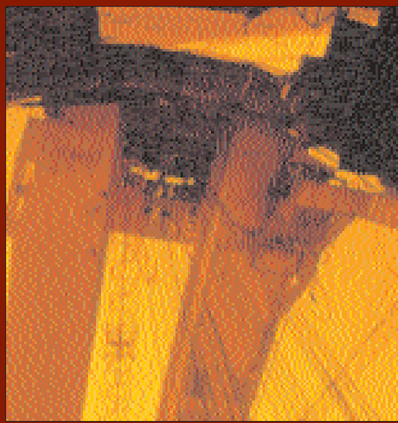
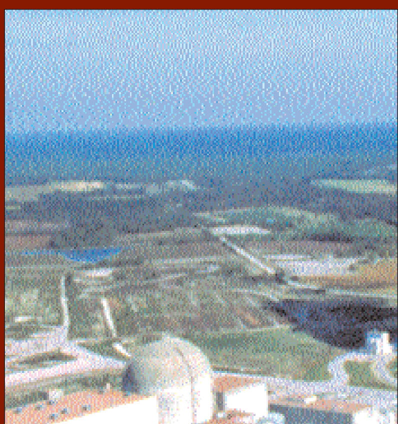
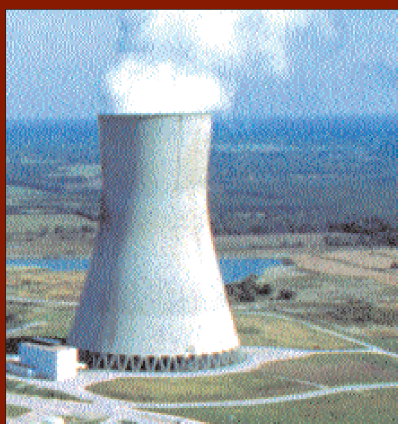
# NEA News

2001 – No. 19.2









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NUCLEAR • ENERGY • AGENCY

# NEA News

## contents

2001 – No. 19.2

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The OECD Nuclear Energy Agency (NEA) was established in 1958 as the OEEC European Nuclear Energy Agency and took its present designation in 1972 when its membership was extended to non-European countries. Its purpose is to further international co-operation related to the safety, environmental, economic, legal and scientific aspects of nuclear energy. It currently consists of 27 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, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the NEA's work and a co-operation agreement is in force with the International Atomic Energy Agency.

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*Cover page: The inside of a cooling tower of the Asco nuclear power plant, Spain (credit: Empresarios Agrupados SA); the Callaway nuclear power plant, United States (credit: Union Electric Co.).*

## Facts and opinions

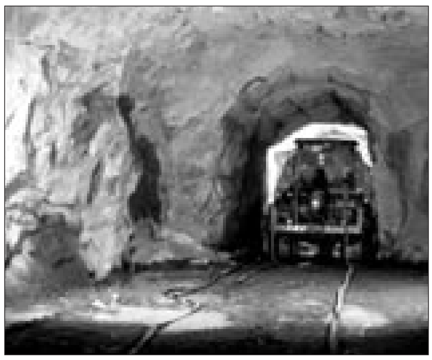


## NEA update

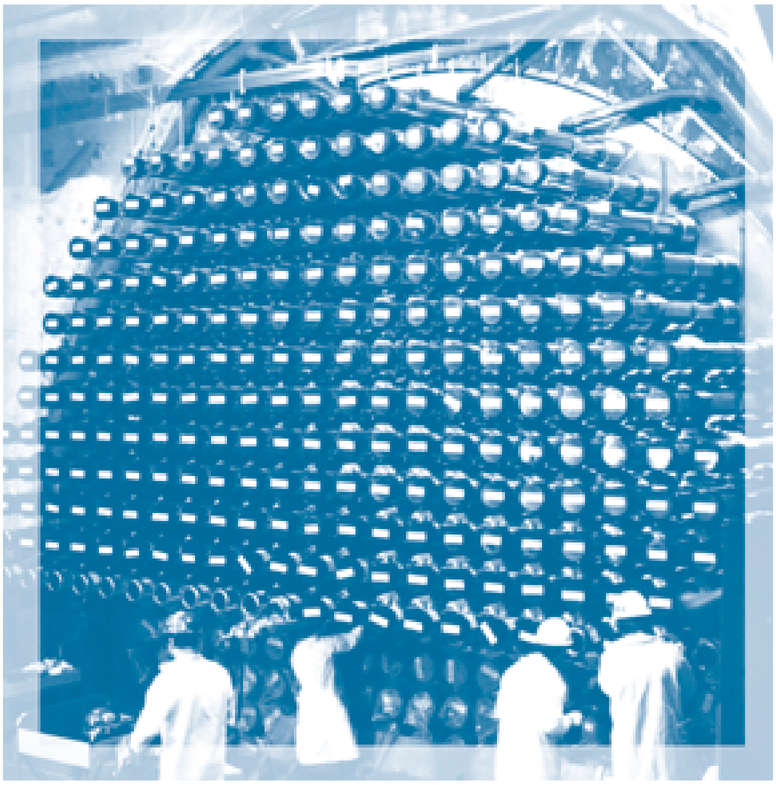


## News briefs





# editorial



AECL, Canada

Installation of fuel rods at the Gentilly 2 nuclear power plant, Canada.

# *The future of nuclear power*

*A number of NEA Member countries have been showing renewed interest in nuclear power over the past year or so. The reasons for this are well known: a broader recognition in public and political circles that nuclear energy produces negligible amounts of greenhouse gases, can ensure a baseload energy supply at stable prices, and is unaffected by regional disruptions. Overall, there is growing recognition that nuclear energy use, when properly regulated and managed, can be compatible with sustainable development objectives.*

*Countries pursuing the nuclear energy option are therefore beginning to seriously plan ahead and to investigate developments that may further improve the competitiveness and sustainability of nuclear generating systems in the medium to long term. The NEA has just completed a study addressing trends in the nuclear fuel cycle, the main conclusions of which are reported herein. The Agency is also involved in the Generation IV International Forum (GIF), a large-scale international project presently involving nine countries, which was launched by the United States to look into new designs for the "fourth generation" of nuclear reactors to be built in some 30 years from now (see page 8).*

*At the same time, however, our industrialised societies are increasingly confronted with the difficult issue of risk acceptance and management. As there is no guaranteed zero risk – whether with nuclear power plants or any other installation of an industrial nature – it is only via clearly understood and accepted trade-offs that an agreed-upon level of risk can be established in exchange for identified benefits. Addressing risk in a socially acceptable way will be important to the future use of nuclear energy. This issue of risk, and its implications for radiation protection decision making, are addressed in the article entitled "Radiation protection in a social perspective".*

*Ensuring continuing high levels of safety and reliability in the nuclear industry will require maintaining solid nuclear energy infrastructures, technological know-how and research capabilities as well as human competence. At a recent international gathering organised by the NEA (see page 16), senior officials from NEA Member countries and industry joined together to address the vital contribution that effective research infrastructure provides. They agreed to a collective statement to this effect.*

Luis E. Echávarri
NEA Director-General

G. Pauluis, L. Van den Durpel*

# Trends in the nuclear fuel cycle

## Economic, environmental and social aspects

**Nuclear energy has been part of the world's energy mix for almost fifty years. However, over the past thirty years increased public concern over this form of energy has resulted in socio-political constraints on its use. At the same time, while over these past thirty years the world was able to cope with an increasing energy demand by relying more on fossil fuels, growing consideration for achieving sustainable development and alleviating climate change has led to renewed interest in the potential role of nuclear energy in the world's future energy supply mix.**

The role of nuclear energy in a sustainable energy future has multiple facets, a significant number of which relate to the nuclear fuel cycle. Indeed, many sustainability issues are associated with the fuel cycle: use of natural resources, economics, waste arisings, public acceptance, proliferation resistance, to name only a few. In addition, the development of new reactor types with improved characteristics in some of those aspects generally will entail concurrent positive developments in the related fuel cycle.

It is therefore generally agreed that a fresh look at the nuclear fuel cycle options may be worthwhile in order to investigate the possible interactions between the different fuel cycle steps and technology choices. In that respect, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) created an expert group in 1998 to prepare a report on the developments and trends in the nuclear fuel cycle that may improve the competitiveness and sustainability of nuclear generating systems in the medium to long term. The expert group comprised representatives of the nuclear industry, government agencies and research organisations involved in various aspects of nuclear fuel cycle development. The report will be available by the end of 2001.[1]

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### The nuclear fuel cycle in perspective

The nuclear fuel cycles in use today are the result of four decades of technological development aiming at the establishment of a reliable, secure, safe and cost-effective energy source. However, the basic elements of these fuel cycles were established early in this period, when the "ground rules" and development objectives were different from those existing today. Many decisions made at that time still affect the fuel cycle industry today. To meet the needs of an already large military programme, and given the anticipated rapid growth of nuclear production, large fuel cycle facilities were constructed for the mining, conversion and enrichment stages of the fuel cycle, and reprocessing facilities were constructed to provide plutonium for fuelling the expected introduction of breeder reactors. The slowdown in civilian nuclear power programmes that has occurred since the 1980s, together with the agreements reached for reducing nuclear weapons programmes, has led to the current situation where the production capacities of fuel cycle facilities, with the exception of uranium mining, exceed demand.

Current demand for natural uranium amounts to around 60 000 tonnes per year. Stockpiles and known uranium resources could cover some 60 years of consumption by present reactors, and the actual uranium resources are thought to be much larger. Conventional uranium resources are estimated to be about 15 million tonnes, representing some 250 years of present consumption.[2] With such reserve levels and given the uncertain future for new nuclear power plant construction, there is currently little economic incentive to explore for uranium. Additional resources might be found by extracting uranium from seawater (some 4 000 million tonnes), a virtually unlimited supply, provided its development would become economically viable and environmentally acceptable. Less uranium resources would be necessary if use was made of recycling, fast breeder reactors or thorium.

While the availability of uranium may not constitute a constraint to using nuclear energy on a larger scale, other fuel cycle steps, e.g. waste disposal, may become limiting factors and will require fuel cycle choices in the coming decade.

Several technological developments have therefore been initiated over the past decades, both at the front-end and the back-end of the nuclear fuel cycle. Some of these developments are part of a longer term endeavour, such as complete recycling. Other short-term, ongoing industrial development programmes include important elements for further reductions in cost and environmental impact. For example, new uranium mining techniques have been developed and environmental measures adopted to reduce the impacts of the extraction and processing of uranium to very low levels, comparable to natural background radioactivity. In the field of uranium enrichment, the development of centrifuge technology has led to a reduction of costs mainly due to a reduction of


Energy Resources of Australia Ltd.

Determining ore grade with a radiometric discriminator at the Ranger Mine in Australia.

the energy consumption by a factor of fifty as compared to gas diffusion technology. This process will likely dominate the enrichment field in the medium term. However, laser enrichment should not be ruled out in the longer term, as it allows for even greater economy and selective re-enrichment of reprocessed uranium.

There is continuous improvement towards higher performance, reliability and safety of fuel design and fabrication. Fuel optimisation addresses the integration of front-end and back-end issues together with improving the operational performance of the nuclear power plants. In that respect, innovative fuel forms are in development, partly in the framework of a life-cycle approach, to bring about reductions in spent fuel quantities, and hence long-term liabilities, better resource conservation, and at the same time improvements in plant availability and reductions in fuel cycle costs.

While the economic merit of reprocessing may vary over time, it has the potential of reducing the consumption of uranium as well as the amount of waste to be disposed of and its overall radiotoxicity. Further towards the back-end of the fuel cycle, the waste disposal solutions proposed today are mainly country specific. Several solutions have been proposed for the final disposal of high-level, long-lived waste, reaching a stage of advancement where the scientific and technical experts feel confident in their feasibility and safety. However, limited social and political consensus has postponed the implementation of these solutions.

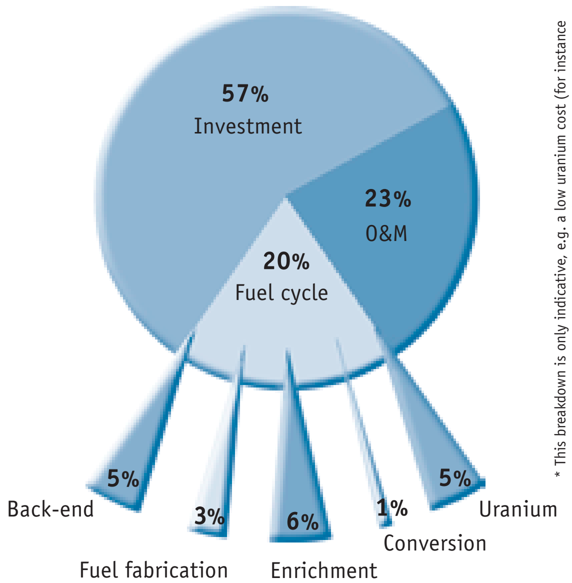
Two additional waste management options often discussed in public and scientific debates today are the extended storage of the waste (rather than irretrievable disposal) and the partitioning and transmutation of the long-lived radionuclides contained within the waste. Partitioning and transmutation involves processing the waste to extract the long-lived radionuclides, especially the minor actinides, which are then irradiated in a nuclear reactor system to yield products with shorter half-lives, thereby reducing the time required for their isolation from the environment. Special industrial facilities would have to be built and operated over long time periods in order to achieve this result. In any case, it is recognised that it would not be feasible to apply this technique to all types of waste, such that some quantities of radioactive materials would still require long-term isolation. Although both options might be components of an overall waste management strategy, and extended storage over a few decades is already planned in some countries, neither option completely avoids the need for some sort of final disposal, such as a geologic repository. Scientists and managers responsible for developing waste management solutions therefore generally remain convinced that progress should continue to be made towards the implementation of permanent disposal.

Dry storage containers for spent nuclear fuel at the Doel nuclear power plant in Belgium.

Electrabel, Belgium

In the context of these fuel cycle developments, it should be noted that nuclear power has a very high degree of long-term stability with respect to the price of the raw material for nuclear fuel (uranium). The cost of the nuclear fuel cycle is about 20% of the total nuclear electricity generating cost, whereas fuel costs may represent up to 80% of fossil fuel electricity generation cost. It is also of particular importance to note that the costs of waste management and disposal, as well as the decommissioning of nuclear power plants and fuel cycle facilities, are already "internalised" in the costs of nuclear electricity production.

**Nuclear electricity generation cost breakdown***




* This breakdown is only indicative, e.g. a low uranium cost (for instance ≤USD 40/kgU) will result in an even lower fraction of the electricity generation cost.

Today, much of the current public opposition to nuclear energy is focused on the transport of spent fuel and high-level waste, in spite of the fact that the industry has accumulated more than 40 years of experience in this regard, without experiencing a single accident with radiological consequences to the public or the environment.

Only a small number of accidents with significant radiological consequences have occurred in OECD Member countries during the past 50 years in a few nuclear fuel cycle facilities. These events, while rare, call for continued strict compliance with regulatory requirements as well as quality management at every stage of the fuel cycle.

Proliferation risk has also been part of public and political concerns. An institutional safeguards regime has been established to prevent the diversion of material from the civil nuclear fuel cycle for military or terrorist purposes. New developments in reactor and nuclear fuel cycle technologies may also enhance the proliferation resistance of fuel cycle facilities, providing even greater protection from this type of diversion.

## Challenges for future development

Given today's market-driven environment, there is limited potential for industry to fund the long-term R&D needed to develop and implement advanced fuel cycles. Political pressure and competing budget priorities have worked to reduce nuclear R&D funding by governments as well. There are some signs that government funding may increase in the near future, but budget constraints are likely to limit the number of fuel cycle options that can be investigated.

Comprehensive planning that includes consideration of economic, environmental and social factors in a well-balanced and integrated comparative assessment of different options will become increasingly important in formulating and taking decisions on long-term R&D programmes and energy policies, including for nuclear power. Nuclear power faces major challenges with respect to the nuclear fuel cycle, including:

- Implementation of advanced reactor concepts and fuel cycles will remain a lengthy and expensive process. Multilateral or international co-operative R&D programmes will therefore become increasingly important in order to pool limited financial resources and obtain the benefits of synergy among R&D activities, thereby shortening the process that spans from concept to industrial reality. Indeed, there already are some examples of such co-operative activities, including the US-initiated Generation IV International Forum (GIF), the IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), and the multi-national interest in the Pebble Bed Modular Reactor (PBMR).
- Facilities for the final disposal of spent fuel and high-level waste should be put in place in order to demonstrate to the public that the industry is managing its wastes, and that the disposal systems, for which the necessary technologies already exist, can be operated with very limited impact on the environment.
- From a long-term perspective, it is important to further develop advanced reactors and fuel cycles, incorporating full recycling of actinides, in order to reduce the overall amount of waste requiring disposal or to reduce the necessary confinement times, as well as to improve the efficiency of using natural nuclear fuel resources.


TVO, Finland

Construction of a radioactive waste repository at Olkiluoto in Finland.

## Conclusion

The different developments, as analysed in the report, show that nuclear power has potential as a sustainable energy source. Governments and industry have already developed environmental protection measures in the nuclear fuel cycle, including transport, and continue to improve those measures. No major technical problems remain in the short term, and current fuel cycles may essentially be seen as a mature business activity with a very low impact on the environment in OECD countries. Ongoing technological developments offer various possibilities for using nuclear energy in a sustainable development context. The final choice essentially depends on socio-political considerations. In this respect, stakeholder participation will need to be improved and consensus sought if this industry is to develop its potential. ■

### Notes

1. NEA (2001), *Trends in the Nuclear Fuel Cycle: Economic, Environmental and Social Aspects*, OECD, Paris.
2. NEA and IAEA (2000), *Uranium 1999: Resources, Production and Demand*, OECD, Paris.

W.D. Magwood, IV*

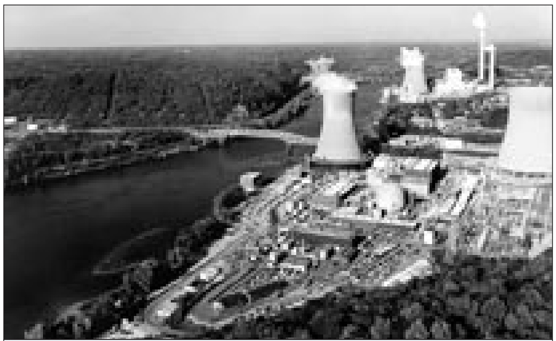
# A new US national energy policy

## The nuclear energy future

The United States was at the forefront of the development of commercial nuclear technology in 1954. During that historic year, the US Congress amended the Atomic Energy Act to allow the private ownership and operation of nuclear reactors. Very soon afterwards, the Atomic Energy Commission, or AEC (the Department of Energy's predecessor), established a co-operative power reactor demonstration programme with the electric utility industry which provided direct and sustained support for the construction of commercial nuclear power plants. On 18 March 1954, this initiative bore its first fruit when a contract was signed between the AEC and Pittsburgh-based Duquesne Light Company to construct Shippingport Station, the first commercial nuclear power plant in the United States.

This early, seminal accomplishment was the result of a clear vision developed at the highest reaches of the US government in the post-war years. This vision recognised the unique strategic and technological role nuclear technology would play in both civilian and security venues and saw that the commercialisation of that new technology was the key to American leadership in the latter half of the 20th century.

The internationalisation of markets has pushed industry to focus its attention on what past leaders of commerce would have thought was an astoundingly near-sighted vista. Worldwide, investment on long-term research and development by industry is falling. The eyes of chief executives are fixed more certainly than ever on the fluctuation of the markets rather than on the future technology needs of their industries. As a result, the role of government in creating long-term visions has become more important.



Shippingport Station, United States.

Over the last decade, at least in the area of nuclear energy, we in the United States may rightly be found lacking in recognising this important governmental role. In fact, it would not be excessive to suggest that in some years, it seemed that US policy had begun to formulate a future with no role for nuclear power. Funding for nuclear energy research and development plummeted in the United States through the 1990s. The US programme almost vanished entirely by 1997 and it lacked clear leadership, consistent purpose and adequate funds to accomplish its basic mission.

Fortunately, this situation has reversed in recent times. The realities of both the current market and the future need for nuclear power became clear and undeniable. At present, US nuclear power plants have achieved an outstanding safety record and have done so while producing more electricity than ever before – despite the closure of several nuclear plants in the 1980s and 1990s. Today, nuclear power plants provide some of the most

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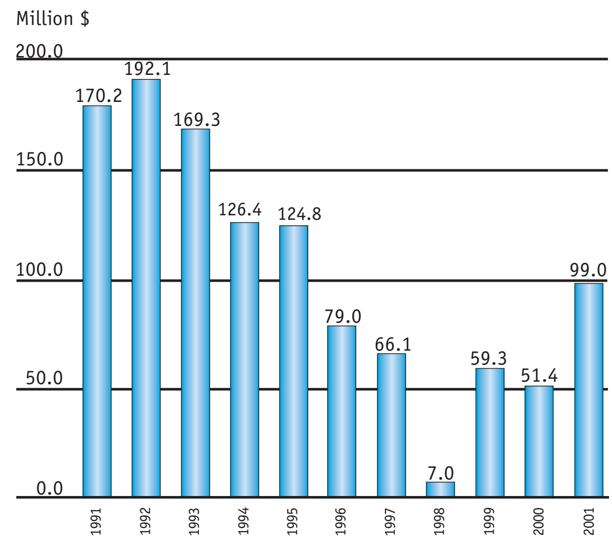
**Research and development budget history FY91-FY02**




* Does not include $34 million of funding for the APT budget which was funded by DP in FY 2001.

cost-effective electric energy available on the US grid. In terms of the future, consideration of the potential threat posed by carbon-dioxide emissions would lead to nuclear energy figuring largely in any realistic scenario to control emissions.

This rendezvous with reality benefited both the Department of Energy's nuclear energy programme and the outlook for industry consideration of new nuclear power plants. Both began looking healthier than at any time since the early 1990s. But US policy regarding the development of nuclear energy technology lacked the clear vision that made its growth possible in the 1950s.

This vacuum was finally filled earlier this year with the issuance of President Bush's *National Energy Policy* which: "*…recommends that the President support the expansion of nuclear energy in the United States as a major component of our national energy policy.*"

The *Policy* provides more detailed recommendations that encourage more efficient regulatory processes for relicensing existing nuclear power plants and constructing new ones, for developing advanced nuclear fuel cycles and next-generation reactor technologies, and for engaging with the international community to explore advanced spent fuel recycling technologies. Since its publication in May 2001, the *National Energy Policy* has provided strategic direction to the Department of Energy and other US Government agencies to plan and implement policies, practices, regulations and programmes to realise the President's vision for assuring a secure and reliable energy supply for the United States now and in the future. The challenge facing us now is to effectively implement this vision.

In the case of the Department of Energy's nuclear energy programme, this has taken the form of two key activities that will establish the basis for the programme over for the foreseeable future. These activities – *Nuclear Power 2010* and the *Generation IV Nuclear Energy Systems Initiative* – reflect the new thinking prompted by the *National Energy Policy* and the realities of nuclear energy research and development in today's world. These two key activities have been planned and initiated under the oversight of the Department's Nuclear Energy Research Advisory Committee's (NERAC) Subcommittee on Generation IV Technology Planning, led by Neil Todreas of the Massachusetts Institute of Technology and Sol Levy formerly of General Electric Company.

## Nuclear Power 2010

*Nuclear Power 2010* is a direct response to the call made in the *National Energy Policy* to support the expansion of nuclear power in the United States. Its goal, quite simply, is to promote the construction of new nuclear power plants in the United States before the end of this decade – with a strong preference that such projects begin before the end of 2005.

With this goal in mind, the Department of Energy is engaging industry in a wide-ranging, co-operative discussion regarding the ways this ambitious goal can be met. Fortunately, the Department has found willing partners in this quest. The Electric Power Research Institute (EPRI) is already working with its utility members to assess many aspects of new reactor technologies. On a more strategic level, the Nuclear Energy Institute (NEI) has issued its plan for the future called "Vision 2020". This plan calls for maintaining nuclear power's approximately 30% share for non-emitting energy technologies as US electricity demand increases by a projected 50% over the next two decades. Meeting this target would require an additional 10 000 MW of electric generation from improvements to existing US nuclear plants and 50 000 MW of electricity added to the US power supply from new nuclear plants, which translates to roughly 40 to 50 new nuclear power plants over the next 20 years.

In practical terms, this has led to the creation of a senior-level New Plants Task Force at the NEI, which is trying to identify and suggest solutions to the regulatory and business issues that industry must resolve to clear the way to build new nuclear power plants. In addition, other efforts are under way to plan for the development and implementation of near-term nuclear power technologies. These include Exelon's consideration of pebble bed modular reactor (PBMR) technology for deployment in the United States and the establishment of interested groups of potential utility buyers of General Atomics' Gas-Turbine-Modular Helium Reactor and Westinghouse's AP-1000. The Department of Energy is engaged in all of these activities, acting as a partner, an advisor and a technical resource as needed. The Department is also conducting research and development activities related to gas reactor technology and passive safety systems for large light water reactors and is working with the US Nuclear Regulatory Commission to develop a framework with which it can develop regulatory criteria for advanced gas-cooled reactors.

Importantly, all of these efforts factor into the *Nuclear Power 2010* effort. For example, many of the participants in the activities mentioned above play a direct role in the creation of the key planning document supporting *Nuclear Power 2010: A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010*. This roadmap, which will be issued by the end of 2001 by NERAC, represents the best thinking in the United States as to what specific steps need to be taken to enable the construction of new nuclear power plants on an aggressive schedule. The Group responsible for the document solicited input from and engaged extensively with technology vendors from all over the world. After a very open process, the Group identified eight reactor designs that served as the candidate technologies for deployment in the United States.

In general, this roadmap highlights co-operative industry-government efforts which should be initiated to enable industry to make business decisions to build new plants. The core of this co-operation would focus on three phases:

- demonstrating the as-yet untested regulatory tools currently in place in the United States to support deployment of new nuclear power plants;
- completing the detailed testing, engineering and planning necessary to deploy market-chosen technologies by 2010; and
- deploying new plants.

Achieving this goal will be of essential importance to the longer-term future. As it is true that without the demonstrable success in the operation

### Near-term deployment technologies

| Design | Supplier | Size and type | Key features |
|---|---|---|---|
| ABWR | GE | 1 350 MWe BWR | Advanced evolutionary LWR, design certified by NRC and built and operating in Japan. |
| SWR-1000 | ANP Framatome | 1 013 MWe BWR | Advanced BWR design, to meet European requirements. |
| ESBWR | GE | 1 380 MWe BWR with passive safety features | Based on earlier passive SBWR design, but higher in capacity and decreased in physical size per installed kWe. |
| AP-600 | Westinghouse | 610 MWe PWR with passive safety features | Advanced passive PWR, design certified by NRC. |
| AP-1000 | Westinghouse | 1 090 MWe PWR with passive safety features | Higher capacity version of AP-600, not yet certified. |
| IRIS | Westinghouse | 100-300 MWe PWR | Integral primary system plant design; eliminates classic LOCA accidents. |
| PBMR | ESKOM | 110 MWe modular pebble bed gas-cooled reactor | Modular direct cycle helium-cooled pebble bed design, currently planned for construction in South Africa. |
| GT-MHR | General Atomics | 288 MWe prismatic graphite moderated gas-cooled reactor | Modular direct cycle helium-cooled reactor being licensed for construction in Russia, for power production and disposition of excess Russian weapons-grade plutonium. |

**Evolution of nuclear power**

| 1950–1960 | 1970–1990 | 2000 | 2010–2020 | 2030 |
|---|---|---|---|---|
| **Generation I** | **Generation II** | **Generation III** | **Generation III+** | **Generation IV** |
| *Early prototype reactors*<br>Shippingport<br>Dresden, Fermi I<br>Magnox | *Commercial power reactors*<br>LWR-PWR, BWR<br>CANDU<br>VVER/RBMK | *Advanced LWRs*<br>ABWR<br>System 80+<br>AP-600<br>EPR | Generation III evolutionary designs offering improved economics | Highly economical<br>Enhanced safety<br>Minimised wastes<br>Proliferation resistant |

of current nuclear power plants over the last 20 years consideration of new reactors by 2010 would be impossible, so it is true that the consideration of longer-term technologies would be meaningless without the successful deployment of new nuclear plants during this decade. Without such deployment, the infrastructure in the United States that would be essential to the future – practical project experience, technical expertise, construction experience, educational infrastructure, etc. – is unlikely to survive into the second decade of the century.

## Generation IV

The Department of Energy is also applying unique mechanisms to implement the longer-term aspects of the *National Energy Policy*. The *Generation IV Nuclear Energy Systems Initiative* represents the belief in the United States – as well as other countries – that the next step in the evolution of nuclear power must be the result of a co-ordinated international effort. The paradigm of the simpler past, where governments and industries in several countries worked domestically to develop nuclear power systems for their home markets with an eye to potential exports, will not support the needs of an internationalised and more competition-driven future. No country will have the resources or the markets to support the development and implementation of technologies aimed only towards a domestic market. The internationalisation of the nuclear power and electric utility industries has made the older model even less practical. Future success depends upon co-operation and co-ordinated efforts.

Thus, the Generation IV initiative, though born in America, has quickly become an international effort. After the DOE's NERAC drafted the comprehensive, aggressive technology goals for next-generation systems, the nine-country Generation IV International Forum refined and accepted the goals and adopted them for its use. These goals – which provide challenging targets in areas of sustainability, safety and reliability, and economics – can be found on the DOE's website at www.nuclear.gov. Now, NERAC and the Forum are working together to apply these goals to scores of nuclear technology concepts identified and characterised by several international technical working groups that organise the efforts of more than 100 technical experts from a dozen countries. Next year, applying an agreed-upon methodology, this effort will identify approximately six concepts around which the members of the Generation IV International Forum will organise joint research projects. We hope to identify specific collaborative projects, many of which would be co-ordinated by the Nuclear Energy Agency, in a meeting of the Forum that will be held late next year.

## Conclusions

It is our objective to work with industry and our international partners to assure a bright future for nuclear energy, both in the United States and internationally. We believe that our efforts represent a solid beginning to the hard work of giving form to President Bush's vision. As it was true 45 years ago, it is true today that this effort will be neither easy nor inexpensive. But unlike the Eisenhower era, this stage of nuclear technology is free of the context of the Cold War. This fact will enable the widest practical co-operation to make advanced nuclear technologies available to the widest practical market. Only in this way, we believe, will nuclear energy truly have a bright, long-term future and be able to provide its benefits safely and economically to the people of an increasingly interdependent world. ■

T. Lazo*

# Radiological risks from a social perspective

**Contemporary society has become increasingly interested in actively participating in public decision making regarding health, safety and environmental protection issues. As governments have tried to better understand society's interests, and to better integrate societal needs in their decision-making processes, it has become possible to begin identifying common policy issues and lessons.**

Trends in the nuclear industry in respect of social considerations mirror those observed for broader governance questions. Within the radiological protection community, stakeholder issues have moved steadily to the forefront of policy discussions, and clearly form key elements in decisions regarding the development and implementation of radiological protection policy.

Society's interest in radiological risk identification, assessment and management issues is often reflected in the press. For example, significant coverage was given to the efforts recently made to investigate the role of depleted uranium in the "Gulf War Syndrome", and in what will no doubt be dubbed the Balkan War Syndrome. This was driven not by concerns from the radiation protection community, but from public and political concerns. Other recent examples of radiological situations that caught the eye of political leaders, the public and the press include:

- the OSPAR Sintra agreement, through which governments will attempt to reduce towards zero the concentrations of various radionuclides in the marine environment; and
- European discussions regarding surface contamination on spent nuclear fuel transport casks.

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On a more local scale, there are numerous cases of sites that have become, for one reason or another, radiologically contaminated. The management of these sites, which often includes clean-up activities aimed at releasing the site from radiological regulatory control, has in many national contexts attracted great interest from local populations, and from national and international NGOs.

These are concrete examples of the type of emerging radiation protection problems that can easily become front-page news and can incite considerable political and public interest. These situations are sometimes characterised by radiation protection professionals as "much ado about nothing" in terms of absolute risk. However, the political and public reactions to these situations illustrate quite clearly that, even though the "experts" may not feel that something is a problem, politicians and the public may feel quite differently.

## How clean is clean enough?

These types of situations tend to raise fairly difficult questions. For example, many sites contaminated by past industrial practices or accidents are in the process of being cleaned up, with the ultimate objective being to release the sites for unrestricted use. Such sites exist in many countries around the world. A key question raised here is, how clean is clean enough?

From the "classical" radiation protection standpoint, a differential cost-benefit analysis, or even a multifactorial analysis can be performed to determine the "optimum" radiation protection approach. This is possible because the absolute value of radiological risks can be estimated, as can the costs associated with the estimated health detriment (usually expressed as a number of cancers) that would result from this radiological risk. In this case, the optimisation would calculate the costs of clean-up activities such that residual contamination levels left in soil and in buildings remaining on the site would not be higher than some predetermined level, and in any case below current regulatory dose limits. From this level of residual contamination, the expected dose to various hypothetical groups living on the site after its release could be calculated, and the health detriment resulting from this exposure could be estimated. The "cost" of clean-up is then compared to the "cost" of the health detriment. Calculations are reiterated until these two costs are equal, and this is defined as the "optimum" radiation protection solution.

However, as with many types of risk in modern society, governments are less and less able to select "acceptable" levels of risk such as those calculated as above without having at the very least consulted the potentially effected public. What is judged to be "acceptable risk" by government and regulatory organisations may be seen by that public as being totally unacceptable.

## The boundary between science and acceptance

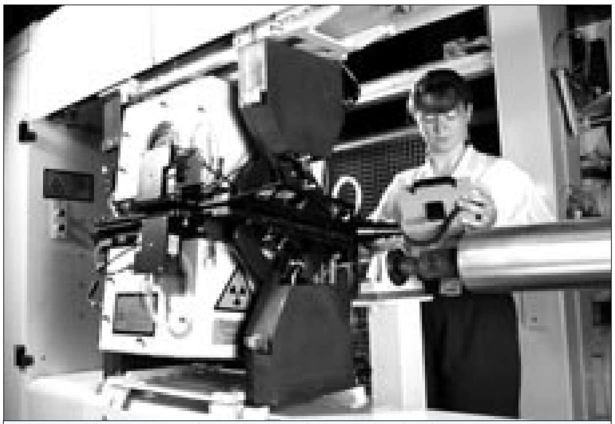
The clear lesson that can be drawn from this is that there is a great need to more clearly recognise the boundaries between the scientific aspects of risk assessment, the social aspects of risk identification and management, and the regulatory aspects of risk management. The question, "how clean is clean enough", is not a scientific question, but a social question. Other questions that need to be asked in this context include:

- How do regulators and governments share the responsibility of making *social judgements* with regard to what is *an acceptable risk*?
- How can the regulator, who is often charged with making these judgements on behalf of the government, develop a *process* that leads to decisions that are sufficiently *open* and *transparent*, while at the same time maintaining *independence*?
- How do regulators judge and balance the needs of often competing interests, such as industry, local public groups, national and international environmental NGOs, and even government officials/politicians from other ministries?

Although it is clear that these questions have no single answer, the radiation protection community is working towards a better understanding of the decision processes that have been accepted by stakeholders, and towards a clearer understanding of the roles and responsibilities of the various stakeholders in these processes.

The radiation protection system has evolved over the years. The photos here show workers in the 1970s checking for release of toxic material during cutting-up operations on steelwork, and sampling firebrick from a demolished furnace at Harwell in the United Kingdom.

UKAEA, United Kingdom


National Radiation Protection Board, United Kingdom

Measuring radiation levels near a thickness gauge in a paper mill.

## The process of stakeholder involvement

There is widespread recognition within the radiation protection community, in a number of countries, that there are new, inclusive processes that enhance the way policy is developed and implemented. A striking feature of innovative, open and democratic examples of stakeholder involvement in decision making is, however, the extent to which approaches have been developed by and large in an ad hoc manner in response to the needs of a given situation. At a workshop organised by the NEA on "Better Integration of Radiation Protection in Modern Society", the various approaches that were presented could be characterised as having been largely successful as a result of the commitment of all the stakeholders to the various processes. Beyond that, some of the key factors of "success" identified were that policy and its implementation must:

- develop context-specific approaches;
- include guiding principles for the development of innovative approaches;
- involve representation from all perspectives on the issue;
- clarify the roles of all stakeholders in decision-making processes;
- foster a better understanding, among stakeholders, of the nature of scientific rationale;
- foster mutual trust, and a mutual learning attitude among stakeholders; and
- adopt an explicitly learning orientation.

## Policy-level implications

The need to make distinctions between the scientifically calculated and the publicly accepted aspects of risk has implications at the international and national levels. These distinctions imply that many situations must be resolved in a case-by-case fashion, and as such, international recommendations must be flexible enough to give governments and regulators the latitude to develop national regulation that can appropriately address local situations. At the same time, governments need internationally agreed-upon criteria such that a homogeneous approach can be taken to issues with international implications.

This international level of agreement is represented by the system of radiation protection as recommended by the International Commission on Radiological Protection (ICRP). Since its inception in 1928, the ICRP has periodically issued "general" recommendations that describe how the public and workers should be protected from the harmful effects of ionising radiation. Its latest recommendations, ICRP Publication 60, were issued in 1990, but the ICRP is currently working on the development of a new set of recommendations due to be published towards 2005.

ICRP Publication 60 recommendations currently provide a somewhat classical approach to radiation protection. Numerical dose limits for the public and for workers are recommended, as well as various other numerical criteria. In the light of societal interest in participation, however, the selection of such numerical criteria should really

A member of the environmental team from the IAEA International Chernobyl Assessment Project collecting vegetable samples at Trakovichi, Ukraine.


Vadim Mouchkin, IAEA, Vienna, Austria


Energy Resources of Australia Ltd.

Measuring levels of radon gas in the atmosphere at a uranium mine.

be based on consensus among the stakeholders, not only on science. But practically speaking, governments have broadly expressed their satisfaction with the dose limits recommended by the ICRP, noting that international technical (or scientific) consensus on such numbers is increasingly useful, particularly because of globalisation and increased worker and public mobility.

On the other hand, other numerical guidance, most notably that related to criteria for the release of sites and materials from radiological regulatory control, has been more socially controversial. As pointed out above, it is increasingly recognised that flexibility is needed when addressing local situations and local stakeholder views and needs. As such, discussions are ongoing regarding how international recommendations should be developed to allow the desired flexibility.

At the national level, this flexibility will most likely find its way into laws and regulations. This may take the form of guidance with regard to, for example, numerical levels above which activities such as unrestricted site and materials release will not be allowed, but below which some sort of optimisation process is required. In addition, in recognition of the need for stakeholder involvement in the decision-making process, the approach to optimisation may be defined so as to require some level of consultation. Again, approaches are currently being studied at the national and international levels.

## The NEA contribution

The NEA Committee on Radiation Protection and Public Health (CRPPH) is working towards building consensus on a way forward in both the areas of international radiation protection recommendations and approaches to stakeholder involvement. In 2000 it published a report entitled *A Critical Review of the System of Radiation Protection: First Reflections of the CRPPH*. This work identified several areas in which the current system of radiation protection should be reviewed and improved, and provided guidance with respect to directions that might be further explored. A more detailed proposal has since been developed, prioritising the areas identified in the previous report, and providing specific suggestions for improvement. This second report on the modernisation of the system of radiation protection will be published in early 2002. In addition, to show whether the suggested changes do "more good than harm", and would genuinely improve the current system, a series of case studies will be developed to "road test" the new suggestions. A workshop in late 2002 will be organised to audition these ideas and to present road-test results. The conclusions, representing regulatory and operational consensus within NEA Member countries, will be offered to the ICRP for consideration in its development of new recommendations.

Progress has also been made in the area of stakeholder involvement and has been documented in the Committee's 1994 Collective Opinion *Radiation Protection Today and Tomorrow*, the proceedings of the workshop on *The Societal Aspects of Decision Making in Complex Radiological Situations* (OECD, 1998) and of another workshop on *Better Integration of Radiation Protection in Modern Society* (OECD, 2001). Material developed during these workshops, which were held in Villigen, Switzerland, will be used as a source from which to draw policy lessons and implications, as well as practical examples of good practice. Because cultural differences are so important to the stakeholder involvement process, a regional approach will be taken to catalogue good practice, focusing on North America, Europe and Asia. Based on this, a third workshop will be organised in the 2003 time frame.

G. Frescura, B. Kaufer*

# The role of research in a nuclear regulatory context

In the present context of deregulation and privatisation of the nuclear industry, maintaining an adequate level of nuclear safety research is a primary concern for nuclear regulators, researchers and nuclear power plant licensees, as well as for government officials and the public. While these different stakeholders may have common concerns and interests, there may also be differences. At the international level, it is important to understand that divisions exist both within and among countries, not only in national cultures but also in the way regulators, researchers and licensees view the role of research.

An international gathering took place in June 2001 under the auspices of the OECD Nuclear Energy Agency (NEA), bringing together heads of nuclear regulatory bodies of NEA Member countries, senior regulators, senior executives of research organisations and leaders from the nuclear industry to discuss their perceptions of the role of research in a nuclear regulatory context.

## Background

The international nuclear community has been concerned for some time about the ability of countries to sustain an adequate level of safety research. In recent years, both government and industry funding of research has decreased in many countries. There is a tendency for governments to believe that nuclear technology is mature and therefore increased reliance should be placed on the industry to fund the necessary research. Industry, in turn, has often reduced its involvement in funding safety research because there is little commitment to building new plants and there is a belief that the research needed to operate existing plants and to prevent and manage possible accidents is largely complete. Furthermore, electricity market competition has tended to focus the industry's attention on short-term profitability, sometimes at the expense of long-term research.

Excessive reductions in safety research lead to losses in the safety knowledge base, the consequent loss of research facilities and expertise, and the loss of academic interest in safety research. This in turn may affect the safe operation of existing nuclear power plants in the medium and long term, the ability of regulatory bodies to meet their obligations in a competent and independent manner and, ultimately, the ability to design and build new plants.

In general, the nuclear community is recognising that reductions in safety research may have gone too far, and efforts are under way to redress the situation. Several countries have conducted or are currently conducting studies to assess the research capability needed and are making arrangements to ensure that essential capability is available.

At the international level, the NEA Committee on the Safety of Nuclear Installations (CSNI) and the NEA Committee on Nuclear Regulatory Activities (CNRA) have been active since the early 1990s in looking into specific issues and promoting international co-operation to deal with the problem of maintaining adequate research capability. Starting in 1992, a Senior Group of Experts on Safety Research (SESAR) was established by the CSNI to review the status of nuclear safety research being carried out and to draw conclusions on future requirements and priorities. The group issued

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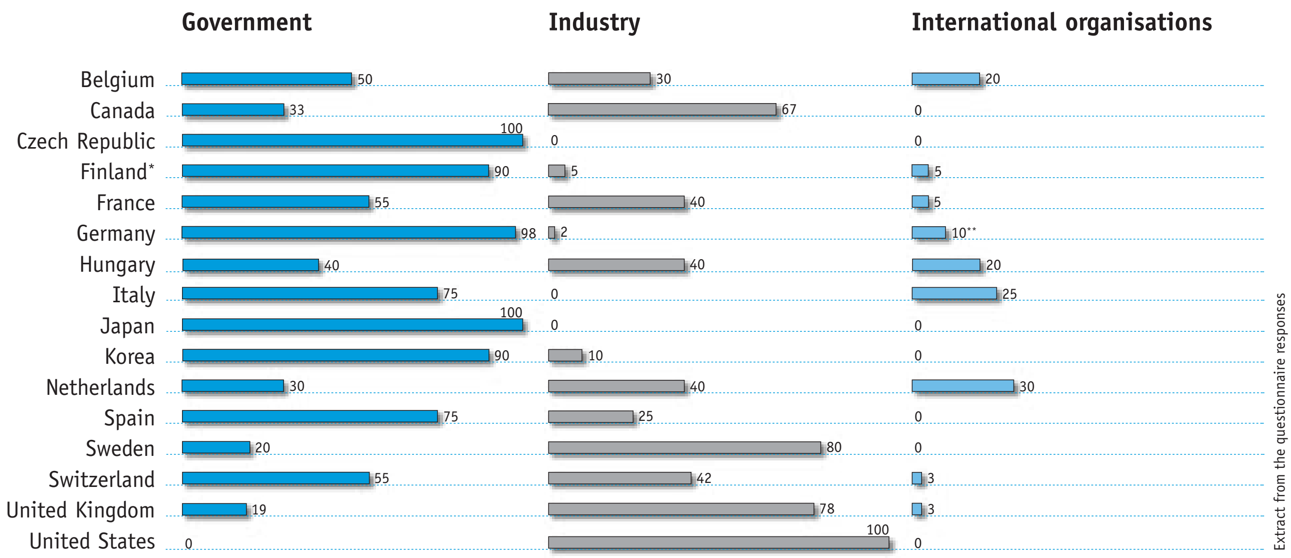
several reports including one on research capabilities and facilities and another on major facilities and programmes at risk. The CSNI continues to monitor developments in the research infrastructure of OECD countries and periodically updates the list of facilities and programmes at risk. The NEA has also considerably expanded the establishment of internationally funded research projects based on the conclusions of the SESAR study and detailed discussion at the technical level.

## Safety research survey

A survey was issued by the CSNI to gather information on regulatory organisations' views regarding the role of safety research in the regulatory context; their needs in this respect; the adequacy of current safety research for regulatory purposes; trends in research programmes funding and staffing; and actions being taken or contemplated to overcome some of the associated problems. Analysis of the results clearly showed commonalities and differences in various aspects of research being performed and in the future perspectives for such research. In most Member countries there is a complicated interplay between the current status and prospects of the nuclear programme; the legal and financial status of the operating utilities; and the role and responsibilities of the regulatory authority. The result is that specific trends are difficult to detect from the responses to the questionnaire. Based on the responses, it was nevertheless possible to identify several major aspects of regulatory-related research, including:

- All countries participate in international research projects, though to widely varying degrees. Typically, countries with small or medium-sized nuclear power programmes devote 20 to 30% of their budget to international projects, while countries with major programmes dedicate approximately 10%.
- No clear trend can be seen regarding past, current or future research funding, although there appears to be a slight overall trend towards maintaining or slightly increasing funding in the next five years.
- The sources of funding in Member countries tend to reflect the extent to which the government or the nuclear industry is regarded as having the prime responsibility for resolving nuclear safety issues. As an example, in countries like Japan, Germany and Spain, a very high proportion of the funding comes from governments, while in countries such as the United States, Sweden and the United Kingdom a very large proportion comes directly from the industry.
- National research priorities often include nuclear safety, ageing and risk-informed regulation.

**What percentage of the funding of regulatory-focused research comes from the following:**




* KTM + VTT + STUK.
** International organisations/participation in EU programmes amounted to approximately 10% extra in BMWi project funding in 2000.

- Essentially all countries share concern about the need to maintain research facilities. A number of countries have undertaken a strategic review of their capabilities and needs.
- The main consequences of losing minimum capability are generally considered to be a loss of technical safety competence and reduced public confidence.

## Role of research workshop

The workshop on the role of research in a nuclear regulatory context was organised such that each major party – the regulator, the researcher and industry – was provided with an opportunity to present its viewpoints on research needs, commonalities and differences in nuclear safety research and how to proceed in the future.

During the workshop, heads of regulatory organisations addressed questions such as why research should be supported, what types of research should be funded and the role of international organisations in setting up and funding research. A common conclusion was that a strong research programme is a central feature of a sound regulatory system.

Research is needed by the regulator to provide independent judgement, to determine areas in which improvements might be necessary, to anticipate potential problems, and in general to improve the effectiveness of the regulatory system and ensure that regulatory requirements are adequate and practical. It was recognised that one of the key challenges for regulators is to maintain the proper balance between confirmatory research (such as that conducted to validate methods) and anticipatory research (such as that conducted to anticipate potential problems and improve knowledge). With a decreasing budget, it is always easier to justify the need for confirmatory research at the expense of anticipatory research.

International co-operation is important for several reasons. One reason is to be able to leverage budgets and to avoid a duplication of programmes. Other reasons include the benefits deriving from the "magnification of intellectual firepower", which comes from interaction among researchers; the possibility to involve countries with limited resources, and in the end to contribute to harmonisation of safety requirements by achieving common technical positions. It can also help by stimulating and motivating young scientists to work in the nuclear field.

Discussions also considered ways to increase co-operation between industry and regulators on research while at the same time maintaining the independence of the regulatory decisions and the freedom to choose the research subjects. Industry representatives emphasised that they should be allowed to choose the method to demonstrate the safety of nuclear installations. Studies, calculations and design modifications, for example, are in many cases an acceptable alternative to further research. They also emphasised the need to establish achievable closure criteria for safety and to improve the alignment between industry and regulatory research, particularly with respect to best-estimate analyses and the determination of safety margins.

The main conclusions of the workshop are reproduced in the *Collective Statement on the Role of Research in a Nuclear Regulatory Context* (NEA, 2001). Specific recommendations made include:

- Individual NEA Member countries need to ensure that adequate research capability is maintained.
- Member countries should recognise the important role that research plays in enhancing educational opportunities and should intensify efforts to allow young professionals to cross borders so as to gain experience and achieve advancement in the nuclear environment. A corollary to this is that all parties should strive to maintain adequate knowledge and to increase the number of professionals entering into the nuclear field.
- The NEA should continue to explore ideas for increasing international co-operation through joint research projects.
- The role of the stakeholders should be recognised by the NEA and its Member countries. Research information should be made available to all stakeholders and the incorporation of their viewpoints into strategic thinking should be encouraged.
- A follow-up workshop should be considered by the NEA in two to three years to review progress and to provide an opportunity for further discussions.

Although the solutions to these problems must primarily be provided at the national level, improved co-operation between the industry and regulators as well as improved international co-ordination and co-operation can provide a very important contribution. Through the CSNI and the CNRA, the NEA will continue to be actively engaged in these efforts.

P.A. Brown, C. Pescatore, T. Sumerling*

# Reversibility and retrievability in geologic disposal of radioactive waste

## A new NEA report

Radioactive waste needs to be managed responsibly to ensure public safety and the protection of the environment, as well as security from unauthorised interference, now and in the future. One of the most challenging tasks is the management of long-lived radioactive waste that must be isolated from the human environment for many thousands, or even hundreds of thousands, of years.

There is a consensus among the engaged technical community that engineered geologic disposal provides a safe and ethical method for the long-term management of such waste. This method is also cited in the national policies of several countries as either a promising or appropriate method for dealing with long-lived radioactive waste.

Engineered geologic disposal means emplacement of waste in repositories constructed deep underground in suitable geologic media. Thus the waste is contained, and safety assured by passive barriers with multiple safety functions, so that there is no need for any further actions by future generations. Primary principles of the engineered geologic disposal concept are that waste will only be emplaced in a repository when there is high confidence in the ultimate long-term safety, and that the long-term safety must not rely on actions following the closure of the repository. This does not mean, however, that actions cannot be taken. Most repository development programmes include the possibility of post-closure activities for security and monitoring purposes.

### Reasons for introducing reversibility

Many radioactive waste disposal organisations have chosen to consider the possibilities for incorporating the concepts of reversibility and retrievability in their programmes. This is to increase the level of flexibility in their programmes and, thus, their ability to respond to changes in technical information and policy factors. It is also considered important to recognise ethical concerns which may contribute to achieving wider societal confidence in the engineered geologic disposal option.

In order to gain this confidence it is important to show that progress towards disposal will be made by a cautious and flexible stepwise approach, with opportunities for review, taking account of both technical and public interest

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matters. Flexibility of the decision-making process is not an objective in itself, but is good practice. It can contribute both to technical confidence in the ability to safely manage the waste and also to a confidence in wider audiences that an irreversible decision is not being made. Ultimately, if engineered geologic disposal, either in general or at a specific site, is found to be an unsatisfactory solution, then it must be possible to reverse steps towards disposal, and the waste management community must show that it is ready for this possibility.

Even if choices between management options are left open for future generations, the primary responsibility to solve the problem posed by radioactive waste still rests with the present generation. This generation has to decide on the balance between efforts made to maintain and monitor conditions in a repository and the resulting ease of retrievability. These decisions will have a bearing on the options available to, and burdens placed on, future generations. We cannot anticipate the conditions or the ethical and practical judgements that may be made by future generations. Decisions to be taken today must be based on present-day values and understanding of ethical issues and other national concerns. Measures that favour flexibility in decision making are, however, consistent with the ethical principle that the needs and aspirations of future generations should be respected, including their freedom to make their own decisions.

## Practical considerations and caveats

The integration of reversibility in a stepwise repository development programme, which may include measures to enhance the retrievability of waste, presents opportunities to take advantage of advances in scientific knowledge and technology, as well as the ability to respond to changes in national policy, regulations and social attitudes. Reversibility of decisions and retrievability of the waste must be coupled with other options, however, as reversibility implies reversal to follow some other course, and waste should not be retrieved unless an alternative, more acceptable, waste management solution is available. Retrievability is not introduced to improve the long-term passive safety of a repository and is not a primary goal in waste disposal concepts, but only a preference that favours flexibility. The introduction of measures

### The concepts of reversibility and retrievability

The terms reversibility and retrievability are used differently by various organisations. In NEA reports, the following definitions are used.

**Reversibility denotes the possibility of reversing one or a series of steps in repository planning or development at any stage of the programme.** This implies the review and, if necessary, re-evaluation of earlier decisions, as well as the means (technical, financial, etc.) to reverse a step. In the early stages of a programme, ***reversal*** of a decision regarding site selection or the adoption of a particular design option may be considered. At later stages, during construction and operation, or following emplacement of the waste, reversal may involve the modification of one or more components of the facility, or even the retrieval of waste packages from parts of the facility.

**Retrievability denotes the possibility of reversing the action of waste emplacement.** It is thus a special case of reversibility. ***Retrieval*** is the action of recovery of the waste or waste packages. Retrievability could, for example, refer to: retrieval of individual waste packages which are identified as faulty or damaged, even as emplacement of other packages continues; retrieval of some or all of the waste packages at some time after emplacement; or retrieval of the waste materials if the packages are no longer intact. Retrievability may be facilitated by the repository design and operational strategies, for example, by leaving underground access ways open and emplacement/retrieval systems in place until a late stage, and through the development and use of durable containers and easily excavated backfill.

to facilitate retrievability does not lessen the need for thorough safety assessments and assurance of operational and long-term safety and security of a repository.

Waste retrieval is possible in all geologic formations considered for radioactive waste disposal today, but some disposal concepts may be more easily adapted to allow for more convenient and cost-effective retrieval. Such adaptations of the repository design or operational plan are likely to involve a cost. This must be balanced against the value that the additional flexibility gives, whether in terms of technical opportunities or acceptance by society.

Retrievability should not be an excuse for indefinite delay of repository development decisions and is not a substitute for a well-designed repository that has a defensible basis for closure. Closure is a significant milestone in the development of a repository from technical, administrative and social perspectives. It marks the transition from an underground facility from which retrieval may still be contemplated to a final disposal facility. Final closure should be performed when adequate confirmatory data have been collected to provide reasonable assurance that the facility will perform as intended, and public confidence is sufficient to warrant the associated cessation of underground monitoring and increase in the difficulty of retrieval. The likelihood that waste would need to be retrieved after this step would thus be very low. Clear plans for repository development, including closure, must be made even if flexibility is given to future decision makers in their implementation of the plan.

## Retrievability of waste

Largely because of the large margins of passive safety built into an engineered geologic repository, no circumstances have been identified that would require urgent retrieval of waste. Thus, even if a decision was some day made to retrieve waste, there would always be time to implement an orderly programme of waste retrieval, and time to construct any facilities necessary for waste storage prior to investigating alternative disposal routes.

If retrievability is claimed, certain practical requirements must be met to assure its feasibility. The technical complexity and cost of retrieval will tend to increase as steps towards closure are taken. During the waste emplacement period and before extensive placing of backfill, waste retrieval could usually be achieved by the reverse use of emplacement systems. After placing of backfill, special techniques may be necessary to retrieve waste. Special measures would also be necessary to undertake mining and retrieval operations at the high temperatures and radiation levels that will persist around spent fuel and high-level waste containers. R&D should continue in technologies relevant to waste retrieval and, in particular, demonstrations of retrieval technologies should be encouraged in the various national and international research programmes. Such demonstrations contribute to technical confidence in the feasibility of waste retrieval and also to a wider, non-technical confidence in the feasibility and the seriousness of the waste management organisations about retrievability.

For waste retrieval to be feasible, institutional arrangements must also be made to ensure that: an appropriate level of technical ability to retrieve is maintained at each stage following waste emplacement; the methods for retrieval are defined, including retrieval under foreseeable component-failure and accident conditions; and periodic evaluations are made of the appropriateness and need to proceed with the next step towards repository closure, maintain at the current step, or reverse a step, including retrieval of the waste if necessary. Monitoring will also be required to verify that the conditions under which retrieval could be performed still exist.

## Governments' roles

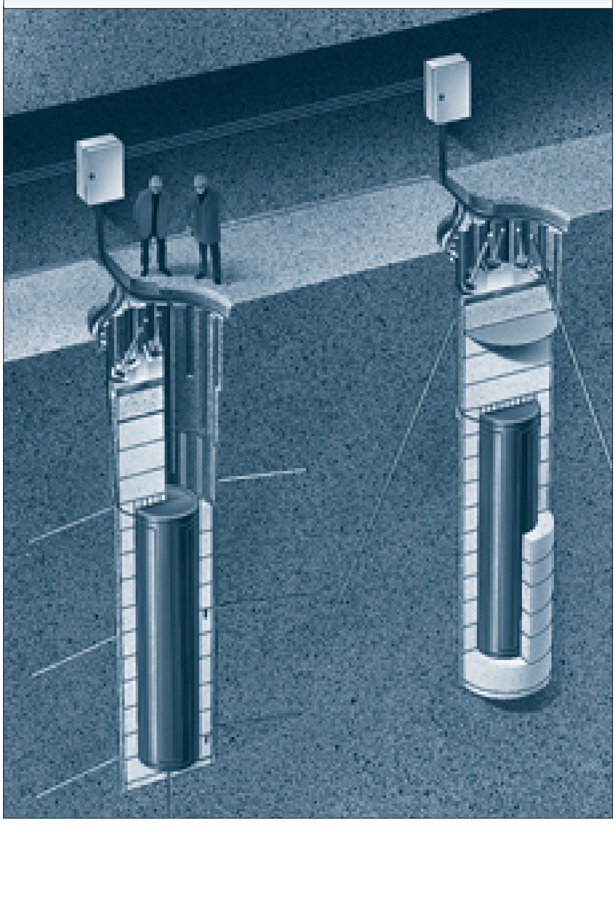
Governmental policies that outline the principles under which radioactive waste will be managed in a safe, environmentally sound and cost-effective manner should include an indication of the degree to which retrievability should be considered for different waste types, taking account of possible resource values and other factors. Governments also need to ensure the financial, organisational and regulatory arrangements to carry through the policy.

The financial implications of reversibility and retrievability include the cost of changing designs to facilitate retrievability and, more significantly, the costs of monitoring, safeguarding and maintaining the repository for decades, even centuries, if an extended open period is required. Whereas the nuclear industry can set aside funds for a defined plan of repository development, including a period of monitoring and control, governments may have to take on this responsibility if maintaining retrievability is to become an open-ended commitment. The decision to devote substantial sums of money to maintain retrievability should be taken in the context of the overall allocation of national resources.

Governments must also ensure that organisational arrangements are in place to maintain the technical expertise necessary for retrievability, including capability for dealing with radiological issues. This expertise is presently centred in the nuclear industry and associated regulatory and research institutions. In many countries, however, the continuation of the nuclear industry is in doubt, and government intervention may be necessary to ensure that an adequate level of expertise is maintained.

In most countries, regulatory guidelines have not yet been given on how requirements for retrievability, if any, should be implemented. Where retrievability is mentioned, there is usually an overriding requirement that any measures to enhance retrievability should not compromise the passive long-term safety of a repository. If national waste management policy requires retrievability, then regulatory requirements should be reviewed to check that they reflect the aspects of maintaining security and safety, including radiological protection and nuclear safeguards, both during possibly prolonged open periods and over the long term.

Representation of the Canister Retrieval Test carried out by the Swedish Nuclear Fuel and Waste Management Company (SKB).



SKB, Sweden

## Conclusions

In most concepts, waste retrieval will become more technically demanding as stages towards closure, e.g. progressive filling of disposal vaults and access ways and placing of seals, are taken. Although waste retrieval may be possible at all stages, including after closure, it is suggested retrievability should be considered mainly in the period before closure and R&D should be focused on the possibilities for retrieval in this period. Similarly, institutional arrangements and plans for retrieval of the waste should be focussed on the period preceding closure. Retrieval after repository closure, although technically possible, will require substantial resources to re-establish above- and below-ground facilities and access to the waste. If the need to reverse course is carefully evaluated with appropriate stakeholders at each stage of repository development, a high level of confidence should be achieved by the time a closure decision is taken that there are no technical or social reasons for waste retrieval.

Reversibility of decisions is increasingly included in the stepwise decision-making process that is foreseen for engineered geologic disposal. The implications of retrievability of the waste within disposal strategies, and the desirability (or not) of including specific measures to enhance retrievability, are currently being considered within the national programmes of several countries. Consensus on the meaning and value of reversibility and retrievability may develop in time and it is hoped that NEA work in this area will contribute to this development. Still, it must be recognised that for issues such as this, that combine technical, policy and ethical aspects, the solution adopted in any country must, above all, be fitted to the specific technical disposal system of that country and also be acceptable within the national policy framework.

### Note

1. This article features extracts from the NEA report published in November 2001 under the title *Reversibility and Retrievability in Geologic Disposal of Radioactive Waste: Reflections at the International Level*. The report was prepared by the NEA Secretariat based on national contributions and discussions within the NEA Ad Hoc Group on Reversibility and Retrievability and the Radioactive Waste Management Committee.

F. Mompean*

# The NEA Thermochemical Database (TDB) Project

In 1923 Lewis and Randall wrote in their famous textbook on thermodynamics that "the fascination of a growing science lies in the work of the pioneers at the very borderland of the unknown, but to reach this frontier one must pass over well-travelled roads; of these one of the safest and surest is the broad highway of thermodynamics". Nearly 80 years after, this statement still reflects the position of this branch of physics and chemistry as one of the pillars of contemporary science and technology. The spectacular development experienced by microscopic physics in the $20^{th}$ century did not cast any shadow on the validity of thermodynamics. On the contrary, it reinforced the well-known laws on the conservation of energy and the increase of entropy that the earlier thermodynamicists had extracted from the direct observation of their nearest universe.

Thermochemistry is the branch of thermodynamics aiming at answering the question of what chemical reactions are allowed by thermodynamic laws under given conditions. The answer is not limited to a mere qualitative prediction: thermodynamics and therefore thermochemistry are excellent tools for quantitative evaluations and it is possible to predict which chemical reactions will lead to compounds that are chemically more stable than others. By an ingenious application of the early concept of thermal cycles to chemical systems, thermochemistry allows the quantitative characterisation of compounds and chemical species for which direct measurements are not feasible using data for other related species more amenable to accurate experimental determination. Such procedure rests on a condition: that all magnitudes involved in the calculations are referred to a single, common and well-defined, reference state.

The remarkable power of thermodynamics is achieved at the expense of its total lack of interest in the temporal scale over which the phenomena being studied take place. The rate of the processes allowed by thermodynamics cannot be predicted with the sole use of thermodynamic information. Chemical kinetics and transport theory are needed for this purpose.

## How can thermochemistry be used in waste management safety assessment?

In underground repositories for high-level and long-lived radioactive waste, the different engineered barriers are designed to prevent the release of radioactive material to the surrounding geological formations. Performance assessment of these designs has to contemplate the possibility that there could be accidental releases of the contained material, and to estimate what would be the fate of the released chemical compounds, most notably whether radionuclides would be able to migrate to the biosphere. Thermochemistry can be applied to identify which chemical species would be present in each particular geological environment and which reactions could be expected among them. Mass transport phenomena are faster in fluids than in solids, so the particular chemical reactions controlling the formation of species in aqueous solutions attract considerable interest. Thermochemistry plays the initial role of identifying the characters (the chemical species) that will be used in the transport calculations.

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## The thermochemical databases at the NEA

Thermochemical data originates from chemical research carried out in many laboratories around the world. Considerable ingenuity has to be shown by the researchers in many cases in order to be able to report in the scientific literature experiments conducted under reliable conditions. Indeed, one of the main difficulties encountered in performance assessment exercises was the dispersion in the thermochemical values obtained from different literature sources.

A major step was taken to overcome this problem with the critical reviews produced by Phase I of the NEA Thermochemical Database (TDB) Project during 1984-2000. Over this period, four teams of internationally recognised experts in chemical thermodynamics revised all the available scientific literature and critically compiled thermochemical data for inorganic chemical species and reactions involving the following elements: uranium, americium, technetium, neptunium and plutonium. Following well-documented procedures, these expert review teams re-evaluated the existing data in many cases in order to bring them to a common reference state and produced sets of recommended values. The conclusions of these review teams were further re-examined by independent peer reviewers before their publication. These data were brought together in a consistent and internationally recognised database that can be used to realise thermochemical calculations in different national performance assessments on a common scientific basis. Together with the data related to the elements of environmental interest (due to their toxicity, mobility and radioactive properties), the database also contains critically evaluated data of more general interest such as auxiliary species and reactions.

Phase II of the NEA TDB Project was launched in 1998 as a semi-autonomous project under the guidance of a management board composed of representatives of all of the member country organisations participating in this phase of the project. After consultation with the participants, the primary objectives were identified as follows: update the database compiled during Phase I with the newly published literature and supplement it with data for inorganic chemical species of other elements (namely nickel, selenium and zirconium) which had not been considered during Phase I. Furthermore, attention is being paid to the species formed by selected organic ligands (EDTA, citrate, oxalate and isosaccarinic acid) and all the elements considered in either Phase I or Phase II. The scientific data reduction procedures and the critical reviewer/peer reviewer steps used in Phase I are also being used in Phase II. The first reviews arising from Phase II are expected to be ready for peer review in 2002 and to be published towards the end of the year.

In Phase II of the NEA TDB Project a substantial effort is being devoted to bringing together the communities of scientists and engineers working with thermochemical data, both in chemical research laboratories and agencies modelling radioactive waste repositories. This dialogue is necessary so that, on the one hand, the research can be oriented towards those areas in which present data has to be improved, and on the other hand so that the data selected for the performance assessment exercises always reflect the best possible chemical knowledge. For this purpose, the NEA TDB Project organised a workshop on "The Use of Thermodynamical Databases for Performance Assessment" on 29-30 May 2001 in Barcelona (Spain). The workshop was attended by 50 experts from both communities.

Finally, it is worth noting that thermochemical data do not vary across disciplines or applications. Thus, by providing qualified and consistent data, the NEA TDB Project provides a service to the wider technical and scientific community.

Further information on the NEA TDB Project can be found on the NEA website at

www.nea.fr/html/dbtdb

### Further reading

The NEA TDB reviews published to date are:

- I. Grenthe *et al.* (1992), *Chemical Thermodynamics of Uranium*, Elsevier, Amsterdam, ISBN: 0 444 90381 4.
- R. J. Silva *et al* (1995), *Chemical Thermodynamics of Americium*, Elsevier, Amsterdam, ISBN: 0 444 82281 X.
- J. A. Rard *et al* (1999), *Chemical Thermodynamics of Technetium*, Elsevier, Amsterdam, ISBN: 0 444 50378 1.
- R. J. Lemire *et al* (2001), *Chemical Thermodynamics of Neptunium and Plutonium*, Elsevier, Amsterdam, ISBN: 0 444 50379 X.

A. Nouri, P. Nagel*

# JANIS: new software for nuclear data services

Basic nuclear data are fundamental to all applications involving radioactive materials and nuclear fuels. These data cover both the properties of radioactive nuclei and the elementary laws of nuclear interactions. Two important aspects are to be taken into account when providing nuclear data services:

- The volume of data is large (several hundreds of megabytes for a comprehensive library).
- There is a wide variety of applications and of end users of these data.

The first requirement calls for the utilisation of efficient means to store and to retrieve the data, and for the definition of standardised formats to allow their exchange among users and their treatment with specialised computer codes. The Evaluated Nuclear Data File (ENDF) format, for instance, provides a comprehensive way of representing nuclear data. However, these formats become too complex for a non-specialised user. Furthermore, cross-platform compatibility requires the formats to be based on textual representation of the data. It becomes difficult even for specialised users to check and handle the data contained in large files. Both experienced and non-specialised users would thus benefit from easy and efficient access to nuclear data that does not require prior knowledge of the storage format.

## Background

The OECD Nuclear Energy Agency Data Bank is part of an international network of data centres in charge of the compilation and dissemination of basic nuclear data. The NEA and the other centres provide an essential link between nuclear data producers and users.

The NEA has accumulated experience in the development of user-friendly means for accessing and manipulating data. Two axes of developments were conducted.

Nuclear data display software installed on desktop computers offers flexibility in terms of the users' interface. However, the user does not have access to the latest version of the data. JEF-PC is an example of such software. It was developed by the NEA in the early nineties in collaboration with the University of Birmingham, UK, the *Centre de Spectrométrie Nucléaire et Spectrométrie de Masse*, Orsay, France and the UK nuclear industry. Versions 1.0 and 2.0 were released in 1994 and 1998, and were acquired by more than 500 users. JEF-PC features include the display of evaluated and experimental cross-sections, radioactive decay data and fission yields.

The other option concerns Internet access. The NEA has been using relational databases since 1993 to provide a centralised repository of data and has used web technology to allow interactive retrieval of the data. The NEA website (www.nea.fr) offers interfaces to the main nuclear databases: EVA for evaluated data, CINDA for bibliographical information and EXFOR for experimental data. The latter also includes on-line plotting capabilities. By accessing centralised information, web users benefit from up-to-date data. The drawbacks are that the graphical interface is less sophisticated and the user may be limited by the amount of data he or she can transfer.

Important feedback was received from the users of these two kinds of services. Suggestions for further developments of the JEF-PC program in order to add new features (such as possibilities for plotting angular and energy distributions) faced the problem of software architecture. JEF-PC was developed using Borland C++, which implies limitations in terms of compatibility on different

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operating systems and flexibility of the users' interface. The solution therefore resided in a combination of software development and web-based services.

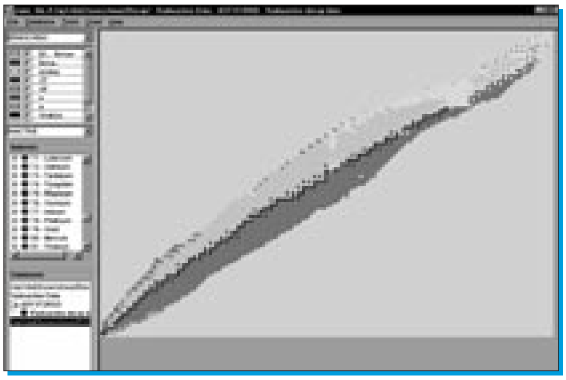
Investigations of different programming languages were carried out in 1998 and 1999 taking into account criteria such as cross-platform portability, performances in terms of execution time and the possibility of having dual usage as explained above (i.e. software and web-based). Java technology offered the optimum choice and a project was launched by the NEA to design a new software called JANIS (Java Nuclear Information System) which would supersede JEF-PC in terms of features and portability while maintaining comparable performances in terms of execution time. This new software would also offer all the necessary connectivity to web services and centralised databases.

## JANIS features

JANIS can access data contained in comprehensive databases (typically all materials contained in an evaluation library) or in a single file (typically data for one nuclide either retrieved from centralised databases or obtained from data processing codes). The formats supported are: ENDF-6 (along with the linearised, pointwise option PENDF and the group-wise option GENDF) and the computerised format derived from EXFOR. Data originating from the major evaluation files ENDF/B, JEF(F), JENDL, BROND... can be displayed and compared.

Various navigation tools are available for helping the user identify the nucleus of interest. Figure 1 shows the "Chart of Nuclides" and "Nuclide Explorer". The properties of the selected nuclide are then displayed using textual, graphical or tabular formats. Search capabilities are also included, enabling the user to query the databases and to identify nuclides that have specific characteristics.

**Figure 1: Chart of nuclides and nuclide explorer**



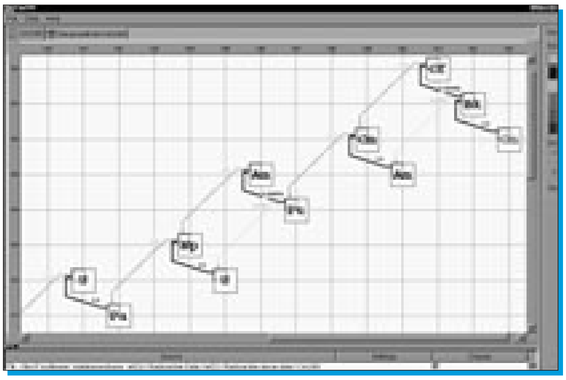
### Radioactive decay data

JANIS provides a summary of important properties of radioactive nuclides. This includes the mass of the nuclide, its excitation energy, the spin and parity, the half-life, the mean decay energies and decay modes. For each decay mode, the corresponding Q value, branching ratio and nuclide produced are given.

The decay path followed by a particular nuclide towards stability (also called the decay chain) can be displayed (see Figure 2). This chain is constructed from the information available in the library (half-life, decay modes, branching ratios). The decay path is produced in tabular and graphical formats.

Discrete and continuous spectra of emitted particles (gamma and X rays, alpha particles, beta+ and beta-) are represented in JANIS using tabular and graphical formats. The information displayed includes: the energy of the emitted particle and the corresponding uncertainty, relative and absolute line intensity and the associated errors.

**Figure 2: Radioactive decay path**

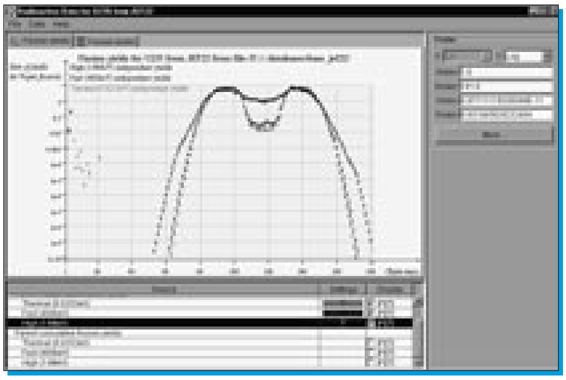


### Fission yield data

Fission yields give the proportion of nuclides produced by fission. Data exist as independent yields (yield directly produced by fission prior to delayed neutron, beta decay, etc.) and cumulative yields (which account for all decay branches after fission). JANIS displays these yields using tabular and graphical formats. The tabular format gives the yield for all products (isotope, excitation energy state) while the graphical representation gives the fission yield as a function of the chain mass (sum of yields for a given mass number A).

Fission yields depend on the energy of the neutron causing fission. Independent and cumulative yields are thus given for typical neutron spectra (thermal neutron-induced, fast neutron-induced and high-energy neutron-induced fission). Spontaneous fission yields are given as well. An example of an independent fission yield graph is given in Figure 3.

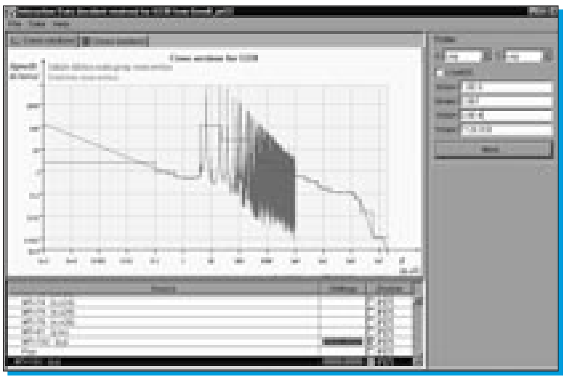
**Figure 3: Fission yield data**



### Interaction data

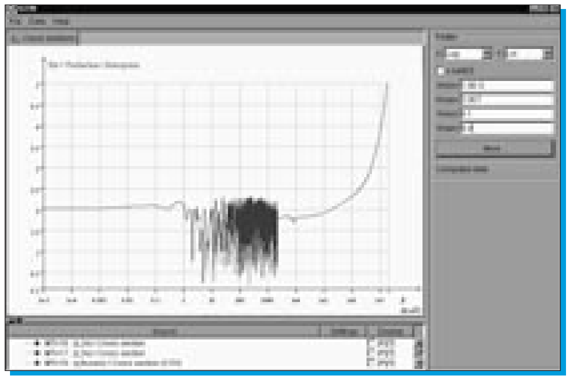
Data displayed in this category include cross-sections (pointwise and mutigroup forms, as shown in Figure 4) and associated uncertainties, resonance parameters, energy distributions, angular distributions and correlated energy-angle distributions. JANIS was specially designed to offer flexibility for the comparison of different data sets.

**Figure 4: Comparison of pointwise and multigroup cross-sections**



Various tools enabling data manipulation are provided including simple operations with cross-sections (linear combination, product, and ratio) and flux weighting. Figure 5 shows a graphical display of $\eta = (\nu\ \sigma_f/\sigma_a)$ obtained from individual components in the ENDF file. Experimental data can be plotted as well with advanced search options combining reaction identifiers, projectile energy range, laboratory and date of the experiments.

**Figure 5: Example of cross-section manipulation $\eta = (\nu\ \sigma_f/\sigma_a)$**



## Future developments

The current version of JANIS can access data from local or network drives and via the Internet. Developments are ongoing in order to fully link JANIS with the relational databases available on the NEA web server using distributed computing technology. The same technology can be extended to provide the user with a package of services in integrated client/server architecture. For instance, the server side can be used for data retrieval and processing at the desired temperature and accuracy using the latest version of well-established tools. The user can then choose the information to be transferred onto his or her local computer. Various options are under study aiming at optimising the amount and format of data to be transferred through the Internet. The client side will be used for the display and manipulation of data sets.

## Conclusions

JANIS is meant to provide both specialised and non-specialised users with easy and efficient access to nuclear data. The software is free and can be downloaded directly from the NEA website (www.nea.fr/janis). Feedback can be posted on the web and updates downloaded automatically through the live-update feature.

The software runs on almost all operating systems and will enable users to access the latest versions of the data and associated tools through its integrated client/server architecture. Prior to its official release, JANIS was tested by more than 100 users in over 20 different countries who provided valuable feedback. ■

# News briefs

## Evaluating integral experiments for criticality safety

The primary purpose of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) is to evaluate and compile critical and subcritical benchmark experiment data into a standardised format that allows criticality safety analysts to easily use the data to validate calculational tools and cross-sections libraries. To carry out this mission, the Group began publishing an International Handbook of Evaluated Criticality Safety Benchmark Experiments in 1995.

A new edition was released in September containing 307 evaluations and describing 2 642 experimental configurations. Detailed "Spectra/Neutron Balance" data for many of the various configurations are included to help characterise the neutronics of each experiment.

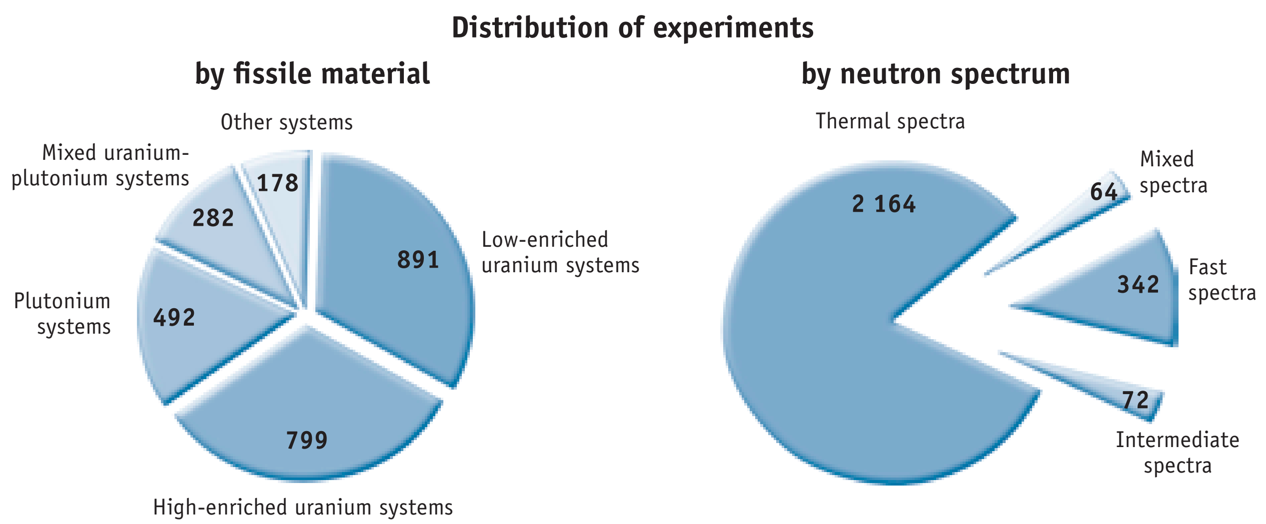
The Handbook is produced in electronic format (pdf files) where the experiments are grouped into evaluations, categorised by:

- fissile media (plutonium, highly enriched uranium, intermediate and mixed-enrichment uranium, low-enriched uranium, uranium-233, mixed plutonium-uranium and special isotope systems);
- physical form of the fissile material (metal, compound, solution and miscellaneous systems); and
- neutron energy range where the majority of the fissions occur (fast, intermediate, thermal and mixed-spectra systems).

DICE, a relational database with a Java users' interface, was developed in order to make more efficient use of the Handbook. Selected information from each configuration was entered into the database. This information provides a synthetic description of the experiments including geometry, fuel composition, moderation and reflection conditions, and spectrum characteristics. The users' interface enables one to perform queries of the database, to generate summary descriptions of each experimental configuration, and to link to the original pdf document. DICE is included in the 2001 edition. ■

### Note

1. For more information about the International Criticality Safety Benchmark Evaluation Project or to order a copy of the Handbook, please contact ali.nouri@oecd.org or bbb@inel.gov.



# Research on self-healing in argillaceous media for geologic disposal

To prevent radioactive contamination and undue exposure to the public, it is necessary to isolate long-lived and/or high-level radioactive wastes from the human environment for a very long period of time. For this purpose, the concept of placing packaged waste in a deep geological formation such as clay has been developed. One of the main functions of the geological formation is to isolate the waste from groundwater, thus minimising lixiviation of the waste and advective radionuclide transport, and hence, the amount of radionuclides that could reach the human environment.

Improving our understanding of the processes that might affect the containment properties of the geological barrier can reduce uncertainties about the performance of the waste repository. In particular, during the stepwise development of the repository research programme, it is important to clarify whether fractures that might be induced by the excavation of the underground facilities might have a significant impact on the radiological safety of the repository in the host formation being studied, such as clay. In this case the self-healing properties of argillaceous media – often quoted as one of the advantages of such host formations – play a major safety role, notably in reducing the long-term impacts of such induced fracturation.

At NEA "Clay Club" meetings in 1999 and 2000, interest was expressed in the preparation of an overview and synthesis of the current understanding of, and conceptual approaches to, the processes that lead to self-healing of natural and induced fractures in typical repository conditions. The question of the applicability of the understanding that exists within the oil and gas industry to repository-relevant conditions was also raised.

It was in this context that a topical session on the "Evidence of, and Approaches to, Self-healing in Argillaceous Media" was organised in Nancy, France on 16 May 2001 and hosted by the French Organisation for Radioactive Waste Management (ANDRA). Twenty-six participants representing several national waste management organisations, regulatory authorities, government agencies and the academic community from NEA Member countries took part. The session was mainly aimed at exchanging information on:

- the general point of view of geomechanical and geochemical experts on self-healing;
- the approaches that are or will be followed by the various organisations in order to deal with self-healing.

The geological settings covered in the presentations related to the whole range of argillaceous media relevant to the disposal of radioactive waste, including poorly indurated clays, indurated mudstones and shales.

Presentations showed the importance of a multidisciplinary approach to this topic and emphasised the interest of a state-of-the-art report on self-healing to provide a sound and disposal-dedicated scientific framework for subsequent studies related to this area. They also demonstrated the need to consider self-healing in all types of argillaceous media being considered as a potential host formation, as well as the need to reconcile the geomechanical and geochemical approaches to self-healing.

In 2002 a multidisciplinary (and multi-authored) synthesis report will be prepared on the "Potential for Self-healing of Fractures in Plastic Clays and Argillaceous Rocks under Repository Conditions". This is a new area of applied science in which there are very few publications that cover the topic and none that address fundamental aspects of material behaviour. Furthermore, the applicability of knowledge and concepts used by the oil and gas industry to repository-relevant conditions (temperature, pressure, time frame) is not straightforward. The report will aim to bring together and synthesise information from very diverse sources in order to provide a sound scientific basis for future safety assessment and site understanding activities. This will clearly go well beyond a basic literature review. The report will also examine the broad class of host media relevant to the disposal of radioactive waste, including plastic clays, mudstones, clayshales and shales. A suitable rock classification system will be used as the basis for comparisons between rock types. ■

### Note

1. For further details regarding this subject, please contact sylvie.voinis@oecd.org.

# New publications

The NEA Catalogue of Publications is available free on request from neapub@nea.fr. The online version may be consulted at www.nea.fr.

## Economic and technical aspects of the nuclear fuel cycle

### Management of Depleted Uranium

A Joint NEA/IAEA Report

*ISBN 92-64-19525-4 – 68 pages – Price: € 20, US$ 19, £ 12, ¥ 1 900.*

Large stocks of depleted uranium have arisen as a result of enrichment operations, especially in the United States and the Russian Federation. Countries with depleted uranium stocks are interested in assessing strategies for the use and management of depleted uranium. The choice of strategy depends on several factors, including government and business policy, alternative uses available, the economic value of the material, regulatory aspects and disposal options, and international market developments in the nuclear fuel cycle. This report presents the results of a depleted uranium study conducted by an expert group organised jointly by the OECD Nuclear Energy Agency and the International Atomic Energy Agency. It contains information on current inventories of depleted uranium, potential future arisings, long-term management alternatives, peaceful use options and country programmes. In addition, it explores ideas for international collaboration and identifies key issues for governments and policy makers to consider.

### OECD Nuclear Energy Data 2001

*Bilingual – ISBN 92-64-08707-9 – 50 pages – Price: € 20, US$ 19, £ 12, ¥ 1 900.*

*Nuclear Energy Data* is the OECD Nuclear Energy Agency's annual compilation of basic statistics on electricity generation and nuclear power in OECD countries. The reader will have quick and easy reference to the status of and projected trends in total electricity generating capacity, nuclear generating capacity, and actual electricity production, as well as to supply and demand for nuclear fuel cycle services.

## Nuclear regulation/nuclear safety

### Collective Statement on the Role of Research in a Nuclear Regulatory Context

*16 pages – Free: paper or web versions.*

# Radiation protection

## Occupational Exposures at Nuclear Power Plants

### Tenth Annual Report of the ISOE Programme, 2000

*ISBN 92-64-18473-2 – 104 pages – Free: paper or web versions.*

The ISOE Programme was created by the OECD Nuclear Energy Agency in 1992 to promote and co-ordinate international co-operative undertakings in the area of worker protection at nuclear power plants. The programme provides experts in occupational radiation protection with a forum for communication and exchange of experience. The ISOE databases enable the analysis of occupational exposure data from the 452 commercial nuclear power plants participating in the programme (representing some 90 per cent of the world's total operating commercial reactors). The Tenth Annual Report of the ISOE Programme summarises achievements made during 2000 and compares annual occupational exposure data. Principal developments in ISOE participating countries are also described.

## Policy Issues in Radiological Protection Decision Making

### Summary of the 2nd Villigen (Switzerland) Workshop, January 2001

*ISBN 92-64-18474-0 – 28 pages – Free: paper or web versions.*

The societal aspects of risk governance are increasingly becoming a part of public decision-making processes. This tendency is particularly evident in matters dealing with the protection of human health and the environment. The NEA Committee on Radiation Protection and Public Health (CRPPH) organised a workshop to probe stakeholder involvement processes and their limitations in the field of radiation protection. An example of an area in which stakeholder involvement is particularly important is the clean-up of sites contaminated by accidents or by past industrial or research activities. Based on discussions during the workshop and previous CRPPH work in this area, this summary addresses the policy development and implementation issues that are key to identifying broadly accepted solutions for radiological protection situations in which stakeholders are an important part of the decision-making process. Applicable in a wide variety of national contexts, enhanced understanding of these policy issues will assist governments and regulatory authorities in better integrating stakeholder concerns in decision making.

## Second International Nuclear Emergency Exercise INEX 2

### Final Report of the Canadian Regional Exercise

*Bilingual – ISBN 92-64-09532-2 – 80 pages – Price: € 23, US$ 21, £ 14, ¥ 2 300.*

The Nuclear Energy Agency (NEA) initiated its programme of International Nuclear Emergency Exercises (INEX) by a table-top exercise (INEX 1) which allowed the 16 participating countries to examine how their response mechanisms addressed the international aspects of a large-scale nuclear emergency. Based on the experience thus gained, a series of more realistic exercises, INEX 2, was organised by the NEA. These exercises used as a basis a national-level emergency exercise at an existing power plant, and aimed to achieve three international objectives: the real-time exchange of information, public information and decision making based on limited information and uncertain plant conditions. This report summarises the experience gained and lessons learned during the fourth and final INEX 2 regional exercise which took place in Canada.

## Reversibility and Retrievability in Geologic Disposal of Radioactive Waste

### Reflections at the International Level

*ISBN 92-64-18471-6 – 52 pages – Free: paper or web versions.*

Reversibility of decisions is an important consideration in the stepwise decision-making process that is foreseen for engineered geologic disposal of radioactive waste. The implications of favouring retrievability of the waste within disposal strategies and the methods to implement it are also being considered by NEA Member countries. This report reviews the concepts of reversibility and retrievability as they may apply to the planning and development of engineered geologic repositories. The concepts span technical, policy and ethical issues, and it is important that a broad understanding is developed of their value and implications. Furthermore, improved comprehension and communication of these issues will clarify the value of flexible, stepwise decision making in repository development programmes and may help to generate a climate conducive to the further progress of such programmes.

## The Role of Underground Laboratories in Nuclear Waste Disposal Programmes

*ISBN 92-64-18472-4 – 48 pages – Free: paper or web versions.*

Underground research laboratories (URLs) are essential to provide the scientific and technical information and practical experience that are needed for the design and construction of nuclear waste disposal facilities, as well as for the development of the safety case that must be presented at various stages of repository development. This report provides an overview of the purpose of URLs within repository development programmes; the range of URLs that have been developed, or are planned, in NEA Member countries to date; the various contributions that such facilities can make to repository development programmes and the development of a safety case; considerations on the timing of developing a URL within a national programme; and the opportunities and benefits of international co-operation in relation to URLs.

## Scenario Development Methods and Practices

### An Evaluation Based on the NEA Workshop on Scenario Development, Madrid, Spain, May 1999

*ISBN 92-64-18722-7 – 244 pages – Price: € 65, US$ 58, £ 40, ¥ 6 550.*

Analysis of the long-term safety of radioactive waste repositories, using performance assessment and other tools, is required prior to implementation. The initial stage in developing a repository safety assessment is the identification of all factors that may be relevant to the long-term safety of the repository and their combination to form scenarios. This must be done in a systematic and transparent way in order to assure the regulatory authorities that nothing important has been forgotten. This report is a review of developments in scenario methodologies based on a large body of practical experience in safety assessments. It will be of interest to radioactive waste management experts as well as to other specialists involved in the development of scenario methodologies.

# Nuclear law

## Nuclear Law Bulletin

### No. 67 + Supplement (Volume 2001/1)

*2001 Subscription (2 issues + supplements) – ISSN 0304-341X – Price: € 71, US$ 80, £ 48, ¥ 9 550.*
*Single issues on sale on request – ISBN 92-64-19109-7 – 86 pages – Price: € 43, US$ 50, £ 29, ¥ 5 750.*

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, bilateral and international agreements and regulatory activities of international organisations.

# Nuclear science and the Data Bank

## Boiling Water Reactor Turbine Trip (TT) Benchmark

### Volume I: Final Specifications

*ISBN 92-64-18470-8 – 96 pages – Free: paper or web versions.*

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 for current nuclear 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 (PWR, BWR, VVER) need to be compared against each other and validated against results from experiments. International benchmark studies have been set up for the purpose. The present volume describes the specification of such a benchmark. The transient addressed is a turbine trip (TT) in a BWR involving pressurisation events in which the coupling between core phenomena and system dynamics plays an important role. In addition, the data made available from experiments carried out at the plant make the present benchmark very valuable. The data used are from events at the Peach Bottom 2 reactor (a GE-designed BWR/4).

## Forsmark 1 & 2 Boiling Water Reactor Stability Benchmark

### Time Series Analysis Methods for Oscillations During BWR Operation: Final Report

*ISBN 92-64-18469-4 – 152 pages – Free: paper or web versions.*

Events involving unnoticed power oscillations have occurred at different boiling water reactors (BWRs) in the past, and have led to the implementation of interim corrective actions to avoid their repetition. Despite these measures, power oscillations continue to occur. In response to this situation, a great deal of research and analytical activities have been undertaken to improve the knowledge of the underlying phenomenology, and to define final solutions to handle this type of event. An OECD/NEA expert group has carried out studies in which the predictive capability of the codes and models for stability analysis are compared. This report provides the results of a specific study investigating the possibility of determining the main stability parameters from the neutronic signals time series with sufficient reliability and accuracy. It is based on a series of six complex cases derived from measurements carried out at the Forsmark nuclear power plant in Sweden.

## International Evaluation Co-operation

### Volume 10 – Evaluation Method of Inelastic Scattering Cross-sections for Weakly Absorbing Fission-product Nuclides

*100 pages – Free: paper or web versions.*

## Utilisation and Reliability of High Power Proton Accelerators

### Workshop Proceedings, Aix-en-Provence, France, 22-24 November 1999

*ISBN 92-64-18749-9 – 476 pages – Price: € 130, US$ 116, £ 80, ¥ 13 100.*

High power proton accelerators are being studied for their potential use in the transmutation of nuclear waste. The Second Workshop on Utilisation and Reliability of High Power Proton Accelerators, organised by the NEA Nuclear Science Committee, placed special emphasis on accelerator-driven system (ADS) concepts comprising a sub-critical reactor coupled with a high power accelerator. The information provided in these proceedings will primarily be of interest to scientists working on accelerator-driven systems, but also to those involved in the construction of high power accelerators.

## International Handbook of Evaluated Criticality Safety Benchmark Experiments

### A Project by the NEA Nuclear Science Committee

*CD-ROM – Free on request.*

## International Nuclear Data Evaluation Co-operation

### Complete Collection of Published Reports as of October 2001

*CD-ROM – Free on request.*

## JANIS

### A New Java-based Nuclear Data Display Program

*CD-ROM – Free on request.*

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### Complete Collection of JEFF Reports, Numbers 1-18

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## Employment Opportunities

## OECD Nuclear Energy Agency

Vacancies occur in the OECD Nuclear Energy Agency Secretariat in the following areas:

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- Radioactive Waste Management
- Radiation Protection
- Nuclear Energy Economics
- Nuclear Science
- Nuclear Law
- Nuclear Engineering
- Computing

**Qualifications:**

Relevant university degree; at least two or three years of professional experience; very good knowledge of one of the two official languages of the Organisation (English or French) and ability to draft well in that language; good knowledge of the other.

Vacancies are open to candidates from NEA Member countries. The NEA is an equal opportunity employer.

**Initial appointment:**

Two or three years.

**Basic annual salary:**

From approximately € 50 650 (Administrator) and € 72 650 (Principal Administrator), supplemented by allowances depending on residence and family situation.

Applications, in English or French (specifying area of specialisation and enclosing detailed curriculum vitae) should be marked “NEA/NL” and sent to:

Human Resources Management
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2, rue André-Pascal
F-75775 Paris Cedex 16, France

www.nea.fr

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