermodynamic data for solid solutions. These solids have not been systematically examined for database work so far, but they may provide more accurate information in relation to waste migration as well as the performance of engineered and natural barriers. The book on solid solutions was published in 2007 as volume 10 in the series of TDB books. The review of thorium data is expected to be issued in 2008, followed by the reviews of tin (Sn) and iron (Fe) in early 2009.

A fourth phase of the NEA TDB project was started in February 2008 and is planned to be completed in 2012. The project is, as in the two previous phases, guided by a Management Board, which consists of representatives from 17 organisations[1] with responsibilities in radioactive waste management in 13 OECD member countries. The Board has decided to perform:

- complementary studies of inorganic species and compounds of iron (Fe);
- a review of auxiliary data;
- an update of the selected value database accrued during the first three phases of the project;
- a review of inorganic species and compounds of molybdenum (Mo).

The first year of the project will be devoted to preparatory work and to establishing the review team, consisting of world experts in each field. The following two years will be devoted to reviewing available literature and data and to recommend selected values. The final year of the project will include peer reviews and editing for publication.

Further information on the TDB project, its database and publications is available at www.nea.fr/html/dbtdb. ■

Note:

1. The following organisations are participating in the fourth phase of the TDB project: NIRAS/ONDRAF (Belgium), NWMO (Canada), RAWRA (Czech Republic), POSIVA (Finland), ANDRA (France), CEA (France), FZK INE (Germany), JAEA (Japan), KAERI (Korea), ENRESA (Spain), SKB (Sweden), HSK (Switzerland), NAGRA (Switzerland), PSI (Switzerland), Nexia Solutions (UK), NDA (UK) and the Department of Energy (USA).

Einar SAELAND (1915-2008)

NEA Director-General 1964-1977

It is with great sadness that we learned that Einar Saeland passed away on 25 May 2008.

Einar was born on 3 April 1915 in Trondheim, Norway. His father was Sem Saeland, physicist and President of the University of Oslo, and his mother Gudrun Schöning Saeland, one of the first female Medical Doctors in Norway. Einar graduated in Physical Chemistry from the University of Oslo in 1939. In 1951, he married Elsebe Stoltenberg (1921-2000). They had two children: Sem (born 1952) and Nanna (born 1956).

In the early 1950s, Einar helped establish the Norwegian Nuclear Energy Research Institute at Kjeller, Norway. In 1955, he represented Norway at the 1st International Conference on the Peaceful Uses of Atomic Energy. He served as a Norwegian representative to the European Atomic Energy Society between 1951 and 1956. In 1958, he joined the OECD as NEA Deputy Director. He served as NEA Director-General from 1964 until his retirement in 1977.

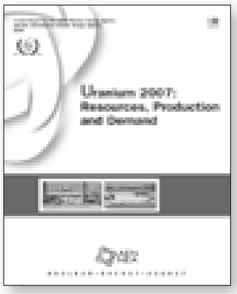
All those who knew Einar will undoubtedly remember an exceptional human being, whose intelligence, modesty, generosity, and sense of humor, served as a model to many. He will be greatly missed.

Uranium: Resources, Production and Demand

World demand for electricity is expected to continue to grow rapidly over the next several decades to meet the needs of an increasing population and economic growth. The recognition by many governments that nuclear power can produce competitively priced base-load electricity that is essentially free of greenhouse gas emissions, combined with the role that nuclear can play in enhancing security of energy supplies, has increased the prospects for growth in nuclear generating capacity.

With several countries building nuclear power plants and many more considering using nuclear power, uranium supply issues have become the focus of considerable attention. In response to rising demand and declining inventories, uranium prices have surged upward in recent years. As a result, the uranium industry is undergoing a significant revival, bringing to an end a period of over 20 years of underinvestment.

As the market price for uranium increases, worldwide uranium exploration and mine development



expenditures are rising significantly. Although the majority of global exploration activities remain concentrated in areas with potential for hosting unconformity-related and sandstone deposits amenable to *in situ* leach extraction in close proximity to known resources and existing production facilities, exploration efforts are also being expended in regions known to have good potential based on past work and in areas where little previous exploration has also taken place.

Higher uranium prices in the last few years have not only increased investment in such exploration but have led to the delineation of new resources through the re-evaluation of existing deposits and new discoveries. At current rates of consumption, identified resources are sufficient for about 100 years of supply. However, uranium resource figures are a "snapshot" of the available information on resources of economic interest. They are not an inventory of the total amount of mineable uranium contained in the earth's crust. Should favourable market conditions continue to stimulate exploration, additional discoveries can be expected, just as has been the case during past periods of intense exploration activity. For example, Australia's uranium resource base was increased by over 275 000 tonnes between 1 January 2007 and mid-2007 as a result of deposit extensions and new discoveries.

In contrast to the rapid response in exploration activity and resource assessments to increased uranium prices, mine production has not yet responded to the strengthened market. A combination of lower than expected ore grades, extreme weather events, supply chain disruptions and technical difficulties resulted in lower than expected output in recent years in several producing countries (e.g. Australia, Canada, Namibia and South Africa), offsetting significant production increases recorded in Kazakhstan and, to a lesser extent, the United States. Although major expansions in mine production are being implemented or are planned in several countries, including Australia, Canada, Kazakhstan, the Russian Federation and the United States, and rapid development of new production centres is proceeding in Africa (Malawi, Namibia and South Africa), all these facilities will need to be developed in a timely fashion and produce near designed capacity in order to meet rising demand. It is clear is that a sustained strong demand for uranium will be needed to stimulate the timely development of production capability and to further increase the uranium resource base.

Uranium 2007: Resources, Production and Demand (the "Red Book"), jointly prepared by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, provides readers with a comprehensive update of these and other significant developments in the uranium mining industry. This recognised world reference on uranium, published in June 2008, is based on official information received from 40 countries. It provides a comprehensive review of world uranium supply and demand as of 1 January 2007, as well as data on global uranium exploration, resources, production and reactor-related requirements. Also included are substantive new information and updates on major uranium production centres in Africa, Australia, Central Asia, Eastern Europe and North America. Projections of nuclear generating capacity and reactor-related uranium requirements through 2030 are also featured, along with an analysis of long-term uranium supply and demand issues.

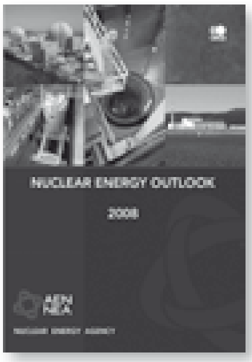
Although the focus of the Red Book remains uranium resources, production and demand, environmental aspects of the uranium production cycle are once again included in the 2007 volume. Information presented in a number of national reports include descriptions of monitoring programmes at mines currently in production (India, Kazakhstan and Ukraine), updates on decommissioning and remediation efforts at closed mines (Brazil, Bulgaria, Czech Republic, Germany, Hungary, Poland, Slovenia, Spain and the United States) and environmental assessments of proposed production increases (Canada and Niger). The book can be purchased online at www.oecdbookshop.org. ■

New publications

Economic and technical aspects of the nuclear fuel cycle

Nuclear Energy Outlook (NEO)

ISBN 978-92-64-05410-3. 460 pages. Price: € 105, US$ 161, £ 81, ¥ 16 800.



This *Nuclear Energy Outlook* (NEO) is the first of its kind and responds to the renewed interest in nuclear energy by many OECD member countries. World energy demand continues to grow unabated and is leading to very serious concerns about security of supply, soaring energy prices and climate change stemming from fossil fuel consumption. Nuclear energy is being increasingly seen as having a role to play in addressing these concerns. This Outlook uses the most current data and statistics available and provides projections up to 2050 to consider growth scenarios and potential implications on the future use of nuclear energy. It also offers unique analyses and recommendations on the possible challenges that lie ahead. Topics covered by the NEO include nuclear power's current status and projected trends, environmental impacts, uranium resources and security of supply, costs, safety and regulation, radioactive waste management and decommissioning, non-proliferation and security, legal frame works, infrastructure, stakeholder engagement, advanced reactors and advanced fuel cycles.

Market Competition in the Nuclear Industry

ISBN 978-92-64-05406-6. 124 pages. Price: € 39, US$ 60, £ 30, ¥ 6 200.

Nuclear power plants require a wide variety of specialised equipment, materials and services for their construction, operation and fuelling. There has been much consolidation and retrenchment in the nuclear industry since the 1980s, with the emergence of some large global nuclear companies. Electricity market liberalisation in many OECD countries has meanwhile placed nuclear plant operators under increased competitive pressure. These structural changes in both the producer and consumer sides of the nuclear industry have had implications for the level of competition in the nuclear engineering and fuel cycle markets. With renewed expansion of nuclear power now anticipated, this study examines competition in the major nuclear industry sectors at present, and how this may change with a significant upturn in demand.

Nuclear Energy Data 2008/Données sur l'énergie nucléaire 2008

ISBN 978-92-64-04796-9. 116 pages. Price: € 30, US$ 46, £ 21, ¥ 4 100.

This new edition of *Nuclear Energy Data*, the OECD Nuclear Energy Agency's annual compilation of essential statistics on nuclear energy in OECD countries, provides information on the latest plans for new nuclear construction, nuclear fuel cycle developments and projections of installed nuclear capacity to 2030 in member countries. This comprehensive overview of the current situation and expected trends in various sectors of the nuclear fuel cycle is an authoritative reference for policy makers, experts and academics working in the nuclear energy field.

Timing of High-level Waste Disposal

ISBN 978-92-64-04625-2. 132 pages. Price: € 45, US$ 69, £ 32, ¥ 6 200.

This study identifies key factors influencing the timing of high-level waste (HLW) disposal and examines how social acceptability, technical soundness, environmental responsibility and economic feasibility impact on national strategies for HLW management and disposal. Based on case study analyses, it also presents the strategic approaches adopted in a number of national policies to address public concerns and civil society requirements regarding long-term stewardship of high-level radioactive waste. The findings and conclusions of the study confirm the importance of informing all stakeholders and involving them in the decision-making process in order to implement HLW disposal strategies successfully. This study will be of considerable interest to nuclear energy policy makers and analysts as well as to experts in the area of radioactive waste management and disposal.

Uranium 2007: Resources, Production and Demand

ISBN 978-92-64-04766-2. 420 pages. Price: € 120, US$ 186, £ 86, ¥ 16 600.

With several countries building nuclear power plants and many more considering the use of nuclear power to produce electricity in order to meet rising demand, the uranium industry has become the focus of considerable attention. In response to rising demand and declining inventories, uranium prices have increased dramatically in recent years. As a result, the uranium industry is undergoing a significant revival, bringing to an end a period of over 20 years of underinvestment. The "Red Book", jointly prepared by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, is a recognised world reference on uranium. It is based on official information received from 40 countries. This 22nd edition provides a comprehensive review of world uranium supply and demand as of 1st January 2007, as well as data on global uranium exploration, resources, production and reactor-related requirements. It provides substantive new information from major uranium production centres in Africa, Australia, Central Asia, Eastern Europe and North America. Projections of nuclear generating capacity and reactor-related uranium requirements through 2030 are also featured, along with an analysis of long-term uranium supply and demand issues.

Nuclear safety and regulation

CSNI Collective Statement on Support Facilities for Existing and Advanced Reactors

The Function of OECD/NEA Joint Projects - NEA Committee on the Safety of Nuclear Installations (CSNI)

ISBN 978-92-64-99052-4. 16 pages. Free: paper or web.

The NEA Committee on the Safety of Nuclear Installations (CSNI) has recently completed a study on the availability and utilisation of facilities supporting safety studies for current and advanced nuclear power reactors. The study showed that significant steps had been undertaken in the past several years in support of safety test facilities, mainly by conducting multinational joint projects centred on the capability of unique test facilities worldwide. Given the positive experience of the safety research projects, it has been recommended that efforts be made to prioritise technical issues associated with advanced (Generation IV) reactor designs and to develop options on how to efficiently obtain the necessary data through internationally co-ordinated research, preparing a gradual extension of safety research beyond the needs set by currently operating reactors. This statement constitutes a reference for future CSNI activities and for safety authorities, R&D centres and industry for internationally co-ordinated research initiatives in the nuclear safety research area.

The Regulatory Goal of Assuring Nuclear Safety

ISBN 978-92-64-99044-9. 56 pages. Free: paper or web.

The fundamental objective of all nuclear safety regulatory bodies is to ensure that nuclear facilities are operated, as well as decommissioned, in an acceptably safe manner. However, in meeting this objective the regulator must keep in mind that it is the operator that has responsibility for safely operating a nuclear facility; the role of the regulator is to oversee the operator's activities as related to assuming that responsibility. There are currently many sources of information available to the regulator pertaining to safety at any given nuclear facility, such as inspection reports, operating experience reports, research results, periodic safety reviews, probabilistic safety analysis (PSA) results, insights from IAEA reviews and other similar information. A major challenge for the regulator is to systematically collect and analyse this information in order to arrive at an integrated assessment of the level of safety of the particular facility and then to make a judgement about its acceptability. In order to assist member countries in addressing this challenging question, the NEA Committee on Nuclear Regulatory Activities (CNRA) has sponsored this report. The primary focus of the report is on how the regulatory body can systematically collect and make an integrated analysis of all the relevant safety information available to it and arrive at a sound judgement on the acceptability of the level of safety of the facilities that it regulates. It therefore follows that the target audience for this report is primarily nuclear regulators, although the information and ideas may also be of interest to nuclear operators, other nuclear industry organisations and segments of civil society.

The Role of Research in a Regulatory Context (RRRC-2)

Workshop Proceedings, Paris, France, 5 December 2007

ISBN 978-92-64-99045-6. 136 pages. Free: paper or web.

This workshop enabled the exchange of experience among regulators, research managers and industry on the needs, priorities and foreseeable trends for nuclear safety research in a regulatory context. It also addressed the means that are or can be used for effectively performing such research. The presentations highlighted priority safety issues, at present and in the near term, for operating plants and new reactors. During the workshop, participants discussed the challenges that the nuclear community will face in the long term for performing safety evaluations of advanced reactor designs, and explored various avenues for organising the research and infrastructure that will be needed. These proceedings will be of particular interest to nuclear specialists and research managers wishing to obtain an international perspective of current and foreseeable needs in regulatory-driven nuclear safety research.

Radiological protection

A Stakeholder Dialogue on the Implications of the ICRP Recommendations

Summary of the Three NEA/ICRP Conferences

ISBN 978-92-64-99033-3. 44 pages. Free: paper or web.

Since its inception the NEA Committee on Radiation Protection and Public Health (CRPPH) has been involved in the assessment and implementation of the recommendations of the International Commission on Radiological Protection (ICRP). The development of new general ICRP recommendations, to replace those of the 1990 ICRP Publication 60, was thus of great interest to the NEA and its member countries. As a result, the NEA initiated a process of interaction and dialogue with the ICRP to ensure that the views and concerns of NEA member countries could be voiced and appropriately addressed in the new ICRP recommendations. The new ICRP recommendations were approved by the ICRP Main Commission in March 2007, by which point the NEA had sponsored 7 international conferences and produced 13 publications on the subject. This report is the summary of the three international dialogue conferences (held in Tokyo, 5-6 July 2006, Washington, DC, 28-29 August 2006, and Prague, 24-25 October 2006) that were organised to provide the ICRP with feedback regarding the June 2006 draft of its new recommendations. It includes a presentation of the key points of the draft recommendations, a summary of the suggestions made during the three conferences, and an assessment of the significant evolution that has been seen in the ICRP's presentation of its draft recommendations over the course of the conference series.

Occupational Exposures at Nuclear Power Plants

Sixteenth Annual Report of the ISOE Programme, 2006

ISBN 978-92-64-99042-5. 120 pages. Free: paper or web.

The Information System on Occupational Exposure (ISOE) was created by the OECD Nuclear Energy Agency in 1992 to promote and co-ordinate international co-operative undertakings in the area of worker protection at nuclear power plants. ISOE provides experts in occupational radiological protection with a forum for communication and exchange of experience. A total of 71 utilities in 29 countries participate in the programme as well as the regulatory authorities of 25 countries. The ISOE databases enable the analysis of occupational exposure data from 401 operating commercial nuclear power plants (representing about 91% of the world's total operating commercial reactors), as well as 80 units undergoing decommissioning. The Sixteenth Annual Report of the ISOE programme summarises achievements made during 2006 and compares annual occupational exposure data. Principal developments in ISOE participating countries are also described.

Radioactive waste management

Moving Forward with Geological Disposal of Radioactive Waste

A Collective Statement by the NEA Radioactive Waste Management Committee (RWMC)

ISBN 978-92-64-99057-9. 24 pages. Free: paper or web.

The NEA Radioactive Waste Management Committee (RWMC) has underscored the environmental and ethical basis for geological disposal as well as its technical feasibility in a number of previous collective statements. In the intervening period there have been advances and evolving views regarding the appropriate methodologies, policies and decision-making processes. In addition, much further practical experience has accumulated regarding the development of geological repositories. In the statement the RWMC expresses, in a concise form, its collective views on why geological disposal remains an appropriate waste management choice for the disposal of the most hazardous and long-lived radioactive wastes, on the current status of geological disposal, on challenges and opportunities for implementation, and expectations for further developments.

Regulating the Long-term Safety of Geological Disposal

Towards a Common Understanding of the Main Objectives and Bases of Safety Criteria

ISBN 978-92-64-99031-9. 84 pages. Free: paper or web.

Regulating the long-term safety of geological disposal of radioactive waste poses special challenges due to the very long timescales involved. This report has been prepared to help foster a common understanding of the fundamental safety objectives of deep geological repositories and the applicable criteria. It provides important guidance for the national programmes that are developing or refining regulations. A common understanding may also contribute to clearer communication and public understanding of regulatory criteria.

Safety Cases for Deep Geological Disposal of Radioactive Waste: Where Do We Stand?

Symposium Proceedings, Paris, France, 23-25 January 2007

ISBN 978-92-64-99050-0. 424 pages. Free: paper or web.

The OECD Nuclear Energy Agency (NEA) hosted an international symposium on "Safety Cases for the Deep Disposal of Radioactive Waste: Where Do We Stand?" in January 2007. The NEA has spearheaded important developments in defining, and in developing methodologies to support, demonstrations of safety for deep disposal, including a similar symposium nearly two decades ago that provided the basis for a 1991 NEA collective opinion that the technical basis and methods exist for undertaking safety assessment of deep geological disposal. The 2007 symposium, co-sponsored by the European Commission and the International Atomic Energy Agency, provided the opportunity to review progress and to identify emerging trends and challenges. It brought together experts in the field of radioactive waste disposal from waste management organisations, regulatory agencies, scientific support organisations, international agencies, private sector consultants, and public interest groups both within and beyond NEA member countries.

The symposium showed that safety cases for radioactive waste disposal have evolved to become important tools both to assess safety and to aid in decision making. There is a good, shared understanding of what a safety case is and what comprises its main components. Importantly, the concept of a safety case today encompasses not only quantitative assessments of potential repository performance but also includes additional (and often more qualitative) lines of evidence and arguments that can contribute to confidence in safety. There has been significant evolution in terms of the analytical tools, lines of evidence, range of performance indicators and communication of the safety case. The value of international co-operation and dialogue in developing the concept and methodology of safety cases was underscored. These proceedings describe the discussions and conclusions of the symposium, and provide copies of the technical papers presented.

Nuclear law

Nuclear Law Bulletin

ISSN 0304-341X. 2009 subscription: € 114, US$ 150, £ 79, ¥ 16 500.

Considered to be the standard reference work for both professional and academics in the field of nuclear law, the *Nuclear Law Bulletin* is a unique international publication providing its subscribers with up-to-date information on all major developments falling within the domain of nuclear law. Published twice a year, it covers legislative developments in almost 60 countries around the world as well as reporting on relevant jurisprudence and administrative decisions, bilateral and international agreements and regulatory activities of international organisations.

Nuclear science and the Data Bank

Analytical Benchmarks for Nuclear Engineering Applications

Case Studies in Neutron Transport Theory

ISBN 978-92-64-99056-2. 296 pages. Free: paper or web.

Preservation of know-how in the nuclear field is promoted through the activities of the OECD Nuclear Energy Agency Data Bank. One area of importance concerns methods for solving radiation transport problems, especially with regard to neutrons. This handbook (in the form of a case study), prepared by Barry D. Ganapol, is the result of such an initiative. It is a compilation of solutions to the transport equation for which analytical representations can be found. It is designed for educational use in courses on analytical transport methods and numerical methods with application to reactor physics. In addition, it contains elements for the continuous improvement of transport methods and for computer code verification. The areas of neutron slowing down, thermalisation and one-, two- and three-dimensional neutron transport theory are covered. A series of training courses, based on this compilation of solutions, has recently begun.

Burn-up Credit Criticality Benchmark

Phase II-C: Impact of the Asymmetry of PWR Axial Burn-up Profiles on the End Effect

ISBN 978-92-64-99049-4. 512 pages. Free: paper or web.

Since 1991, the NEA has conducted a number of scientific studies to examine nuclear fuel burn-up issues as applied to criticality safety in the transport, storage and treatment of spent fuel. They have covered a wide range of fuel types, including UOX and MOX fuels for PWR, BWR and VVER reactors. The objective of the current study was to examine the axial burn-up profiles of PWR UO_2 spent fuel assemblies and specifically the fuel assembly end effects and the axial fission density distributions. The study was based on the evaluation of a database of experimentally measured axial burn-up profiles of the Siemens Convoy fuel assemblies, irradiated in the German nuclear power plant Neckarwestheim II. The report analyses and summarises the solutions to the specified benchmark exercises provided by ten contributors from seven countries. It shows that there is a significant correlation between the asymmetry of axial fuel assembly burn-up profiles and both the end effect and the axial fission density distribution. The results also illustrate the importance of using accurate axial fuel burn-up profiles when designing transport/storage fuel casks.

International Evaluation Co-operation

Uncertainty and Target Accuracy Assessment for Innovative Systems Using Recent Covariance Data Evaluations (Volume 26)

ISBN 978-92-64-99053-1. 196 pages. Free: paper with CD-Rom or web.

This publication reports the conclusions from the work undertaken by Subgroup 26 of the NEA Working Party on International Nuclear Data Evaluation Co-operation (WPEC), which focused on the development of a systematic approach to define data needs for advanced reactor systems and to make a comprehensive study of such needs for Generation IV (Gen-IV) reactors. A comprehensive sensitivity and uncertainty study has been performed to evaluate the impact of neutron cross-section uncertainty on the most significant integral parameters related to the core and fuel cycle of a wide range of innovative systems. A compilation of preliminary "Design Target Accuracies" has been put together and a target accuracy assessment has been performed to provide an indicative quantitative evaluation of nuclear data improvement requirements by isotope, nuclear reaction and energy range, in order to meet the design target accuracies, as compiled in the present study. First priorities were formulated on the basis of common needs for fast reactors and, separately, thermal systems.

Structural Materials for Innovative Nuclear Systems (SMINS)

Workshop Proceedings, Karlsruhe, Germany, 4-6 June 2007

ISBN 978-92-64-04806-5. 544 pages. Price: € 110, US$ 170, £ 79, ¥ 15 200.

Structural materials research is a field of growing relevance in the nuclear sector, especially for the different innovative reactor systems being developed within the Generation IV International Forum (GIF), for critical and subcritical transmutation systems, and of interest to the Global Nuclear Energy Partnership (GNEP). Under the auspices of the NEA Nuclear Science Committee (NSC) the Workshop on Structural Materials for Innovative Nuclear Systems (SMINS) was organised in collaboration with the *Forschungszentrum Karlsruhe* in Germany. The objectives of the workshop were to exchange information on structural materials research issues and to discuss ongoing programmes, both experimental and in the field of advanced modelling. These proceedings include the papers and the poster session materials presented at the workshop, representing the international state of the art in this domain.

Utilisation and Reliability of High Power Proton Accelerators (HPPA5)

Workshop Proceedings, Mol, Belgium, 6-9 May 2007

ISBN 978-92-64-04478-4. 456 pages. Price: € 100, US$ 140, £ 72, ¥ 13 900.

The accelerator-driven system (ADS) is one of the viable concepts for transmuting the long-lived isotopes contained in spent nuclear fuel and for this reason has been receiving considerable interest. In turn, attention must be given to the high power proton accelerators whose reliability and performance are key to the functioning of the ADS. It is in this context that the NEA organised the fifth workshop on the Utilisation and Reliability of High Power Proton Accelerators (HPPA5) which was held on 6-9 May 2007 in Mol, Belgium. The workshop included a special session on the MEGAPIE programme as well as five technical sessions: accelerator programmes and applications; accelerator reliability; spallation target development and coolant technology; subcritical system design and ADS simulations; and ADS experiments and test facilities. These proceedings contain all the technical papers presented at the workshop and will be of particular interest to scientists working on ADS development.

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