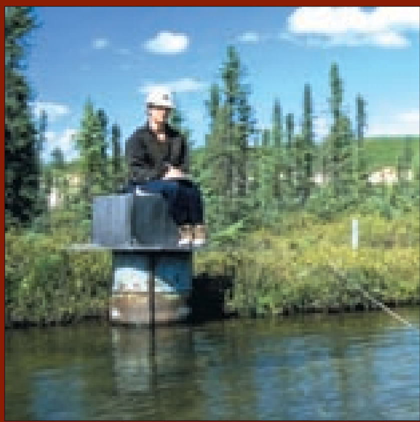
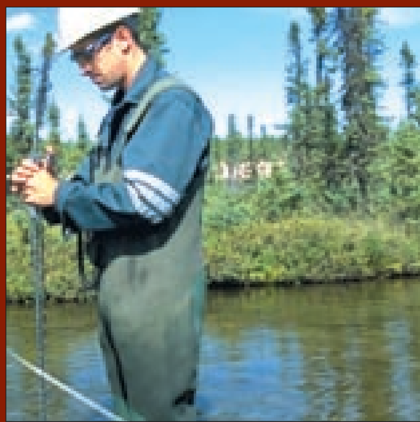
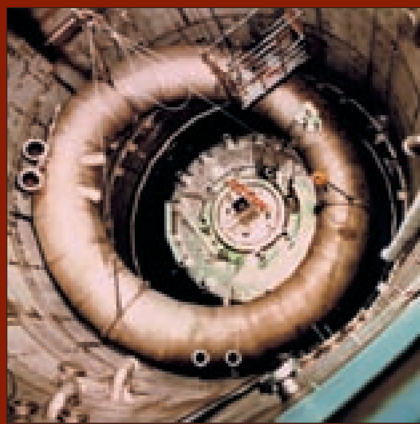
NEA News

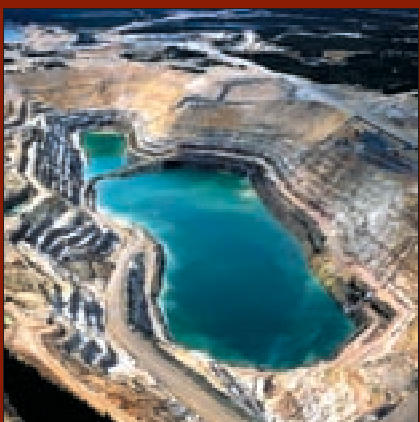
2002 – No. 20.2

In this issue:









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NEA News

contents

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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 28 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the NEA's work and a co-operation agreement is in force with the International Atomic Energy Agency.

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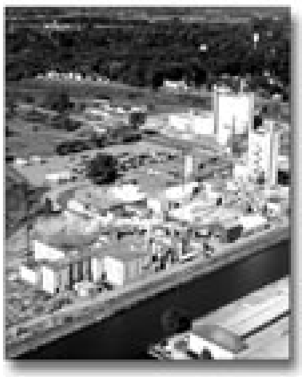
Cover page: Environmental monitoring, McArthur River, Canada (Cameco); field investigation of a uranium deposit in Australia (PCN); internal structures of the Pegase reactor, France; tailings pond, Key Lake, Canada (Cameco); low-level waste packages: transversal view, USA (NEI).

Facts and opinions

NEA updates

News briefs



editorial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T. Lazo
J.M. Taillat

Protecting man and the environment

Technology is critical to support economic development, but needs careful control and monitoring to be consistent with the social and environmental goals of sustainable development. Energy production by any source or technology has the potential to affect human health and the environment. Nuclear energy researchers and industrialists alike have therefore been seeking to make continued improvements in both of these fields. Results are becoming manifest in several areas.

Thanks to the pursuits of the radiological protection community, notably on work management, radiation exposure of workers has been halved over the last decade. Efforts continue to be made to improve the overall system of radiological protection; numerous actors are involved, including the NEA, in the revision of the 1990 Recommendations of the International Commission on Radiological Protection (ICRP), on which national radiological protection regulations are based. Similar efforts are being extended to develop a system for protecting the environment against harmful effects of radiation. Up until now, it was assumed that by protecting man, the environment would also be protected. An overview of this issue and recent developments is provided in the article on page 7.

Work on future nuclear reactors is also intent on maximising protection of man and the environment. Enhanced safety features and reduced waste generation are among the criteria being considered in NEA review activities of advanced nuclear reactors (see page 14) as well as those used by the Generation IV International Forum (GIF) during its recent roadmap phase involving the selection of six reactor concepts for continued research and development.

In 2002, the revision of the Paris Convention on Third-party Liability in the Field of Nuclear Energy was successfully completed, resulting in substantially increased amounts of protection made available in the case of a nuclear accident to compensate potential victims and damage to the environment. The Brussels Supplementary Convention was also revised. Together they represent a five-fold increase in the compensation amounts available. Details of these revisions will be provided in the next issue of NEA News.

Luis E. Echávarri
NEA Director-General

K. Shiraga*

Understanding society and nuclear energy

While signs of a possible nuclear energy renaissance are visible worldwide, it is crucial to gain a better understanding of civil society's views on nuclear technologies, how people perceive risks, and how to establish effective communication among all stakeholders so as to produce a consensus prior to decision making.

Nuclear energy is an important component of electricity supply in many countries. Currently, nearly one quarter of the electricity consumed in OECD countries is generated by some 360 nuclear units operating in 17 member countries. Furthermore, several OECD countries consider that nuclear energy will continue to play a key role in alleviating the risk of global climate change, reducing local pollution and more globally in sustainable energy supply mixes.

However, the implementation of nuclear energy projects often raises social concerns about risks associated with a potential release of radioactivity in routine or accidental conditions, radioactive waste management and disposal, and proliferation of nuclear weapons. Democratic societies recognise that those concerns need to be addressed, in particular by informing and consulting all stakeholders and involving them in decision-making processes aimed at consensus building.

Societal concerns are a component of sustainable development objectives. Integrating economic, environmental and social dimensions in decision-making processes is essential to achieve these objectives, and requires involving civil society in certain aspects of policy making. As a result, a key issue for decision and policy makers is to develop and implement new approaches and methods for facilitating civil society involvement while maintaining a high level of economic efficiency.

In the nuclear energy sector, the lack of understanding and consensus between civil society and decision makers have led to conflicting situations in some instances, and might result in energy policies and supply-mix choices that are not optimised from the viewpoint of society as a whole. It is generally agreed that enhanced communication among stakeholders and exchange of information covering a broad range of topics are necessary, although not sufficient, to promote such consensus building.

Some of the types of issues concerned, however, are not unique to the nuclear energy sector. For example, risk perception and communication and evolution of decision-making processes in modern society are relevant not only for analysing relations between civil society and nuclear energy, but also for a broad range of advanced technologies, such as biotechnologies.

Risks constitute an intrinsic and inseparable part of life, and are recognised as such by society. However, risk acceptance by the public is generally not objective. It operates via perceptions

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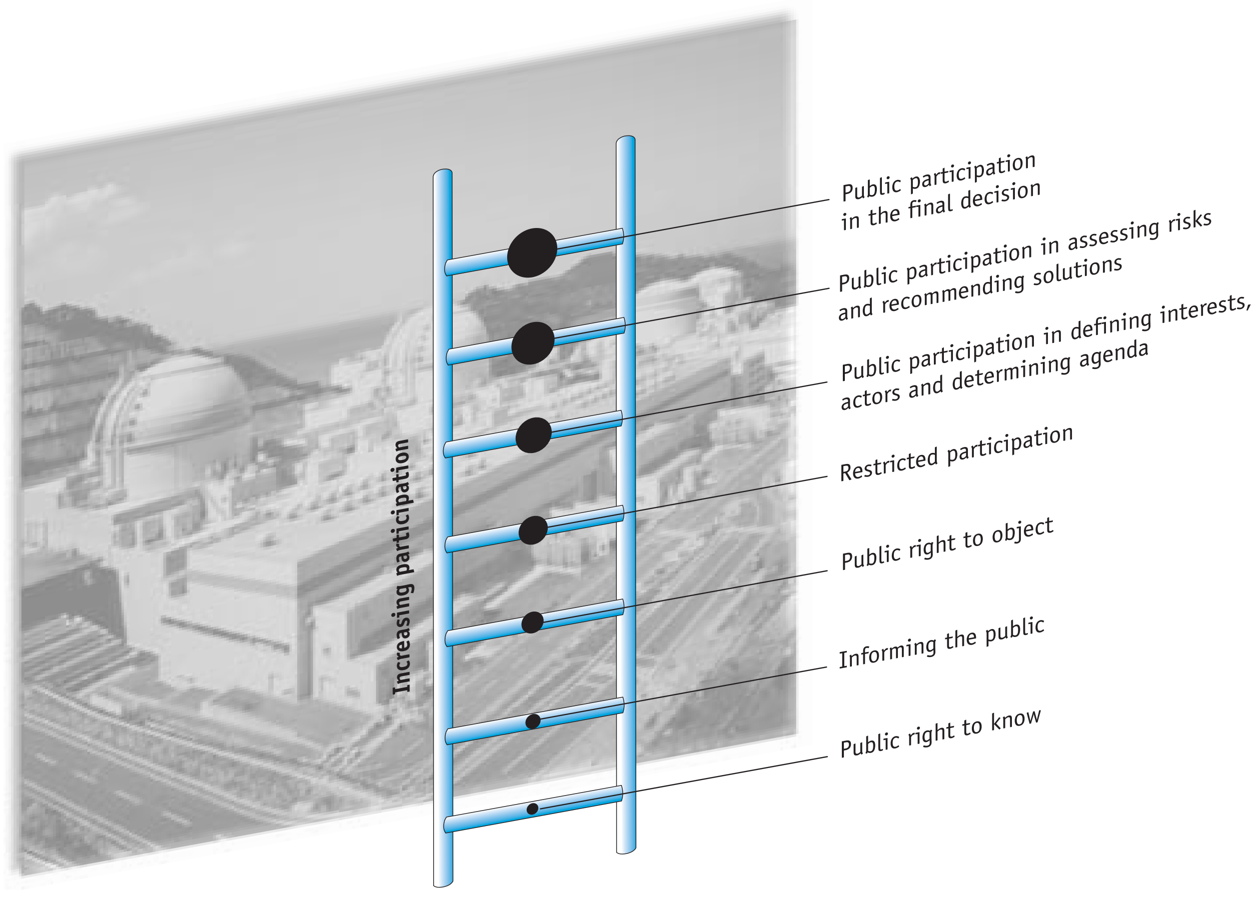
governed by many widely varying factors. Ultimately, the approval or rejection of a given project that involves the public acceptance of certain risks will depend on a complex trade-off between its perceived risks and benefits.

An understanding of the process of risk acceptance and risk-benefit trade-offs, as well as of a whole range of factors involved therein, can aid in the development of communication and decision-making processes that reduce the disparity between the technical definition of risk and the lay perception of it. The importance of risk perception and communication has been highlighted in related literature. Additional work in this field would be relevant to facilitate the dialogue between experts, policy makers and civil society about nuclear energy issues, eventually leading to more effective decision-making processes.

Traditionally, risks associated with nuclear energy have been estimated using a technical and quantitative approach, called probabilistic risk assessment, and it is recognised that the use of this approach has generally not been well received by the public. The public perception of nuclear energy risks differs markedly from the scientists' view of these risks. The subjective, non-scientific criteria that affect public perception of risk regarding nuclear energy include: the invisibility of radioactivity; the complexity of nuclear technologies; the potential consequences of a lack of democratic, social control of nuclear projects; and the catastrophic aspect of nuclear accidents. This may be compounded by the lack of a clear need for, and benefit from, nuclear energy in countries where security of electricity supply is of no immediate concern.

The need for greater public participation in scientific and technical decision making is being recognised more and more by the scientific community and there is agreement that higher levels of public involvement can, and should,

The public participation ladder



Adaptation from Weidemann and Femers, 1993 (Photo: Ohi NPP, courtesy of KEPCO, Japan) be achieved. Public involvement in decision making constitutes an active research area and the outcomes of ongoing investigations should contribute to the design and implementation of innovative approaches in the future. The opening-up of new decision-making processes, e.g. via web-based approaches, may help push public involvement further up the participation ladder. Ultimately, however, how far the public should be allowed to climb up this ladder will be decided by each country taking into account the specific national context and the views of stakeholders.

Evaluation of new methods of public involvement should take into consideration both the added qualitative values that public deliberation may bring to a decision, and the potential for increased democratic legitimacy of decisions. Since no single method is perfect, there is often a trade-off to be made between the deliberative dimension some methods offer and the representative capacity of others. Experience shows that a high degree of trust and transparency needs to be established and maintained within the public realm to give public participatory processes legitimacy and accountability.

Recognising that some important aspects of decision making in the nuclear sector are undertaken at the political level, the direct contribution of decision-making research to progress in the nuclear energy field is arguably limited. Nevertheless, two particular perspectives are of real significance for those decision makers who look to gain a better understanding of interactions between society and the nuclear energy sector in terms of how decisions are reached. First, formal processes that are based on ideas developed in decision-research literature, e.g. following a multi-criteria decision support perspective, can provide a foundation for complex decisions that often need to be made in the nuclear energy sector. Indeed, the absence of such support is very likely to induce sub-optimal decision making in many circumstances. Second, it is of critical importance to bring a full understanding of intuitive judgements vis-à-vis decision processes into play, even in cases where structured support methods are applied.

Analysing data from public opinion surveys already carried out in OECD member countries has proven to be difficult owing to differences in scope, coverage and methods adopted in each survey. Nevertheless, two main features of public opinion and concerns about nuclear energy issues can be identified in such surveys. First, in several cases, public attitudes towards nuclear energy do not seem to be fully reflected in the national energy policy pursued by governments, including nuclear phase-outs and moratoria. This may result from the intrinsic inertia of large technological and political systems or the diversity of democratic traditions, but it may also indicate that public involvement in policy and decision making concerning the nuclear energy sector is insufficient. Second, people appear to be interested in having access to more information on nuclear energy. Recognising that knowledge is important to allow the public to understand nuclear energy issues better, this declared interest offers opportunities to eventually enhance confidence in nuclear energy through more effective information.

Another important observation drawn from opinion polls is that access to comprehensive information may enhance public trust in the bodies – such as governments and industries – that provide this information, especially if they do so in an open and transparent way. Building trust through information sharing and effective communication is essential for the further use and development of nuclear energy. In modern democratic countries, civil society is likely to play an increasingly important role in all decision-making processes, and accordingly, nuclear energy policy is likely to be increasingly influenced by public opinion. In this context, carrying out and thoroughly analysing public opinion polls on major aspects of nuclear energy constitute an integral part of nuclear energy policy making.

In the light of the importance of risk perception and communication for a better understanding of relations among civil society, nuclear experts and policy makers, the NEA continues to work in this field in order to provide useful information to member countries in the implementation of their own decision-making frameworks. Within the broad NEA programme, a desk study has been carried out under the auspices of the NEA Nuclear Development Committee (NDC); it has resulted in the very recent publication of a report entitled *Society and Nuclear Energy: Towards a Better Understanding* (see page 31 for further details). In addition, the NDC will undertake an analysis of practical experience in different member countries, providing opportunities for sharing information, drawing lessons from failures and successes, and eventually identifying best practices for the benefit of experts and policy makers.

S. Mundigl*

Radiological protection of the environment

Recent debates on radiological protection have begun to raise the question of establishing a system for protecting the environment. Until now, the system of radiological protection has focused on the protection of humans, implicitly assuming that this would also appropriately protect the environment. However, an evolving civil society is increasingly unsatisfied with such an approach, and it is becoming imperative to demonstrate that the environment is protected.

Since the early part of the 20th century, the primary aim of radiological protection has been to provide an appropriate standard of protection for humans, without unduly limiting the beneficial use of radiation exposure, for example for medical treatment. Over time, as new studies on the effects of ionising radiation have been carried out, the system of radiological protection has evolved. The current system based on the Recommendations of the International Commission on Radiological Protection (ICRP) is presently under review in order to see where improvements can be made.

One of the goals of the review is to make the system of radiological protection more coherent and concise. Consideration is also being given to the protection of the environment. In various international groups, work is under way to develop a rationale for radiological protection of the environment that is comprehensive and can be implemented in an efficient manner. The NEA proposed to contribute to this work by promoting and establishing a process for the development of a policy that is as broadly informed as possible. This approach was also designed to foster information exchange among the various initiatives.

A new system for protecting the environment

Based on discussions held at an NEA-ICRP forum[1] early in 2002, the system for protecting the environment will have to be built on solid scientific foundations, and lead to the formulation of clearly defined regulations so that situations can be properly assessed and monitored. This will help ensure successful implementation. While predicated on scientific considerations, it will have to include social, philosophical, ethical, political and economic considerations as well. It will also draw upon those aspects of the precaution principle that are relevant to this application. In the end, the systems for protecting humans and protecting the environment should clearly take mutually coherent approaches. This will be important for societal acceptance, but it does not necessarily mean adopting strictly identical systems, which could be difficult to achieve.

The current notions of justification and optimisation will have to be redefined in order to integrate the environmental component into the broader system. Trends that go beyond the current

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anthropogenic definition of optimisation are already emerging. Indeed, there is currently a notable shift in the ALARA (as low as reasonably achievable) principle as it applies to the management of discharges into the environment. With increasing pressure from society, regulators are beginning to consider ALARA in parallel with the notion of BAT (best available techniques). This clearly corresponds to the public's demands to discharge as little waste into the environment as possible – as a precaution, but also in response to a new notion of maintaining a "clean environment".

Defining the environment to be protected

If the environment is confined to the human habitat, the existing system of radiological protection, if applied correctly, is sufficient. By protecting people on an individual basis the environment is respected. Under the current anthropocentric approach, for example, the environment is monitored to ensure that the public is not overexposed. To this end, regulatory limits are imposed on what can be discharged into water or the atmosphere, and regulators already take these factors into account when licensing nuclear facilities. Such aspects are also considered when contaminated sites are rehabilitated and subsequently reoccupied by the public. The drawbacks of such a system are most evident in the cases of sparsely populated or uninhabited areas of the planet. In addition, the co-factors classically studied for humans, namely chemical, physical or bacteriological toxins, are more extensive in the case of the environment.

If the definition of the environment is broader than just humans and their immediate surroundings, and extends to uninhabited areas, the tenet of "protection through protection of man" remains to be proven, and would, in fact, seem not to hold true under all circumstances. It would notably fail to addresses the issue of sites from which humans are absent, such as the Kara Sea, but which is nonetheless the subject of deep concern. Nor does it address the issue of environmental protection in connection with the management of deep geological disposal sites, even though as much as possible is being done to ensure that the current and future impacts on humans and their environment are either negligible or acceptable. Other "hybrid" cases can also be imagined, such as releases which cause little exposure to humans or to parts of the human food chain, but which significantly expose other components of the environment.

Radiological monitoring of the environment at the McArthur River uranium mining site in Canada.

A biocentric approach in which certain species would be designated for protection runs the risk of being both subjective and incomplete. An ecocentric approach, based on the preservation of ecosystems, seems best suited to protecting the environment as a whole. This is supported by the growing ability of scientists to demonstrate that an action at one level, however trivial, can have a delayed impact in both time and space.[2] Actions leading to climate change and problems of the ozone layer are examples. However, once the target of protection has been identified, the problems of assessing effects and estimating risks remain to be resolved.

Setting protection levels

If the system is to be practicable, regulators will require clear definitions of the objectives and the methods for attaining them. The same principles of protection should also apply to all environmental pollutants, be they radiological, chemical or biological. The system will have to be pragmatic if it is to be credible, and if it is to be understood by users and by the public. Regulators also need numbers in order to monitor the system's application. Obviously, the simpler these numbers are, and the easier they are to check, the more likely the system will be implemented and understood. A performance-based regulatory system may also be appropriate.

Given the global nature of environmental protection, it would seem necessary to devise a system that is coherent at the international level, and also provides guidance and boundaries that are sufficiently clear and specific to preclude differing local interpretations of environmental protection levels. However, coherency does not necessarily mean uniformity, and the environmental protection system will have to be flexible enough to allow for local initiatives, since public acceptance of an environmental policy requires consensus between stakeholders at different levels.

In the case of "highly mobile pollutants" that are able to cross borders easily, and that can be found anywhere on the planet, an international consensus is clearly desirable. This would cover pollution of the air as well as the seas and oceans. Such pollution could be brought on, for example, by atomic weapons testing and extremely serious accidents such as Chernobyl.

In other situations, in which the impact of discharges is confined to a certain space, a regional consensus would be enough, bringing together a number of affected countries but not going beyond the limits of a given geographical area. This is the case with certain factory discharges that, because of their ecological behaviour or half-life, will affect limited geographical areas only.

For pollutants with limited dispersion, such as radioactive waste that is to be stored deep underground, the consensus will have to be achieved at the national and even local level, because populations living tens of kilometres from a storage site may not perceive the site's hazards in the same way as those living nearby. This geographic definition alone may greatly help in resolving certain potential conflicts. For example, some populations in locally contaminated areas may prefer to run slightly higher risks rather than lose jobs or be forced to relocate.

The figures adopted could convey dose rates (Gy/Unit of time) to which targets (reference species for example) are subjected, and/or concentrations (Bq/Unit of mass or volume) in which targets live. To define an internal dose, as for humans, would seem almost impossible and unnecessary, and could only complicate the system. A simple dose rate or concentration approach would allow better comparisons with other environmental pollutants. For this, studies to define "sentinel species", representative of the "health" of an ecosystem, will be necessary.

With evolving technology, the system will have to be flexible, and designed to allow for advances. With the acceptability of some risks being subjectively judged at the local and/or national level, it is conceivable that the system allow for a given country's level of development, with more being asked of the most technologically advanced countries while not being lax vis-à-vis others. Protecting the environment will clearly be a long-term process, and the speed with which the system is applied will have to take societal context and national priorities into account. Such discussions, for example, are ongoing with regard to the atmospheric pollutants that threaten world climates, and consideration must be given to a similar approach to discussions between countries so as not to unduly penalise the developing world.

Public consultation and societal aspects

Few would question the need for dialogue with all segments of society before such a system is instituted, but this will also be necessary when the system is put in place. Populations face a variety of different social constraints, and foremost among these is the need for employment. Stringent protection that would jeopardise that paramount consideration would be rejected sooner or later, and it could trigger secondary effects in society that would be worse than the hazard being combated. Any international organisation that proposes a new system, such as the ICRP, will have to dialogue with, listen and be responsive to users.

Conclusions

Protection of the environment with the current system of radiological protection is sufficient, as long as humans are part of the ecosystem. In situations where man is absent, the system cannot prove that the environment is adequately protected. The future system for the radiological protection of the environment will need to be pragmatic, and flexible enough to provide for regional solutions. The process for developing the system will need to involve a wide range of stakeholders so as to ensure its acceptance, which can greatly influence future implementation. The series of NEA-ICRP fora, the next of which will be held in April 2003 in Spain, are part of a positive process of dialogue that is being put in place. Co-operation among the scientific community and other interested parties should lead to the development of a widely beneficial and efficient system of protection. ■

Notes

1. The NEA-ICRP forum on "Radiological Protection of the Environment, The Path Forward to a New Policy?", was held on 12-14 February 2002 in Taormina, Italy. A second forum will be held on "The Future Policy for Radiological Protection" on 2-4 April 2003 in Lanzarote, Canary Islands, Spain.
2. Bréchignac, F. "Environment versus man radioprotection: The need for a new conceptual approach?", *Radioprotection*, Vol. 37, C1, pp. 161-166.

R. Price, J.R. Blaise*

Nuclear fuel resources: Enough to last?

The need to meet ever-growing energy demands in an environmentally sustainable manner has turned attention to the potential for nuclear energy to play an expanded role in future energy supply mixes. One of the key aspects in defining the sustainability of any energy source is the availability of fuel resources. This article shows that available nuclear energy fuel resources can meet future needs for hundreds, even thousands, of years.

Uranium availability

The 2001 edition of the NEA publication on *Uranium: Resources, Production and Demand* (popularly known as the "Red Book") provides official estimates of uranium resources worldwide.[1] Traditionally, these resources are categorised based on their economic attractiveness and on the confidence in their existence.

Conventional resources

The most readily accessible resources, i.e. resources that are known to exist and are inexpensive to exploit using conventional mining techniques, are classed as "known conventional resources". These resources are categorised into two sub-groups: reasonably assured resources (RAR) and estimated additional resources category I (EAR-I). Known conventional resources are normally reported in terms of the amount of uranium recoverable, taking into account mining and milling process losses. They are reported in cost categories of resources recoverable at less than USD 40/kilogram of uranium (kgU), less than USD 80/kgU and less than USD 130/kgU. It should be noted that the current market price for uranium is about USD 20-30/kgU.

Table 1: Estimated uranium resources

Resource type	Estimate (1 000 t)
Known conventional resources	
Reasonably assured resources (RAR)	2 850
Estimated additional resources cat. I (EAR-I)	1 080
Undiscovered conventional resources	
Estimated additional resources cat. II (EAR-II)	2 330
Speculative resources (SR)	9 940
Secondary sources	
Commercial inventories	220
Surplus defence inventories	250
Re-enrichment	440
Sub-total	17 110
Unconventional resources	
In phosphates	22 000
In seawater	4 000 000
Total	4 039 110

Resources believed to exist and to be exploitable using conventional mining techniques, but not yet physically confirmed, are classed as "undiscovered conventional resources". These resources include estimated additional resources category II (EAR II), uranium resources that are expected to be located in well-defined geological trends of known ore deposits, or mineralised areas with known deposits; and speculative resources (SR), uranium resources that are thought to exist in geologically favourable, yet still unexplored areas. Almost all EAR-II and SR are reported as *in situ* resources, that is without providing for mining and milling losses. A number

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A note on generating costs

The nature of nuclear energy generating costs allows for significant increases in the costs of uranium before the costs of generating electricity significantly increase. For example, a 100% increase in the cost of uranium would only result in approximately a 5% increase in the cost of nuclear electricity using current reactor technology, and even less if fast reactors were used.

of countries, including Australia, did not report undiscovered conventional resources in the 2001 edition of the Red Book, although these countries are considered to have significant resource potential in sparsely explored areas.

Unconventional resources

There are additional resources classified as unconventional, in which uranium exists at very low grades, or can be recovered as a minor by-product. Unconventional resources include the uranium contained in phosphate deposits and in seawater. The technology to recover the uranium from phosphates is mature and has been utilised in the past; it is only the high costs of recovery that limits the desirability of recovering these resources. Research has hinted that it is possible to tap the vast resources of uranium contained in the world's oceans. At present, only laboratory-scale quantities have been extracted and as yet the cost to extract uranium from seawater is estimated to be very high, approximately five to ten times the cost of conventionally mined uranium. This technology would require additional time and investment to bring to deployment. Given the current low cost of uranium, with low-cost resources sufficient for several decades at current demand rates, it is doubtful that any significant funding will be made available in the foreseeable future.

Secondary sources

Secondary sources of uranium, though small compared with the resources described above, play a significant role in supplying current nuclear fuel requirements and are expected to continue to do so through the near future.[2] Important secondary sources of uranium are:

- Inventories of previously mined uranium held by both government and commercial organisations. These include strategic stocks, pipeline inventory and excess stocks available to the market.
- Large inventories of previously mined uranium derived from military applications in both the United States and the Russian Federation are becoming available for commercial applications. Highly enriched uranium (HEU) and natural uranium held in various forms by the military sector could total a few years' supply of natural uranium equivalent. In addition, surplus plutonium is available which, converted to mixed-oxide fuel, displaces the need for fresh uranium.
- Large inventories of depleted uranium, the by-product of the uranium enrichment process, represent a major reserve of uranium that could displace primary production of uranium. As of 1999, the depleted uranium stockpile of 1.2 million tU could provide up to 452 000 tU of equivalent natural uranium.[3]

Table 1 provides estimates of the various resource categories discussed above, as of the end of 2000. The table highlights that over 75% of the conventional uranium resources are in the undiscovered conventional resources category. Thus, as known conventional resources become exhausted, future production will have to come from new projects. Based on data from the 2001 Red Book, known conventional resources could last about 75 years at the 2000 demand rate. While this is some time into the future, low cost resources will deplete sooner. Because new projects take a long time to reach production level, timely development decisions will be needed to ensure that resources become available when required. For example, the McArthur River deposit in Canada was discovered in 1988 and began production in 1999; eleven years were needed to bring the mine into production. Similarly, the Cigar Lake deposit, also in Canada, was discovered in the early-1980s but production is not expected to start before 2005. Numerous factors can influence the time necessary to develop a new mine project, including regulatory processes, legal challenges and economic conditions.

Geographical distribution and security of supply

Another aspect of resource availability is the distribution of that resource around the world. Oil and natural gas have a fairly limited geographical availability, with the Middle East and the Russian Federation controlling some 70% of world crude oil and natural gas reserves.[4] Conversely, the

OECD share of known uranium resources is roughly 40%, about the same as its share of coal reserves. This is much higher than its share of oil reserves (about 7%) and natural gas reserves (roughly 12%). Looking to the future, any country with access to the sea could ultimately have access to the vast uranium resources of the planet's oceans.

In addition, OECD countries are self-sufficient in the essential services that turn the uranium raw material into the finished nuclear fuel, that is, conversion, enrichment and fuel fabrication. Thus, nuclear power plants, once constructed, provide a largely if not entirely domestic source of electricity.

Effect of advanced reactor technology and fuel cycles

Advanced technology is particularly important to any discussion on the availability of nuclear fuel resources because of its potential to radically extend the resource base and increase the efficiency of use. Light water reactors make up almost 80% of the reactors in operation worldwide. Most use a "once-through" fuel cycle in which the uranium placed in the reactor to produce energy is removed after a period of time and treated as waste for disposal. In this once-through fuel cycle about 99% of the potential energy content in the nuclear fuel remains unused. Other reactors use recycled fuel which improves the energy yield. Recycling spent nuclear fuel in current plants can save up to approximately 10 to 15% of the initially mined uranium through the use of the remaining uranium and the plutonium created during the fission process in the original uranium fuel. Plutonium is extracted from the spent fuel and recycled in mixed-oxide (MOX) fuel, but the number of recycles is currently limited because of the buildup of undesirable isotopes. After a few cycles the fuel would have to be managed as a waste similar to the once-through cycle. At present only a single recycle is used.

Yet, with already identified advances in technology these resources can be extended so that nuclear fuel resources become virtually unlimited. The introduction and use of fast reactors would provide significant benefits over current thermal reactor technology:

- They permit the more efficient use of fertile materials as nuclear fuel, such as uranium-238 and thorium, thereby expanding the available resource base.
- In a breeder configuration, fast reactors can produce more fuel than they consume, with this fuel being recovered and used to produce energy.

Fertile material

A fertile material is a material that is capable of becoming fissile, that is capable of fission, following the capture of a thermal neutron. Important examples are ^{238}U, which can become fissile ^{239}Pu, and ^{232}Th, which can become fissile ^{233}U.

For example, fast breeder reactors could use the depleted uranium tails discussed above that have already been refined and are in storage. This by-product of uranium enrichment would therefore become a fuel resource available for producing energy, augmenting natural uranium resources.

Thorium, an abundant and widely dispersed natural resource can also be used as a fuel resource (see Table 2). Existing estimates of thorium resources should be considered conservative for two reasons:

- Data from China, central and eastern Europe, and the former Soviet Union have not yet been published.
- Historically weak market demand has limited the exploration for thorium.

It is possible, even likely, that much more thorium exists than has been documented and would be discovered if concerted exploration became warranted.

Implementation of these technological innovations remains for the future and will require considerable research and development effort and investment. Although no commercial deployment of fast reactors is yet planned, they remain a promising opportunity in respect of resource utilisation.

Table 2: Nuclear fuel resources useable in fast reactors

Resource category	Estimate (1 000 t)
Thorium reserves[1]	2 160
Additional thorium resources[1]	2 350
Depleted uranium tails[2]	1 200 (758)[3]

1. Data from China, central and eastern Europe, and the former Soviet Union not available. *World Energy Assessment*, United Nations Development Program, New York, 2000; German Federal Institute for Geosciences and Natural Resources data bank.
2. At the end of 1999. *Management of Depleted Uranium*, OECD, Paris, 2001.
3. If the depleted uranium tails are re-enriched to the extent possible, about 758 000 tU will remain with 0.06% ^{235}U assay.

Table 3: Effect of technology advances on resource availability

Reactor/fuel cycle[i]	Potential energy production – conventional resources only (TWh)[ii]	Potential energy production – total resources (TWh)[iii]	Years at 1999 world nuclear electricity generation[iv] (conventional)	Years at 1999 world nuclear electricity generation (total)
Current fuel cycle (LWR, once-through)	827 000	21 200 000	326	8 350
Recycling fuel cycle (Pu only, one recycle)	930 000	23 900 000	366	9 410
Light water and fast reactor mixed with recycling	1 240 000	31 800 000	488	12 500
Pure fast reactor fuel cycle with recycling	26 000 000[v]	630 000 000	10 000	250 000
Advanced thorium/uranium fuel cycle with recycling	43 200 000[vi]	90 200 000[vii]	17 000	35 500

i. For a fuller description of the technologies listed and their resource requirements, see reference 5 below.

ii. Conventional resources were calculated using known conventional and undiscovered conventional resources plus secondary sources, from Table 1, for a total of 17 110 000 tonnes.

iii. Total resources assumes conventional resources plus the phosphate resources, but only 10% of seawater uranium is recovered (400 million t), added together for a total of 439 110 000 t.

iv. *Key World Energy Statistics*, IEA, Paris, 2001. Total 1999 (latest year data available) electricity generation by nuclear power was 2 538 TWh, rounded to 2 540 TWh.

v. Assumes use of conventional uranium resources plus 758 000 t of depleted uranium tails remaining after re-enrichment.

vi. Assumes use of only the thorium reserves base of 2 160 000 t with a matching amount of depleted uranium.

vii. Assumes thorium reserves base plus resources of 4 510 000 t with a matching amount of depleted uranium. This also assumes that no further discoveries of thorium are made.

Longevity

With these resource estimates and technology options, for how long will we be able to produce nuclear energy? The answer depends on many factors, including levels of electricity demand. Table 3 demonstrates how long estimated resources would be able to produce electricity for various nuclear reactor and fuel cycle technology options. Illustrative assumptions were made as to the resources consumed by each technology as well as the levels of demand. Nevertheless, even at generation rates ten times greater than current levels, there are sufficient resources for many centuries of energy production, and technology developments would greatly extend these periods.

Conclusion

Vast uranium resource potential supplemented by the possible use of fast breeder reactors and thorium-based fuel cycles point to a nuclear energy future that can meet sustained demand.

In considering the question, “Are there enough resources to meet the needs of the current generation without compromising the ability of future generations to meet their own needs?”, that answer has to be yes. Sufficient nuclear fuel resources exist to meet the energy demands of this and future generations well into the future at current and increased demand levels. However, to use this potential, considerable effort and investment will be needed to develop new mining projects and to bring advanced technologies to bear in a timely manner. ■

References

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2. IAEA (2001), *Analysis of Uranium Supply to 2050*, IAEA-SM-362/2, IAEA, Vienna.
3. NEA (2001), *Management of Depleted Uranium*, OECD, Paris.
4. US Energy Information Administration (2002), *International Energy Annual 2000*, Washington D.C.
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J. Royen*

Advanced reactors: Safety issues and research needs

The NEA organised in February 2002 a "Workshop on Advanced Nuclear Reactor Safety Issues and Research Needs". The meeting was co-sponsored by the IAEA and organised in collaboration with the European Commission. It was attended by more than 80 participants, representing 18 countries and 4 international organisations. This article is adapted from the Conclusions and Recommendations prepared by the workhop's Organising Committee for the NEA Committee on the Safety of Nuclear Installations (CSNI).

Currently, advanced nuclear reactor designs range from the development of evolutionary and advanced light water reactor (LWR) designs to designs that go beyond advanced LWR technology such as high-temperature, gas-cooled reactors and liquid metal reactors. These advanced designs include a greater use of advanced technology and safety features in addition to those employed in currently operating plants or approved designs, including passive safety features, reduced reliance on human actions, longer response times, adapted implementation of the defence-in-depth principle, improved analytical methods, and greater reliance on advanced instrumentation and control systems. The purpose of the workshop was to bring together a broad cross-section of parties – designers, utilities, regulators and researchers – with a potential stake in the development and deployment of advanced nuclear power plants, to:

- facilitate early identification and resolution of safety issues by developing a consensus among participating countries on the identification of safety issues, the scope of research needed to address these issues and a potential approach to their resolution;
- promote the preservation of knowledge and expertise on advanced reactor technology; and
- provide input to the Generation IV International Forum (GIF) Technology Roadmap development.

During the workshop, efforts were also made to link advancement of knowledge and understanding of advanced designs to the regulatory process, with emphasis on building public confidence.

Workshop conclusions

The basic principle of nuclear safety defence-in-depth continues to be employed in advanced reactors. However, it was recognised that future and advanced reactors pose several questions and challenges to the implementation of defence-in-depth. In the past, this has been achieved primarily through deterministic implementation of provisions and multiple physical barriers against the release of fission products, and by measures to prevent accidents and mitigate their consequences. The emphasis put on prevention and/or mitigation differs among the various advanced concepts. The approach to the safety of future reactors will need to be derived from a more advanced interpretation of defence-in-depth fully integrated with probabilistic safety analysis (PSA) insights. How the best integration of the deterministic and probabilistic concepts will be achieved is still a major question as PSA may suggest strategies and tactics that differ

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from, and occasionally conflict with, prescriptive defence-in-depth requirements.

The advanced reactor concepts discussed in the workshop were mostly limited to advanced light water reactors (ALWR), high-temperature gas-cooled reactors (HTGR) and liquid-metal-cooled reactors (LMR). The concepts discussed can be divided roughly into two categories: mature ones, more or less ready for market, such as the Framatome-ANP SWR-1000 and Westinghouse AP-600 concepts, and preliminary ones, such as IRIS (an ALWR), and most LMRs and HTGRs. A common feature to all advanced reactor types is that they promise safety enhancement over the current generation of plants; likewise, the safety significance and provisions to be made against external hazards are common questions that pertain to all future designs.

Mature ALWR concepts are characterised by increased simplicity and streamlining in their safety system design, a significant amount of passive system features, and an explicit consideration of severe accidents as a part of their design basis. Regarding severe accidents, the ambitions of their technical and regulatory treatment varies between Europe and the United States. European vendors and regulators specifically require qualification of the dependability of their severe accident capabilities. This does not mean, however, that all related technical issues have already been categorically resolved; design features are also selected on the basis of PSA insights to effectively eliminate severe accident sequences that would be overly complex to manage. In the United States, PSAs are relied upon more extensively to identify severe accident vulnerabilities and appropriate measures to reduce the risk from severe accidents.

As to LMRs, extensive experience from operating sodium-cooled reactors exists, and convergence seems to be occurring in the treatment of certain major issues such as core disruptive accidents and sodium-related issues. As far as lead/bismuth-cooled reactors are concerned, significant remaining questions relate, among others, to materials and thermal-hydraulics issues: integrity, corrosion, thermal loads and heat transfer, irradiation effects, etc. It should be noted, though, that considerable operating experience (about 80 reactor-years) has been gained with Russian submarines using the same type of coolant. Several research institutions in OECD member countries are building research facilities to intensify experimental and analytical investigations in the area of heavy liquid metals.

Advanced nuclear reactor concepts

Deployed in the near term (by 2015)

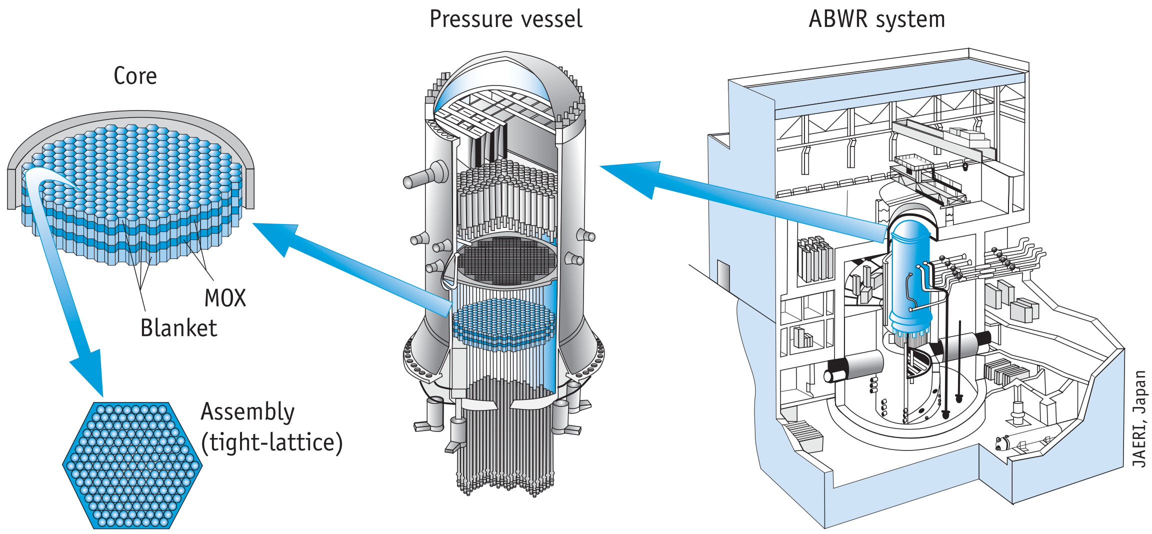
- *Advanced pressurised water reactors*
- *Advanced boiling water reactors*
- *Advanced pressure tube reactors*
- *Integral primary system reactors*
- *Modular, high-temperature, gas-cooled reactors*

Deployable in the longer term

- *Sodium liquid-metal-cooled reactors*
- *Very high temperature reactors*
- *Gas-cooled fast reactors*
- *Lead-alloy-cooled reactors*
- *Supercritical-water-cooled reactors*
- *Molten salt reactors*

As to HTGRs, some amount of actual operating experience exists, and in terms of future HTGRs, the main picture is clear: HTGR safety cases, as presented so far, rely very heavily on the fuel as the main – if not sole – fission product barrier, and hence all fuel issues become prominent. These include fuel concept qualification with a very high confidence level, manufacturing issues, fuel handling during operation, and improved understanding of fuel failure mechanisms and modes. HTGR designs include promising features against functional concerns related to both criticality and decay heat removal, but ultimately their success will depend on the quality of the fuel. Furthermore, certain well-known systemic safety issues such as air-water ingress into the reactor and reactor vessel integrity with respect to thermal shock remain to be addressed to an extent that convinces the whole reactor safety community. Most of the fundamental research into currently fashionable HTGR design features seems to date from 20 to 30 years back, and there does not appear to be much from recent experimental efforts to satisfy this need, by either confirming earlier results or closing existing gaps. Proponents of HTGR maintain that the plant needs no leak-tight containment in the conventional sense against its internal threats due to greatly enhanced safety. However, recent attention to external hazards and the fact that the relative importance of external hazards increases with enhanced safety against internal hazards may raise the question of the need for a containment or other adequate protection against external hazards.

Schematic diagram of a reduced-moderation water reactor (RMWR) being developed in Japan



Specific research needs for any reactor type can only be identified once a consistent overall safety case has been established for it. This safety case helps identify where remaining research needs are and what level of uncertainty reduction (confidence) is necessary. Ideally, the safety case should render manageable all confidence requirements of each individual safety question and safety factor; only then can research problems be formulated properly; that is, problems can be defined in such a way that they will have a definite solution knowable to adequate accuracy and obtainable at reasonable cost. Research supporting the passive systems development of mature ALWR concepts seems to fulfil this objective, or at least comes close.

Recommendations

The Organising Committee made several recommendations to the CSNI regarding future actions:

- Workshops to discuss the safety cases and their supporting evidence should be arranged, with priority on near-term deployable design concepts.
- Countries that have immediate interest in these options should lead the preparation of such workshops. The meetings should also be open to capable and interested non-OECD participants, because much actual work on future reactors is being done outside the OECD.
- Possibilities of international co-operative research projects should be explored and identified.
- Actions should be taken to compile and preserve the existing knowledge bases, especially for technologies developed more than 20 years ago (e.g. key HTGR fuel testing). A good example of how to do this exists in the form of Computer Code Validation Matrices, developed for (mainly) LWR applications; the most important part of this effort is storage of the results of the chosen experiments, for example in the NEA Data Bank. Internationally recognised and guaranteed storage is the only way of ensuring that essential data, knowledge and understanding are not lost. Irretrievable loss of some LWR test data has already occurred. In order to avoid loss of essential test data related to other reactor types, it would be advisable to start setting up corresponding international databases as a first priority (as a minimum, as soon as any new data start to become available).
- More generally, in order to maintain competence, action should be taken to preserve acquired knowledge and experience in areas where R&D is at a standstill, such as liquid metal fast breeder reactor development. Such action would cover aspects of information storage and retrieval, and information transfer, in industry, universities and regulatory bodies.

Reference

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C. Pescatore*

Decommissioning and dismantling nuclear facilities in NEA countries

The OECD/NEA member countries were among those involved in the earliest developments of nuclear technology in the 1940s and 1950s. They thus have a range of plant and equipment that has now served its purpose, and needs to be decommissioned and dismantled. A new range of challenges opens up as the more modern nuclear power programmes mature and large commercial nuclear power plants approach the end of their useful life by reason of age, economics or change of policy on the use of nuclear power. The scale of such challenges may be judged from the fact that over 500 nuclear power plants have been constructed and operated worldwide, most of them in NEA member countries. Given an average planned operating life span of 30 to 40 years and that the average age of nuclear power plants is about 15 years, the rate of withdrawal from service will peak some time after 2015. The statistical distribution is wide, however, with some countries having already retired certain commercial nuclear power plants from service, and having even decommissioned and dismantled them in some cases, whilst in other countries it will be some years before any plants are retired.

The decommissioning and dismantling (D&D) work done on earlier facilities has provided a substantial body of knowledge and experience over a wide range of complex technical issues, but the requirement now is to apply the available techniques to the D&D of the larger commercial facilities. In addition to technical issues, plans and procedures will need to address other major issues associated with impacts on society and the environment, regulatory arrangements and long-term funding. In other words, although much has already been accomplished, much also remains to be done.

The NEA has long recognised the importance of D&D of nuclear facilities, and this since the early 1980s. The NEA Working Party on Decommissioning and Dismantling (WPDD) has just issued an overview of the status of D&D of nuclear facilities and associated issues in NEA member countries.[1] The report draws upon a database of fact sheets produced to a standard format by individual member countries that can be accessed online from the NEA website.[2] The WPDD plans to update this database regularly. Some of the main points are presented hereafter.

The purpose of D&D is to allow removal of some or all of the regulatory controls that apply to a nuclear site.

The term "decommissioning", when applied in its broadest sense to nuclear facilities, covers all of the administrative and technical actions associated with cessation of operation and withdrawal from service. It starts when a facility is shut down and extends to eventual removal of the facility from its site (termed "dismantling" in this article). These actions may involve some or all of the activities associated with the dismantling of plant and equipment, decontamination of structures and components, remediation of contaminated ground and disposal of the resulting wastes. The purpose of D&D is to allow removal of some or all of the

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regulatory controls that apply to a nuclear site whilst securing the long-term safety of the public and the environment, and continuing to protect the health and safety of decommissioning workers in the process. Underlying this are other practical objectives including release of valuable assets such as site and buildings for unrestricted alternative use, recycling and reuse of materials, and the restoration of environmental amenity. In all cases, the basic objective is to achieve an end-point that is sensible in technical, social and financial terms, that properly protects workers, the public and the environment and, in summary, complies with the basic principles of sustainable development.

There is no unique or preferred approach to D&D of nuclear facilities.

It is generally presumed that the eventual end-point of D&D activities is return of the site to a condition in which it can be released for unrestricted use. Within NEA member countries, however, there is a wide range of opinions and policies on the route and time scales to arrive at this eventual end-point. These opinions and policies are influenced by national positions, or lack of them, on such matters as the future use of nuclear power, the continued availability of trained staff, societal issues associated with impact on neighbouring communities, possible alternative uses for the facility and the sites – e.g. for new nuclear installations – technical and regulatory issues, arrangements for waste management, and on economic issues associated with costs and cash flow.

Two main strategic approaches that are being implemented are the "Immediate Decontamination and Dismantling" and "Safe Storage" options, or some combination of the two. For example, early decontamination and dismantling of bulky peripheral equipment may be carried out in order to reduce the visual impact of the facility, the remainder of which may be left under safe storage.

In the Immediate Decontamination and Dismantling option, after a period of up to a few years to allow cooling and decay of the short-lived radionuclides, the equipment, buildings, and parts of the facility and site that contain radioactive contaminants are decontaminated to a level that permits removal of regulatory control. They are dismantled to the extent necessary shortly after cessation of operations. Residual radioactive waste is treated, packaged and removed to an appropriate waste storage or disposal site.

In the Safe Storage option, the facility is placed in a stable, safe condition and maintained in that state until it is subsequently dismantled and decontaminated to levels that permit removal of regulatory controls. To prepare for safe storage, any fuel is removed, and radioactive liquids are drained from systems and components and then processed. During the period of safe storage, the facility is kept intact while radionuclide decay occurs, thus reducing the quantity of contaminated and radioactive material that must be disposed of during later decontamination and dismantling. This period of safe storage can last from a few tens of years up to a hundred years or so.

Decommissioning work at a nuclear power plant in Germany.

Techniques for D&D are already available, and valuable experience is being fed back into plant design and decommissioning plans.

Techniques for decontaminating and dismantling nuclear facilities are already available. It is now standard practice in the design of facilities and selection of materials to facilitate the implementation of these techniques. It is important for the future to ensure that the accumulating experience of applying these techniques to large plants is shared throughout the D&D community, and that lessons continue to be fed back into new facility designs and D&D plans.

Many nuclear facilities have already been successfully decommissioned and dismantled.

Techniques are available and have been successfully applied to the D&D of many early facilities used for development and demonstration of nuclear power. Some sites have already been returned to a condition suitable for unrestricted reuse. This has provided a substantial body of experience on a wide range of complex applications that is now being used on larger commercial facilities. The challenges for the future are to further improve strategies and processes for securing safety, environmental protection and economy.

Current systems for protecting workers, the public and the environment are satisfactory for implementation and regulation of D&D.

The effects of D&D on the health and safety of both workers and the public, as well as on the environment, are well understood and the protection systems already in place will deal with them satisfactorily. However, because there are significant differences between operation and D&D of nuclear facilities, it is intended to review these issues in order to ensure the continuing safety of workers, the public and the environment over the whole D&D process, and to ensure continuity and transparency of the regulatory process.

Current institutional arrangements for D&D are sufficient for today's needs.

The bodies currently in place for establishing policy, legislation and standards; for operating nuclear facilities and managing radioactive waste; and for regulating these activities, are adequate for dealing with D&D. Depending upon individual national circumstances, however, it may be convenient to modify practical arrangements by creating new bodies, such as dedicated liabilities management organisations, to assume responsibility for D&D on behalf of operators that are no longer in business, and to maintain and further develop the related expertise.

Arrangements are in place for funding D&D, but evaluation of costs requires further attention.

It is recognised that provisions for funding D&D need to be made during the operating lifetime of a facility, and arrangements are now established in OECD/NEA member countries. The challenges are to ensure that D&D costs are calculated correctly and that sufficient funds will be available when required.

Fund management systems vary from country to country, depending upon the D&D strategies adopted, and may or may not involve liabilities management organisations of the kind described above. Waste management costs are a significant element of the overall costs of D&D and may dominate in some cases depending on how the costs, of residual spent fuel management for example, are assigned. Hence, it is important not only that waste quantities are minimised but also that the costs of waste treatment, storage and disposal are separately identified and assigned.

Most D&D wastes are similar to normal operational wastes but some present new challenges that will need to be addressed.

The management and disposal of radioactive waste is a key element in the satisfactory completion of D&D of nuclear facilities and is a major contributor to its overall costs. Much of the waste produced during D&D of nuclear facilities is similar to that produced during their operational lifetime, so a major part of this new challenge is already shared with current activities. The new element, characteristic of D&D specifically, is the large quantity of waste containing only small concentrations of radionuclides. This requires serious attention to development and application of principles by which valuable materials may be released from regulatory control for re-use or recycling, thus minimising the need for disposal as radioactive waste. The management of specific wastes containing materials such as graphite, beryllium, sodium, asbestos, etc. will also need further attention.

Local communities are increasingly demanding involvement in planning for D&D.

It is widely accepted that openness and transparency are essential for winning public approval of D&D plans. The local public is increasingly demanding to be involved in such planning and this may accelerate the introduction of concepts such as "stepwise decision making". The challenge for the future, therefore, will be satisfactory development of systems for consulting the public, local communities in particular, and the creation of sources of information in which the public can have full confidence. ■

Notes

1. The report, entitled *The Decommissioning and Dismantling of Nuclear Facilities: Status, Approaches, Challenges*, may be obtained free of charge by writing to neapub@nea.fr.
2. See www.nea.fr/html/rwm/wpdd.html/ for more information regarding the database of fact sheets and the activities of the NEA Working Party on Decommissioning and Dismantling (WPDD).

E. Bertel, L. Van den Durpel*

P&T: A long-term option for radioactive waste disposal?

The long-term hazard of radioactive waste arising from nuclear energy production is a concern for the public and policy makers. The use of partitioning and transmutation (P&T) of the actinides and some of the long-lived fission products can reduce the radiotoxicity of high-level waste (HLW) and, possibly, the safety requirements for its geological disposal as compared with the current once-through fuel cycle. However, to make the technologically complex P&T enterprise worthwhile, a reduction in the HLW radiotoxicity by a factor of at least 100 is desirable. This requires very effective reactor and fuel cycle strategies, including fast reactors (FRs) and/or accelerator-driven, sub-critical systems. The accelerator-driven system (ADS) has recently received increasing attention due to its perceived potential to improve the flexibility and safety characteristics of transmutation systems.

A recent NEA study on P&T systems,[1] published in 2002, compares actinide transmutation strategies for fast reactors and ADS's in order to highlight the specific role that ADS's might play and the main differences between ADS's and FRs with respect to reactor properties, fuel cycle requirements, economic aspects and R&D needs.

The strategies investigated in the study include two broad classes: in the first class plutonium and minor actinides (MA) are managed separately while in the second they are managed together. In the first class, the use of ADS's for transmutation may provide additional flexibility by confining minor actinides in a small, dedicated part of the fuel cycle while plutonium is managed in more conventional fast reactors. Both classes require advanced technologies, but the first class is more evolutionary. The second class, which is more innovative, may enhance proliferation resistance. The main outcomes of the study are summarised in Box 1.

In the early days of nuclear energy, the availability of uranium was considered to be a major limiting factor for nuclear deployment, while radioactive waste was not a main concern. This early

Box 1:
Key messages from the NEA study on P&T

- *Fuel cycles with multiple recycling of the fuel and very low fuel losses are required to achieve a hundred-fold radiotoxicity reduction.*
- *The full potential of a transmutation system can be exploited only if the system is utilised for a minimum time period of about 100 years.*
- *All transmutation strategies with multiple recycling of the fuel can achieve similar radio-toxicity reductions, but the choice of the strategy strongly influences fuel cycle requirements.*
- *The ADS is particularly suited as a "dedicated" minor actinide burner in steady-state scenarios and provides flexibility in transient scenarios.*
- *The ADS-based evolutionary and the FR-based innovative approaches appear to be the most attractive transmutation strategies, from both technical and economic viewpoints.*
- *A considerable amount of R&D on sub-critical reactors, advanced fuels and materials is needed before ADS-based transmutation technology can be deployed.*

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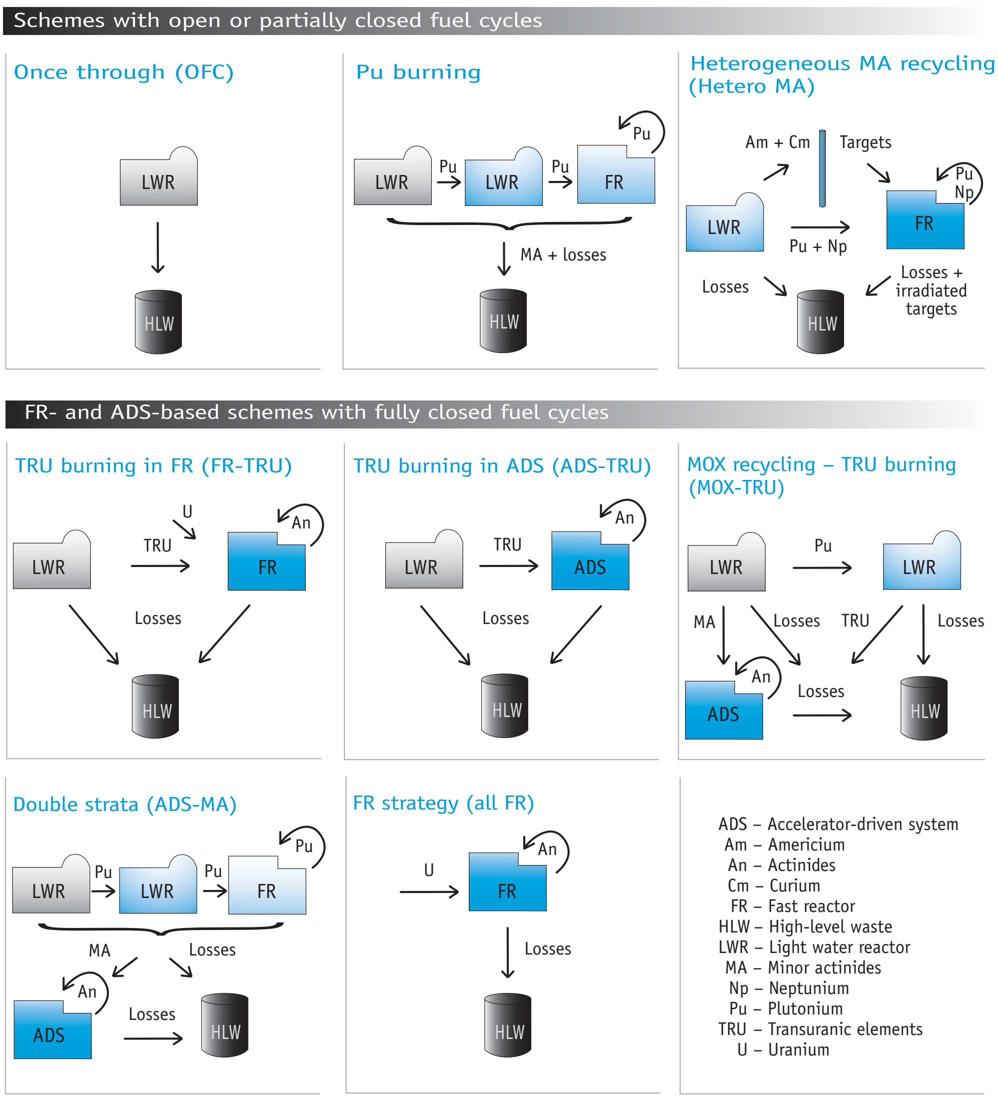
perspective called for a rapid introduction of fast reactors making efficient use of conventional, uranium-plutonium mixed-oxide (MOX) fuel. Furthermore, closing the fuel cycle for plutonium was considered worthwhile because of its projected economic attractiveness. The reduction of waste radiotoxicity, which also calls for closure of the fuel cycle for minor actinides, was less attractive because minor actinides have a limited economic value in reactors.

Today, while uranium is still abundant, the amount of radioactive waste and its long-term stewardship are raising more concern. Closing the fuel cycle for plutonium and minor actinides becomes a relevant goal in a sustainable development perspective. The partitioning and transmutation of actinides and fission products would improve the "radiological cleanliness" of nuclear energy, and thus address one of the most important requirements for an environmentally friendly nuclear energy system.

Figure 1 presents the fuel cycle schemes used in the NEA study to carry out a quantitative assessment of different strategies for burning plutonium and minor actinides and their comparison with the once-through fuel cycle.

A key finding from the comparative analyses carried out is that all transmutation strategies with fully closed fuel cycles can, in principle, achieve similar reductions in the actinide inventory and the long-term radiotoxicity of high-level waste. These reductions are comparable with those

Figure 1: Fuel cycle schemes considered in the study



obtained in an exclusively fast reactor strategy. This implies that there are no distinct differences between the respective potentials of FR- and ADS-based strategies. However, the technological challenges of both strategies differ.

The P&T strategies analysed can achieve more than a hundred-fold reduction in the long-term waste radiotoxicity, and even higher reductions in the quantities of heavy metal and transuranic elements (TRU) requiring disposal, as compared with the once-through fuel cycle. However, very low losses in reprocessing and fuel fabrication in multiple recycling as well as high fuel burn-ups are necessary to obtain such reduction factors.

The FR-TRU and ADS-MA schemes offer similar advantages regarding actinide waste reduction and technological aspects. The FR-TRU scheme can gradually evolve to an exclusively fast reactor strategy, but requires high initial investment in fast reactor and advanced fuel cycle technologies. The ADS-MA scheme confines the minor actinides to a small side-stream of the fuel cycle, but requires very innovative technology for that purpose. The ADS has the advantage that it can burn pure minor actinides while avoiding a deterioration of the core safety characteristics.

The economic analysis indicates that electricity costs of ADS-based transmutation scenarios can be improved by burning as much plutonium as possible in conventional reactors, i.e. MOX-fuelled LWRs and FRs. The ADS-MA and FR-TRU schemes have the lowest electricity costs of all the schemes considered. In these two schemes, P&T is estimated to add a relatively modest 10-20% to the electricity generation costs as compared with the once-through fuel cycle.

While competitiveness in present electricity markets is not compatible with any increase of nuclear electricity generation costs, the added costs associated with P&T may become acceptable in the future in the context of energy policies integrating sustainable development goals and taking into account the premium placed by society on reducing waste radiotoxicity. Also, in the long term, a rise by some 10 to 20% of nuclear electricity prices could be more than compensated by fossil fuel price increases resulting from resource exhaustion and/or environmental protection regulations.

The introduction and phase-out of nuclear energy systems implies inherently very long transient periods due to physical limitations associated with the production and destruction of in-pile and out-of-pile fuel inventories. Therefore, achieving the hundred-fold reduction in the long-term waste radiotoxicity through deployment of P&T technology requires a commitment for at least a century. In particular, its full benefit can be realised only if the TRU inventory of the system is ultimately burnt and not put to waste. In this context, it is worth mentioning that the ADS-TRU strategy features a lower steady-state TRU inventory and, in a nuclear phase-out scenario, can burn this inventory more quickly than the other strategies.

While FRs and ADS's perform similarly with respect to environmental friendliness criteria, they differ considerably from technology, operation and safety viewpoints. The development of fuel cycle technology is, however, the prime criterion for achieving the benefits of P&T, whatever the system used. The fuel cycle challenges are a direct consequence of the goal of transmutation, which implies the contamination of the fuel cycle by high concentrations of minor actinides. A central issue is the reprocessing of the fuel, but fuel fabrication, handling and transportation also pose new problems.

Transmutation systems involve unusual fuels with high decay heat and neutron emission. A significant effort is required to demonstrate that these fuels can be manufactured and reprocessed, and to investigate their burn-up behaviour. ADS fuels are particularly enriched in minor actinides and can probably be reprocessed only with the help of pyrochemical methods. These methods have to be further developed in order to tolerate from ten to more than twenty times higher decay heat levels than those encountered in the pyrochemical reprocessing of fast reactor fuels.

The introduction of pyrochemical processing technologies at the industrial level will require the development of new process flow-sheets and the use of potentially very corrosive reagents in hostile environments. These processes will generate chemical and radiological hazards that will have to be mitigated.

PUREX aqueous reprocessing can be considered as valid for FR-MOX fuel in the plutonium-burning and double strata schemes. Reprocessing this fuel within short cooling times and with the required high recovery yields will, however, require the plutonium dissolution yield to be improved and the PUREX process to be modified.

Owing to its high radioactivity, the handling of FR-MOX fuel requires measures to be taken to reduce the radiation doses in the fabrication plant and during the transportation of the fuel assemblies. The increased requirements for shielding and the preference for short transportation paths for multiple recycled fuels favour building the pyrochemical reprocessing plant at the reactor site.

Pyrochemical reprocessing in an exclusively FR scheme is more demanding than in transmutation schemes. This is a consequence of accommodating the driver and the blanket fuel in the same fuel rod and blending the two components before reprocessing. The blending has the advantage of reducing the decay heat of the fuel to be reprocessed and increasing the proliferation resistance of the system, but imposes high fuel throughput, and hence economic penalties as well. These penalties could be reduced if the blanket was separated from the driver fuel and reprocessed using PUREX or UREX technology. It is obvious that, from a decay-heat viewpoint alone, it would be preferable to circumvent the transmutation strategy and move directly to a fast reactor strategy.

While fuel cycle development serves both FR- and ADS-based transmutation scenarios, ADS's require additional R&D. The sub-critical ADS concept enables the design of reactor cores that would not have acceptable operating characteristics as critical systems, which allows a larger reactivity margin before reaching prompt criticality, thereby reducing the potential of the core for a power excursion. These advantages have to be balanced against the technological challenges arising from the coupling of a reactor and an accelerator, and the necessity to accommodate new types of operational and accidental transients.

Although the development of accelerators is well-advanced, with beam powers up to 10 MW for cyclotrons and 100 MW for linear accelerators appearing feasible, beam losses and, most importantly, beam trip frequency must be further reduced to satisfy activation, fast temperature fluctuation and mechanical stress criteria for sensitive structures. Various problems related to accelerator-reactor coupling, especially the target and beam window, must still be investigated.

Controlling an ADS with beam power rather than an absorber-based reactivity compensation system reduces the potential of the core for reactivity-induced transients. For a sub-critical TRU burner, however, this advantage has to be weighed against the economic penalty arising from the high burn-up reactivity loss, which implies a higher beam current to maintain power at the end of the reactor cycle. The comparison is complicated because it also involves the balancing of safety-grade requirements for the two control systems.

In contrast to the steady-state behaviour of sub-critical cores, their response to reactivity and source transients has not yet been studied extensively. The presence of an external neutron source that can change very rapidly, in combination with very weak reactivity feedback, implies fast and (depending on the sub-criticality level) violent responses to accelerator trips and control actions, which put additional demands on the control actuators, the fuel behaviour and the heat removal processes. In particular, the fuel should be capable of buffering the respective heat balance disturbances. The study of feedback mechanisms in the coupled accelerator, target and sub-critical core is therefore of importance.

The development of advanced reactors and fuel cycle schemes, and their industrial and commercial deployment will require very long lead-times. In order to keep the P&T option open, R&D should be continued on critical and sub-critical fast reactors, advanced fuels, structural and coolant materials, and irradiation targets containing transmutable elements, focusing on key areas (see Box 2).

Finally, to assess the relevance of P&T as a long-term option for radioactive waste disposal, a thorough analysis of the performance of geological repositories for alternative compositions of HLW, i.e. with and without minor actinides, is necessary. Such an integrated view of nuclear energy systems is essential to ascertain whether the benefits from P&T can outweigh the necessary technological and financial investments required. ■

Box 2: Key R&D areas for P&T

R&D should be pursued in the following key areas if the P&T option is to remain open:

- *experimentation on fuel characterisation, fabrication, irradiation and reprocessing;*
- *demonstration at industrial scale of the performance of pyrochemical processes, in order to assess in more detail the technical and economic viability of the respective fuel cycle options;*
- *comparative assessment of different coolants for fast-spectrum systems;*
- *development of improved modelling tools to simulate material behaviour under mixed irradiation conditions and high temperatures;*
- *safety analyses of ADS's to investigate possible paths to hypothetical core disruptive accidents, if such accidents cannot be excluded deterministically;*
- *demonstration experiments to validate the ADS concept from the operation and safety viewpoints, for countries embarking on ADS-based schemes.*

Reference

1. NEA (2002), *Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study,* OECD, Paris.

D. Metcalfe, C. Pescatore, S. Voinis*

Developing the safety case for deep geological repositories

In recent years, it has become increasingly evident that the development of a geological repository will involve a number of stages punctuated by interdependent decisions on whether and how to move to the next stage. These decisions require a clear and traceable presentation of technical arguments that will promote confidence in the feasibility and safety of the proposed concept. The depth of understanding and technical information available to support decisions will vary from step to step. A safety case provides an important basis for deciding to move to the next stage in repository development.

The concept of a "safety case"[1] has been progressively clarified through a series of NEA initiatives over the past decade, which culminated with the publication of *Confidence in the Long-term Safety of Deep Geological Repositories* (NEA, 1999) and the findings from the three Integrated Performance Assessment Group (IPAG) exercises.[2]

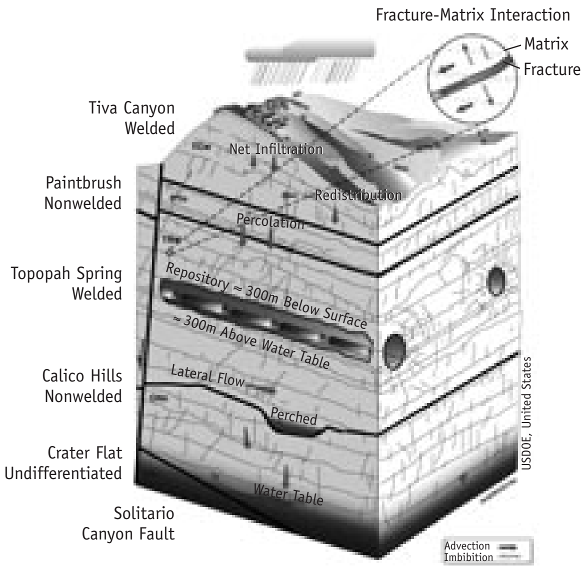
The IPAG initiative started in 1994 with the aim to provide an international forum to examine the overall status of safety cases for deep disposal of radioactive waste and their supporting integrated performance assessment (IPA) studies. The work was carried out in three phases: IPAG-1 from 1995 to 1996, IPAG-2 from 1997 to 1998 and IPAG-3 from 1999 to 2000. The number of national organisations participating in these exercises increased from 10 organisations in IPAG-1 to 20 in IPAG-3, demonstrating the growing interest in the safety case. The IPAG findings, and the compilations of questions and answers for each IPAG exercise, constitute a useful summary and database of national safety cases.

** Mr. Doug Metcalfe (e-mail: metcalfed@cnsc-ccsn.gc.ca), from the Canadian Nuclear Safety Commission, was the Chairman of the last two IPAG Phases. Dr. Claudio Pescatore (pescatore@nea.fr) and Mrs. Sylvie Voinis (sylvie.voinis@oecd.org) have assured the secretariat of the IPAG Project. They are both members of the NEA Radiation Protection and Radioactive Waste Management Division.*

IPAG-1: Lessons learnt from ten performance assessment studies

The IPAG-1 study[3] aimed to examine completed IPA studies as a practical body of evidence that would indicate the current status of performance assessment (PA). On the basis of the examination of ten PA studies, it was noted that no new insurmountable problems had been encountered in the application of PA since the NEA/IAEA/CEC Collective Opinion[4] of 1991. The following progress had been observed since 1991:

- a more comprehensive identification of relevant "features, events and processes" (FEPs) and a tracking of decisions on the treatment and incorporation of FEPs into assessment models;
- the use of large site data sets and more formal methods of reduction of data for use in assessment models;
- a more sophisticated use of geochemical codes and data to simulate porewater composition and evolution to arrive at radionuclide speciation and solubility equilibria;
- the use of three-dimensional models of groundwater flow taking into account the spatial variability of the hydrogeological properties of the site and including variable density and transient effects;
- a greater understanding of transport of contaminants through fractured rock and unsaturated rocks;



Conceptual drawing of Yucca Mountain flow processes.

- improved models of specific processes, e.g. volcanism and its effects, treatment of colloids, gas-mediated releases;
- a more sophisticated use of probabilistic codes including representation of time-dependent processes and events;
- the application of more rigorous quality assurance procedures for assessment decisions, control of input/output data sets, and code development;
- the incorporation of qualitative understanding in the arguments related to long-term safety.

Areas for improvements were also identified. Namely:

- IPAs should strive to provide an unambiguous and complete record of the decisions and assumptions made, and of the models and data used in arriving at a given set of results (improve traceability).
- IPAs should be documented in such a way that the readers can gain a clear picture of what has been done, the findings of the assessment and their significance, and the rationale for the results obtained (improve transparency).
- Co-ordination should be enhanced between site characterisation and performance assessment, and in particular to better explain the process used to select the geosphere model parameter values based on site data.
- The management of uncertainty should address scenarios, models and parameters, and the issue of the completeness of their analysis.
- Terminology such as performance "assessment" and "analysis", and safety "assessment", "analysis" and "case" should be clarified, and the definitions of those terms as used in the IPA should be clearly stated.

IPAG 2: Regulatory reviews of assessments of deep repositories

The IPAG-2 study[5] examined international experiences of peer reviews of IPAs, and in particular reviews performed in support of regulatory assessments, from both the implementers' and regulators' points of view. Findings from IPAG-2 included the following:

- Regarding the **conduct of a review**, dialogue is important and of benefit to both implementers and regulators. Implementers and regulators should discuss approaches for maintaining dialogue that benefits the review process and, at the same time, preserves independence. Making written records and documentation from the dialogue publicly available could enhance the overall credibility of the process.
- Concerning **the safety case**, the benefits of using multiple lines of reasoning and a variety of assessment techniques for evaluating safety were noted. Also, it was noted that better use could be made of qualitative, or "soft" information in a safety case, particularly for illustrating and describing the intrinsic safety provided by the repository site and design. The use of complementary methods for demonstrating the overall safety of the disposal system will help to build confidence in the safety case. The multi-barrier concept was confirmed to be one of the key bases for the long-term safety of deep geological disposal systems, and implementers need to clearly explain in their IPAs how they have used and applied this concept in developing their repository design.
- Further to the work performed in IPAG-1 on traceability and transparency, IPAG-2 advised that IPAs prepared for licensing purposes need to be traceable, transparent, reproducible and publicly available. One aspect of developing traceability and understanding between the implementer and the regulator is consistency of the methods and documentation structure and style. Other, non-technical stakeholders also review IPAs and have different needs with regard to traceability and transparency. An integration of their viewpoints is needed. Regulatory

guidance should clearly state the requirements and expectations for demonstrating compliance with regulatory criteria.

IPAG 3: Approaches and arguments to establish and communicate confidence in safety

The IPAG-3 study[6] focused on the evaluation of the state of the art for obtaining, presenting and demonstrating confidence in long-term safety, and made recommendations on future directions and initiatives for improving confidence. It focused on the arguments that are required to build confidence in both the intrinsic safety and the assessment of the long-term performance of the disposal system. Key confidence arguments were identified and classified in six categories as follows:

- confidence in the proposed disposal system (supported by the intrinsic robustness of the multi-barrier system, and comparisons with familiar examples and natural analogues);
- confidence in the data and knowledge of the disposal system (e.g. the quality of the research programme and site investigations, the quality assurance procedures);
- confidence in the assessment approach (enhanced by a logical, clear, systematic assessment approach, and an assessment conducted within an auditable framework);
- confidence in the IPA models (testing models against experiments and observations of nature, model comparison exercises);
- confidence in the safety case and the IPA analyses (demonstrating that assumptions are representative or conservative, sensitivity studies);
- confidence via feedback to design and site characterisation (e.g. overall quality and safety of the disposal system).

IPAG-3 also concluded that even if the multi-barrier system is common to all disposal systems, its meaning and role in each safety case needs to be well explained by its proponent.

Furthermore, IPAG-3 provided or confirmed recommendations regarding the following key topics:

- The main challenge for any safety case and its supporting IPA concerns the inevitable uncertainties that arise from the long time scales associated with repository performance. An IPA needs to address such uncertainties in a comprehensive manner and show that, based on the available data and information, the repository can be expected to provide for the long-term protection of human health and the environment.
- Confidence in the data employed in the safety case rests on the assurance that the research and site characterisation work has been properly carried out and the data correctly understood and interpreted within the performance assessment. The IPAG-3 study recommended that key assumptions and their justifications be clearly stated within a dedicated section of the safety case or IPA documentation.
- A safety case should include a clearly developed "confidence statement" (as proposed in *Confidence in the Long-term Safety of Deep Geological Repositories*), which should explain how the assessment results compare with the appropriate regulatory criteria. It could make comparisons with levels of naturally occurring radiation and other everyday risks in order to put the radiological risks arising from the repository into perspective.
- The safety case is a management issue. Feedback to each part of the safety case such as design and site characterisation is possible if it is planned and managed during the repository development process.

The three IPAG exercises covered a mix of waste management programmes, disposal concepts and geological media, as well as different types and amounts of waste. They offered a unique opportunity for exchanging information, assessing progress and identifying trends. Further information about IPAG and its reports is available at www.nea.fr/html/rwm/ipag.html. ■

Notes

1. A safety case is a collection of arguments at a given stage of repository development, in support of the long-term safety of the repository. It comprises the findings of a safety assessment and a statement of confidence in these findings. It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages.
2. The three IPAG studies produced the reports cited in notes 3, 5 and 6.
3. NEA (1997), *Lessons Learnt from Ten Performance Assessment Studies*, OECD/NEA, Paris.
4. NEA (1991), *Disposal of Radioactive Waste: Can Long-term Safety Be Evaluated? An International Collective Opinion*, OECD/NEA, Paris.
5. NEA (2000), *Regulatory Reviews of Assessments of Deep Geologic Repositories: Lessons Learnt*, OECD, Paris.
6. NEA (2002), *Establishing and Communicating Confidence in the Safety of Deep Geologic Disposal: Approaches and Arguments*, OECD, Paris.

News briefs

Forum on stakeholder confidence (FSC)

Exchanges between institutions involved with nuclear energy and civil society are no longer confined to rigid mechanisms provided by the law. A more complex interaction is now taking place amongst players at national, regional and especially at local levels, and a broader, more realistic view of decision making, encompassing a range of actors in civil society, is emerging. Any significant decisions regarding the long-term management of radioactive waste are thus being accompanied by comprehensive public reviews with the involvement of a diverse range of stakeholders. These stakeholders include not just the waste generators, waste management agencies and regulatory authorities, all of whom have a primarily technical focus, but also interested or concerned parties with a non-technical focus such as local communities, elected officials, non-governmental organisations and the general public. The NEA Forum on Stakeholder Confidence (FSC) facilitates the sharing of international experience in addressing the societal dimension of radioactive waste management, explores means of ensuring an effective dialogue with the public, and considers ways to strengthen confidence in decision-making processes.

The Forum was created under a mandate from the NEA Radioactive Waste Management Committee (RWMC). The FSC convenes a series of regular sessions, complemented with workshops held in a national context. The annual sessions include topical discussions on specific issues of interest and are used to elaborate further on lessons learnt. At the latest meeting in April 2002 the topical session focused on the environmental impact assessment as a tool for stakeholder involvement. The workshops, also held annually, focus on stakeholder involvement in dealing with waste management issues in the host country. A wide spectrum of stakeholders from the host country are invited to express their views on the project and the nature of their involvement in the decision-making process. The workshops are run in a highly interactive fashion, and all viewpoints are documented in the workshop proceedings.

The Forum was launched in August 2000, in Paris, by holding an international workshop. It addressed a variety of topics ranging from evolving participatory democracy, stakeholder identity, and trust in the international framework, to the role of open dialogue in all aspects of radioactive waste management. During the three-day meeting, worldwide experience in the field of stakeholder confidence and radioactive waste disposal was reviewed by participants with backgrounds spanning both the technical and social sciences. Affiliations included universities, national academies, technical oversight bodies, safety authorities, implementing agencies and advisory bodies to government. In addition, a mayor from Sweden and a parliamentarian from France were amongst the inauguration speakers.

The first workshop held in a country context was organised in Finland, in November 2001. Similarly to the first workshop, all stakeholder representatives – from the local to the national level – were able to review in a highly interactive format the sequence of decisions that ultimately led to the Parliament's approval, in May 2001, of the siting of a spent fuel repository in the municipality of Eurajoki. Although the experience and the lessons learnt were closely connected to the national context and culture, general indications of successful principles for stepwise decision making could also be drawn. In particular, workshop participants found that:

- Stakeholders should be allowed to participate from the very early stages of the siting process.
- Public interest in participation can be maintained only if stakeholders believe that they can have an influence on key decisions.
- Continued dialogue between the implementers and local people is crucial.

The workshop was preceded by an encounter with the Eurajoki municipality, where the values as well as the policies and the economic standing of the community were discussed.

The second national site visit and workshop was held in Canada, in October 2002. The past two years have been a defining period for radioactive waste management in Canada. In March 2001, an agreement was reached between the Government and three communities in southern Ontario to clean up and locally manage radioactive waste from past uranium refining and conversion activities. In June 2002 the *Nuclear Fuel Waste Act* became law, enabling Canada to move effectively towards a solution for the long-term management of "spent fuel waste", including the selection of a technical approach for long-term disposal of the spent fuel to be implemented by waste owners, financial responsibilities of waste owners and government oversight processes. Three key areas of inquiry were examined. Namely, what are the social concerns at play; how can these concerns be addressed; and development opportunities for local communities. The site visit allowed the FSC delegates to gain first-hand experience of the decision process for the final clean-up and disposition of mill tailings in the Port Hope, Ontario community. The workshop, which included a wide range of Canadian stakeholders, enabled an analysis and appraisal of the Port Hope solution and the longer range spent fuel disposal programme. The discussions provided useful information by and for the FSC members and Canadian stakeholders and should assist Canada in undertaking the next steps. The workshop is currently being documented; an executive summary will be posted on the NEA website shortly.

Additional workshops and regular meetings of the FSC are planned, along with publications that will abstract the lessons that have been learnt.

For further information concerning the FSC and available reports, see www.nea.fr/html/rwm/fsc. html. ■

The uranium conversion facility at Port Hope, Canada, and the surrounding residential community.

GIF and NEA: Recent news

Since the previous edition of *NEA News*, some major steps have been achieved by the Generation IV International Forum (GIF). The most important is the completion of the Generation IV Technology Roadmap, with its main results:

- the selection of six Generation IV nuclear energy systems considered as the most promising to meet the eight Generation IV goals;
- the identification of the R&D needed to advance these systems for potential commercialisation.

The six selected systems are shown below.

- a continuous system integration and assessment to check the viability and performance of each system taking into account the success and difficulties of the development of the key technologies and the updating of the figures of merit used in the system selection process.

Naturally, only the funding countries will participate in the management of the specific R&D projects and own the resulting technologies. The Technical Committees in charge of the system integration and assessment will have the same membership as the GIF.

The six systems selected in the Generation IV Technology Roadmap

Acronyms	Selected systems	Spectrum	Fuel cycle
GFR	Gas-cooled fast reactor system	Fast	Closed
LFR	Lead-alloy-cooled reactor system	Fast	Closed
MSR	Molten salt reactor system	Thermal	Closed
SFR	Sodium-cooled fast reactor system	Fast	Closed
SCWR	Supercritical-water-cooled reactor system	Thermal and fast	Once-through and closed
VHTR	Very high temperature reactor system	Thermal	Once-through

A "system" must be understood as comprising not only the nuclear reactor itself and its conventional island, but also the entire associated fuel cycle.

For each system, the technical gaps in current knowledge and the key technologies to be developed have been identified in the roadmap. In September in Tokyo, the GIF member countries expressed their preliminary interest in collaborative R&D for each system. A lead country was designated to facilitate further discussions among interested countries, and especially to specify more precisely the scope of each R&D project to be undertaken in the framework of the GIF.

The GIF R&D organisation will combine two aspects:

- the specific R&D projects aimed at developing and/or proving the key technologies in each selected system;

At the same meeting in Tokyo, the GIF requested the NEA to provide technical secretariat support to the forthcoming R&D phase of its activities. This would include the secretariat of the specific R&D projects, the Technical Committees and the GIF Experts Group for its technical tasks. This request follows the highly efficient involvement of the NEA in the Roadmap phase, and takes into account NEA experience in R&D joint projects and running international committees.

At its October 2002 meeting, the NEA Steering Committee was informed of this potential new role for the NEA, which is consistent with the Agency's mission and the orientation described previously when it became involved in the Generation IV Technology Roadmap. This NEA activity would be totally funded by voluntary contributions. ■

New publications

Economic and technical aspects of the nuclear fuel cycle

Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles

A Comparative Study

ISBN 92-64-18482-1 – Free on request.

The long-term hazard of radioactive waste arising from nuclear energy production is a matter of continued discussion and public concern in many countries. Through partitioning and transmutation (P&T) of the actinides and some of the long-lived fission products, the radiotoxicity of high-level waste (HLW) can be reduced by a factor of 100 compared with the current once-through fuel cycle. This requires very effective reactor and fuel cycle strategies, including fast reactors (FR) and/or accelerator-driven, sub-critical systems (ADS). The present study compares FR- and ADS-based actinide transmutation systems with respect to reactor properties, fuel cycle requirements, safety, economic aspects and R&D needs. Several advanced fuel cycle strategies are analysed in a consistent manner to provide insight into the essential differences between the various systems in which the role of ADS is emphasised. The report includes a summary aimed at policy makers and research managers as well as a detailed technical section for experts in this domain.

Nuclear Energy and the Kyoto Protocol

ISBN 92-64-18486-4 – Free on request.

The implementation of the Kyoto Protocol and the application of its "flexible mechanisms" are at the forefront of energy policy debates in most OECD countries. The potential role of nuclear energy in this context is viewed very differently and assessed against various criteria by the range of stakeholders in governments and civil society according to their interests and priorities. This book provides key facts concerning nuclear energy and the Kyoto Protocol. It highlights the challenges and opportunities for the future development of nuclear energy in the context of implementing the Kyoto Protocol, and more broadly in alleviating the risks of global climate change. The report will be of interest to energy policy makers and senior experts in the field as well as to members of civil society eager to better understand the issues raised within the debate on the role of nuclear energy in sustainable development. It will assist in making the necessary trade-offs involved in addressing global climate change concerns.

Nuclear Energy Data – 2002

ISBN 92-64-09899-2 – Price: € 20, US$ 20, £ 13, ¥ 2 350.

This new edition of *Nuclear Energy Data*, the OECD Nuclear Energy Agency's annual compilation of essential statistics on nuclear energy in OECD countries, offers additional textual and graphical information as compared with previous editions. It provides the reader with a comprehensive but easy-to-access overview on the status of and trends in the nuclear power and fuel cycle sector. This publication is an authoritative information source of interest to policy makers, experts and academics involved in the nuclear energy field.

Society and Nuclear Energy: Towards a Better Understanding

ISBN 92-64-18494-5 – Free on request.

While signs of a possible nuclear energy renaissance are visible worldwide, it is highly important to understand better the views of civil society on nuclear technologies, how their risks are perceived, and how to establish effective communication between all stakeholders aiming at enhancing consensus building prior to decision making. This report is based upon an in-depth analysis of research work and published literature on risk perception and communication, public participation in policy and decision making and the evolution of public opinion on nuclear energy. It will be of interest to policy makers, governmental agencies and industry. Additionally, members of civil society and various stakeholders eager to learn more about social issues related to the development of nuclear energy will find relevant information in this report.

Uranium 2001: Resources, Production and Demand

ISBN 92-64-19823-7 – Price: € 85, US$ 74, £ 52, ¥ 9 850

The "Red Book", jointly prepared by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, is a recognised world reference on uranium. Its contents are based on official information received from 45 countries, supplemented by unofficial information for two others. This edition, the 19th, presents the results of a thorough review of world uranium supply and demand as of 1 January 2001 and provides a statistical profile of the world uranium industry in the areas of exploration, resource estimates, production and reactor-related requirements. It provides substantial new information from all major uranium production centres in Africa, Australia, Eastern Europe and North America and, for the first time, includes a report on Tajikistan. This edition also features international expert analyses and projections of nuclear generating capacity and reactor-related uranium requirements through 2020.

Radiation protection

ISOE – Information System on Occupational Exposure

Ten Years of Experience

ISBN 92-64-18480-5 – Free on request.

The Information System on Occupational Exposure (ISOE) was created in 1992 to provide a forum for radiation protection experts from both utilities and national regulatory authorities to discuss, promote and co-ordinate international co-operative undertakings in the area of worker protection at nuclear power plants. The ISOE System is jointly managed by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). This report provides an overview of the experience gained from, and benefits provided by, the ISOE System over the past ten years. Active participation of a large number of utilities in ISOE has contributed to a reduction in occupational exposure at nuclear power plants worldwide.

Occupational Exposures at Nuclear Power Plants

Eleventh Annual Report of the ISOE Programme, 2001

ISBN 92-64-18492-9 – Free on request.

The Eleventh Annual Report of the ISOE Programme summarises achievements made during 2001 and compares annual occupational exposure data. Principal developments in ISOE participating countries are also described.

The Way Forward in Radiological Protection

An Expert Group Report

ISBN 92-64-18489-9 – Free on request.

Virtually all national and international radiation protection regulations and standards are based on the recommendations published by the International Commission on Radiological Protection (ICRP). New recommendations, to replace those issued in 1990, are in the process of being developed for issuance in 2005, and it is in the interest of all NEA member countries to ensure that these recommendations meet the needs of national regulatory organisations and practitioners. Since revisions began at the ICRP in 1999, the NEA Committee on Radiation Protection and Public Health (CRPPH) has been leading discussions regarding what, in the old recommendations, could be improved or changed to make any new recommendations more functional. Based on a preliminary two-year study to identify those areas that should be improved, this report suggests specific improvements that would render the new system easier to understand and apply, and that should be considered for inclusion in the new ICRP recommendations.

Radioactive waste management

The Decommissioning and Dismantling of Nuclear Facilities

Status, Approaches, Challenges

ISBN 92-64-18488-0 – Free on request.

This report, intended for a broad readership, provides a concise overview of the decommissioning and dismantling of nuclear facilities and associated issues in NEA member countries. It draws upon a database of fact sheets produced to a standard format by individual member countries that is accessible online from the NEA website.

Stepwise Decision Making in Finland for the Disposal of Spent Nuclear Fuel

Workshop Proceedings, Turku, Finland, 15-16 November 2001

ISBN 92-64-19941-1 – Price: € 45, US$ 45, £ 28, ¥ 5 250.

On 18 May 2001, the Finnish Parliament ratified the Decision in Principle (DiP) on the final disposal facility for spent nuclear fuel at Olkiluoto, in the municipality of Eurajoki. This followed positive decisions taken earlier by the Municipal Council and the Government. How did these political and societal decisions come about? An NEA workshop held in November 2001 provided the opportunity to present the history leading up to the DiP and to examine future perspectives with an emphasis on stakeholder involvement. The workshop was highly interactive and focused on three main topics: the stepwise decision-making process, stakeholder involvement and confidence building. All relevant stakeholder voices were heard and their viewpoints debated. An account of the individual presentations and the discussions that took place are provided in these proceedings.

Nuclear law

Nuclear Law Bulletin No. 69

Volume 2002/1-2

2002 Subscription (2 issues + supplements) – ISSN 0304-341X - Price: € 75, US$ 80, £ 48, ¥ 9 550.

Supplement to No. 69: Romania, Ukraine

ISBN 92-64-19810-5 – Price : € 20, US$ 20, £ 12, ¥ 2 300.

Nuclear regulation/nuclear safety

Advanced Nuclear Reactor Safety Issues and Research Needs

Workshop Proceedings, Paris, France, 18-20 February 2002

ISBN 92-64-19781-8 – Price: € 75, US$ 65, £ 46, ¥ 8 700.

New nuclear reactor designs are expected to have a higher level of safety than current designs. As part of the efforts to achieve this, important safety issues related to the new designs need to be identified at an early stage, and research required for problem resolution defined. These proceedings bring together the papers presented at the OECD/NEA Workshop on Advanced Nuclear Reactor Safety Issues and Research Needs. Conclusions of the workshop discussions are offered at the end of the book, which will be of particular interest to all those involved in planning and designing the next generation of nuclear reactors.

CSNI Technical Opinion Papers

No. 1: Fire Probabilistic Safety Assessment for Nuclear Power Plants

No. 2: Seismic Probabilistic Safety Assessment for Nuclear Facilities

ISBN 92-64-18490-2 – Free on request.

These technical opinion papers represent the consensus of risk analysts and experts in NEA member countries on the current state of the art in Fire Probabilistic Safety Assessment (PSA) for nuclear power plant design and operation and Seismic PSA for nuclear facilities. The objective is to present clear technical opinions to decision makers in the nuclear community. As such, the intended audience is primarily nuclear safety regulators, senior researchers and industry leaders. Government authorities, nuclear power plant operators and the general public may also be interested.

Improving Versus Maintaining Nuclear Safety

ISBN 92-64-18493-7 – Free on request.

Based on contributions from members of the NEA Committee on Nuclear Regulatory Activities (CNRA), this publication provides an overview of current nuclear regulatory philosophies and approaches, as well as insights into a selection of public perception issues. This publication's intended audience is primarily nuclear safety regulators, but government authorities, nuclear power plant operators and the general public may also be interested.

The Nuclear Regulatory Challenge of Judging Safety Backfits

ISBN 92-64-18484-8 – Free on request.

The economic pressures of electricity market competition have led nuclear power plant operators to seek ways to increase electricity production and to reduce operating costs at their plants. Corresponding pressures on the regulatory bodies include operator demand to reduce regulatory burdens perceived as unnecessary and general resistance to consider safety backfits sought by the regulator. The purpose of this report is to describe potential situations giving rise to safety backfit questions and to discuss regulatory approaches for judging the backfits. The intended audience for this report is primarily nuclear regulators, although the information and ideas may also be of interest to nuclear operating organisations, other industry organisations and the general public.

Nuclear science and the Data Bank

Advanced Reactors with Innovative Fuels

Workshop Proceedings, Chester, United Kingdom, 22-24 October 2001

ISBN 92-64-19847-4 – Price: € 130, US$ 113, £ 79, ¥ 15 000.

At this workshop, information on R&D activities for advanced reactor systems was exchanged and research areas in which international co-operation could be strengthened were identified, in particular the roles that could be played by existing experimental facilities and the possible needs for new infrastructure.

Physics of Plutonium Recycling

Volume VI: Multiple Plutonium Recycling in Advanced PWRs

ISBN 92-64-19957-8 – Price: € 45, US$ 45, £ 28, ¥ 5 250.

Although the recycling of plutonium as thermal mixed-oxide (MOX) fuel in pressurised water reactors (PWRs) is now well-established on a commercial scale, many physics questions remain. The main question addressed in this report is the number of times plutonium can effectively be recycled in a PWR. This report describes in particular an exercise based on a realistic, multiple-recycle scenario, which followed plutonium through five generations of recycling in a PWR. It considered both a standard PWR design currently in use and a highly moderated design. The latter is a possible option for a dedicated, MOX-fuelled PWR in which it would be possible to optimise the moderation for plutonium. The study of these two designs in parallel has provided a better understanding of their relative merits, as well as insight into the limitations of multiple recycling and the long-term toxicity of fission products and actinides.

Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources

Workshop Proceedings, Grenoble, France, 10-12 September 2000

ISBN 92-64-18485-6 – Free on request.

This NEA Workshop and Euroconference was the second in a series devoted to the application of synchrotron-based techniques to radionuclide and actinide sciences. The unique properties of synchrotron radiation allow one to obtain information about the molecular structure of radionuclides and actinide species, which is essential for understanding and predicting the behaviour of these hazardous elements in the environment. Application areas include risk assessment of nuclear waste storage, remediation of contaminated sites, and development of effective separation technologies, as well as radiopharmaceutical chemistry. These proceedings contain the abstracts and some of the full papers presented at the meeting. In addition to presenting the latest experimental and theoretical results, the meeting was aimed at providing opportunities for learning and scientific discussions between experts in the field and young scientists.

The Use of Thermodynamic Databases in Performance Assessment

Workshop Proceedings, Barcelona, Spain, 29-30 May 2001

ISBN 92-64-19846-6 – Price: € 55, US$ 50, £ 34, ¥ 6 350.

Performance assessment of repository concepts for the geological disposal of long-lived radioactive waste relies on the availability of thermodynamic data for many radionuclides and other elements under a wide range of physico-chemical conditions. For the past ten years, the OECD Nuclear Energy Agency (NEA) has been co-ordinating a multinational effort to produce a database of selected thermochemical values that would satisfy the requirements of the various national programmes in member countries. This project is known as the NEA Thermochemical Database (TDB) Project. This publication contains the full papers and summary discussion records of a workshop attended by scientists active in the field of chemical thermodynamics and experts in repository performance assessment who use the thermochemical databases for their evaluations. During the workshop, participants discussed current experimental and theoretical standpoints, new data requirements and the peculiarities of their application in performance assessment.

A VVER-1000 LEU and MOX Assembly Computational Benchmark

Specification and Results

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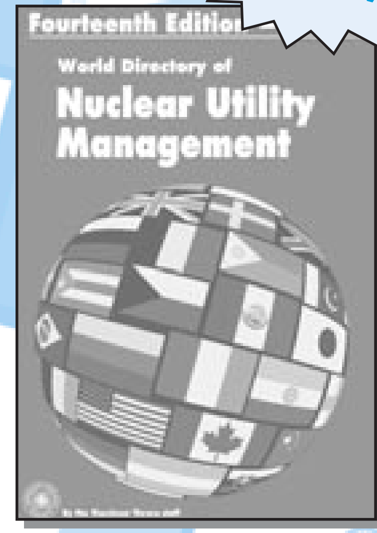

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PRINTED IN FRANCE
(68 2002 02 1 P) – ISSN 1605-9581