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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

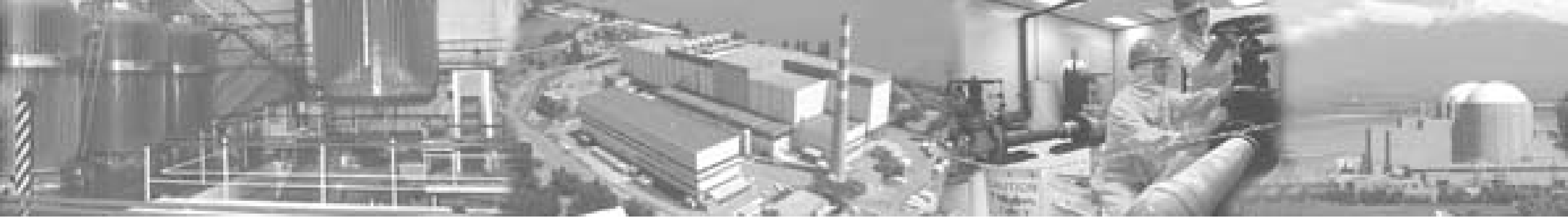
Cover page: MOX fuel studies at Cadarache (Joly, CEA, France), Olkiluoto-3 mock-up (TVO, Finland), vitrified waste store (BNFL, United Kingdom), monitoring radioactivity (P. Berenger, EDF, France).

Nuclear energy is making its case

In the face of growing energy challenges, nuclear energy is appearing more and more often in the lists of top energy policy choices. Its supply is secure. Its prices are competitive and stable. Its production is virtually CO_2-free.

In OECD/NEA member countries, new build is under way in Finland and starting to take shape in France and the Slovak Republic. And for the first time in 30 years, the US Nuclear Regulatory Commission has begun receiving applications for the construction of new units (applications for 5 units thus far, and expected for a total of 32 units over the 2007-2009 period). These developments are bolstered in the OECD Pacific region with 13 new units firmly committed in Japan and Korea.

As readers will find in the article on "Nuclear energy risks and benefits in perspective", nuclear power also has other benefits to offer; its main drawback appears to lie in the management of the radioactive waste that it generates. But progress is being made in this area too. Innovative solutions are being sought for the "Management of recyclable fissile and fertile materials" (see page 9) and being backed up by definitive emplacement strategies relying on the deep geological disposal of radioactive waste (see page 13). To ensure the safety of the nuclear power plants and those who work there, studies continue in the relevant disciplines and are also discussed in this issue of *NEA News*.



Finally, several NEA member countries are committed to making nuclear energy even safer still, while improving its economic competitiveness. Through its multinational research projects, the Generation IV International Forum (GIF) is seeking to offer significant improvements over existing nuclear energy systems in the areas of economics; safety and reliability; proliferation resistance and physical protection; and sustainability. An update on the work of the GIF, for which the NEA acts as Technical Secretariat, is provided on page 30. In order to establish reference regulatory practice and regulation to enhance the safety of new reactor designs, several countries are also participating in the Multinational Design Evaluation Programme (MDEP), whose current phase of work is described on page 36.

Against this backdrop, the NEA looks forward to a dynamic work setting for the years to come, and to helping its member countries make the most of international co-operation in the field.

Luis E. Echávarri
NEA Director-General

Nuclear energy risks and benefits in perspective

S. Gordelier*

Energy demand, rising prices, security of supply, climate change... these are major issues facing today's energy policy makers. In response, the NEA has recently published a study on *Risks and Benefits of Nuclear Energy* in order to provide these policy makers with authoritative information in support of their decision making. The study has also provided much of the basis for this article.

Energy demand and efficiency

World energy demand continues to increase in an apparently inexorable manner. According to the International Energy Agency (IEA),[1] demand has more than doubled from around 5 500 Mtoe (million tons of oil equivalent) in 1970 to around 11 200 Mtoe in 2005. It also predicts that, based on current government policies, it will continue to increase, reaching about 17 400 Mtoe by 2030, a further increase of 55% over 2005 levels and a factor of more than three above the 1970 levels. Of these increases, coal is expected to rise most in absolute terms.

Electricity demand, as a component of the overall demand, is continuing to grow at an even faster rate, as the world's economies continue to develop. The IEA predicts that electricity demand will have increased by 100% by 2030[1] and that it will have reached 260% of the 2005 value by 2050.[2]

Energy efficiency is important and it is worth making efforts to improve it. However, it is often presented as a solution to the problem. Unless one believes (and can prove!) that world energy demand will cap out, energy efficiency, worthwhile though it is, only buys time to find a real solution, almost certainly technological.

By way of example, assume that overnight one could make an energy efficiency saving of 10%. Total primary energy supply (TPES) is growing by around 1.9% per year. In less than six years one would be back to the same level. Be more ambitious and improve overnight by 20%; in less than 12 years one would again be back to the same level. This is not to say that energy efficiency improvements should not be sought. Rather the time gained should be used to seek the technology developments needed to provide the real answers.

Greenhouse gas emissions

In terms of CO_2 emissions, while the carbon intensity of TPES has improved a little, and emission intensity of gross domestic product (GDP) has fallen more, CO_2 emissions have followed closely in line with population, GDP/capita and TPES. Figure 1 shows CO_2 emissions in terms of the various forms of energy use. For energy-related emissions, it is clear that electricity generating plants are by far the biggest culprit in terms of emissions growth. They are twice the next largest energy contributor, and are growing much faster. Road transport, which has attracted a great deal of media

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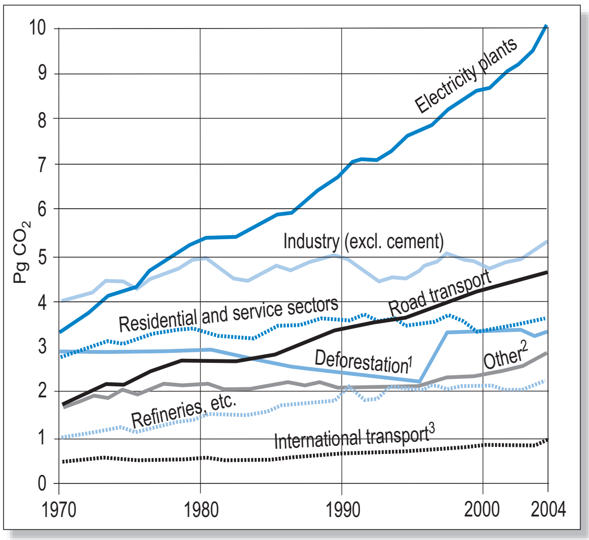
and political attention, is only half the size and is growing more slowly, although it is the second fastest growth area. International transport, including aviation, which has also attracted a great deal of attention, seems in reality to be one of the lesser concerns on a global scale.

Figure 1 – **Sources of global CO_2 emissions, 1974-2004**

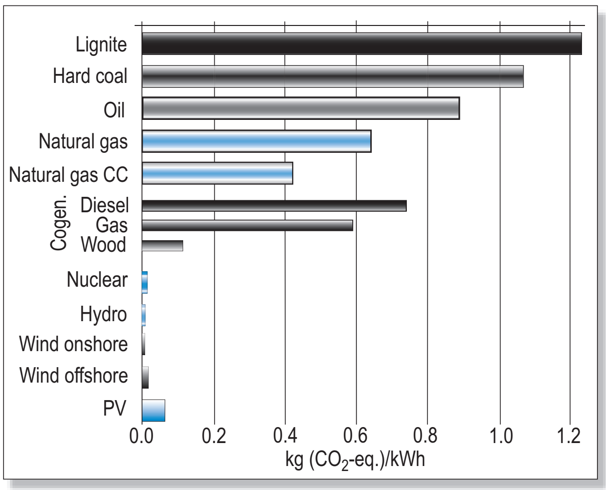
(only direct emissions by sector)



1. Including fuel wood at 10% net contribution. For large-scale biomass burning, averaged data for 1997-2002 are based on Global Fire Emissions Database satellite data (van der Werf et al, 2003). Including decomposition and peat fires (Hooijer et al, 2006). Excluding fossil fuel fires.
2. Other domestic surface transport, non-energetic use of fuels, cement production, and venting/flaring of gas from oil production.
3. Including aviation and marine transport.

Source: IPCC (2007), *Climate Change 2007: Mitigation of Climate Change*, Working Group III Report, Cambridge University Press, Cambridge.

Figure 2 – **Greenhouse gas emissions of selected energy chains**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Hence, power plants are clearly **THE** big issue. This is not to say that the other sectors do not merit attention, but it would seem that unless the emissions from power plants are addressed one cannot really hope to make a significant impact on emissions reduction. Nuclear power can clearly play a role, but it remains a relatively minor player at present, contributing 16% (25% in the more developed economies of the OECD) of world electricity production and only 6% of TPES. Its growth has been curtailed by its contentious nature with politicians and their publics.

Figure 2 shows an analysis for full life cycle emissions from various means of generating electricity. The horizontal axis is expressed in normalised kilograms of CO_2 equivalent, taking into account the warming potential of each gas. All figures shown refer to the UCTE* member countries in the year 2000. Greenhouse gas (GHG) emissions of nuclear and renewable energy are between one and two orders of magnitude below emissions from fossil generation chains. UCTE averages are about 5g CO_2 eq/kWh for hydro and 8g for nuclear, 11g for onshore wind, 14g for offshore, 60g for photovoltaics and 100g for wood co-generation.

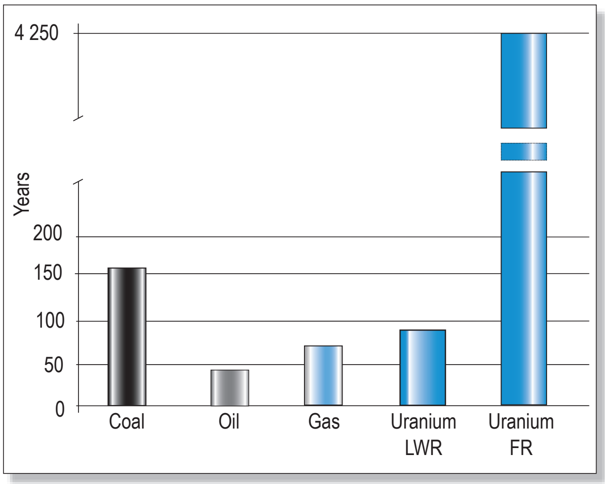
Security of uranium supply

Some suggest that high-grade uranium ores will soon run out and that the life cycle emissions advantages of nuclear will then disappear as uranium extraction becomes much more energy intensive. Official data show otherwise. According to *Uranium 2005: Resources, Production and Demand*[3], the reserves to production ratio for uranium is significantly larger than for oil or gas (see Figure 3). Industry does not dissipate significant exploration expenditures too far in advance of need, whatever the energy source.

Further, in the event of a significant expansion of nuclear power, Table 1 shows that progressive introduction of fast breeder reactors (FBRs), multiplying the energy extractable from a given quantity of uranium by a factor of 50 or more, expands the energy availability dramatically. Given that nuclear

*The Union for the Co-ordination of Transmission of Electricity (UCTE) included, in 2000, Austria, Belgium, Bosnia-Herzegovina, Croatia, Denmark (associate member), France, Germany, Greece, Italy, Luxembourg, the Former Yugoslav Republic of Macedonia, the Netherlands, Portugal, Slovenia, Spain, Switzerland, and Serbia and Montenegro. (The Czech Republic, Hungary, Poland and the Slovak Republic officially joined the UCTE in 2001.)

Figure 3 – **Lifetime of fuel resources* (years)**



* Identified resources, i.e. those resources for which there is already confidence that they are exploitable at reasonable price.

Source: Data taken from NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Table 1 – **Lifetime of uranium resources (years)**

Technology	Identified ** resources ~4.7MtU	Total** conventional resources ~14.8 MtU	Total conventional resources plus phosphates ~36.8 MtU
LWRs once through	85	270	675
Progressive introduction of FBRs*	4 250	13 500	33 750

* Here it is assumed that the progressive introduction of fast breeder reactors (FBRs) multiplies by 50 the amount of electricity generated by 1 tonne of uranium.

** See reference 3 at the end of this article for an explanation of identified resources and total conventional resources.

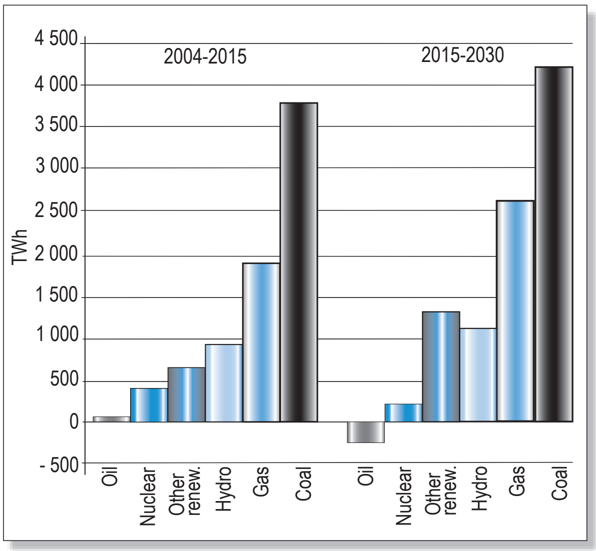
power currently contributes 6% of TPES, the uranium already known to exist in conventional and phosphate resources can quickly be shown to have the energy equivalent of 2000 years of current TPES, largely CO_2-free.

The spot price of uranium has risen from the historic lows of the last two decades to a point where commercial extraction of the very small amounts of uranium residing in some coal ash is under serious consideration. If the extracted uranium were to be used in fast reactors, it would produce more energy than the coal from which it was derived. A thorium fuel cycle is also possible, but has not been commercially developed thus far. Thorium is some three times more abundant in the earth's crust. Hence, there does not appear to be any shortage of largely CO_2-free energy, should one choose to use it.

The need for new power plants – an opportunity and a threat

According to the *World Energy Outlook*[1], some USD 5 trillion will need to be invested in power plants between now and 2030. Given that such investments have typical economic lives of 40 years or so, their normal turnover rate is very low. This represents a major opportunity to invest in low emissions plants for the future. Alternatively, if fossil fuel plants are constructed, they will lock the regions concerned into their continuing emissions up to 2050 and possibly well beyond (it is possible that carbon capture and storage, CCS, could alleviate this if the technology is developed and demonstrated at commercial scale and fossil plants are built as "CCS ready" for future backfitting). Based on current government policies, Figure 4 shows that the vast majority of new power plants will rely on fossil fuel and that most of the additional demand for electricity is expected to be met by coal, which remains the world's largest source of electricity to 2030. Clearly, this will not help achieve climate change objectives, and government policies will need to change quickly in order to do so.

Figure 4 – **World incremental electricity generation by fuel**

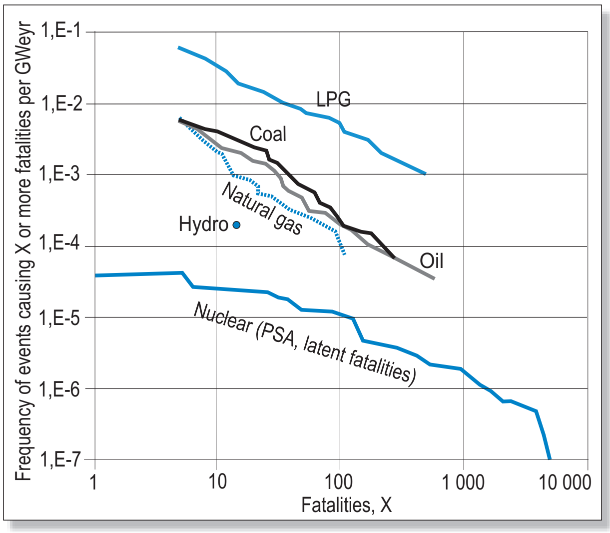


Source: IEA (2006), *World Energy Outlook*, The Reference Scenario, OECD/IEA, Paris.

Risks and benefits study

The recent NEA publication on *Risks and Benefits of Nuclear Energy*[4] covers quantitative and qualitative aspects of these risks and benefits encompassing economic, social and environmental dimensions. It provides numerous comparisons of nuclear and other options for electricity generation and examines techniques by which a wide range of factors can be weighed and balanced in an overall assessment. A small selection will be presented here. The benefits in terms of GHG emissions reduction have already been explored above. In economic terms, nuclear is cost-competitive in many countries that do not charge for carbon releases, and is therefore even more so when and where a carbon charge is levied. For a full description of cost issues and comparisons between energy sources, see the NEA/IEA publication on *Projected Costs of Generating Electricity*[5].

Figure 5 – **Comparison of frequency-consequence curves for full energy chains in OECD countries for the period 1969-2000**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Accident risks

A continuing concern for the public and politicians is the safety of nuclear power. ENSAD, the Energy-related Severe Accident Database established by the Paul Scherrer Institute in Switzerland, contains data on over 18 400 accidents, mainly between 1969 and 2000, of which 35% are energy-related, and 3 117 of which are rated as severe (with five or more prompt fatalities). Figure 5 shows frequency/consequences curves for this data, for OECD countries. The data for LPG, coal, oil and natural gas are data from real accidents. During this period there has only been one severe hydro power accident in OECD countries, resulting in 14 prompt fatalities. There have been no OECD nuclear accidents in this "severe" classification.

To enable some comparison, Figure 5 also shows the probabilistic safety analysis (psa) for a Swiss nuclear power plant. Note that this line is not directly comparable, in that it is for the latent deaths (in contrast with prompt deaths for other data) from theoretically possible releases (not actual releases or accidents). From this figure, one may nevertheless conclude that nuclear energy is much safer, in comparison with other energy sources, than the general public would believe. In OECD countries, both hydro and nuclear are much safer than other sources.

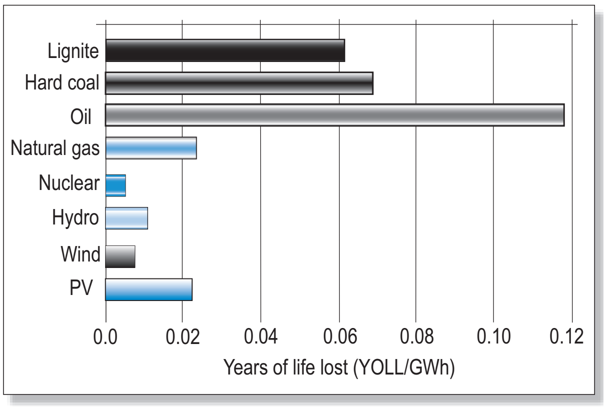
This particular plot could be subject to criticism from a number of positions. In choosing OECD countries, it ignores Chernobyl, but the Chernobyl plant also used a design not licensed in OECD countries and severe as it was, the accident only caused about 40 prompt deaths. It could also be criticised for ignoring the latent death estimates from Chernobyl; but in that case it should also include latent deaths from both operation and accidents, and fossil technologies come out quite badly (see Figure 6). The biggest energy-related accidents outside the OECD area were caused by oil (3 000 fatalities in the Philippines in 1987; 2 700 fatalities in Afghanistan in 1982), hydro (1 000 fatalities in India in 1980) and LPG (600 fatalities in Russia in 1989).

Why then, does nuclear seem to provoke unique safety fears in the public mind? It could likely be some combination of the association with nuclear weapons, the fear of very low probability, but very large accidents, the fact that latent deaths are associated with cancer, a disease much feared in its own right (and cancer can affect "me", whereas oil and gas accidents generally impact those working with the industry, except for the huge accidents), and the publicity that nuclear attracts because of these factors. Almost everyone remembers Chernobyl and even Three Mile Island (no prompt fatalities). Who remembers (or ever heard of) the oil, hydro and LPG accidents listed above, which occurred around the same time and directly killed thousands?

Human health impacts from normal operation

Human health impacts due to normal operation may be represented by "mortality", defined by reduced life expectancy calculated in terms of years of lost life (YOLL). Figure 6 shows, by way of example, an analysis of mortality resulting from the emissions of major pollutants specific to German energy chains. Nuclear, wind and hydro have very low mortality rates associated with normal operation. Mortality for natural gas and solar PV are somewhat higher, and other fossil systems are significantly higher. It is worthwhile noting that, for all chains, mortality due to accidents (as discussed above) is practically negligible compared with the corresponding effects of normal operation. Again this does not seem to be widely known among the public and decision makers.

Figure 6 – **Mortality associated with normal operation of German energy chains in the year 2000**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Decision-making aids

Two decision-aiding techniques are explored in *Risk and Benefits of Nuclear Energy:* internalisation of external costs and multi-attribute decision analysis. An externality exists when some negative or positive impact is generated by an economic activity and imposed on third parties without being priced by the market[6]. If the inventory of externalities could be exhaustive and if their value could be estimated in an accurate and reliable manner, the internalisation of external costs would lead to the best choice. Unfortunately, those two conditions can seldom be fully met. Nevertheless, the technique is of value if it can capture reasonably reliable key components.

Multi-criteria decision analysis can be used as a separate decision aid, or as a complementary technique. It enables a more extensive representation of social criteria, but these are the most difficult to define, select and measure, and are therefore the most controversial. Examples are discussed using three branches of impact factors (those factors which are evaluated and weighed against each other): economic, environmental and social. In general, only if very high weight is given to social factors (e.g. aversion towards hypothetical severe accidents) does the analysis show that nuclear power is not in the group of the most advantageous generating technologies. Many of these social issues remain controversial and, depending on the socio-political perspective of those involved, can be of paramount importance. Otherwise, with balanced weightings, nuclear power regularly ranks amongst the best generating technologies available.

Conclusions

The world's energy challenges are serious. Power plants are the biggest and fastest growing contributors to greenhouse gas (GHG) emissions. They are already twice the size of the next largest sector for energy consumption.

Due to the rapid growth in energy demand in developing countries, and the need to replace the ageing stock of power plants in developed economies, some USD 5 trillion will need to be spent over the coming two decades. This provides an excellent opportunity to invest in largely GHG-free generating capacity. Governments and industry must act decisively if this opportunity is not to be missed.

Nuclear electricity is virtually CO_2-free and, in principle at least, there are vast amounts of energy available for the countries that decide to use it. Known available uranium resources have a potential energy equivalent of 2000 years' worth of the current global total primary energy supply.

However, nuclear energy remains contentious in many countries. The OECD/NEA has published its study on *Risks and Benefits of Nuclear Energy* to provide policy makers with authoritative information in support of their decision making and public debate. ■

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1. IEA (2006), *World Energy Outlook*, OECD/IEA, Paris.
2. IEA (2006), *Energy Technology Perspectives*, OECD/IEA, Paris.
3. NEA (2006), *Uranium 2005: Resources, Production and Demand*, OECD, Paris.
4. NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.
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Management of recyclable fissile and fertile materials

E. Bertel, T. Dujardin*

The possibility of recycling fuel is a very attractive – and nearly unique – feature of nuclear energy systems. The fissile and fertile materials contained in spent nuclear fuels and enrichment plant tails, for example, may be retrieved and re-used to provide additional energy. Doing so also reduces the amount and radiotoxicity of waste that will ultimately need to be sent to repositories.

While recycling spent nuclear fuel becomes increasingly attractive in the context of renewed interest for nuclear energy and of sustainable development goals, extended interim storage and direct disposal of recyclable materials remain the favoured options by many countries. The recyclable materials which are not intended to be re-used may be disposed of in a safe way, guaranteeing their isolation from the biosphere over very long periods of time until they become harmless for humans and the environment.

The NEA study[1] on recyclable fissile and fertile materials was carried out in order to review technical, strategic and policy issues raised by the management of such materials, and to provide insights into the opportunities and challenges offered by alternative options. The materials considered include: spent fuel; depleted uranium from enrichment plant tails; separated uranium and plutonium from commercial reprocessing plants; ex-military materials (highly enriched uranium and plutonium) declared excess to national security by the Russian Federation and the United States; and thorium inventories.

This article is based on the study's analyses, findings and conclusions. It provides an overview of the quantities and potential energetic value of recyclable materials available worldwide. The main advantages and drawbacks of the two management options that may be adopted are also described.

Inventories of recyclable materials

Existing inventories of recyclable fissile and fertile material represent a potential energy source important enough to be of significance in a long-term policy perspective, and more recyclable materials are arising continuously. The operation of the current fleet of nuclear power plants results in some 10 000 tonnes of spent fuel per year.

Table 1 gives an overview of the amounts of separated recyclable materials in stock worldwide at the end of 2005 and provides estimates of their potential value in terms of fuel supply. It shows that the present stockpile of recyclable materials represents almost 4 000 reactor-years worth of fuel

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Table 1. **Inventory of separated recyclable materials**

Source	Quantity (tHM)	Natural U equiv. (10^3 tU)	Reactor-years of supply *
Ex-military highly enriched uranium (HEU)	230	70	420
Ex-military plutonium	70	15	90
Plutonium	320	60	380
Reprocessed uranium	45 000	50	300
Enrichment tails	1 600 000	450	2 650

** Based on a 1000 MWe LWR operating at 80% load factor.*

with existing reactor technology. In other words, recycling the entire inventory of separated materials in reactors currently in operation would provide them with an additional 10 years of fuel supply, increasing by more than 10% the 85 years of supply offered by identified uranium resources.[2]

The enrichment plant tails represent by far the largest potential energy content, but their exploitation would require extensive re-enrichment capacity which is not industrially available today. Furthermore, the economic viability of this option might be questionable with current technologies and at present natural uranium prices, even after recent spot price increases.

The inventories included in Table 1 do not include spent fuels accumulated in interim storage facilities which would require reprocessing prior to their eventual recycling. If all accumulated spent fuel were to be reprocessed, some 1 700 tonnes of plutonium and 190 000 tonnes of natural uranium equivalent would be made available for fuelling nuclear power plants, representing around seven and a half years of supply for the fleet currently in operation.

Management options

There are two options for the management of recyclable materials: final disposal and recycling. Both options will ultimately require final waste repositories, but the approach chosen will have a drastic impact on the size and commissioning date of the required repositories. Long-term storage is not a viable alternative; it is an interim measure that allows postponing a final decision.

The inventories of materials that are not being processed in nuclear fuel cycle facilities are stored in different physical and chemical forms on various sites. In all OECD countries, stringent regulations and norms are in place regarding the transport, storage and processing of those materials, ensuring that radiological impacts to health and the environment are as low as reasonably achievable.

The disposal of recyclable materials, including spent fuel, can be achieved in a safe and economically viable way with currently available technologies. While no spent fuel has been packaged for final disposal yet, approaches which exist or are under development for low-level, intermediate-level and high-level waste will be considered for suitability in spent fuel disposal applications. Regarding disposal, there is a general consensus that geological disposal offers a reliable and safe solution for present and future generations at affordable costs. Projects under development in several countries should lead to the commissioning of repositories within one or two decades.

In countries which are not considering the recycling option, timely disposal of recyclable materials is a relevant solution to avoid long-term storage burdens and costs, and to eliminate future financial liabilities associated with extended interim storage. On the other hand, final disposal of potentially valuable materials may be considered a "non-sustainable" option by some stakeholders. Therefore, current approaches tend to favour retrievable solutions that would eventually allow recycling if and when it becomes the preferred solution.

All options will ultimately require the disposal of radioactive waste, but some alternatives reduce the volumes and radiotoxicity of waste more than others. Repository designs and sizes should be adapted to the options chosen.

Recycling fissile and fertile materials can significantly increase the energy content extracted from natural uranium and thorium, extend the lifetime of nuclear fuel resources and enhance the sustainability of nuclear energy. When the recycling option is adopted, its main goals are generally a better utilisation of the energy content of natural resources and a reduction of the volumes and radiotoxicity of waste. Recycling fissile and fertile materials provides additional fuel resources and decreases the amount of plutonium and minor actinides to be disposed of, thereby reducing the long-term stewardship of radioactive waste.

A few examples illustrate the wide range of opportunities offered by alternative recycling options. The reprocessing of spent fuel from current light water reactors (LWRs) followed by recycling of uranium and plutonium in those reactors can reduce the specific, per kWh, fresh uranium consumption of existing nuclear energy systems by 50%. Advanced systems based on fast neutron reactors, on the other hand, could multiply by more than 50 the energy produced per tonne of natural uranium consumed.

The efficiency of recycling depends on the mix of nuclear energy systems used and on the timing of their deployment. A major finding from the analysis of alternative options for the management of recyclable materials is that the amount of energy retrieved is highly sensitive not only to reactor types and the fuel cycle schemes chosen, but also to the timing of their deployment. The most efficient strategies are likely to involve nuclear systems capable of using various materials in a synergetic manner (e.g., plutonium and depleted uranium in fast neutron reactors). Transition scenarios from once-through to fully closed fuel cycles deserve thorough analyses in order to identify the best strategies, taking into account the size and development rate of the national, regional and/or global nuclear fleet.

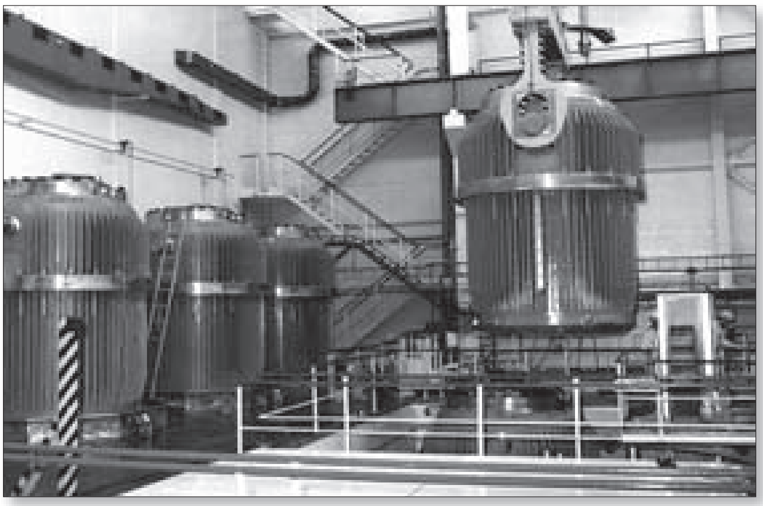
Regarding the minimisation of waste volumes and radiotoxicity – a major issue for nuclear energy deployment in a long-term, sustainable development perspective – recycling provides significant benefits. It postpones the need for final disposal of high-level waste and, more importantly, reduces the amount and radiotoxicity of waste to be disposed of, especially if advanced systems designed for partitioning and transmutation of minor actinides are included in the nuclear power fleet.

Issues, challenges and opportunities

All strategies to manage recyclable materials require the implementation of strict measures to ensure adequate levels of safety, radiological protection, proliferation resistance and physical protection. The legal and regulatory regimes in place in OECD countries provide robust frameworks in this regard.

There is significant industrial experience in several countries on various steps of the alternative options (recycling some fissile materials, mainly plutonium, for example), and experts are confident that all recyclable fissile and fertile materials can be managed in a safe and reliable manner. Existing technologies already enable the partial exploitation of the energy content of recyclable materials. For example, the retrievable energy content of depleted uranium inventories using current technologies is very high, exceeding the energy content retrievable from plutonium inventories used in nuclear energy systems of the

How much waste will ultimately need to be sent to repositories?



M. Durisova, Slovak Republic.

present generation. However, industrial enrichment capabilities would need to be adapted in order to process depleted uranium stockpiles.

The energy content that may be recovered from recyclable fissile and fertile materials would vary dramatically depending on the recycling options chosen and the strategies adopted for their implementation. Energy content could be multiplied by 2 to more than 50 times, as described above.

At the policy level, international co-operation is essential to address some of the issues raised by the management of recyclable fissile and fertile materials, which are difficult to tackle on a national level, especially for countries with limited nuclear energy infrastructures. Collaboration between countries could help to provide solutions which are optimised from a global perspective and facilitate the implementation of adequate infrastructures which would not otherwise be viable at the national level.

The management of recyclable fissile and fertile materials requires infrastructures and facilities that are unlikely to be technically and economically viable in all countries where nuclear power plants are or will be operated. The implementation of multinational, regional and/or international facilities could provide a broader range of options to all countries, including those with small- or medium-size nuclear power programmes.

Research and development programmes undertaken in many countries aim at enhancing the technological performance, safety and economics of disposal and recycling options. Joining strengths within international R&D endeavours offers effective means to develop advanced technologies adapted to the social, environmental and economic requirements of future generations.

Concluding remarks

Inventories of recyclable fissile and fertile materials represent a large potential energy resource which could help countries relying on nuclear energy to enhance their security of supply while reducing greenhouse gas emissions from their energy sector at affordable costs. A thorough review of management options available to store, re-use or dispose of recyclable materials demonstrates that a range of technically, environmentally and economically viable solutions are in place or being developed for all materials.

There is no single option that is optimal in all cases, but there is a broad range of solutions from which to chose according to each specific case and taking into account the priorities of policy makers. These solutions need to be integrated into long-term national energy policies and to include prospective views on the evolution of the role of nuclear systems in global energy supply.

The best option for the management of recyclable materials will depend on such factors as the specific situation of the owners of the materials, the national energy policy of the country concerned, the size and characteristics of its nuclear fleet, the availability of a repository, the nuclear industry infrastructure available and the national regulatory framework.

The assessment of alternative options for the management of recyclable materials should be based on a multi-criteria analysis taking into account economic, environmental and social factors in the overall context of national energy policies. Issues such as security of energy supply, stewardship burden imposed on future generations and proliferation resistance have a much larger impact on the assessment of alternatives than variations in the fuel cycle cost, which in any case represents today less than 20% of the total cost of electricity generated by nuclear power plants.

A prerequisite to decision making in this field is to identify irreversible measures which would foreclose the choice of other options at a later date. Generally, reversibility is a desirable characteristic as it keeps the possibility of re-considering options in the future open, as well as taking advantage of technology progress and changes in the socio-economic landscape. ■

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Geological disposal: key observations and lessons learnt

L. Echávarri, C. Pescatore*

The NEA has long been, and continues to be, a leading organisation in the field of radioactive waste management, and in particular as concerns geological disposal. The Agency's activities are broad in scope and address the policy, regulatory, technical and public-involvement aspects of this issue. It has helped the field move forward through joint and pioneering projects, such as the Stripa project in the 1980s, as well through regulatory and policy reflection. The NEA has developed what is today considered to be the reference approach to producing a disposal safety case.

The NEA's first major report dates from 30 years ago, when it issued the so-called "Polvani report" of September 1977 on *Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programmes*. Since then much has been learnt.

Why geological disposal?

Whatever the future of nuclear power, it is generally recognised that safe and acceptable disposal solutions for existing and already committed long-lived, high-level radioactive waste must be pursued. There are no miracle solutions: physical transmutation of some of the waste or advanced fuel cycles will not eliminate the need for disposal. In addition, long-lived, high-level radioactive wastes are also generated from non-power applications of nuclear materials and isotopes, such as in medicine, industry and research.

Mature and safe methods for the management of radioactive waste are currently available and are being implemented. Society, as an extra precaution, has determined that some long-lived wastes, including high-level radioactive waste and spent fuel, should be disposed of such that they are contained and isolated from humans and the accessible environment without the need for continued human intervention.

International conventions prohibit disposal in the sea bed which, for all practical purposes, restricts disposal to land-accessible locations. Underground disposal is thus being investigated worldwide as the ultimate waste management end-point. The concept anticipates that any releases are small both relative to the overall inventory of waste and in absolute terms, and that these proportionately small releases migrate very slowly, resulting, at most, in a negligible incremental impact on public health.

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The level and time frame of protection that is demanded of, and can be provided by, a geological disposal system is unprecedented when compared to other practicable options, including those in common use for many non-radioactive but hazardous wastes. The placement of these wastes deep underground, in a robust engineered system matched to a suitable geological setting, is thus felt to afford appropriate protection for present and future generations.

The geological disposal concept, including its safety and ethical implications, has been debated in national legislatures, in state, provincial and local fora, by individuals, in peer-reviewed literature, in international organisations and by national scientific bodies. This reflects a general consensus on the geological disposal option, achieved through a broad societal process.

Delaying work on geological disposal, or adopting a "wait-and-see strategy", results in continuing and increasingly demanding care, which cannot be guaranteed. A long-term management option without a definite end-point is thus not only unacceptable ethically, but it is also potentially unsafe. Given this background, most countries have inscribed geological disposal in their policy objectives.

Where do we stand with geological disposal?

Since the Stockholm Conference of December 2003, important milestones in geological disposal have been reached in a number of NEA member countries. Having taken into account important public and stakeholder involvement, geological disposal is now the recognised reference solution in Canada, France and the United Kingdom. In France, a siting region has been identified for all long-lived, high-level radioactive waste. In Canada, a deep repository is being constructed for operational waste while a process is being defined for siting a repository for used nuclear fuel. The United Kingdom is now reflecting on how to set up a decision-making process that would associate local communities in the identification of a geological disposal site for radioactive waste.

In the meantime, other NEA countries which had already committed themselves to geological disposal have made important progress as well. In Finland and the United States, sites and designs have been identified and work is ongoing to develop the repositories. In Sweden, two localities have been short-listed and are now being investigated for the final siting of a deep repository. In Switzerland, after the promulgation of the new Atomic Energy Law, a plan has been drafted and is being implemented to search for repository sites. In Germany, a license has been granted to operate the deep repository at Konrad for "non-heat-emitting wastes", which include waste with long-lived components. Finally, it is worth noting that the Waste Isolation Pilot Plant (WIPP), a deep repository for transuranic waste, continues its successful operation in the United States.

Geological disposal is technically feasible

Central to successfully implementing geological disposal is the ability to demonstrate and communicate the safety and security of the repository system far into the future in a manner that is clear, scientifically sound and persuasive to decision makers and the public.

A wide consensus prevails on the general approach for the technical and safety assessments for geological disposal, and many examples exist of recent successful uses of safety cases for national decision making. Switzerland (2005) and France (2006) constitute the most recent examples. Exchanging information and working co-operatively under the aegis of international organisations such as the International Atomic Energy Agency (IAEA) and the OECD Nuclear Energy Agency (NEA) have been important factors in this progress.

NEA peer reviews have proven to be significant contributors to improving safety cases and to final decisions in moving national programmes to the next stage. This has been the case, for instance, in Japan, the United States, Switzerland and France. It may be noted that the two peer reviews concerning the United States were co-organised with the IAEA.

The deep disposal concept relies on the capabilities of both engineered barriers and the local geology to fulfil specific safety functions either in a complementary or in a redundant fashion. Considerable amounts of data and experience have been accumulating for sites and materials. In particular, there is an improved understanding of processes at various spatial and temporal scales, and significant advances in modelling techniques have been achieved. There are also several underground research, demonstration and/or development facilities. Overall, both the experts and the members of the public who have been involved feel that sufficient evidence exists to conclude that geological disposal is a technically achievable and safe solution.

Some broader challenges in practical implementation

Many national programmes are now facing the challenge of practical implementation of geological disposal through further development and licensing. From a regulatory point of view, the recommendations of the International Commission on Radiological Protection (ICRP), the IAEA Safety Fundamentals, and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management provide a framework of common objectives to guide this implementation. This international framework provides goals and objectives for achieving an appropriate level of protection, including such elements as requiring a suitable regulatory framework, applying a stepwise approach in decision making, and protecting future generations without imposing undue burdens.

Although countries are implementing the international framework and pursuing common safety objectives, every country is at a different juncture in the process and has different needs. Some countries have found it essential to reflect unique repository attributes in the selection of repository performance criteria.

Regulators, implementers and policy makers have become more aware that confidence by the technical community in the safety of geological disposal is, by itself, not enough to gain public confidence and acceptance. There is now agreement that a broadly accepted national strategy is required to provide not only the means to build the facility, but also a framework and roadmap to provide both decision makers and the affected publics with the time and means to develop sufficient confidence in the various decisions at hand and, ultimately, in the achieved level of long-term protection. A first step in the strategy is the definition of a national energy policy which addresses the role of nuclear power and in which the waste arisings are recognised. The issuance of a national plan with indications for the final management of all types of radioactive waste is an important addition and basis for discussion and public acceptance.

Very importantly, the international framework, as embodied for instance in the Aarhus and Espoo conventions, also requires public information and stakeholder involvement, both nationally and across borders. Similar requirements are reflected in national laws, such as those concerning transparency in decision making and those requiring environmental impact studies.

The legitimacy of the process is paramount: national policy making and legislative bodies must put the process in place and provide the means to follow it. The quality of the process is also essential: roles must be clear; there should be adherence to both one's own roles and to the rules of the process; and all participants in the process must behave and be viewed as trustworthy and accountable.

It is interesting to note that there has been considerable evolution in the expected roles of the various actors over time (see Table). For example, the public increasingly views regulators as the "people's expert" and expects them to play this role. A capital role in the new decision-making environment is being taken on by the host communities. More and more often, they are becoming partners in negotiating locally acceptable solutions that minimise negative impacts and provide for local development, local control, partnership and, ultimately, a durable relationship between the facility and the host community.

A common objective, a variety of paths

Culture, politics and history vary from country to country and provide different contexts for establishing and maintaining public confidence. What works in one country may not be as effective in another. As a result of being open to different perspectives, it follows that there must be openness to countries reflecting individual cultural and societal values in their processes and regulatory criteria, which may result in similarities as well as differences on an international scale. For instance, what was expected to be a common regulatory approach and common safety criteria and time frame is now a more complex reflection of national and pan-national interests, local and regional cultural views and societal values. Differences in regulation and implementation may not only be appropriate, but may even be critical for public confidence and acceptance.

Cultural, societal and geographical similarities and differences may have resulted in a variety of paths, but common safety and security objectives underlie these paths in national disposal solutions. What is needed is a continued, shared understanding of how this progress is being achieved and how one might achieve the same objectives in one country while using a different path in another. International fora are important for identifying similarities and differences, as well as for identifying overarching themes and lessons to be learnt.

Traditional and evolving roles and responsibilities

Stakeholders	Traditional roles and responsibilities	Evolving roles and responsibilities
Policy makers	Defining policy options, investigating their consequences under different assumptions, making policy choices.	Informing and consulting stakeholders about policy options, assumptions, anticipated consequences, values and preferences. Setting the "ground rules" for the decision-making processes. Communicating the bases of policy decisions.
Regulators (policy makers in safety authorities)	Defining regulatory options, investigating their consequences under different assumptions, making choices regarding regulatory options.	Informing and consulting stakeholders about regulatory options, assumptions, anticipated consequences, values and preferences. Communicating the bases of regulatory decisions. Providing independent expertise for local communities.
Scientific experts, consultants	Providing qualified input for the decision makers.	Providing balanced and qualified input for stakeholders and encouraging informed and comparative judgement. Acting as technical intermediaries between the general public and the decision makers.
Implementers	Finding a solution for radioactive waste management and implementing that solution.	Co-operating with local communities to find an acceptable solution for radioactive waste management. Co-operating with local communities in implementing the solution.
Potential host communities	Accepting or rejecting the proposed facility.	Negotiating with implementers to find locally acceptable solutions for radioactive waste management that minimise negative impacts and provide for local development, local control and partnership.
Elected local or regional representatives	Representing their constituencies in debates on radioactive waste management facilities.	Mediating between several levels of governments, institutions and local communities in seeking mutually acceptable solutions.
Waste generators	Providing (partial or full) financing for radioactive waste management.	Providing financing for radioactive waste management under transparent arrangements and demonstrating this transparency.

Conclusions

At one time geological disposal of radioactive waste was viewed as if it were a relatively short-lived activity to be completed in the time span of perhaps a single generation, the goal being to provide a facility that could safely contain radioactive waste without any further action or intervention by future generations. Increasingly, the implementation of a disposal project has come to be viewed as an incremental process, perhaps taking several decades to complete. This changing vision involves not only the concept of protection of future generations, but also incorporates an assumption of their involvement in the process and a need to preserve their ability to exercise choice. The last decade or so has seen an evolution in the roles and number of relevant actors and, with that, a gradual shift in the complexity of the approach in implementing a disposal facility.

NEA work has considerably influenced the field of radioactive waste management and corresponding approaches around the world. At the October 2007 International Conference on Geological Repositories in Berne, Switzerland, countries reaffirmed the common objective of safe geological disposal and reinforced the message that continued attention by decision makers is an important element in helping to keep on course a process that will take decades to complete. They also reached a common understanding that the varieties of paths available represent complementary avenues, which arise from modern and democratic, but nation-specific approaches to governance. The communication of this shared understanding by decision makers can have a significant impact on the confidence of all stakeholders. ■

The impact of financing schemes and income taxes on electricity generation costs

E. Bertel, J. Planté*

The NEA carries out economic studies on a regular basis to assist member countries in their own assessments in support of decision making for the power sector. As part of the studies carried out under the NEA Nuclear Development Committee, several computer tools have been used to calculate the costs of electricity generation, their various elements and their sensitivity to different parameters. The model presented in this article was developed in order to assess the impact of financing schemes and income taxes on generation costs.

Electricity generation cost estimates reported in many national and international studies provide a wealth of data to support economic assessments, and eventually to guide choices on generation sources and technologies. However, although the electricity generating cost is the criterion generally selected to present results, it is calculated by various means in different studies because the chosen approach must be relevant to the context of the specific project (private vs. stated-owned investor, regional differences...).

The traditional constant-money levelised generation cost methodology is widely used by utilities, government agencies and international organisations to provide economic assessments of alternative generation options. It gives transparent and robust results, especially suitable for screening studies and international comparisons. However, the method, which is strictly economic, does not take into account all the factors influencing the choice of investors in liberalised electricity markets. In particular, it does not take into account financing schemes and income taxes which may have a significant impact on the capital cost to be supported by the investor.

The approach described below is based on the overall framework of average levelised lifetime cost evaluation, but it takes into account the financing scheme adopted by the investor and the income taxes supported by the plant operator/utility. It is similar to models which are used to analyse the economics of competing electricity generation sources in liberalised electricity markets, such as the merchant plant cash flow model adopted in the MIT study.[1]

The model, or computer tool, developed to implement the approach was used in sample calculations carried out for nuclear, coal and gas power plants to illustrate concretely the application of the methodology. The purpose of the sample calculations was to estimate the impact of financing and taxes on the relative competitiveness of different generation sources and technologies.

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The results provide detailed electricity generation costs estimated within different financing and income tax contexts; they show how the associated conditions affect generating costs, and how the impacts differ according to the generating source. In particular, they demonstrate that both factors have an impact on the capital component of generation costs which is not technology-neutral.

The assumptions adopted for input data, including unit costs and economic conditions, reflect the present situation but do not refer to any specific technology, reactor type or country. Two different financing contexts are considered: moderate and tight financing constraints. With input data corresponding to the condition applying in a given investor/utility project, the computer tool developed to implement the model may be applied to specific case studies on concrete choices of generation technologies.

Methodology

In order to put the adopted approach in perspective, it is worth highlighting the basic principle of the constant-money levelised cost method, used for example in OECD studies.[2] This method discounts the time series of expenditures to their present value in a specified reference year by applying a discount rate. A similar process is used for electricity generation to calculate its present value equivalent. The ratio of discounted expenditures versus discounted electricity generation provides the levelised lifetime cost of electricity, which is expressed in constant money of the reference year. This cost, often called "bus-bar cost", is generally split into its capital, fuel and operation and maintenance (O&M) components.

The approach used below differs from the constant-money levelised cost method mainly in the treatment of investment/capital costs. The calculations are performed in nominal/current money, meaning that all costs, starting from an initial value adopted for the base year, are escalated according to an assumed inflation rate; a positive or negative trend over time can be added to the inflation rate if needed. Loan paybacks are computed according to the loan interest rate which, in itself, includes inflation trends.

The annual outlays related to capital investment, fuel costs and O&M costs, as well as income tax payments, are calculated taking inflation into account. Outlays include waste management and disposal, and decommissioning costs as applicable (for example in the case of nuclear power plants). Capital investment is handled in two parts: the equity component and the loan component (outlays occurring during the pay-back period). Appropriate annual capital depreciation is also computed for tax calculation purposes, the income taxes being charged on the taxable income calculated by deducting asset depreciation from total net income.

The annual revenues are calculated by multiplying the annual electricity generation by the wholesale price of electricity. The electricity selling price escalates according to the inflation rate, but remains unchanged over the plant lifetime in constant money value.

The cash flow is then obtained by deducting expenses from revenues. From this cash flow, the internal rate of return (IRR) or return on equity (ROE) is calculated year by year, its value becoming positive when the cumulated cash flow becomes positive.

The model can be operated as a profitability or generating-cost calculator:

- **Profitability calculator.** The electricity price is an input value and the model computes the IRR. This IRR figure is available either for the plant's entire economic life or for any specific number of operating years, should the shareholders want their return on equity over a shorter period.
- **Generating-cost calculator.** The IRR after a certain number of operating years is an input, and the model computes the electricity selling price which allows this return. Since this selling price stays the same over the years in constant money, it can be assimilated to a levelised electricity generation cost corresponding to the preselected return on equity.

The additional capability of the model is that it includes, together with the cash flow-based estimation of IRR or electricity selling price, a calculation of discounted outlays estimated with a discount rate (including inflation) equal to the IRR. Starting from the outlay schedules computed in the merchant plant cash flow model, discounted outlays are calculated and the yearly power generation amounts are also discounted. This part of the model is similar to the classic economic model used in levelised generation cost calculation, with the exception that a nominal discount rate has to be used in order to discount outlays expressed in nominal values.

This additional capability allows a detailed assessment of the impact of financing schemes and income taxes on levelised costs of electricity generation. As shown in the sample calculations presented below, it is possible with the model to calculate the three components of levelised generation cost (capital, fuel and O&M) and to display the income tax separately from the capital cost component.

Assumptions

The calculation is performed for three generating sources: nuclear, gas-fired and coal-fired power plants operating in the context of liberalised markets corresponding to the average conditions prevailing in the United States. The technical and unit-cost assumptions (see Table 1) are not intended to reflect any specific design but are illustrative of state-of-the-art units currently available on the market.

Table 1. **Technical and cost data**

	Unit	Nuclear	Gas	Coal
Overnight capital cost	$/kW	2000	650	1400
Plant life	years	40	25	40
Construction time	months	60	24	48
Capacity factor	%	90	90	90
Thermal efficiency – LHV	%	33	58	44
Decommissioning	$ million	350	0	0
Fuel cost	$/MBtu or tonne	0.50/ MBtu	6.0/ MBtu	40/ tonne
Fuel cost escalation rate	%	0	0	0
Waste management	cents/kWh	0.1	0	0
O&M	$ per kW per year	50	25	50
O&M cost escalation rate	%	0	0	0
Annual incremental capital cost	$/kW	20	6	12

For convenience, the calculations are normalised to 1000 MWe capacity plants but the results are valid irrespective of the size of the plant, provided that the specific overnight capital costs assumed ($/kWe installed) are appropriate for the plants being considered. Input cost data and results, i.e., generation costs per kWh, are expressed in year 2007 US dollars ($).

As indicated above, calculations were performed in two contrasted economic and financing contexts (moderate and tight financial constraints) recognising that the financial parameters may change depending on the perception of risks by investors and banking institutions. The corresponding financial parameters are summarised in Table 2.

Table 2. **Financial parameters**

		Moderate			Tight		
	Unit	Nuclear	Gas	Coal	Nuclear	Gas	Coal
Inflation rate	annual %	3	3	3	3	3	3
Equity portion	%	30	30	30	60	60	60
Equity return	%	12	12	12	15	15	15
Equity recovery period	years	40	25	40	25	25	25
Debt portion	%	70	70	70	40	40	40
Debt interest rate	%	7	7	7	9	9	9
Debt term	years	15	15	15	15	15	15
Income tax rate	%	38	38	38	38	38	38
Depreciation term	years	15	15	15	15	15	15
Depreciation schedule		MACRS*			MACRS*		

* *MACRS = modified accelerated cost recovery system.*

The tight financial context corresponds to a low degree of investor confidence in electricity generation projects requiring a high ratio of equity versus debt, high return on equity and high interest rates. The moderate context assumes a higher confidence of potential investors in the economic viability of electricity generation projects leading to lower ratio of equity versus debt, lower return on equity and lower interest rates.

It has been assumed that financing conditions will be the same for the three technologies, i.e., nuclear, coal and gas. In some studies, this is not the case because it might be argued that some sources or technologies are perceived to be riskier than others by potential investors. With the model used, it would be easy to perform sensitivity analyses showing the impact of assuming different financial constraints for different technologies.

Impact of financing schemes

Tables 3 and 4 provide the electricity generation costs in the case of moderate and tight financial constraints respectively, calculated for coal, gas and nuclear power plants with the input data and financial parameters given in Tables 1 and 2. Figures 1 and 2 provide a graphic representation of those results.

Table 3. **Electricity generation costs ($/MWh) – Moderate financial constraints**

	Nuclear	Gas	Coal
Capital without income tax	2.49	0.79	1.63
Income tax	0.39	0.10	0.25
Capital including income tax	2.88	0.89	1.88
O&M	0.63	0.34	0.63
Fuel	0.62	3.92	1.33
Total without income tax	*3.74*	*5.05*	*3.59*
Total including income tax	**4.13**	**5.15**	**3.84**

Table 4. **Electricity generation costs ($/MWh) – Tight financial constraints**

	Nuclear	Gas	Coal
Capital without income tax	3.77	1.05	2.45
Income tax	1.08	0.26	0.69
Capital including income tax	4.85	1.31	3.14
O&M	0.63	0.34	0.63
Fuel	0.62	3.92	1.32
Total without income tax	*5.02*	*5.31*	*4.40*
Total including income tax	**6.10**	**5.57**	**5.09**

Figure 1. **Electricity generating costs – Moderate financial constraints**

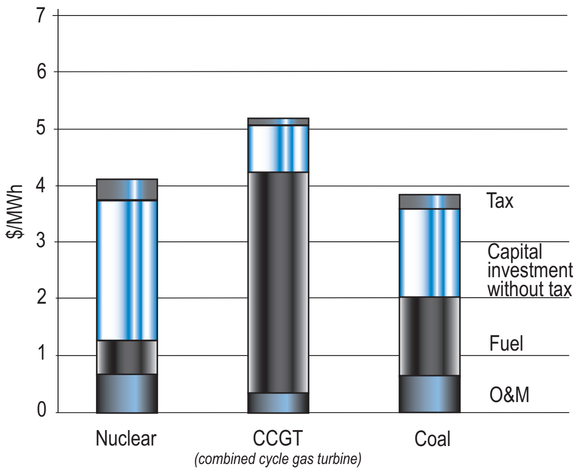
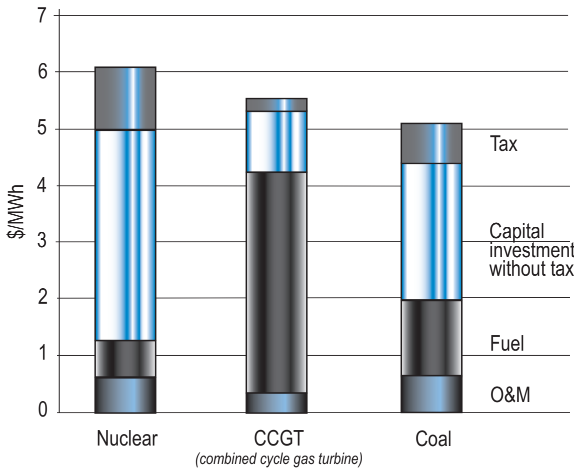


Figure 2. **Electricity generating costs – Tight financial constraints**



The different cost components, including income tax, illustrate that while generating costs increase for all three electricity generation technologies when income taxes are included in the calculation, the impacts of financing schemes and income taxes differ significantly from technology to technology. The reason for those differences is that the specific (per kWh) taxable income is very sensitive to the cost structure of the generation source considered.

The annual taxable income, which corresponds to the revenue that will be allocated to pay the expected return on equity, is equal to the revenue less operating expenses, including fuel and O&M costs, less interest payments and asset depreciation. As this taxable income depends on the capital investment required to finance the plant, on the equity/debt ratio and on the required return on equity, the specific annual taxable income will be higher for capital-intensive electricity generation sources such as nuclear, less so for coal, and lastly gas.

- Under moderate financial constraints, the generation cost increases by 10% for nuclear, 7% for coal and only 2% for gas.
- Under tight financial constraints, the gaps are even wider as the increase is 22% for nuclear, 16% for coal and 5% for gas.

Including income tax in the generating cost may change the relative competitiveness of electricity generation sources. For example, with the assumptions and input data adopted in the present study, under the tight financial constraints, nuclear is cheaper than gas when excluding tax, but gas is cheaper when taxes are included. This highlights the importance of presenting the detailed results together with all assumptions, input data and boundary conditions adopted in any cost estimation.

Figure 3. **Income tax/electricity generating cost ratio – Moderate financial constraints**

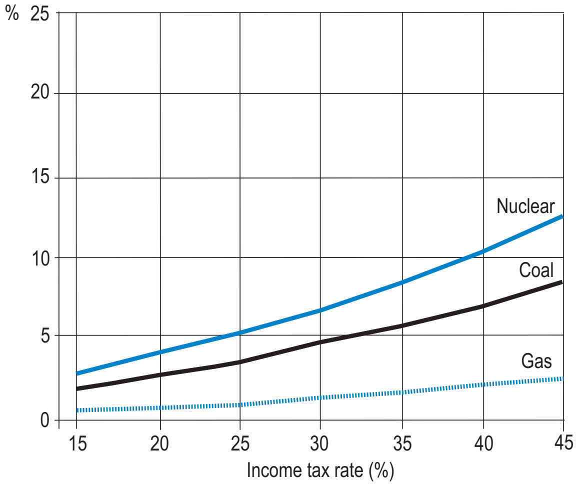
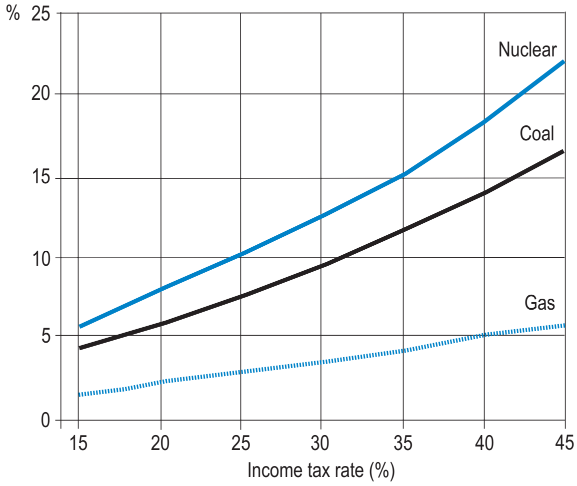


Figure 4. **Income tax/electricity generating cost ratio – Tight financial constraints**



Sensitivity to income tax rates

As previously noted, the base calculation was performed in the context of liberalised markets corresponding to the average conditions prevailing in the United States. Consequently, the income tax rate was estimated at 38%.

However this rate varies widely from country to country, ranging from some 15% to above 40%. It is therefore interesting to see how the results would be affected by such a variation, all other parameters remaining unchanged. The sensitivity calculation takes into account an income tax rate range of 15% to 45%.

As in the base case, the sensitivity calculation is performed for coal, gas and nuclear power plants. Figures 3 and 4 illustrate the impact of such a variation in income tax rate on the electricity generation cost, expressed in a percentage of this cost.

In the case of moderate financial constraints (Figure 3), the income tax/generating cost ratio varies from 2.9% to 12.4% for nuclear, from 0.6% to 2.5% for gas and from 1.9% to 8.4% for coal. In the case of tight financial constraints (Figure 4), the income tax/generating cost ratio varies from 5.8% to 22.4% for nuclear, from 1.3% to 6.0% for gas and from 4.3% to 17.3% for coal.

It should be stressed that the results presented in Figures 3 and 4 are valid in the framework of the assumptions and input data summarised in Table 1. Outside of this context, results may differ significantly, in particular in cases where the relative importance of capital cost versus fuel and O&M costs is different from the sample calculations. When capital cost is proportionally higher, the sensitivity of generation costs to tax rates is higher and vice versa.

Conclusions

Levelised generation costs estimated with the traditional approach, where financing schemes and income taxes are not taken into account, provide a relevant basis for screening studies and international comparisons. However, they do not reflect the full range of parameters that affect investor choices. Including financing constraints and taxes in the cost calculation provides estimates that are better adapted to understanding investor choices in liberalised electricity markets.

The illustrative calculations carried out for a range of income tax rates in two contrasted financial constraint frameworks show that taking those parameters into account may change the relative competitiveness of electricity generation sources. This highlights the importance of presenting detailed results together with all assumptions, input data and boundary conditions adopted in any cost estimation.

The results obtained show that tax regimes implemented by governments have an impact on generation costs which is not technology-neutral. Government policy makers may choose to take this into account in order to implement a tax regime consistent with national energy policy goals. ■

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Radiological protection at the NEA: 50 years and thriving

T. Lazo*

On 21 March 1957, the Steering Committee for Nuclear Energy of the Organisation for European Economic Co-operation (OEEC) created the Working Party on Public Health and Safety, the predecessor of the current NEA Committee on Radiation Protection and Public Health (CRPPH). In May 2007, the Committee celebrated 50 years of accomplishments and member service in a one-day, forward-looking event embedded within the Committee's 2007 annual meeting. The objectives were to recognise the achievements of the CRPPH, to identify potential emerging challenges for the radiological protection (RP) community as a whole, and to encourage an active dialogue among national regulatory and international organisations to identify new opportunities and approaches to address these challenges.

The event was attended by many of the Committee's past chairs and eminent members, as well as by several heads of regulatory authorities and high-level officials from international organisations. The day opened with a brief review of the Committee's history and achievements, and then focused on the future. With references to the Committee's recent report *Radiation Protection in Today's World: Towards Sustainability* (NEA, 2007), speakers highlighted emerging challenges and how national governments and international organisations could work together to pro-actively address them.

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The CRPPH and its origins

The story of radiological protection at the NEA truly began with the creation of the Working Party on Public Health and Safety, almost a year before the creation of the OEEC European Nuclear Energy Agency itself. The Steering Committee for Nuclear Energy asked the Working Party to develop a programme of work in the area of radiological protection and public health and to establish a mechanism to implement it. That mechanism would be the Health and Safety Sub-committee (HSC), which was created on 21 February 1958 and renamed the Radiation Protection Committee before becoming the Committee on Radiation Protection and Public Health (CRPPH) in 1973.

The early days of the Working Party and the HSC marked the beginnings of international co-operation in the nuclear field. Common concerns quite naturally brought the main national public health authorities and specialists in radiological protection together in a standing forum with very broad competencies. Among those concerns were the potential consequences of atmospheric nuclear weapons tests, the prospects of developing nuclear electricity generation programmes and various applications of radioisotopes, set against a backdrop of early awareness of the need to protect people and the biosphere against the effects of radiation. These concerns gave way to numerous others over the Committee's history, including radiological protection norms and standards, radioactive waste disposal, nuclear emergency management, radiation biology and radiological protection science, and stakeholder involvement issues. The key radiological protection issues of each period (e.g. ICRP recommendations, sea dumping of radioactive waste, Chernobyl) can all be identified in the Committee's programmes of work, which contributed to national governments' and international organisations' responses to these questions. In short, over the past 50 years the CRPPH has focused its work on the most pressing topics of the day, while simultaneously looking forward to identify possible new issues in a timely fashion.

Key CRPPH accomplishments

Throughout its history, the CRPPH has actively examined the concepts and principles of radiological protection as well as their regulatory and operational application. The Committee has continually accompanied nuclear energy's development, even occasionally anticipating and judiciously acting to confront situations that have been difficult, or even dramatic. Examples like the Co-ordinated Research and Environmental Surveillance Programme (CRESP) and the work that was carried out to manage radioactive waste, as well as the Committee's work following the Chernobyl catastrophe, illustrate this and have undeniably influenced the orientations of the Committee.

The short list below highlights some of the most significant work that the CRPPH has done over its first 50 years.

Early RP standards

The CRPPH issued Radiation Protection Norms in 1959, 1963 and 1968 before abandoning this activity in favour of endorsing the norms of the European Union and of the International Atomic Energy Agency. The CRPPH continued, however, to issue recommendations in other areas, such as for the management of consumer products, gaseous tritium light devices, ionising chamber smoke detectors and cardiac pacemakers during the 1970s and into the 1980s. Again, this activity was gradually abandoned in favour of leaving standards development to other organisations.

Relationship with the ICRP

Throughout its existence, the CRPPH has collaborated with the International Commission on Radiological Protection (ICRP), initially through the review and assessment of newly issued ICRP standards, but more recently providing an active forum for dialogue with the ICRP during the development of new standards.

CRESP

Beginning in 1974, radioactive waste sea dumping operations by several NEA member countries had been carried out in a single site located in the North-East Atlantic. To fulfil the objectives of an OECD Council Decision, an international group of oceanographic and radiological protection experts was convened by the NEA in 1979 to undertake a review of the continued suitability of the dumping site, taking into account the relevant provisions of the London Dumping Convention and the IAEA Definition and Recommendations for the purposes of the Convention. The Co-ordinated Research and Environmental Surveillance Programme, or CRESP, was subsequently initiated in 1981, with the objective to continue to strengthen the scientific and technical bases of future assessments of the North-East Atlantic dump site. This programme was carried out under Article 2(a)iii of the OECD Council Decision establishing a multilateral consultation and surveillance mechanism for sea dumping of radioactive waste. Sea dumping of radioactive waste ended in 1982, and the NEA's surveillance of the dump site was officially terminated in 1995.

Scientific reports

As a Committee of scientists as well as regulatory experts, the CRPPH has always performed scientific studies of highly appreciated quality. Over the years, the subjects addressed by the Committee have included:

- *Marine Radioecology* (1968);
- *The Radiological Significance and Management of Tritium, Carbon-14, Krypton-85 and Iodine-129 Arising from the Nuclear Fuel Cycle* (1980);
- *Environmental and Biological Behaviour of Plutonium and Some Other Transuranium Elements* (1981);
- *Dosimetry Aspects of Exposure to Radon and Thoron Daughter Products* (1985);
- *Gastrointestinal Absorption of Selected Radionuclides* (1998);
- *Developments in Radiation Health Science and Their Impact on Radiation Protection* (1998);
- *Scientific Issues and Emerging Challenges for Radiation Protection* (2007).

CRPPH collective opinions

The CRPPH played another role by preparing conferences and drafting the Committee's resulting "collective opinions", which were then submitted for international discussion. Examples include the collective opinions on *Radiation Protection Today and Tomorrow* (1994), *Developments in Radiation Health Science and Their Impact on Radiation Protection* (1998), *A Critical Review of the System of Radiation Protection* (2000), and *Radiation Protection in Today's World: Towards Sustainability* (2007).

Stakeholder involvement

The appreciation of radiological protection decisions as "one part science, four parts social judgement" has grown slowly but surely among professionals, largely due to the CRPPH studying this issue as early as 1994. Through a series of three workshops held in Villigen, Switzerland, the CRPPH has helped to increase the understanding of where and when stakeholder involvement in radiological protection decisions is needed, and of approaches of how it can best be accomplished to increase the applicability and sustainability of decisions.

The Information System on Occupational Exposure (ISOE)

Beginning in 1992, the NEA created a "club" of radiological protection experts from nuclear power plants and nuclear regulatory organisations in order to facilitate the exchange of data, experience and lessons learnt. Since that time, the ISOE occupational exposure database has become the largest in the world for nuclear power plants (including data from over 400 power plants around the globe), and the ISOE network has facilitated that exchange of exposure management experience such that, since 1992, occupational exposures have been cut in half.

International Nuclear Emergency Exercises (INEX)

Particularly since the Chernobyl accident, nuclear emergency management has been a central topic for nuclear safety regulatory authorities. To assist NEA member countries in improving their capabilities in this area, the CRPPH established the Working Party on Nuclear Emergency Matters. A major source of experience and lessons for the Working Party has been the INEX exercises. Held in 1993 (INEX 1), from 1996 to 2000 (INEX 2), and in 2006 (INEX 3), this series of international exercises has allowed emergency response organisations to test and to improve their approaches, processes and procedures to address the international and national aspects of large-scale nuclear accidents.

The Chernobyl accident

The CRPPH has published seven reports on the accident, assessing its impacts on NEA member countries as well as analysing lessons learnt in rehabilitation. The lessons from Chernobyl have significantly influenced the approaches adopted by the INEX programme.

Future challenges in decision making

Advances in radiological protection science, increasing experience in implementing radiological protection and social evolution all condition the way in which radiological protection principles are interpreted and implemented. In reviewing the current situation, the CRPPH collective opinion of 2007 pointed out that the evolution in these areas will increasingly challenge our current approaches to radiological protection policy, regulation and application and will demand new perspectives and new thinking.

The need for new perspectives and thinking does not arise from any particularly significant change coming from science, experience or society. Rather, the smaller, incremental changes in these three areas as a whole suggest the need for change. It is possible to characterise how certain types of situations will be affected and will need to be viewed in order to provide the most appropriate radiological protection under the prevailing circumstances. In this context, the CRPPH has identified four key areas where new approaches will be needed. The first area, which reflects challenges at the policy and regulatory level, concerns the balancing of local, national and international needs in order to identify and implement sustainable radiological protection solutions. The second area, which relates to implementation challenges, concerns approaches to identify appropriate protection for workers and the public. The third area concerns the implementation of radiological protection principles in four specific circumstances: contaminated areas and materials; decommissioning and dismantling; medical exposures; and radiological emergencies and malevolent acts. The fourth area, which reflects the rapid expansion of radiation uses, concerns the maintenance of competence and the intergenerational transmission of knowledge.

Scientific evolution

The capability to assess radiological risks continues to progress as a result of scientific research. Historically, the complexities of radiation biology and cancer genesis have required assessments to be based primarily on "macroscopic" epidemiological studies of exposed populations of humans, animals, insects and plants. However "microscopic" studies from modern cellular and genetic biology have significantly contributed to our knowledge of how humans and the environment react to exposures to various sorts of ionising radiation, and under different types of exposure situations. It is a continuing challenge to bridge radiobiology and epidemiology studies of risk assessment to assist decision making concerning risk management in the face of scientific uncertainties.

Based on ongoing and recently published studies, the CRPPH has identified several key issues and emerging challenges to the scientific bases and application of the overall system of radiological protection. These key issues and scientific challenges are:

- the non-target effects of radiation exposure that challenges the universality of the target theory of radiation-induced effects;
- individual sensitivity effects on patients, workers and members of the public to provide adequate radiological protection;
- greater use of molecular epidemiology to further refine the dose-response curve;
- the adequacy of the concept of dose to estimates of risk as we learn more about biological processes in response to radiation exposure;
- radiological protection in medical exposures to optimise exposures;
- radiological protection of the environment to better understand possible effects and end points;
- the health impacts of malevolent actions using sources of radiation;
- the need to interface with other disciplines and international organisations to optimise resources and enhance collaboration.

These decision-making and scientific challenges found broad agreement during the CRPPH 50th Anniversary, reemphasising the need for the Committee, and other national and international organisations, to address these issues in a timely fashion. In addition, the senior regulators participating in the event as well as the senior representatives from several relevant international organisations (IAEA, ICRP, EC, UNSCEAR and IRPA) provided further input to the CRPPH as to where future challenges may lie, in particular:

- The safety-security interface, and the exchange of knowledge between radiological protection and security (and their synergies) needs to be enhanced, and the sustainability of safety and security infrastructures reinforced.
- Malevolent acts involving radioactive materials need further consideration in an emergency management context.
- The tracking and monitoring of transboundary radiation sources need to be upgraded, as well as the evaluation of national infrastructures.
- Specific training is needed for the radiological protection aspects of decommissioning.
- Clear roles and responsibilities should be established between the licensees and the regulator.
- The reduction of funds for radiological protection research and development (R&D) will impact the ability to protect in the future.
- Some attention needs to be accorded to the framework for the radiological protection of the environment.
- Early co-ordinated response actions are needed to prevent local incidents from escalating into large-scale emergencies. Lessons need to be captured and widely disseminated.
- The transport of radioactive materials raises several issues requiring international resolution, in particular the denial of shipments.
- There is a need for international organisations to enhance collaboration among themselves to ensure safety and quality through their activities.
- Medical exposures are increasing very rapidly, often effectively beyond the control of national regulatory authorities. There is a need to enhance radiation safety culture in the medical field.

Conclusion

Routine can be a handicap for an organisation and often brings with it a corollary tendency towards self-satisfaction and even inward focus. For its part, the CRPPH has remained open-minded and attentive to its members' preoccupations, and beyond this, to those of many of radiological protection's other stakeholders. The Committee has organised itself so as to integrate and to anticipate, scientific, technical and even social, economic and political evolution into its work. As a result, the CRPPH has always been a trail-blazer in many areas of radiological protection, and is increasingly seen as providing the necessary link between authorities, radiological protection professionals and society. ■

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The International School of Nuclear Law

S. Kus*

The International School of Nuclear Law (ISNL) was established in 2000 by the OECD Nuclear Energy Agency and the University of Montpellier 1. It benefits from the support of the International Nuclear Law Association (INLA) and the International Atomic Energy Agency (IAEA). The school offers a high-quality educational programme acknowledged for its intensive courses, professional lecturers, as well as its academic and practical balance. In the past seven years, the ISNL has been attended by approximately 400 participants from 78 countries around the world.

The NEA awards scholarships to enable certain meritorious students from its member countries to benefit from the course. The IAEA also awards a number of fellowships to participants from its member countries. This helps ensure broad representation from different countries and bestows the ISNL with the different views, experience and legal backgrounds of its participants. The applicants are mostly but not necessarily lawyers. Such diversity is welcomed as the interdisciplinary composition of classes contributes to the dialogue and mutual learning between lawyers and scientists or economists for example.

The programme

Each session of the ISNL consists in a two-week course, held exclusively in English. Lectures are complemented by case studies, group work and class discussions.

Participants enrolled in the ISNL programme have the possibility of applying for a University Diploma (*Diplôme d'université* – DU) in International Nuclear Law. The diploma is awarded based on assessments during the course, a take-home exam to be completed by the candidates over a period of approximately ten days, and a dissertation to be submitted on a subject of international nuclear law. The diploma represents 12 ECTS credits (European Credit Transfer System).

ISNL subjects

The international law governing the peaceful uses of nuclear energy is covered broadly during the course, bearing in mind its uniqueness and particular traits. The legal efforts by the international community to harmonise domestic legislation and regulations, especially in follow-up to the Chernobyl accident, is a focal point of the academic programme. The military origins of nuclear energy constitute another particularity, which has led to an exceptional regime of controls and restrictions upon international nuclear trade so as to prevent the proliferation of nuclear material for non-peaceful purposes. At the same time, nuclear energy law is in a constant state of evolution in order to adapt to technological and political developments and to better control the risks associated with the use of nuclear energy for peaceful purposes. The ISNL organisers and lecturers therefore tackle one of the most complex, challenging and sensitive subject areas of the legal discipline.

The course begins with presentations on the various international organisations under whose auspices an international legal framework has been developed. The OECD Nuclear Energy Agency (NEA), the International Atomic Energy Agency (IAEA) and European Atomic Energy Community (EURATOM) are represented by their respective experts who portray the history, status, structure, competencies and the main purposes of the international organisations. The international legal

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framework governing the peaceful uses of nuclear energy is then addressed in several lectures. The framework includes:

- **nuclear safety** (the Convention on Nuclear Safety, the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency);
- **non-proliferation and physical protection** (the Treaty on the Non-Proliferation of Nuclear Weapons, the Convention on the Physical Protection of Nuclear Material, the IAEA safeguards system, the physical protection and illicit trafficking of nuclear materials);
- **radioactive waste management** (the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, implementation of the Joint Convention into national law);
- **radiological protection** (the Basic Safety Standards, the recommendations of the International Commission on Radiological Protection, the European Community Urgent Radiological Protection Information Exchange (ECURIE) system, the International Nuclear Emergency Exercises (INEX) programme, philosophy and guiding principles in radiological protection);
- **safety of transport** (the International Law Governing the Safe and Secure Transport of Nuclear and Radioactive Materials);
- **nuclear trade** (EURATOM trade rules, nuclear trade rules in connection with general trade rules and competition rules);
- **liability and compensation for nuclear damage** (the Paris Convention on Third Party Liability in the Field of Nuclear Energy, the Brussels Convention Supplementary to the Paris Convention, the Vienna Convention on Civil Liability for Nuclear Damage, the Convention on Supplementary Compensation for Nuclear Damage, the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention, third party liability insurance).

The interdisciplinary character of the nuclear energy domain is reflected in lectures and discussions which cover such aspects as the ethical, legal and financial issues surrounding radioactive waste and spent fuel management, the economics of nuclear energy in perspective, and technical questions (supported by videos on the transport of radioactive material and the nuclear fuel cycle). The closing session of the ISNL is dedicated to guest speakers on current topics.

The seventh session of the ISNL

The seventh session of the ISNL was held from 27 August to 7 September 2007 in Montpellier, France, with 60 people from 35 countries and the European Commission participating. The different subjects of international nuclear law were taught by 23 lecturers in 35 presentations, each of which was followed by discussions. Participants shared their experiences and openly discussed challenges facing their domestic legal system. The aim of the ISNL to communicate and exchange experience was fully achieved. The lectures triggered extensive and interesting discussions, which demonstrated the complex and controversial elements of nuclear law. The courses on non-proliferation, the economics of nuclear energy, liability and compensation for nuclear damage, and the legal framework against terrorism clearly showed the vigilance of nuclear lawyers and their creativity to form a fair and reliable legal framework.

A technical visit to a nuclear power installation, which in the previous years was organised by the NEA, could not be offered to this year's participants. Instead, an information session on the nuclear fuel cycle with an overall introduction and an in-depth picture of the management of radioactive waste in France was given by Jean-Louis Tison from ANDRA, the French Radioactive Waste Management Agency.

The closing session of the ISNL featured guest speakers Dr. Walter Gehr, who spoke about "The Global Legal Framework against Nuclear Terrorism", and Dr. Pierre Goldschmidt, who addressed participants on the "Rule of Law, Politics and Nuclear Non-Proliferation".

Conclusions

The ISNL brings together various lecturers and speakers from regulatory bodies, international organisations, universities, industry and research institutions. In addition to the academic training obtained, participants are able to benefit from the expert network and to engage in a sharing of knowledge to help prepare their future commitments.

The ISNL is a well-known institution in the international nuclear community and can be of particular benefit to students and young professionals considering a career in the nuclear law field. ■

International Standard Problem ISP-47 on Containment Thermal-hydraulics

H. J. Allelein, K. Fischer, J. Vendel, J. Malet, E. Studer, S. Schwarz, M. Houkema, H. Paillère, A. Bentaib*

The objective of the OECD/NEA International Standard Problem ISP-47 programme was to assess the capabilities of lumped parameter (LP) and computational fluid dynamics (CFD) analysis codes in the area of containment thermal-hydraulics. Following the recommendations made in the "State-of-the-art Report on Containment Thermal-hydraulics and Hydrogen Distribution", experimental data from different complementary experimental facilities were employed for the benchmark analyses applying a progressive modelling difficulty. The three experimental facilities – TOSQAN, MISTRA and ThAI – provided good quality experimental data suitable for CFD and LP code benchmarking both for steady-state and transient conditions.

The ISP-47 programme was successfully completed in 2007. Nineteen organisations from fourteen countries participated by contributing experimental results, analyses with twelve different codes and reviews. The programme's final report, which contains a full range of figures and details concerning the results, is available online at: www.nea.fr/html/nsd/docs/2007/csni-r2007-10.pdf.

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Experiments and benchmark exercises

The ISP-47 programme was carried out in two steps:

- Step 1 was dedicated to code validation using test data from the separate effects facility TOSQAN (7 m^3 volume) and the larger-scale MISTRA facility (100 m^3 volume). In the TOSQAN tests, wall condensation, steam injection in air or air/helium atmospheres, and buoyancy were addressed under well-controlled initial conditions in a simple geometry. The interactions of phenomena such as condensation/stratification and turbulence/buoyancy were addressed in the MISTRA tests. Both TOSQAN and MISTRA were specifically designed to produce data for CFD codes with state-of-the-art instrumentation. The TOSQAN benchmark was open, whereas the MISTRA benchmark was blind.
- Step 2 was devoted to code validation using an experiment in the multi-compartment ThAI facility (60 m^3 volume) with different steam and helium injection phases, transient stratification and mixing conditions in the atmosphere, development of natural convection, wall condensate distribution, fog formation, and transient thermal response of heat-conducting walls. From this experiment, detailed measurement data on velocity, temperature and gas concentration fields are provided for detailed code validation. The ThAI benchmark covered three sets of calculations: completely blind, partly blind and open.

Results

The three experimental facilities provided experimental data of high quality, using highly accurate measurement techniques suitable for CFD and LP code benchmarking in steady-state and transient conditions. In addition to pressure and atmospheric temperature measurements, detailed gas velocity and gas concentration (air, steam and helium) data were obtained for the first time.

For Step 1, the TOSQAN open benchmark results indicate that the model predictions generally fit the experimental results obtained during condensation steady-state conditions with good accuracy. However, some of the major transient phenomena are not always reproduced by the models. Some multi-dimensional models reproduce the kinetics of the transient stratification whereas most lumped-parameter models only reproduce the final level of concentration.

In the MISTRA blind benchmark, LP models, which usually incorporate fog modelling, give reasonable results if the nodalisation is sufficient to capture the main findings of the flow pattern. From the CFD contributions, open questions concerning simulation of a rising jet and the thermal behaviour of the steel vessel wall were identified. Mean values such as total pressure are predicted rather well by all the codes. Some computations reproduced the gas temperature profiles well; others showed large deviations that are mainly due to overpredicting the superheating. This overprediction has only a minor effect on the calculated helium concentrations, which are generally well-reproduced.

In the Step 2 ThAI benchmark, major improvements in the predictions have been achieved by several participants when moving from blind to half-blind calculations, mainly by refinement of the nodalisation and more systematic treatment of the injection jet entrainment. In particular, the atmospheric stratifications during the phases in which the injection jets are located inside the upper light gas cloud are reproduced well by several LP models. Generally, however, they are underestimated by most LP and CFD contributions. The very challenging conditions leading to maintain the stratification in the phase which has the steam injection at the lower nozzle are in most cases not met, neither by CFD nor LP contributions. The reason why two LP models have been able to predict this stratification blindly is related to nodalisation and entrainment simulation.

Conclusions and recommendations

In view of the high quality of the ISP-47 tests it is recommended that containment codes should be validated against ISP-47 tests before using the code for the assessment of hydrogen distribution in plant applications. This recommendation pertains to lumped parameter codes as well as to nuclear research and industrial CFD codes.

Evidently, LP models are currently the main tools for general containment thermal-hydraulic analysis. LP models require much less computing time than CFD models, and are thus suitable for parametric analysis and PSA level 2 studies. However, LP codes have some inherent limitations due to the simplified flow model applied. These limitations can apparently be overcome by an appropriate user modelling by taking into account the expected relevant phenomena: the best blind predictions for Step 2 have been achieved by two LP codes.

For assessing the hydrogen safety issue in a PWR containment, combined use of both LP and CFD codes is recommended. LP codes may serve as the basic tool for containment analyses, whereas CFD should be used to compute:

- accident scenarios which require more detailed analyses of the (local) phenomena that occur;
- critical accident scenarios which are difficult to analyse using LP codes due to their inherent limitations.

On the other hand, however, LP calculations show a large scattering due to the strong user influence: not only the best, but also the worst predictions are obtained. The user influence appears to be particularly dominant with respect to nodalisation.

Based on the experience gained with this programme, especially with respect to LP codes, it is recommended to initiate an international activity for elaborating general guidelines (especially regarding nodalisation) for LP codes including specific requirements for user manuals. For CFD codes, further improvements in the modelling of condensation and turbulence, including the wall treatment related to these two issues, are recommended.

The ISP-47 tests provide a good database for further code development. However, experimental data on some phenomena are still poor. The analysts should specify the data needed for designing further tests.

At present, there is no proposal for an additional containment thermal-hydraulics benchmark programme. This situation may change following further investigations of the ISP-47 tests and after performing the envisaged ISP on hydrogen combustion. Scaling from tests to real-plant applications remains a major issue: hence, a plant application benchmark should be envisaged in order to study, *inter alia*, nodalisation effects and the impact of steam and light gas injection based on a generic (and probably simplified) PWR containment. ■

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News briefs

Update on the Generation IV International Forum

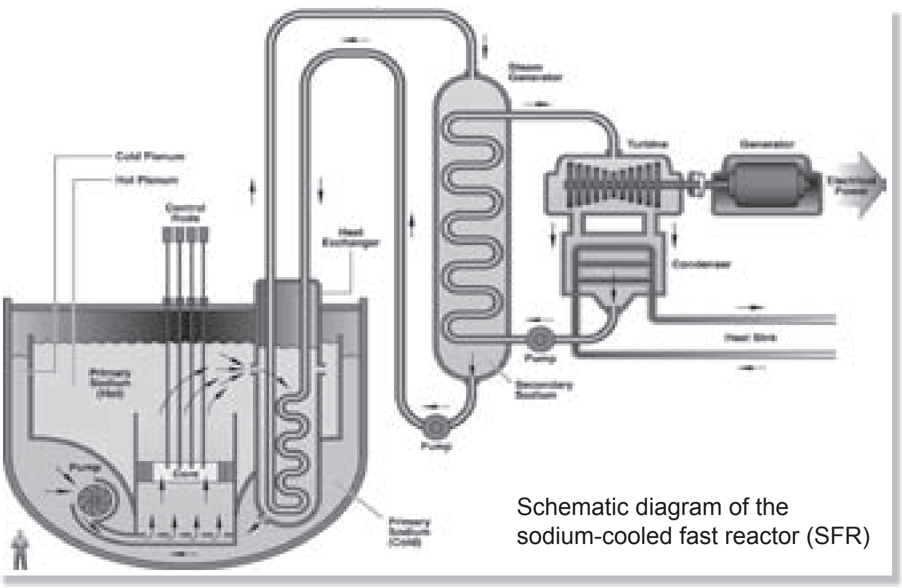
Generation IV nuclear energy systems are expected to offer significant improvements over existing systems in the areas of economics; safety and reliability; proliferation resistance and physical protection; and sustainability. The GIF Technology Roadmap evaluated over 100 system concepts, identified six with the greatest promise and outlined the R&D necessary to bring them to commercialisation in the 2030 time frame. The Generation IV International Forum (GIF) members are collaborating on the R&D needed to develop generation IV nuclear energy systems, beyond what is currently being undertaken by industry.

GIF members include the initial signatories to the GIF Charter – Argentina, Brazil, Canada, France, Japan, Korea, South Africa, the United Kingdom and the United States – as well as Switzerland (which signed the Charter in 2002), Euratom (2003), China (2006) and the Russian Federation (2006). Among the founding members, four have not signed or ratified the GIF Framework Agreement, which officially places them on "non-active" member status.[1]

The Forum has created a legal framework for its co-operation, as well as an organisational framework for co-ordinating and managing the work. System steering committees have been put in place to implement the R&D for each of the six reactor concepts, as set out in the system research plans (SRPs). Within each SRP, project arrangements, overseen by project management boards, are established with well-defined deliverables, milestones and a timetable.

2007 update

The Forum's most notable achievement in 2007 was the signing of the first GIF project arrangement in March. It was signed by five GIF members (Euratom, France, Japan, Korea and the United States) and concerns advanced fuel for the sodium-cooled fast reactor system (SFR). Additional progress made in advancing the six chosen concepts during 2007 follows below.



Schematic diagram of the sodium-cooled fast reactor (SFR)

Gas-cooled fast reactor system (GFR)

Negotiations advanced during 2007 to put in place GFR research projects on the integration, design and safety of GFR systems, as well as the fast neutron fuel, core materials and fuel cycle processes specific to the GFR system. The aim is to have an experimental technology demonstration reactor in place by 2020.

Lead-cooled fast reactor system (LFR)

The LFR system research plan, which sets out the research required on the system design, fuel and lead technology and materials, was updated in the course of 2007. The LFR plan incorporates two tracks of development leading to a single joint demonstration facility by 2018. Separate designs for a small, transportable LFR with a long core life and a moderate-sized power plant will be investigated in the demonstration facility.

Molten salt reactor system (MSR)

A draft system research plan for the MSR was updated during 2007. As part of the overall roadmap for the system's development, a scoping and screening phase will continue until 2011. At that point, confirmation of the potential of salt (selection, properties and compatibility with other materials) will have been established. The selection of reference designs will be made by 2018, when the project will move into its performance phase.

Sodium-cooled fast reactor system (SFR)

In addition to the project arrangement signed on advanced fuel in March, two others have since been signed in the areas of component design and balance-of-plant (CD&BOP) and the global actinide cycle international demonstration (GACID). The CD&BOP project aims to develop key components and devices of the plant system and to investigate safe and effective power conversion concepts. The GACID project sets out to demonstrate on a significant scale that fast neutron reactors can manage the whole actinide inventory.

Supercritical-water-cooled reactor system (SCWR)

A draft SCWR system research plan was completed in 2007. Project management boards have been established in the following areas: thermal-hydraulics and safety; materials and chemistry; and design and integration. Negotiations to put in place project arrangements for all these areas advanced significantly during 2007.

GNEP and GIF: Distinguishing features and dynamics

The Global Nuclear Energy Partnership (GNEP) is an international framework which aims to expand nuclear power worldwide while managing radioactive waste and reducing proliferation risks. The GNEP statement of principles recognises the GIF as a vehicle for multilateral R&D collaboration. The GNEP stated aim is to complement, not replace, existing co-operative mechanisms such as the GIF.

The GIF is focused on a future generation of nuclear energy systems, addressing both fuel cycles and reactor technologies. The GNEP is, in a sense, both more narrowly focused on nuclear energy systems that consume transuranic elements from recycled spent fuel, as well as more broadly focused on its objectives to enhance nuclear safeguards, establish international fuel services and promote nuclear energy in developing countries and regions. The GNEP plans to use the existing arrangements established within the GIF to carry out any R&D work in common. GIF members have indicated that they welcome the opportunity to carry out R&D on advanced nuclear energy systems in co-operation with the GNEP.

Very high temperature reactor system (VHTR)

A system research plan was put in place for the VHTR in 2007. Currently, project arrangements to study the following areas are in the final stages of negotiation: the development and validation of materials to be used in the VHTR system; associated fuels and fuel cycle issues; and the use of the VHTR system to produce hydrogen. The overall aim of these research efforts is to define the system's baseline concepts by 2010 and to optimise their design and operating features by 2015.

The NEA acts as the Technical Secretariat of the Generation IV International Forum. More information about the GIF is available at: www.gen-4.org. ■

Note

1. Current non-active members include Argentina, Brazil, South Africa and the United Kingdom. The latter intends to participate in the GIF activities through Euratom.

NEA joint projects: *nuclear safety, radioactiv*

NEA joint projects and information exchange programmes enable interested countries, on a cost-sharing basis, to pursue research or the sharing of data with respect to particular areas or issues in the nuclear energy field. The projects are carried out under the auspices, and with the support, of the NEA. All NEA joint projects currently under way are listed below.

Project	Participants	Budget
Behaviour of Iodine (BIP) Project Contact: carlo.vitanza@oecd.org Current mandate: July 2007-June 2010	Belgium, Canada, Finland, France, Germany, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 1 million
Cabri Water Loop Project Contact: carlo.vitanza@oecd.org Current mandate: 2000-2010	Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 60 milion
Computer-based Systems Important to Safety (COMPSIS) Project Contact: jean.gauvain@oecd.org Current mandate: January 2005-December 2007	Chinese Taipei, Finland, Germany, Hungary, Japan, Korea, Slovak Republic, Sweden, Switzerland, United States	€ 100 K /year
Co-operative Programme on Decommissioning (CPD) Contact: patrick.osullivan@oecd.org Current mandate: January 2004-December 2008	Belgium, Canada, Chinese Taipei, France, Germany, Italy, Japan, Korea, Slovak Republic, Spain, Sweden, United Kingdom	≈€ 60 K /year
Fire Incidents Records Exchange (FIRE) Project Contact: jean.gauvain@oecd.org Current mandate: January 2006-December 2009	Canada, Czech Republic, Finland, France, Germany, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, United States	≈€ 91 K /year
Halden Reactor Project Contact: carlo.vitanza@oecd.org Halden contact: Fridtjov.owre@hrp.no Current mandate: January 2006-December 2008	Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Japan, Korea, Norway, Russia, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 15 million /year
Information System on Occupational Exposure (ISOE Programme) Contact: brian.ahier@oecd.org Current mandate: 2002-2007	Armenia, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Korea, Lithuania, Mexico, Netherlands, Pakistan, Romania, Russia, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States	≈€ 370 K /year
International Common-cause Data Exchange (ICDE) Project Contact: jean.gauvain@oecd.org Current mandate: April 2005-March 2008	Canada, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 140 K /year

e waste management, radiological protection

At present, 14 joint projects are being conducted in relation to nuclear safety, two in support of radioactive waste management and one in the field of radiological protection. These projects complement the NEA programme of work and contribute to achieving excellence in each of the respective areas of research.

Objectives
• Provide separate effects and modelling studies of iodine behaviour in a nuclear reactor containment building following a severe accident. • Provide data and interpretation from three radioiodine test facility (RTF) experiments to participants for use in collaborative model development and validation. • Achieve a common understanding of the behaviour of iodine and other fission products in post-accident reactor containment buildings.
• Extend the database for high burn-up fuel performance in reactivity-induced accident (RIA) conditions. • Perform relevant tests under coolant conditions representative of pressurised water reactors (PWRs). • Extend the database to include tests done in the Nuclear Safety Research Reactor (Japan) on BWR and PWR fuel.
• Define a format and collect software and hardware fault experience in computer-based, safety-critical NPP systems in a structured, quality-assured and consistent database. • Collect and analyse COMPSIS events over a long period so as to better understand such events, their causes and their prevention. • Generate insights into the root causes of and contributors to COMPSIS events, which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for efficient feedback of experience gained in connection with COMPSIS events, including the development of defences against their occurrence, such as diagnostics, tests and inspections. • Record event attributes and dominant contributors so that a basis for national risk analysis for computerised systems is established.
• Exchange scientific and technical information amongst decommissioning projects on nuclear facilities.
• Collect fire event experience (by international exchange) in the appropriate format and in a quality-assured and consistent database. • Collect and analyse fire events data over the long-term with the aim to better understand such events, their causes and their prevention. • Generate qualitative insights into the root causes of fire events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for the efficient feedback of experience gained in connection with fire including the development of defences against their occurrence, such as indicators for risk-based inspections. • Record characteristics of fire events in order to facilitate fire risk analysis, including quantification of fire frequencies.
Generate key information for safety and licensing assessments and aim at providing: • extended fuel utilisation: basic data on how the fuel performs, both under normal operation and transient conditions, with emphasis on extended fuel utilisation in commercial reactors; • degradation of core materials: knowledge of plant materials behaviour under the combined deteriorating effects of water chemistry and nuclear environment, also relevant for plant lifetime assessments; • man-machine systems: advances in computerised surveillance systems, virtual reality, digital information, human factors and man-machine interaction in support of control room upgradings.
• Collect and analyse occupational exposure data and experience from all participants to form the ISOE databases. • Provide broad and regularly updated information on methods to improve the protection of workers and on occupational exposure in nuclear power plants. • Provide a mechanism for dissemination of information on these issues, including evaluation and analysis of the data assembled and experience exchanged, as a contribution to the optimisation of radiation protection.
• Provide a framework for multinational co-operation. • Collect and analyse common-cause failure (CCF) events over the long term so as to better understand such events, their causes and their prevention. • Generate qualitative insights into the root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for the efficient feedback of experience gained in connection with CCF phenomena, including the development of defences against their occurrence, such as indicators for risk-based inspections. • Generate quantitative insights and record event attributes to facilitate the quantification of CCF frequencies in member countries. • Use the ICDE data to estimate CCF parameters.

Project	Participants	Budget
Melt Coolability and Concrete Interaction (MCCI) Project Contact: carlo.vitanza@oecd.org Current mandate: April 2006-December 2009	Belgium, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Norway, Spain, Sweden, Switzerland, United States	€ 0.9 million /year
Piping Failure Data Exchange (OPDE) Project Contact: alejandro.huerta@oecd.org Current mandate: July 2005-July 2008	Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United States	≈ € 54 K /year
PRISME Project Contact: carlo.vitanza@oecd.org Current mandate: January 2006-December 2010	Belgium, Canada, Finland, France, Germany, Japan, Korea, Netherlands, Spain, Sweden	€ 7 million
Rig of Safety Assessment (ROSA) Project Contact: carlo.vitanza@oecd.org Current mandate: April 2005-December 2009	Belgium, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, United Kingdom, United States	€ 0.7 million /year
SESAR Thermal-hydraulics (SETH-2) Project Contact: jean.gauvain@oecd.org Current mandate: March 2007-December 2010	Czech Republic, Finland, France, Germany, Japan, Korea, Slovenia, Sweden, Switzerland	€ 0.8 million /year
Steam Explosion Resolution for Nuclear Applications (SERENA) Project Contact: carlo.vitanza@oecd.org Current mandate: October 2007-September 2011	Canada, Finland, France, Germany, Japan, Korea, Slovenia, Sweden, United States	€ 2.6 million
Stress Corrosion Cracking and Cable Ageing (SCAP) Project Contact: akihiro.yamamoto@oecd.org Current mandate: June 2006-June 2010	Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Korea, Mexico, Norway, Slovak Republic, Spain, Sweden, United States	€ 480 K /year
Studsvik Cladding Integrity Project (SCIP) Contact: carlo.vitanza@oecd.org Current mandate: July 2004-June 2009	Czech Republic, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	€ 1.4 million /year
Thermal-hydraulics, Hydrogen, Aerosols, Iodine (ThAI) Project Contact: carlo.vitanza@oecd.org Current mandate: January 2007-December 2009	Canada, Finland, France, Germany, Hungary, Korea, Netherlands, Switzerland	€ 2.8 million
Thermochemical Database (TDB) Project Contact: nea.tdb@oecd.org Current mandate: February 2003-January 2008	Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 400 K /year

Objectives
• Provide experimental data on melt coolability and concrete interaction (MCCI) severe accident phenomena. • Resolve two important accident management issues: – the verification that molten debris that has spread on the base of the containment can be stabilised and cooled by water flooding from the top; – the two-dimensional, long-term interaction of the molten mass with the concrete structure of the containment, as the kinetics of such interaction is essential for assessing the consequences of a severe accident.
• Collect and analyse piping failure event data to promote a better understanding of underlying causes, impact on operations and safety, and prevention. • Generate qualitative insights into the root causes of piping failure events. • Establish a mechanism for efficient feedback of experience gained in connection with piping failure phenomena, including the development of defence against their occurrence. • Collect information on piping reliability attributes and influence factors to facilitate estimation of piping failure frequencies, when so decided by the Project Review Group.
• Answer questions concerning smoke and heat propagation inside a plant, by means of experiments tailored for code validation purposes. • Provide information on heat transfer to cables and on cable damage.
• Provide an integral and separate-effect experimental database to validate code predictive capability and accuracy of models. In particular, phenomena coupled with multi-dimensional mixing, stratification, parallel flows, oscillatory flows and non-condensable gas flows are to be studied. • Clarify the predictability of codes currently used for thermal-hydraulic safety analyses as well as of advanced codes presently under development, thus creating a group among OECD member countries who share the need to maintain or improve technical competence in thermal-hydraulics for nuclear reactor safety evaluations.
• Generate high-quality experimental data that will be used for improving the modelling and validation of computational fluid dynamics (CFD) and lumped parameter (LP) computer codes designed to predict post-accident containment thermal-hydraulic conditions (for current and advanced reactor designs). • Address a variety of measured parameters, configurations and scales in order to enhance the value of the data for code applications. • Study relevant containment phenomena and separate effects, including effects of jets, natural convection, containment coolers and sprays.
• Provide experimental data to clarify the explosion behaviour of prototypic corium melts. • Provide experimental data for validation of explosion models for prototypic materials, including spatial distribution of fuel and void during the pre-mixing and at the time of explosion, and explosion dynamics. • Provide experimental data for steam explosions in more realistic, reactor-like situations to verify the geometrical extrapolation capabilities of the codes.
• Establish two complete databases on major ageing phenomena for stress corrosion cracking (SCC) and for degradation of cable insulation. • Establish a knowledge base by compiling and evaluating collected data and information systematically. • Perform an assessment of the data and identify the basis for commendable practices which would help regulators and operators to enhance ageing management.
• Assess material properties and determine conditions that can lead to fuel failures. • Improve the general understanding of cladding reliability at high burn-up through advanced studies of phenomena and processes that can impair fuel integrity during operation in power plants and during handling or storage. • Achieve results of general applicability (i.e. not restricted to a particular fuel design, fabrication specification or operating condition).
• Address outstanding questions concerning the behaviour of hydrogen (combustion and removal using recombiners), iodine and aerosols (wall deposition, wash-out and interaction) in severe accident situations. • Improve understanding of the respective processes for evaluating challenges to containment integrity (hydrogen) and for evaluating the amount of airborne radioactivity during accidents with core damage (iodine and aerosols). • Generate data for evaluating the spatial distribution of hydrogen in the containment, its effective removal by means of equipment such as passive autocatalytic recombiners, and slow hydrogen combustion.
Produce a database that: • contains data for elements of interest in radioactive waste disposal systems; • documents why and how the data were selected; • gives recommendations based on original experimental data, rather than on compilations and estimates; • documents the sources of experimental data used; • is internally consistent; • treats all solids and aqueous species of the elements of interest for nuclear waste storage performance assessment calculations.

Progress in the Multinational Design Evaluation Programme (MDEP)

As previously reported in *NEA News*,[1] the NEA was selected to perform the technical secretariat functions for Stage 2 of the Multinational Design Evaluation Programme (MDEP). The MDEP was set up to enable the sharing of resources and knowledge accumulated by national nuclear regulatory authorities during their assessment of new reactor designs, with the aim of improving both the efficiency and effectiveness of the process. Although its multinational dimension is part of its strength, a key concept of the MDEP is that national regulators will retain sovereign authority over all licensing and regulatory decisions.

Stage 2 of the MDEP focuses on enhanced multinational co-operation and convergence of codes, standards and safety goals. This includes trying to more closely align differing national regulatory frameworks in consideration of new reactor designs. The work was initiated by an MDEP2 Policy Group, chaired by Mr. André-Claude Lacoste, Director-General of the French Nuclear Safety Authority, at the end of 2006. Ten countries[2] are participating in the first phase of Stage 2, which is soon to be completed.

A one-year pilot project was undertaken at the beginning of MDEP Stage 2 to identify areas for potential convergence of regulatory requirements and enhanced co-operation among regulators. Two aspects were addressed: one broadly based on the licensing basis and safety goals, and another more specific one on component manufacturing oversight. The first was carried out by the MDEP Steering Technical Committee (STC), while a working group was formed to carry out the second.

To work effectively, the Steering Technical Committee focused its attention on the regulatory requirements, programmes and practices in three selected areas: severe accidents, emergency core cooling systems (ECCS) performance, and digital instrumentation and control (I&C). The working group limited the scope of its studies to the highest safety class pressure boundary components (e.g., pumps, valves, piping and pressure vessels). At the start, each of the groups followed similar approaches in that they used surveys and analysed the results to develop a better understanding of the current state of affairs.

Based on initial survey results, the STC concluded that additional meetings of technical experts in each of the three specific areas were necessary to provide more complete information on the regulatory policies and practices in each country and to pinpoint similarities and differences. In addition, a separate expert group met to look at generic issues across the three areas. Each of the expert groups looked at a number of specific aspects and categorised the existing level of similarity (high, moderate or low), and performed a cost-benefit analysis to determine the feasibility of convergence.

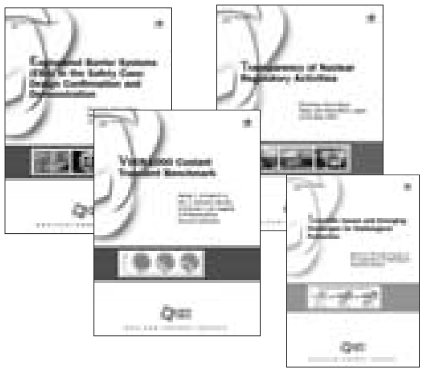
For its part, the working group focused on the use of codes and standards, quality assurance/management programmes, inspection programmes by the manufacturer, designated third-party inspection agencies and the regulatory authority. In addition to the survey and group discussions, the group communicated with, and met with, other interested and affected parties including vendors and codes and standards organisations. Group members were also in contact with manufacturers.

The results from the expert groups and the working group were discussed at a fall meeting of the STC, and were used to develop a broad understanding of the regulatory activities in each country and to begin establishing a revised programme that will focus on enhanced co-operation on design evaluations and related inspections. The Steering Technical Committee is currently compiling this information into a final pilot project report, to be completed by January 2008. The Policy Group will then meet to review the report and determine the feasibility of initiating the next step, the MDEP Stage 2 Implementation Phase, during which it is envisaged that additional topics will be pursued. ■

Notes

1. NEA (2006), *NEA News*, No. 24.2, OECD/NEA, Paris.
2. Ten countries are participating in the first phase of MDEP Stage 2, of which seven are NEA members (*): Canada*, China, Finland*, France*, Japan*, the Republic of Korea*, the Russian Federation, South Africa, the United Kingdom* and the United States*. The International Atomic Energy Agency (IAEA) also takes part in the work of MDEP Stage 2.

New publications



Nuclear safety and regulation

Transparency of Nuclear Regulatory Activities

Workshop Proceedings,Tokyo and Tokai-Mura, Japan, 22-24 May 2007

ISBN 978-92-64-04095-3, 316 pages. Price: € 60, US$ 78, £ 43, ¥ 8 300.

One of the main missions of nuclear regulators is to protect the public, and this cannot be completely achieved without public confidence. The more a regulatory process is transparent, the more such confidence will grow. Despite important cultural differences across countries, a number of common features characterise media and public expectations regarding any activity with an associated risk. A common understanding of transparency and main stakeholders' expectations in the field of nuclear safety were identified during this workshop, together with a number of conditions and practices aimed at improving the transparency of nuclear regulatory activities. These conditions and practices are described in the proceedings, and will be of particular interest to all those working in the nuclear regulatory field. Their implementation may, however, differ from one country to another depending on national context.

Radiological protection

The Process of Regulatory Authorisation (English-Japanese version)

規制認可のプロセス

ISBN 978-92-64-99028-9, 148 pages. Free: paper or web.

In parallel to the work carried out by the International Commission on Radiological Protection (ICRP) to review the broad principles of protection, the NEA Committee on Radiation Protection and Public Health (CRPPH) has examined how radiological protection could be better implemented by governments and/or regulatory authorities. To this end, the CRPPH has developed a concept that it calls "the process of regulatory authorisation". It is described in detail in this report, and is intended to help regulatory authorities apply more transparently, coherently and simply the broad recommendations of the ICRP to the real-life business of radiological protection regulation and application. The CRPPH recognises the importance of an appropriate level of stakeholder involvement in the process of regulatory authorisation.

Scientific Issues and Emerging Challenges for Radiological Protection

Report of the Expert Group on the Implications of Radiological Protection Science

ISBN 978-92-64-99032-6. Free: paper or web.

Scientific knowledge is constantly evolving as more advanced technologies become available and more in-depth research is carried out. Given the potential implications that new findings could have on policy decisions, in 1998 the NEA Committee on Radiation Protection and Public Health (CRPPH) performed a survey of state-of-the-art research in radiological protection science. This study suggested that, while the current system of radiological protection was well-underpinned by scientific understanding, growing knowledge in several areas could seriously impact policy and regulation. Ten years later, the CRPPH has again performed a survey of state-of-the-art research which reiterates and clarifies its earlier conclusions.

This report summarises the results of this latest CRPPH assessment of radiological protection science. Specifically, it explains that knowledge of non-targeted and delayed effects, as well as of individual sensitivity, have been significantly refined over the past ten years. Although at this point there is still no scientific certainty in these areas, based on the most recent studies and results, the report strongly suggests that policy makers and regulatory authorities should consider possible impacts that could arise from research in the next few years. Further, the report identifies research areas that should be supported to more definitively answer scientific questions having the most direct impacts on policy choices.

Radioactive waste management

Engineered Barrier Systems (EBS) in the Safety Case: Design Confirmation and Demonstration

Workshop Proceedings, Tokyo, Japan, 12-15 September 2006

ISBN 978-92-64-03995-7, 150 pages. Price: € 45, US$ 58, £ 32, ¥ 6 200.

The presence of several barriers serving complementary safety functions enhances confidence that radioactive waste placed in deep geological repositories will be adequately isolated and contained to protect human health and the environment. The barriers include the natural geological barrier and the engineered barrier system (EBS). The EBS itself may comprise a variety of sub-systems or components, such as the waste form, container, buffer, backfill, seals and plugs. Given the importance of this subject, the Integration Group for the Safety Case (IGSC) of the OECD Nuclear Energy Agency (NEA) sponsored a series of workshops with the European Commission to develop greater understanding of how to achieve the necessary integration for the successful design, testing, modelling and performance assessment of EBS for deep underground disposal of radioactive waste.

These proceedings present the main findings from, and the papers delivered at, the fourth NEA-EC workshop on EBS, which took place in Tokyo, Japan, in September 2006. This final workshop of the series focused on strategies and methods to demonstrate that EBS designs will fulfil the relevant requirements for long-term safety, engineering feasibility and quality assurance. The workshop highlighted that large-scale experiments have confirmed the feasibility of techniques for manufacturing and installing engineered components in disposal systems and have also provided valuable lessons to improve designs and refine practical aspects to construct and implement EBS.

Radioactive Waste Management in Spain: Co-ordination and Projects

FSC Workshop Proceedings, L'Hospitalet de l'Infant, Spain, 21-23 November 2005

ISBN 978-92-64-03941-4, 142 pages. Price: € 40, US$ 52, £ 28, ¥ 5 500.

The sixth workshop of the OECD/NEA Forum on Stakeholder Confidence (FSC) was hosted by ENRESA, the Spanish agency responsible for the management of radioactive waste and the dismantling of nuclear power plants, and the Council of Nuclear Safety (CSN), with the support of the Association of Spanish Municipalities in Areas Surrounding Nuclear Power Plants (AMAC). The workshop took place at L'Hospitalet de l'Infant, Catalonia, Spain, on 21-23 November 2005. At this workshop, Spanish stakeholders and delegates from 14 countries discussed current co-ordination of radioactive waste management decision making in Spain. Findings were shared from Cowam-Spain, a co-operative research project on the involvement of local stakeholders, the relationship between national and local levels of decision making, and the long-term sustainability of decisions regarding the siting of a centralised interim storage facility for high-level waste. These proceedings include the workshop presentations and discussions, as well as the rapporteurs' reflections on what was learned about policy making and participative decision making.

Nuclear law

Nuclear Law Bulletin

ISSN 0304-341X. Yearly subscription (two issues): € 99, US$ 125, £ 68, ¥ 13 400.

Considered to be the standard reference work for both professionals 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 in both English and French, it covers legislative developments in almost 60 countries around the world as well as reporting on relevant jurisprudence and administrative decisions, international agreements and regulatory activities of international organisations.

Nuclear science and the Data Bank

Actinide and Fission Product Partitioning and Transmutation

Ninth Information Exchange Meeting, Nîmes, France, 25-29 September 2006

ISBN 978-92-64-99030-2, 752 pages. Free: paper or web.

Partitioning and transmutation (P&T) has the potential of significantly reducing the radiotoxicity of nuclear waste and thus minimising the amount of it that needs to be stored in deep geological repositories. In order to provide experts with a forum to present and discuss developments in the field of P&T, since 1990 the OECD Nuclear Energy Agency (NEA) has been organising biennial information exchange meetings on actinide and fission product partitioning and transmutation. These proceedings contain all the technical papers and posters presented at the Ninth Information Exchange Meeting, which was held on 25-29 September 2006 in Nîmes, France. The meeting covered such issues as progress in fuels and targets, partitioning and waste forms, spallation targets, dedicated transmutation systems, coolants, and physics and nuclear data. In addition, the integration of P&T programmes within different fuel cycle strategies was discussed, as well as the potential transmutation of waste in Generation IV reactors. The implications for waste management strategies, in particular for geological disposal, were also explored. More than 100 papers were presented during the meeting.

Assessment of Fission Product Decay Data for Decay Heat Calculations

International Evaluation Co-operation, Volume 25

ISBN 978-92-64-99034-0, 60 pages. Free: paper or web.

This publication presents the conclusions of the work undertaken by Subgroup 25 of the NEA Working Party on International Evaluation Co-operation, which focused on the assessment and improvement of the evaluated decay data sub-libraries in order to obtain more accurate estimations of decay heat. Recommendations have been prepared for total absorption gamma-ray spectroscopy (TAGS) measurements of specific fission product nuclides to be undertaken in close collaboration with experimentalists in Subgroup 25.

Chemical Thermodynamics of Solid Solutions of Interest in Nuclear Waste Management - Volume 10

A State-of-the-art Report

ISBN 978-92-64-02655-1, 288 pages. Price: € 80, US$ 104, £ 57, ¥ 11 100.

This volume provides a state-of-the-art report on the modelling of aqueous-solid solution systems by the combined use of chemical thermodynamics and experimental and computational techniques. These systems are ubiquitous in nature and therefore intrinsic to the understanding and quantification of radionuclide containment and retardation processes present in geological repositories of radioactive waste. Representative cases for study have been chosen from the radioactive waste literature to illustrate the application of the various approaches. This report has been prepared by a team of four leading experts in the field under the auspices of the OECD/NEA Thermochemical Database (TDB) Project. The team comprised Jordi Bruno (Enviros, Spain), Dirk Bosbach (FZK, Germany), Dmitrii Kulik (PSI, Switzerland) and Alexandra Navrotsky (UC Davis, USA).

JANIS-3.0 (DVD)

Free on request.

The goal of the NEA Data Bank is to be the international centre of reference for its member countries with respect to basic nuclear tools, such as computer codes and nuclear data, used for the analysis and prediction of phenomena in the nuclear field; and to provide a direct service to its users by developing, improving and validating these tools and making them available as requested. JANIS (Java-based nuclear information software) is a display program designed to facilitate the visualisation and manipulation of nuclear data. Its objective is to allow the user of nuclear data to access numerical values and graphical representations without prior knowledge of the storage format. It offers maximum flexibility for the comparison of different nuclear data sets.

VVER-1000 Coolant Transient Benchmark

Phase I (V1000CT-1), Vol. 3: Summary Results of Exercise 2 on Coupled 3-D Kinetics/Core Thermal-hydraulics

ISBN 978-92-64-99035-7, 92 pages. Free: paper or web.

In the field of coupled neutronics/thermal-hydraulics computation there is a need to enhance scientific knowledge in order to develop advanced modelling techniques for new nuclear technologies and concepts, as well as current applications. Recently developed best-estimate computer code systems for modelling 3-D coupled neutronics/thermal-hydraulics transients in nuclear cores and for the coupling of core phenomena and system dynamics need to be compared against each other and validated against results from experiments. International benchmark studies have been set up for this purpose. The present volume is a follow-up to the first two volumes. While the first described the specification of the benchmark, the second presented the results of the first exercise that identified the key parameters and important issues concerning the thermal-hydraulic system modelling of the simulated transient caused by the switching on of a main coolant pump when the other three were in operation. Volume 3 summarises the results for Exercise 2 of the benchmark that identifies the key parameters and important issues concerning the 3-D neutron kinetics modelling of the simulated transient. These studies are based on an experiment that was conducted by Bulgarian and Russian engineers during the plant-commissioning phase at the VVER-1000 Kozloduy Unit 6. The final volume will soon be published, completing Phase 1 of this study.

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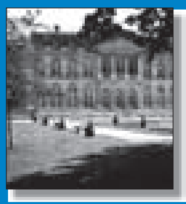

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