NEA News

2002 – No. 20.1

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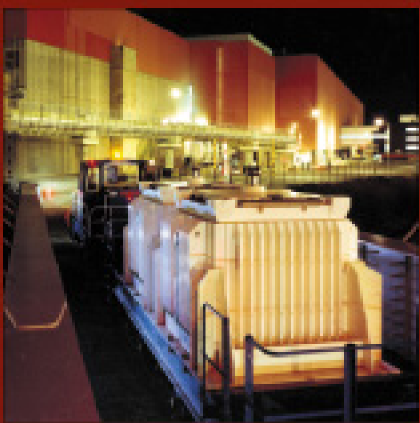

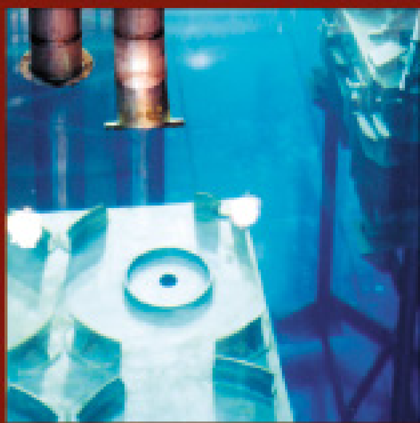

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NEA News

contents

2002 – No. 20.1

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The OECD Nuclear Energy Agency (NEA) was established in 1958 as the OEEC European Nuclear Energy Agency and took its present designation in 1972 when its membership was extended to non-European countries. Its purpose is to further international co-operation related to the safety, environmental, economic, legal and scientific aspects of nuclear energy. It currently consists of 27 Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the NEA's work and a co-operation agreement is in force with the International Atomic Energy Agency.

For more information about the NEA, see:

www.nea.fr

Cover page: La Haba uranium mine before and after restoration (ENUSA); Sellafield feed pond (BNF plc); maintenance at Barsebäck (Pierre Mens, Press Promotion); fuel transport at Sellafield (BNF plc); vitrified waste storage (BNFL).

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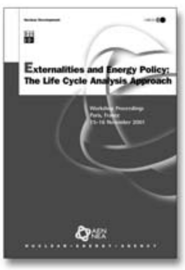

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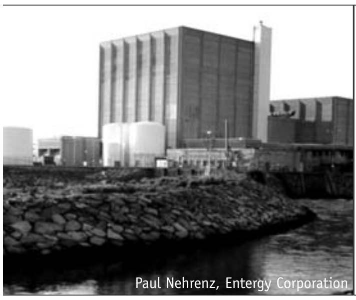
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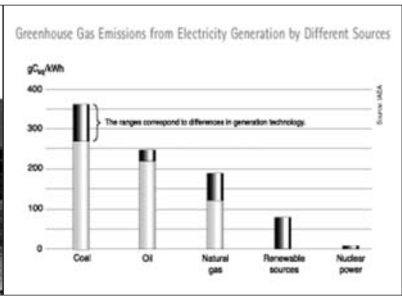


Peter Mens, Press Promotion

Sustained interest in the role of nuclear power

Sustained interest in nuclear power has been confirmed in several NEA Member countries in recent months. Following the "nuclear renewal" of 2001 in a number of countries, at the turn of the year some questioned whether the momentum gained would continue as strongly in 2002, notably given some national tendencies towards nuclear phase-out. Based on two recent international gatherings, the answer would still appear to be yes.

At the informal seminar of European energy ministers in April, EU Transport and Energy Commissioner Loyola de Palacio made the choices very clear: "Either we fulfil Kyoto and keep nuclear (energy) or we renounce Kyoto and abolish nuclear energy." OECD Secretary-General Donald Jonhston, speaking from a personal point of view, referred to the advantages of nuclear energy and stated that "…we have to take another look at nuclear – a very sober look at nuclear."

The advantages of nuclear energy were also explicitly acknowledged in the G8 meeting of energy ministers in May, during which ministers "discussed how energy security, economic growth, environmental protection and, therefore, sustainable development are supported by improved energy efficiency, and diversification of energy sources and fuels." Ministers found that "Countries can improve their ability to respond to changing energy supply conditions through increased energy efficiency and a mix of energy sources and types… Most G8 members stress the value of nuclear energy in this context, providing optimal safety and waste handling are ensured."

This last point is heeded by the nuclear community. Extensive R&D projects are being conducted at national and international levels to provide even safer nuclear power plants. Indeed, it is one of the main objectives to be achieved by the nuclear systems being considered for future use (see the articles on "Opportunities for international co-operation in the development of innovative reactors" and "Generation IV and the NEA"). Regarding radioactive waste management, important steps forward have been taken in the United States (see the NEA news brief on the international peer review concerning the Yucca Mountain Project), as well as in Finland where a parliamentarian "decision in principle" has been taken in favour of beginning work to implement a deep geological repository for radioactive waste.

The nuclear community is also looking into various economic and environmental issues concerning nuclear energy, as readers will discover in the pages that follow.

Luis E. Echávarri
NEA Director-General

T. Lazo, S. Mundigl*

Radiological protection, society and the environment

Evolving social, economic and technological contexts have led the international community to review the current system of radiological protection. The review is seeking, *inter alia*, to make the system less complex, improve stakeholder involvement in the decision-making process and provide for protection of the environment.

The current system of radiological protection is based upon the recommendations laid down in *Publication 60: 1990 Recommendations of the International Commission on Radiological Protection* (ICRP). Historically, the ICRP has issued new general recommendations approximately every 15 years. Possible changes to these recommendations, which would be published towards 2005, are currently the subject of much discussion.

One motivation for changing the system is related to its complexity. As new questions and issues in radiological protection have emerged over the years, the ICRP system of radiological protection has evolved to address each new issue more or less on an individual basis. This has led to the evolution of a system which, while very comprehensive, is also complex. With such a complex system it is not surprising that there are some perceived inconsistencies which may lead to concerns that certain radiation protection issues are not being adequately addressed. Different stakeholders in decisions involving radiological protection tend to focus on different elements of this incoherence when calling for change.

For example, following the nuclear accidents at Three Mile Island (1979) and Chernobyl (1986) it was clear that the radiological protection system should provide more detailed guidance regarding how populations should be protected against the accidental releases of large quantities of radioactive materials into the atmosphere. While under normal circumstances the population is protected on the basis of fixed dose limits, in accident situations, which have numerous possible scenarios, it was decided that the best possible solution would be to focus protection actions on reducing the amount of dose received. A flexible system was therefore adopted proposing ranges of dose limits. In practical terms, however, this means that the limits actually applied may vary from one geographical area to another and from one accident to another.

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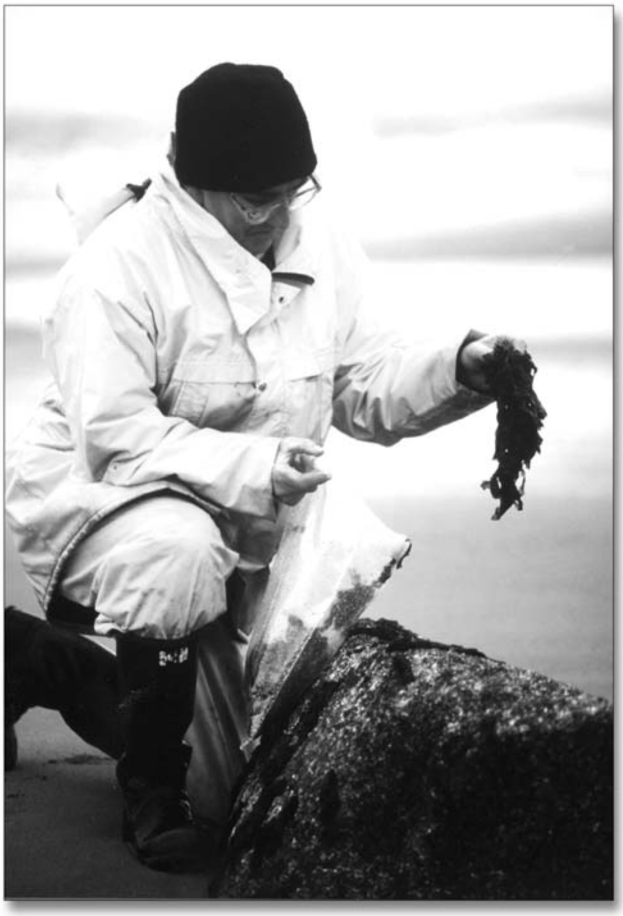
There are several other examples of apparent incoherence or insufficient guidance in the system of radiological protection, or of areas needing some clarification: protection against radon gas, consideration of risks transferred from the public to workers, and intergenerational equity are just a few. While it is considered important to explain these inconsistencies, a growing motivator for change is the increasing desire of the public and other stakeholders to participate in decision making that affects public health or the state of the environment, and who then demand coherence.

The most recent thinking with regard to stakeholder involvement has focused on ways to "better integrate radiological protection in modern society", which includes making a better distinction between the roles and responsibilities of the various stakeholders in the process of decision making. In particular, it is widely felt that a modern system of radiological protection should clearly recognise the boundaries between the scientific aspects of risk assessment, the social aspects of risk evaluation and management, and the regulatory aspects of risk management. Better understanding and definition of these distinctions should greatly facilitate the development of new radiological protection recommendations. One of the most tangible results of making such distinctions will be a clear rationale with regard to where, in the system of radiological protection, international agreement is needed, and where, on the contrary, flexibility for national and local approaches is necessary.



BNF plc, United Kingdom

Collection of seaweed near Sellafield for environmental monitoring purposes.

Radiological protection and the environment

Another key issue that has been gaining importance in NEA Member countries is the radiological protection of the environment. This has become a part of the more general interest in identifying opportunities to enhance protection of the environment as part of sustainable development initiatives. Discussions of this issue have focused on developing a rationale for this protection that is comprehensive and comprehensible, and thus can be implemented in an efficient manner.

Several efforts have recently been initiated, including at the NEA, in order to promote and establish a process for developing a policy on radiological protection of the environment that is as broadly informed as possible. These have led to progress in defining an international rationale in this area; in assessing the availability of scientific information to develop a broadly accepted policy; and in evaluating the socio-political dynamics of this endeavour.

Some aspects key to the further development of a policy for the radiological protection of the environment have begun to emerge. They include the following:

- The major objective of radiological protection of the environment is to prevent harm. Some precision and consensus on what is meant by "harm" is, however, needed.
- The radiation protection community believes that currently the environment is sufficiently protected against harmful effects of ionising radiation in a majority of cases. However, the current system fails to demonstrate the level of protection that has been attained. A modified system must provide tools that allow the demonstration of the level of protection.

- In order to gain credibility and acceptance, radiological protection of man and the environment must be considered and assured together, using a consistent rationale. Protection against the harmful effects of ionising radiation should also be harmonised with protection approaches used for other similar hazards.
- Depending on the area affected, the protection of the environment may be dealt with on different levels. Radioactive releases to the air and to the sea, for example, may have a transboundary component and should be considered on a global level. Other situations, such as releases to a river, may require only a regional approach, e.g. within the river Rhine Convention. Finally, situations entirely restricted to the area of one country may be best solved with national approaches.
- The ICRP is seen as the appropriate organisation to develop recommendations for the radiological protection of the environment globally. At the same time, the radiation protection community welcomes open dialogue with, and consultation of, other stakeholders.

Evolving towards a new system

It should be noted that the development of a new system of radiological protection has become a very open stakeholder process, which is encouraging in terms of achieving a widely accepted outcome. The NEA has been contributing actively to this effort in order to ensure that future recommendations will better address the needs of radiation protection regulators and implementers. This NEA involvement has included several broad dialogues with Professor Roger Clarke, the Chair of the ICRP, to provide direct feedback on the ideas and concepts of the ICRP as they have evolved. The NEA has also developed its own line of thinking on how the current system could be improved through its Committee on Radiation Protection and Public Health (CRPPH).

The CRPPH feels that the current system of radiological protection is comprehensive, and affords a level of protection that does not underestimate risks. As such, the CRPPH has focused its work on providing suggestions as to how this system could be improved. In early 2000 the Committee published *A Critical Review of the System of Radiation Protection*, identifying areas that could usefully be improved.[1] This was followed by further work suggesting specific improvements. As with the Critical Review, this work will be published and submitted to the international community and the ICRP for consideration.

In addition, a series of fora, organised in collaboration with the ICRP, have been established to build consensus. The first such forum took place in February 2002, addressing radiological protection of the environment. The objectives of this work were to reach a general understanding of which issues should be addressed in radiologically protecting the environment and what input (scientific, social) policy makers will need to address them. Information from this forum, other CRPPH activities and further consultations with the ICRP will result in drafts of new ICRP recommendations in the second half of 2002. The second NEA/ICRP forum will discuss the implications that these recommendations would have should they be implemented. The objective of this forum will be to help ensure that practical application aspects are taken into account by the ICRP in its new recommendations. It is expected that this forum will take place in late spring 2003. Finally, the third NEA/ICRP forum will take place after the ICRP has issued its new recommendations and will address very concretely how they should be implemented.

Through this process, it is hoped that the new system of radiological protection will reflect the needs of a wide range of stakeholders, including policy makers, regulators, radiation protection experts and implementers, the affected public, workers, industry and the environmental protection community. ■

Note

1. *A Critical Review of the System of Radiation Protection* is available free of charge from the NEA Publications Section (neapub@nea.fr).

T. Dujardin*

Generation IV and the NEA

In the previous edition of *NEA News*, W. D. Magwood of the US Department of Energy (DOE) outlined the future of nuclear energy in the context of the new US national energy policy. He cited the Generation IV initiative as a mechanism to implement a longer-term aspect of this policy. Although initiated in the US, the Generation IV initiative has quickly become an international effort and today ten countries[1] are participating in the Generation IV International Forum (GIF). This article briefly reviews the context of Generation IV and describes NEA involvement in the Generation IV process.

What is "Generation IV"? In short, the Generation IV initiative concerns the identification, development and demonstration of one or more new nuclear energy systems that offer advantages in the areas of economics, safety and reliability, and sustainability, and could be deployed commercially by 2030. The driving force behind this initiative is the strong belief shared among the participating countries that the future of nuclear energy will depend upon or at least be strengthened by increased international co-operation. The rationale lies not only in the need to share the development costs of new nuclear technologies in the context of international, deregulated electricity markets, but also in the need to obtain better public acceptance of nuclear energy.

Eight goals have been developed for Generation IV nuclear energy systems. In the area of **economics**, Generation IV nuclear energy systems will:

1. have a clear life-cycle cost advantage over other energy sources;
2. have a level of financial risk comparable to other energy products.

In competitive markets, this is an absolute necessity. The risks associated with construction (cost and duration) are not the only ones to be considered, as external factors such as public acceptance and licensing may be even more important.

Life-cycle costs include capital costs, operation and maintenance costs, fuel cycle costs and decommissioning and dismantling costs. Contrary to other energy sources, nuclear energy already includes decommissioning and dismantling costs in overall production costs in OECD countries. Currently, capital costs and length of construction, including considerable interest payments before any income is earned, seem to be the main obstacles new nuclear energy systems face.

Regarding **safety and reliability**, Generation IV nuclear energy systems will:

3. excel in both of these areas;
4. reduce the likelihood and severity of reactor core damage and enable the rapid return to plant operation;
5. eliminate the need for off-site emergency response.

Existing nuclear power plants in GIF countries are currently achieving a high level of safety and reliability. These three goals aim to extend and further improve this current level. Reducing the number of events that can initiate accidents, reducing the probability of severe core damages and mitigating their consequences, notably potential

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off-site radioactive releases, should be able to be achieved by using future technological advances. It is anticipated that these technologies will also benefit the performance and the economics of Generation IV nuclear energy systems as well as protect the owner's investment and increase local public confidence.

In terms of **sustainability**, Generation IV nuclear energy systems and fuel cycles will:

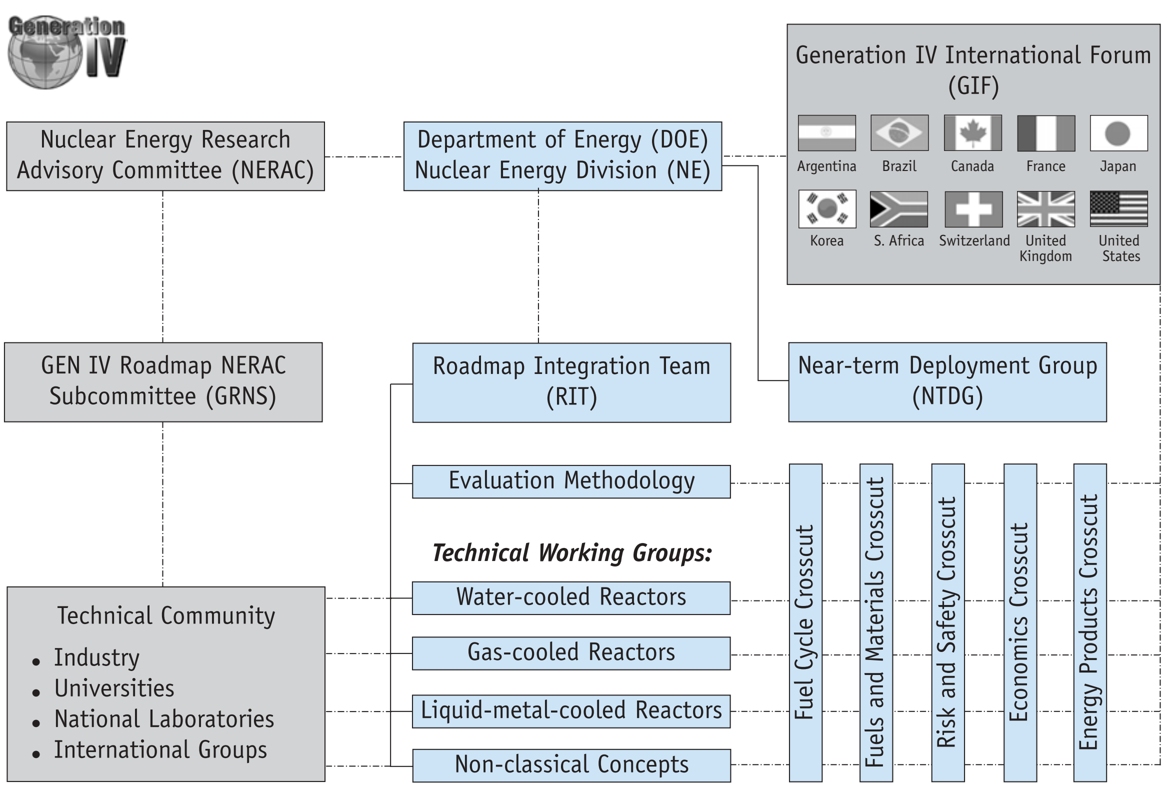
6. provide sustainable energy generation through long-term availability of systems and effective fuel utilisation for worldwide energy production;
7. minimise and manage their nuclear waste, enabling them to surpass current levels of protection for public health and the environment, and notably reduce the long-term stewardship burden in the future;
8. increase the assurance that they are very unattractive and the least-desirable route for the diversion or theft of weapons-usable materials.

Elaborated in the late 1980s, the concept of sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Producing energy in accordance with sustainable development requires the conservation of natural resources, protection of the environment and avoiding, to the greatest extent possible, transmitting burdens on to future generations. Internationally, and especially in the context of the preparation of the World Summit on Sustainable Development to be held in Johannesburg in August 2002, sustainable development is usually examined from three points of view: economic, environmental and social. In the Generation IV context, the "sustainability" category includes aspects related to the above definitions and not previously covered under the economics and safety and reliability goals.

The Roadmap process

In a first phase, the Generation IV technology "Roadmap" is being prepared by GIF members to identify:

Roadmap working structure



- the six to eight most promising reactor systems and fuel cycle concepts;
- the R&D necessary to develop these concepts for potential commercialisation.

A request for information on innovative concepts was issued by the US DOE in March 2001. Nearly 100 concepts were proposed and were subsequently put together in sets of concepts to be analysed by four technical working groups classified by reactor coolant type:

- water-cooled reactors;
- gas-cooled reactors;
- liquid-metal-cooled reactors;
- non-classical concepts.

A methodology has been developed to provide a consistent basis for evaluating the potential of each concept or set of concepts to meet the Generation IV goals. In addition, several "crosscut" groups have been formed to work on horizontal issues that are common to two or more classes of reactors (see figure).

Roughly 100 international experts, half of them American, have contributed to the Roadmap. Initiated in October 2000, the Roadmap is scheduled for completion in September 2002.

NEA involvement in the Generation IV Roadmap

The NEA participated as an observer in the first meetings of the GIF. The NEA experience and expertise that were made evident during these meetings led the GIF members to request NEA support. In particular, the GIF was interested in taking advantage of NEA capability to support international technical working groups and organise joint R&D projects involving voluntary participation by national authorities and organisations. Taking into account the synergy between the NEA programme of work and the studies needed to achieve the technology Roadmap, at its May 2001 meeting the NEA Steering Committee endorsed NEA involvement along the following lines:

- participation of an NEA expert in the evaluation methodology group and in the fuel cycle crosscut group. These two experts were to make NEA experience available for such cross-cutting issues as methodologies for evaluating performance, defining evaluation criteria and metrics (quantitative indicators), and questions related to the nuclear fuel cycle; and
- designation of two NEA experts to perform a secretariat function for two technical working groups, namely the gas-cooled reactors group and the liquid-metal-cooled reactors group.

Following the later setting up of new crosscut groups, NEA experts also participated in the economics; fuels and materials; and risk and safety crosscut groups. In order to finance this participation given that GIF membership is different from NEA membership, NEA activities during the Roadmap phase are being covered by a voluntary contribution from the US DOE.

The NEA is thus actively participating in the different phases of the Roadmap, and its involvement has been recognised by the other participants as highly effective. Many NEA studies were used as input to the Roadmap process. For instance, data and evaluations on partitioning and transmutation, and information on trends in the nuclear fuel cycle proved to be very helpful in implementing the Roadmap screening process. Results of the Roadmap will be communicated by the GIF in due course.

What's next?

Once the selection process of the reactor concepts has been carried out, the main product of the Roadmap will be a recommended R&D programme to develop those chosen.

As part of the NEA mission to promote international co-operation through the organisation of joint R&D projects among countries wishing to participate, and as noted by the NEA Steering Committee, the ultimate goal of NEA participation in the Roadmap phase has been to offer a robust international framework for the joint R&D projects to be developed in the subsequent phase. GIF members have acknowledged the NEA's valuable experience in co-ordinating such projects and have specified in their Charter that methods to facilitate the collaborative research to be conducted "will include co-ordination through international organisations such as the OECD/NEA".

Following GIF agreement on the concepts to be developed, which is likely to be achieved in the coming months, detailed discussions will be held on the R&D to be undertaken. In this context, the NEA is ready to develop its offer to co-ordinate the joint R&D projects that the GIF members decide to undertake. ■

Note

1. Argentina, Brazil, Canada, France, Japan, Korea, South Africa, Switzerland, the United Kingdom and the United States.

E. Bertel, M. Woodruff*

Opportunities for international co-operation in the development of innovative reactors

A number of countries wish to expand their use of nuclear energy or to keep the option open for doing so in the future. Concerns over energy security, the need to reduce emissions of greenhouse gases and other atmospheric pollutants in OECD countries, and a lack of indigenous energy sources adequate to meet increasing demand in non-member countries are key reasons for the interest in nuclear energy. Three international agencies have looked into how this interest may take form in the years to come.

New nuclear power plants will have to face the challenges of privatised and deregulated energy markets coupled with heightened public concern over technological risk. They will have to maintain or surpass current levels of safety and achieve competitiveness with alternative means of generating electricity, especially natural gas combined-cycle plants. Improved ways of dealing with radioactive waste and of addressing non-proliferation concerns will also be important factors for their success.

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Nuclear fission technologies capable of meeting these demands are being researched today by companies, research institutes, universities and governmental organisations worldwide. In some cases, several research groups are working on the same or similar technologies. International co-operation could potentially help technology developers make the most effective use of the limited research funds available today.

The Three-Agency Study

The "Three-Agency Study",[1] a joint project of the International Energy Agency (IEA), the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), investigated ways in which new technologies are being developed to meet the challenges facing nuclear energy today and tried to identify potential areas for co-operation among technology developers. It also sought to identify "enabling" technologies important to one or several designs that could benefit from international collaboration.

The study focused on "innovative" nuclear fission reactor technologies going beyond the incremental, evolutionary changes to current technology. The approach entailed looking at specific innovative reactor designs in order to identify development teams that could supply technical design data as well as information on R&D programmes; but the main purpose of the study was not to evaluate specific design proposals from particular vendors or designers.

The study was based upon information provided by developers of advanced nuclear concepts in a questionnaire on how the features of their innovative designs contribute to enhanced performance relative to the current generation of reactors. Six characteristics, selected by the study team, were used: safety, economic competitiveness, proliferation resistance and safeguards, waste management, efficiency of resource use and flexibility of application.

The twelve designs reviewed in the study were selected by the study team according to generic criteria aimed at choosing complete nuclear system designs for which ongoing, funded R&D programmes could be identified, and representing various primary coolants, operating conditions and moderator characteristics as well as different applications of nuclear energy (e.g. electricity generation, district heating, high-temperature applications). In addition to these criteria, a regional and global balance of designs was sought, as was a wide variety of R&D institutions and designers. An attempt was made to reflect the needs of the countries that are members of the participating agencies, considering both the country of origin of each design and countries where the designs might be used.

Main findings

The initial review of innovative reactor designs and their development illustrated the range of technologies from which countries wishing to expand their use of nuclear energy will be able to choose. These designs make use of a wide variety of innovations in an attempt to tackle head-on the challenges facing nuclear energy today. Many of the innovations and innovative approaches are common to several designs.

The Three-Agency Study Approach

Six main characteristics were selected by the study team:

Innovative reactor designs covered in the study

	Name	Country	Type	Capacity	Developer
Light-water reactors	Barge-mounted KLT-40C	Russia	PWR	35 MWe	OKBM
	CAREM-25	Argentina	PWR	27 MWe	INVAP
	MRX	Japan	PWR	Up to 300 MWe	JAERI
	NHR-200	China	PWR	200 MWth	INET
	SMART	Korea	PWR	100 MWe	KAERI
Heavy-water reactors	CANDU X	Canada	PHWR	350-1150 MWe	AECL
Liquid-metal fast reactors	BREST 300	Russia	LMR	300 MWe	RDIPE
	Energy Amplifier	Europe	Hybrid LMR/ Accelerator	675 MWe	CERN
Gas reactors	GT-MHR	USA/Russia	HTGR	286 MWe	General Atomics
	PBMR	South Africa	HTGR	110 MWe	ESKOM
Molten-salt reactors	FUJI	Japan/Russia/ USA	MSR	100 MWe	ITHMSO
Other	RTFR	Russia/USA/ Israel	PWR/ PHWR	Small to large	RCC-KI/BNL/BGU

The methodology applied for the study – reviewing how specific reactor designs deal with the challenges facing nuclear power, and cataloguing the enabling technology and information underlying or beneficial to the full set of designs – was useful for the limited purposes of this study. It could fruitfully be applied to a broader range of designs.

Most of the design activities reviewed focus on the nuclear steam supply system (NSSS). Because the balance-of-plant (BOP), where heat from the nuclear reactor is converted to useful energy, represents a major portion of both capital and operating costs, its design must be given careful attention if economic objectives are to be met.

Specific attention is needed to reduce operation, maintenance and inspection costs, especially for small reactors, although it can be partially addressed by locating several units at a single site and using common support functions and facilities. Owing to their compact design or the type of coolant they use, several of the innovative reactor designs considered present new challenges to the ability to provide efficient, cost-effective and reliable maintenance and inspection of the reactor, the pressure and containment vessels, and other components important to safety. Obstacles to in-service inspection include restricted access and restricted space resulting from very compact configurations, and the presence of obstacles such as insulation or solidified coolant.

All else being equal, economies of scale, which are applicable to capital, operation and maintenance costs, favour large nuclear power plants. To be economically viable, small plants must achieve simplifications in both the NSSS and BOP or offer higher reactor core outlet temperatures that enable higher thermodynamic efficiency and energy utilisation.

Several of the innovative designs considered in this study were developed with a view that in future energy markets, demand may not be driven solely by the need for electricity, but will also arise from needs for process heat, district heating, sea water desalination or hydrogen production. In general terms, taking advantage of co-production options and improving the flexibility of application can improve the competitiveness of nuclear power plants.

Many components and technologies that have been commercialised by the aerospace, automotive, petro-chemical and other industries may be useful in the nuclear industry. Increased co-operation with non-nuclear researchers, and increased tracking of non-nuclear industrial developments, could benefit innovative reactor design efforts.

The information provided by research and design teams in response to the questionnaire indicate that the R&D and design efforts under way on innovative nuclear reactors are funded at very low levels compared with the efforts made in the 1950s, 1960s and 1970s to develop the current generation of reactors, and compared with the R&D expenditures today on maintaining and enhancing the performance of operating reactors. Assuming continuation of these low levels of investment, for most of the designs considered, commercial availability could require 10 to 15 years or longer.

Based on the modest investment in design development, the potential for cross-fertilisation among development efforts, the broad experience upon which development efforts can draw, and the lack of full assimilation of this experience into current efforts, further collaboration in developing innovative reactor designs appears warranted. Such collaboration has the potential to reduce the time and cost required to make technologies commercially available.

The way forward

A wealth of information is available on experience worldwide flowing from several decades of research in the field of nuclear fission and the operation of numerous prototype and demonstration reactors in the 1950s and 1960s. Strong efforts are needed to ensure that previous design and operating experience with relevant coolants, moderators, systems, components, configurations and procedures is fully incorporated into current R&D programmes.

Increased cross-fertilisation of ideas among reactor-type designers could enhance the overall effectiveness of research. Design groups may wish to familiarise themselves thoroughly with the features and technologies that are currently used or proposed by other design groups, and to evaluate potential alternative approaches to meeting their own design requirements. Also, given the low budgets available for innovative reactor research, development and design, it would be worthwhile to take advantage of relevant components and technologies developed by other industries.

Specific "enabling" technologies are good candidates for broad international collaboration because they are relevant to the development of several types of innovative designs, and should be amenable to joint development without necessitating sharing commercially sensitive information or know-how. Candidates for such joint efforts include: technology assessment; natural circulation; high-temperature materials; passive safety devices; in-service inspection and maintenance methods; advanced monitoring and control technologies; delivery and construction methods; and safeguards technologies. Many other enabling technologies would be well suited to more limited co-operation among a few design groups.

Several international projects on nuclear power have been initiated in recent years. For example, the International Atomic Energy Agency (IAEA) recently launched the "International Project on Innovative Nuclear Reactors and Fuel Cycles" (INPRO). Work on innovative nuclear designs is also ongoing within the Generation IV International Forum (GIF), supported by the United States and nine other countries, and through the Michelangelo Initiative Network under the Framework Programme of the European Commission. Such initiatives are appropriate forums for considering the outcomes of the Three-Agency Study and expanding the analysis to more designs.

Recommendations

The Three-Agency Study offered the following recommendations to reactor design teams for their consideration:

- Make better use of experience to date.
- Increase cross-fertilisation of ideas among reactor types.
- Take greater advantage of components and technologies developed in other industries.
- Increase co-operation in R&D.

Note

1. The main results from the project are summarised in "IAEA, IEA, OECD/NEA, Three-Agency Study – Innovative Nuclear Reactor Development: Opportunities for International Co-operation, Summary Report", to be published in 2002.

E. Bertel, P. Fraser*

Energy policy and externalities

External costs of energy have been assessed in a number of authoritative and reliable studies based upon widely accepted methodologies such as life cycle analysis (LCA). However, although those costs are recognised by most stakeholders and decision makers, results from analytical work on externalities and LCA studies are seldom used in policy making. The International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) convened a joint workshop in November 2001 to offer experts and policy makers an opportunity to present state-of-the-art results from analytical work on externalities and debate issues related to the relevance of external costs and LCA for policy-making purposes. The findings from the workshop[1] highlight the need for further work in the field and the potential role of international organisations like the IEA and the NEA in this context.

Background

Getting the prices right is a prerequisite for market mechanisms to work effectively towards sustainable development in the energy sector. This requires identifying and valuing external costs, and eventually reflecting them in prices. Internalising external costs aims at providing "correct" price signals that drive consumers' choices towards an optimum, taking into account social and environmental aspects as well as direct economic costs.

Economic theory has developed approaches to assessing and internalising external costs that can be applied to the energy sector. The tools developed for addressing these issues are generally based upon a comprehensive (and exhaustive in so far as feasible) inventory of impacts and damages, followed by monetary valuation and eventually integration of the valued "external costs" in the total cost of the product, e.g. electricity.

Life cycle analysis (LCA) provides a conceptual framework for a detailed and comprehensive, comparative evaluation of potential environmental impacts of energy supply options. Traditional LCA involves a complete inventory of resource inputs and outputs in all steps of production and can incorporate indirect emissions. In a second phase, the assessment of the impacts concerning burdens on the environment and resource depletion can be carried out.

The external cost assessment methodology developed by the ExternE project[2] illustrates a bottom-up approach to estimate the impacts of different emissions from different power generation and transportation fuel options through the inventory of each emission; estimate its dispersion; examine the impact based on the dose-response relationship (impacts being measured essentially in terms of years of life lost); and provide an economic valuation of these impacts. The results are subject to a large number of uncertainties that arise not only from data limitations, but also from difficulties in quantifying certain impacts (for example those concerning the ecosystem), assumptions about future management of waste and improvements in technology, and intergenerational considerations.[3]

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Quantifiable external costs of energy systems (in Euro-cents/kWh)

Impact	Coal	Lignite	Gas CC	Nuclear	PV	Wind	Hydro
Health effects	0.8	1.0	0.3	0.2	0.4	0.05	0.04
Crop losses	-0.03	-0.03	-0.01	0.0008	-0.003	0.0005	0.0004
Material damage	0.02	0.02	0.007	0.002	0.01	0.001	0.0007
Noise nuisance						0.006	
Acidification/ Eutrophication [a)]	0.2	0.8	0.04	0	0.04	0	0
Global warming [b)]	1.6	2	0.8	0.03	0.3	0.03	0.03
Sub-total	**2.6**	**3.8**	**1.1**	**0.2**	**0.8**	**0.09**	**0.07**

Source: A. Voss, (2000), "Sustainable Energy Provision: A Comparative Assessment of the Various Electricity Supply Options", SFEN Conference Proceedings, *What Energy for Tomorrow?*

a) Valuation based on marginal abatement costs required to achieve the EU "50% – Gap Closure" target to reduce acidification in Europe.

b) Valuation based on marginal CO_2-abatement costs required to reduce CO_2 emissions in Germany by 25% in 2010 (19 Euro/tCO_2).

The studies carried out so far show that large uncertainties remain concerning dose-effect relationships, and consequently physical damages as well as the monetary value of the damages. Differences in estimates can arise due to different methodologies, technologies, location and population densities. In addition, values given to days of life lost or loss of biodiversity depend on local economic and/or cultural conditions. These uncertainties and differences limit the applicability and relevance of external costs in policy making. However, LCA and external cost valuation may be used in many ways to improve the overall efficiency of various technologies and to measure progress towards sustainable development.

LCA and external cost assessments

Estimates of nuclear power external costs in the ExternE study, based upon the French nuclear chain,[4] show that electricity generation and fuel reprocessing are the main contributors to those costs. Results highlight that impacts take place over a very long period. The external cost is largely attributed to impacts on workers while the cost of impacts on the public are rather small (about 0.00002 € per kWh). This figure is not greatly increased by accidents, using the "large consensus" assumption that such accidents would occur at a frequency of 1 per 100 000 reactor-years and that, in such an accident, 1% of the radioactive materials would be released to the environment. Even if a risk-aversion effect is assumed, the figure for accidents would be only around 0.0001 € per kWh, still a small figure.

Life cycle analyses of coal have focused on its use in both steel and electricity production as a means of identifying opportunities to improve sustainability.[5] In the power production sector, LCA shows the largest possibilities for improvement through use of more efficient technologies, use of biomass to displace coal and utilisation of fly ash in cement making. One interesting technological possibility is combining solar thermal technology with coal power generation, which improves net solar efficiency to 30-40% (compared with 13% for photo-voltaic power). Estimated additional costs for large-scale use of solar thermal in an existing coal plant are about 4 US cents per kWh.

Externalities from hydropower projects have been investigated by the IEA Implementing Agreement for Hydropower[6] that surveyed a large number of LCA studies for this purpose. The motto: "avoid (environmental externalities), mitigate (damages that can't be avoided), compensate (damages that can't be mitigated)", adopted within hydropower projects already actively contributes to reducing externalities. Emissions of greenhouse gases from hydropower dams are normally quite low, with few exceptions. The survey found that other positive benefits of hydropower dams such as irrigation or flood control are not normally taken into account by such studies. Energy security benefits are also not generally recognised, and would represent a useful extension of LCA. However, not all environmental impacts can be usefully internalised by an LCA (e.g. loss of visual amenity is not usually included in LCA), and LCA does not take into account cultural differences of the value of different amenities.

Shortfalls of the life cycle analysis approach applied to the oil[7] and gas[8] sectors may be illustrated by a number of points. Production chains often generate multiple products, some for energy use, some for other uses, and allocation of the emissions is to some degree arbitrary. Given the wide variability of oil and gas production chain characteristics, any emission estimate could be derived given the appropriate selection of wells, extraction processes, etc. More generally, it may be argued that LCA impact assessments fail to take into account unknown health and environmental impacts of new chemicals, have no objective scale, contain many assumptions and are very complex. Therefore, LCA should not be used as the basis for comparing widely different generating options or as the basis for internalising external costs. On the other hand, it is a valuable tool for systematic descriptions of resource use and environmental impact characteristics, and can be used more precisely when the production chains and technology options are all very similar, or in choosing amongst locations for the same technology option.

LCA analyses for photo-voltaic (PV) and wind power illustrate the relevance of the approach to assess changes in technology.[9] Estimates of LCA impacts for PV, originally quite high, have fallen steeply thanks to technological progress and increased efficiency. There are also further improvement possibilities. For wind, externalities are rather low, although the operation phase produces both noise and loss of visual amenity. Damage estimates for wind energy are the lowest of all the ExternE fuel cycles studied. The experience with PV shows the need to look at LCA in a dynamic way, particularly with respect to new technologies. A new international research project, ECLIPSE, will look at the life cycle inventories for future power generation technologies, focusing on PV, wind, fuel cells, biomass and combined heat and power (CHP) technologies. Sensitivity analysis will look at the impact of rapid technological improvement and differences in local conditions.

The results of LCA for power generation based on German conditions[10] show that coal (particularly lignite) power generation has the highest external costs in terms of years of life lost, followed by PV and natural gas while nuclear, wind and hydropower have lower external costs. Coal/lignite external costs are around 3 € cents per kWh; gas and PV around 1 € cent; nuclear, wind and hydropower about 0.1 € cent. If these external cost estimates are combined with direct costs, nuclear, which is already nearly competitive with coal and cheaper than natural gas, becomes the lowest-cost option for power generation. There are, however, large uncertainties remaining in terms of data and choices of discount rate, thus limiting the applicability of LCA in policy making at the national level.

The assessment of greenhouse gas in the US transportation sector shows that relying on LCA rather than on end-use comparisons generally reduces the relative advantages of alternative transportation fuels against a baseline gasoline vehicle. However, the results also show that there would be large savings from the use of ethanol (with ethanol from wood) in a conventional engine. External costs of motor vehicle use, calculated taking into account air and water pollution, noise, congestion and energy security amount to 1.2 US cents per mile travelled in a gasoline-powered vehicle.[11] The most significant externality is related to air pollution. The only other variable of significance is the impact on the economy, through the transfer of wealth outside the US (referred to as a "pecuniary externality") and the oil price shock impacts on the economy. A comparison of external costs and subsidies for different transportation modes in the US (gas or electric cars, transit bus, light rail, heavy rail) showed that making subsidies available to public transit systems greatly outweigh the benefit obtained from reduced externalities. In the comparison of social costs of transportation alternatives, differences in external cost, while not trivial, are outweighed by the differences in direct costs or in subsidies. Additional analyses on this and related subjects may be found in *Externalities and Energy Policy: The Life Cycle Analysis Approach*.[1]

External costs, LCA and policy making

In spite of the many limitations and uncertainties underlying life cycle analysis and the valuation of external costs, the methodology has a wide range of possible applications. It can provide valuable support to decision makers with regard to technology evaluation, comparison of future energy supply options, cost-benefit analysis of policy measures and extension of green-accounting frameworks, for example. LCA is also a useful tool for technology designers, providing indicators of technology-specific sustainability and pointing to priority areas for the reduction of environmental impacts.

LCA analysis can provide a useful set of indicators on the sustainability of different energy technologies and, by extension, the electric power and transport sectors. Such an assessment could help national energy policy making by:

- Providing indicators of the sustainability not only of the power generation sector, but of the other steps in the "fuel cycle" of different energy alternatives. Such indicators might include greenhouse gas emissions, energy diversification and resource depletion.
- Pointing to opportunities to improve the sustainability of full fuel cycle operations (for example by improving the sustainability of mining practices).
- Helping to assess the impacts of different economic instruments (such as carbon taxes or a cap and trade system) on international energy trade (e.g. the international trade of natural gas).
- Providing input to political debate on improving the sustainability of energy systems.

As liberalised electricity markets are becoming the norm in OECD countries, decision making on investments in generating capacity is more commonly made by privately owned companies seeking the most profitable option. They will be influenced not by theoretical considerations of external costs but by government policies that attempt to internalise these costs. In that case, LCA can help governments determine where to apply policy pressure, and companies assess the cost and net environmental impacts of these policies. For example, governments could use LCA to evaluate where in the electricity chain the environmental impacts lie, and how to focus policy intervention to alleviate these impacts. Conversely, companies could use LCA to help assess the potential financial impacts of government policies (such as carbon taxes) on different generating technologies.

While the usual academic conclusion that more research is needed typically frustrates policy makers, it should be recognised that we do need to improve LCA methodology and data. Issues that need to be addressed in order to enhance the applicability of LCA in policy making include: consistency between LCA and economic theory generally; uncertainties with respect to health-related externalities; uncertainties and relevance of discounting costs in relation to global warming; and the empirical underpinnings for "disaster aversion" in externality estimates.[12] Possible areas for future research include: better assessment of externalities such as security and diversity of supply, as well as loss of forest cover; further investigations in the field of discount rates applicable in the very long term and the value of statistical life; incorporation of technology progress in LCA; evaluation of energy policy measures with LCA; further effort to reduce uncertainties in external cost estimates; and establishment of a database containing information on externality assessment and the way it is being used, possibly under NEA/IEA auspices. ■

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J. Geidl, I. Vera, R. Price*

Environmental remediation of uranium production facilities

Human health and the environment figure high among the public's priorities. Civil society is showing increasing concern over the degradation of local environments due to problems such as traffic congestion and air pollution, and through the growing evidence of adverse effects of industrial development on the global environment including acid rain, global warming and loss of biodiversity.

These concerns and priorities are increasingly affecting the uranium mining and ore processing industry owing to:

- stricter requirements for new facilities imposed by many countries in the form of environmental approvals;
- the large numbers of uranium production facilities that have been taken out of operation in recent years and require remediation;
- restoration and reclamation measures that are being considered for many old sites, which have been closed permanently;
- new projects that are being subject to stricter assessments before licenses are granted.

Environmental remediation of uranium sites encompasses:

- dismantling and clean-up of redundant or unused structures on a site;
- correction of any contaminated waters or soils;
- clean-up of the site to a level appropriate to its planned future use;
- management of any resulting wastes.

Environmental Remediation of Uranium Production Facilities, a recently published NEA/IAEA report, looks at how environmental requirements and principles are being addressed at uranium production facilities, particularly after production ceases. It provides a summary of the most relevant issues and practices in remediation programmes of uranium production facilities and an overview of activities and plans in 22 reporting countries (12 OECD and 10 non-OECD countries). Eight major elements of environmental remediation as they apply to uranium production facilities are evaluated: clean-up criteria, policies and regulations; site characterisation; decontamination, dismantling and decommissioning; waste management; water treatment; long-term stewardship and monitoring; costs and funding; and risk analysis and management.

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Clean-up criteria, policies and regulations

Many countries have adopted, or are adopting, policies aimed at improving and reinforcing the health and safety of workers and the public; protection of the environment; sustainable economic, social and environmental development; and public participation in environmental decision making. Remediation programmes have as their major objective the establishment of long-term, stable conditions to ensure the safe use of the site by both current and future generations. Wherever possible, the objective is to return affected areas to pre-uranium production environmental conditions or to a land use agreed upon by all the stakeholders that is sustainable in the long-term. Impacts of restoration work are to be kept to "as low as reasonably achievable" (ALARA) for the community and the environment.

In many instances, communities, ranging in size from small camps to large cities, have been developed in association with, or have become dependent on the mining operations. The cessation of mining and milling operations may have a substantial social impact on these communities and such effects must be taken into account in the planning process.

Site characterisation

Pre-operational and post-operational characterisation of the site forms the basis for formulating any environmental remediation programme and for measuring progress towards compliance. Characterisation includes the collection of data on the hydrological, climatological, geological, geotechnical and ecological properties of the site and its surroundings. The type of mining and processing methods employed over time and the types of waste generated also need to be assessed. The collection and use of site characterisation data are indispensable and their availability is crucial to ensure the successful implementation of remediation programmes.

Decontamination, dismantling and decommissioning

As part of the agreed-upon land use plan, a decision on the future use of the mine-related infrastructure is made. All buildings, mills, laboratories, chemical and product stores, airfields, etc., which are not needed any more are often decommissioned and removed as part of a remediation programme. Roads may also need to be removed, although they are often left to provide access for monitoring and surveillance after the works programme has been completed and for community use.

Many elements of uranium mining and processing facilities are likely to be below ground level. These may include the mine workings themselves, basements, storage facilities, explosives magazines, crushers, silos, service tunnels and cable ducts. Such installations may be either left underground and perhaps backfilled, or may need to be removed to clear the ground for new foundation work.

Radioactively contaminated sites require decontamination as part of the decommissioning process. The rules and regulations relating to public and worker safety must be strictly observed in all decontamination work. Decontamination techniques include scraping or jack hammering, sand blasting, washing and high pressure hosing, chemical solvent washing, stripping paint and water treatment.

Waste management

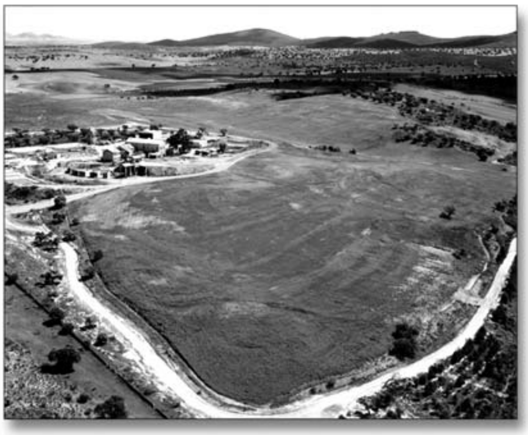
Mining operations produce waste of different types, all of which require appropriate management. These waste materials include development waste from initial excavations such as soil materials, unmineralised rock materials, ores with sub-economic levels of mineralisation or high levels of contaminants, as well as processing wastes, the largest volume of which are the mill tailings. Wastes from water treatment and residues from cleaning and dismantling processes also need to be managed. Upon closure, mining and milling waste management facilities need to be decommissioned and sometimes remediated in order to ensure their long-time stability.

Mill tailings are a type of processing waste that poses particular problems. The final containment of tailings is usually one of the main issues in the restoration of any uranium mine because of the risk to the environment and to the public due to their large physical volume and associated radiological and chemical contaminants.

Water treatment

One of the principal pathways by which contamination may reach the environment from uranium mining and milling operations is through water. In mining operations, dewatering underground

ENUSA, Spain



The La Haba site, in Spain, before and after restoration.

and open pit mines might produce water contaminated with radioactive or chemical pollutants. Water might also become contaminated as a consequence of surface-water runoff from, and seepage through, the waste rock piles and ore stockpiles, and seepage through tailings. Therefore, the environmental restoration of any uranium production facility may need to include the restoration of surface and groundwater and the treatment of effluents from waste management facilities, such as tailings impoundments.

Long-term stewardship and monitoring

When mining facilities are closed, monitoring may be required for an extended period to verify that closed facilities are not causing adverse impacts to human health or the environment. The use of long-term monitoring as a part of the decommissioning plan is, in effect, long-term stewardship or institutional control, which is often provided by government authorities.

Costs and funding

The statutory framework regulating modern uranium mining in many countries makes it mandatory for uranium producers to take into account the costs of decommissioning and remediation and to make appropriate funding provisions during the operating life of the facilities to cover these costs. A major concern, however, is how modern standards of environmental protection can be met in places where past mining practices were not subject to the current, more stringent levels of regulatory control and have left a legacy of abandoned sites and facilities. Many of these sites require remedial action to reduce the levels of risk to workers, the general public and the environment. This problem is especially challenging to countries that are currently facing economic difficulties and where the burden for remediation has fallen on the State.

Risk analysis and management

The remediation of uranium mining and milling facilities is an activity that calls for the application of proper analysis and management of risk at all stages of the process. Environmental risk management in particular should be applied to ensure that optimised outcomes are achieved from the remediation work. The scope of environmental risk analysis in this context is very broad and should consider adjacent communities as part of the environment, which means that health risks become an integral part of the risk analysis. The risk analysis and resulting management steps also must take into account the conventional as well as the radiological risks of the remediation operation, for example, the operation of heavy equipment.

Conclusion

Remediation programmes for uranium production facilities worldwide have a major objective of establishing long-term, stable conditions to ensure the safe use of the site by both current and future generations. Wherever possible, the remedial actions aim to achieve the return of affected areas to prior environmental conditions or to a land use sustainable in the long term. In addition to legislation on remediation activities, many countries have implemented very strict criteria as early as the uranium mine development phase so that subsequent remediation programmes may fully attain these goals. ■

B. Kaufer, K. Asmis*

Indicators for nuclear regulatory effectiveness and efficiency

In 1998, the OECD/NEA Committee on Nuclear Regulatory Activities (CNRA) initiated an activity to investigate how to enhance and measure regulatory effectiveness in relation to nuclear installations. One of the outcomes of this activity was a publication entitled *Improving Nuclear Regulatory Effectiveness*.[1] In preparing the report, the task group discussed such topics as the added value of the regulator in providing a safe, secure and environmentally acceptable regime for the utilisation of nuclear energy. It concluded that every effort should be made to ascertain whether regulatory effectiveness could actually be measured and provide meaningful results. Accordingly, the task group began assembling a demonstration set of indicators to be used in a one-year pilot project commencing in March 2002. Some 45 potential indicators were identified for this purpose.

Performance indicators

Various types of indicators are used in many organisations. Economic indicators are the most common, but many others such as the number of days of staff sick leave, staff turn-over rate or age profile of the work force are also used. Although performance indicators can be categorised in several ways, for regulatory bodies the most useful approach is to consider them under two headings: direct and indirect indicators. Direct performance indicators attempt to measure the results of the regulator's own activities, while indirect performance indicators rely on the performance indicators of other stakeholders, principally the licensees, to deduce the performance of the regulatory body.

The advantage of direct performance indicators is that they can provide a relatively unambiguous measure of relevant aspects of the regulator's performance. The disadvantage is that they do not provide insights into the regulatory body's fundamental mission and desired outcomes in terms of risk reduction or safety achievement amongst its licensees. On the other hand, while indirect performance indicators can shed light on such desired regulatory outcomes, they must be treated with caution since it is difficult to isolate the contribution of the regulatory body to the achievement of the eventual outcome.

Composing a comprehensive picture of how well a regulator is doing requires a number of perspectives. The task group devised a five-part definition for effectiveness in which the effective regulatory body:

- ensures that an acceptable level of safety is being maintained by the regulated operating organisations (licensees);
- develops and maintains an adequate level of competence;

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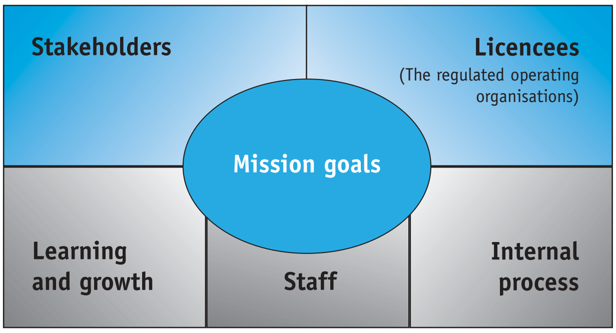
- takes appropriate actions to prevent degradation of safety and to promote safety improvements;
- performs its regulatory functions in a timely and cost-effective manner as well as in a manner that ensures the confidence of the operating organisations, the general public and the government;
- strives for continuous improvements in its performance.

These parts form the five "candidate performance areas" (CPAs) for the pilot project. They also map neatly and compactly into the perspectives commonly used in performance management systems such as the balanced scorecard. The advantage of this mapping is that the literature and lessons learned in the implementation of performance indicator programmes in diverse government agencies can be tapped into and applied, where relevant.

Figure 1. **The "balanced scorecard" for regulatory effectiveness**



The figure shows that central to a regulator's work is the mission and the derived goals. From the sole safety perspective, that mission will be met if the licensees, shown in the top right-hand quadrant, meet their responsibilities and operate safe facilities. However, exclusive focus on the licensees would be akin to an economic organisation focusing only on the bottom line. The balanced scorecard contribution to management is that a broader focus is needed and will pay off in the long run. Preparatory work, coupled with learning feedback mechanisms are needed in staff training and motivation and in the design and provision of high-quality processes and outputs. This "leading" work is shown in the lower quadrants of the diagram. The classical balanced scorecard has four quadrants: financial, customer, learning and growth, and internal process. For nuclear regulatory agencies, in addition to the four basic quadrants covering safety, stakeholders, learning and growth, and internal process, a "fifth quadrant" has been added to emphasise the importance of staff.

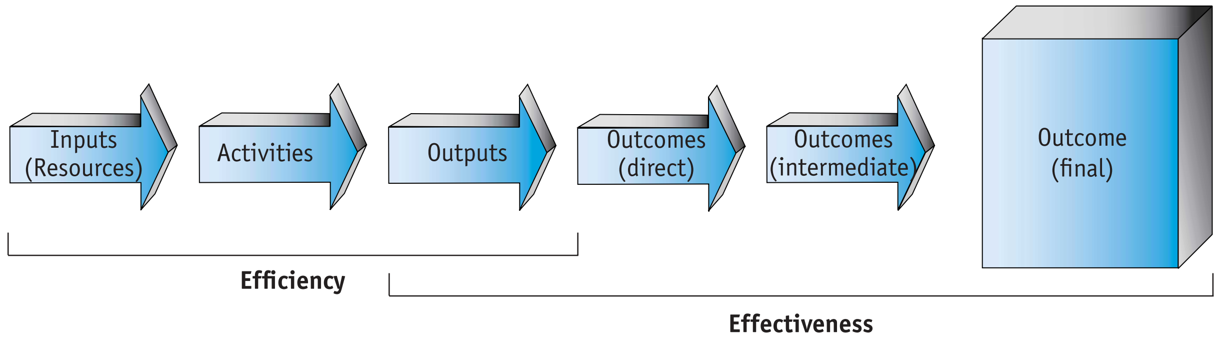
After some considerable thought, it was decided to establish a set of performance indicators that were set within a hierarchical context starting with the end goals and then sub-divided following the reach of the regulator into a logical set of indicators that cover internal and external stakeholders. Internal stakeholders are made up of regulatory staff; external stakeholders include licensees, the public, the technical community and the international community. In this way the performance indicators should provide a holistic picture of the "health" of the regulator, as far as is possible within the limits of the state-of-the-art of results-based performance management.

The pilot project

Several regulatory agencies[2] are participating and will be investigating a selection of the indicators identified for the project. It was decided that this project will only deal with direct indicators, although in parallel with this activity, a joint NEA regulator and safety group has been considering the issue from the point of view of traditional plant performance (indirect) indicators. Most of the selected direct indicators characterise the efficiency of regulatory activities (i.e. outputs); some of the indicators measure elements of the regulator's effectiveness (e.g. measuring the opinion of stakeholders relative to the regulator). The logic chain in Figure 2 shows the different areas in which efficiency and effectiveness can be measured. It also constitutes a "roadmap" that shows how inputs are intended to bring about the desired end-state shown in Figure 1. Performance indicators are placed at various points along this input-outcome chain where they will be useful to decision makers for making any changes that may be needed to achieve the desired end-goals.

The series of linked arrows start with the inputs (resources) used to conduct activities, which then lead to outputs. A typical output might be the number of inspections that are carried out in a licensee's facility over time. The inspections will influence the direct outcome of compliance with rules and regulations by the licensee. An intermediate outcome of the inspection activities is that they

Figure 2. **The "logic chain" for regulatory efficiency and effectiveness**



can bring about a positive, pro-active safety culture among the licensee's staff. The final outcome will be a safe nuclear facility and fewer incidents that will in turn generate public/stakeholder confidence.

The project will also combine a set of leading and lagging measures. In the logic chain, the number of inspections completed in a planning period are lagging indicators and indicate completion of activities according to plan. The indicators measuring a positive, pro-active safety culture among the licensee's staff will be leading indicators for public confidence. The performance indicators will be tracked over one year and reports will be issued on the relevance of the performance indicators to measure overall effectiveness as well as prospects for learning and growth.

The pilot project has six main objectives:

- to obtain practical experience in gathering information/data related to the five candidate performance areas (CPAs);
- to assess whether pilot performance indicators (PIs) relate to specific CPAs (this also tests their usefulness and relevance);
- to identify missing or redundant PIs;
- to assess the value of PIs to promote the development of internal quality, to use the pilot as an information tool as part of the regulatory effectiveness process, and to assist in a continuous feedback improvement process;
- to disseminate lessons learned from the exercise;
- to develop recommendations for implementation.

The results of the pilot project should enable regulatory bodies to gauge the usefulness of the candidate indicators, to propose an indicator system that is flexible (i.e. in which it is easy to remove, add and revise indicators) and to recommend a reporting system that will present a snapshot of the status of an organisation's work and relate those results to the organisation's present strategy and goals. The pilot project is expected to run over a one-year period in order to capture the full effect of a planning, budgeting and reporting cyle.

Closing remarks

The indicators under consideration are intended to measure quantitative as well as qualitative aspects of work, although the latter will be more difficult. One of the roles of the pilot project is to assist in measuring/observing and then characterising the more qualitative aspects of the regulator's outputs or outcomes. In addition to the possibility of establishing a quality management tool for measuring regulatory effectiveness, the pilot project will facilitate self-improvement within each participating organisation. ■

Notes

1. OECD/NEA (2001), *Improving Nuclear Regulatory Effectiveness*, OECD, Paris.
2. The regulatory agencies are: the Canadian Nuclear Safety Commission (CNSC); the Spanish Nuclear Safety Council (CSN); the Swiss Principal Nuclear Safety Division (HSK); the Japanese Ministry of Economy, Trade and Industry (METI); the United Kingdom Nuclear Installations Inspectorate (NII); the United States Nuclear Regulatory Commission (NRC); the Swedish State Nuclear Power Inspectorate (SKI); and the Finnish Centre for Radiation and Nuclear Safety (STUK).

S. Voinis, R. Beauheim*

GEOTRAP: radionuclide migration in geologic, heterogeneous media

Conclusion of the project

Most countries producing nuclear energy are considering, or actively pursuing, a deep geologic repository for radioactive waste. As part of the assessment of the performance or safety of such a repository, radionuclide transport through the heterogeneous, geologic environment must be modelled. In most cases, an important migration mechanism is transport in groundwater and developing an understanding and modelling capability for how radionuclides might migrate away from the repository through the surrounding geosphere is an integral part of making the safety case for a repository. This understanding has been significantly improved through the NEA GEOTRAP Project, the results of which have been documented in a final synthesis report summarising the outcomes of the five GEOTRAP workshops held between 1996 and 2001.

The GEOTRAP Project was initially established with the participation of 29 national organisations from 13 countries, as well as the European Commission. By the final workshop, participants had come from 15 countries, representing 9 implementing agencies, 8 regulatory agencies, 22 research laboratories supporting implementing or regulatory agencies, 18 universities, 17 private engineering companies working in the radioactive waste field and one technical oversight body. Thus, GEOTRAP brought together information from a variety of perspectives as well as a variety of geologic sites, repository design concepts, characterisation methodologies, experiments, models and repository programmes at different stages of development.

Understanding and modelling radionuclide transport through the geosphere involves identification of key processes, such as those that might retard or retain radionuclides, and quantification of the parameters controlling those retardation/retention processes. This information must be assembled into a coherent conceptual model (or models) that is consistent with all available data, and then a numerical representation of that conceptual model must be constructed. Creation of a numerical model inevitably involves simplification, both in terms of the representation of heterogeneity and of processes. The final model used for performance calculations, in particular, may be a simplified representation of more detailed process models that are themselves already simplified representations of nature. To have confidence that the final model is adequate for its intended purpose therefore requires confidence in all the steps leading to that model.

All of these activities have to be co-ordinated and integrated. Hence, a need exists for a mechanism whereby the different types of engineers,

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The five GEOTRAP workshops

	Theme	Location	Date	Host
1	Field Tracer Experiments: Role in the Prediction of Radionuclide Migration	Cologne, Germany	28-30 August 1996	German Company for Facility and Reactor Safety (GRS)
2	Basis for Modelling the Effects of Spatial Variability on Radionuclide Migration	Paris, France	9-11 June 1997	French National Agency for Radioactive Waste Management (ANDRA)
3	Characterisation of Water-conducting Features and Their Representation in Models of Radionuclide Migration	Barcelona, Spain	10-12 June 1998	Spanish National Radioactive Waste Company (ENRESA)
4	Confidence in Models of Radionuclide Transport for Site-specific Performance Assessment	Carlsbad, New Mexico, USA	14-17 June 1999	United States Department of Energy (USDOE)
5	Geological Evidence and Theoretical Bases for Radionuclide-retention Processes in Heterogeneous Media	Oskarshamn, Sweden	7-9 May 2001	Swedish Nuclear Fuel and Waste Management Company (SKB)

scientists and decision makers can discuss experiments, data and models to identify strengths, weaknesses, limitations, assumptions and other aspects of their work. The producers of data (site investigators and lab experimentalists) must communicate with the users of the data (performance assessors) to ensure that the needed data are being produced and that the data are being used properly in modelling. While this communication must occur within each individual repository development programme, added value is found in the communication occurring among a variety of repository programmes, between regulators and implementers, and between the waste disposal community and the wider scientific community. The GEOTRAP Project was created to provide a broad international platform for focused interaction and information exchange related to radionuclide migration through the geosphere. The themes of the five GEOTRAP workshops are shown in the table.

Field tracer experiments

The first workshop focused on field tracer experiments, which are used to study the distribution of groundwater flow, characterise potential flow paths and test different conceptualisations of flow and transport at selected sites and at different scales. Field tracer experiments provide fundamental, and at times unexpected, information useful in developing and testing conceptual models. They are possibly the only way to test assumptions associated with the up-scaling of laboratory experiments to field conditions and, more generally, to test models of transport and retention processes under conditions relevant to performance assessment.

Modelling spatial variability

Variability (or heterogeneity) is a common feature of most geologic media over a wide range of spatial scales and it affects siting feasibility, optimum repository layout and long-term repository safety. A wide variety of techniques exists both to characterise spatial variability in the course of the geologic investigation of a site and to model the consequences of such variability on groundwater flow and radionuclide transport.

Water-conducting features

The characterisation of the structure and properties of preferential flow paths, or water-conducting features, is an important requirement for any performance assessment. These features can, for example, determine the rate at which radionuclides migrate with flowing groundwater and the degree of retention in the geosphere. Radionuclide transport through water-conducting features has, however, mostly been treated through rather simplified, conservative approaches.

Confidence in models

The nature and scope of the confidence-building process is still under discussion by many organisations. The purpose of the fourth GEOTRAP workshop was therefore to examine the approaches that have been taken within national waste management programmes to evaluate, enhance and communicate confidence in models of radionuclide transport for site-specific performance assessment.

Retention processes

Retention of radionuclides for prolonged periods within a multi-barrier system (e.g. waste package, backfill and geosphere) is an important safety function of deep geologic disposal concepts. In the case of the geosphere, a range of characteristics may favour radionuclide retention. The fifth GEOTRAP workshop reviewed the theoretical bases and supporting evidence for the operation and modelling of these processes, with emphasis on geologic and field evidence, and the treatment of retention processes in performance assessment.

Conclusions

Among the conclusions and recommendations made at the GEOTRAP workshops, five points were repeatedly highlighted and can be considered guiding messages for the future:

1. The personnel responsible for site characterisation ("experimentalists") and those responsible for performance assessment ("modellers") should be in close communication at all times. Experimentalists must understand, and approve, how the system is being modelled, how their data are being used in the models, and must also understand the limitations of models and what specific data are needed by models and why. Modellers must understand the system conceptualisation(s) that the experimentalists have developed, the limitations of the existing data, what data are and are not possible to collect, and the contexts in which data can be considered to be valid. This communication and mutual understanding allows for improved scientific progress as well as technical confidence by all parties in the correctness of the work. One way of ensuring this communication is by having experimentalists involved in performance assessment, and modellers involved in experimental design.
2. A much deeper understanding of the system is required for confidence in performanc assessment and the safety case than can or will be represented in necessarily simplified performance-assessment models. Site characterisation is the mechanism through which one develops an overall understanding of the system, including identification of the operative processes and quantification of important parameters.
3. Efforts should continue to be made to improve the integration of different types of data. This integration can take a variety of forms, both quantitative and qualitative. Data collected in the laboratory or field can be used to reduce the number of free parameters in models of other experiments, such as using measurements of the porosity of fracture-infilling material to constrain tracer test models. Data from experiments or observations at different scales can be combined in models at the large performance-assessment scale.
4. Significant benefits can be obtained by looking beyond the field of radioactive waste management and drawing on the knowledge of specialists in others fields of science and engineering. These other technical communities also provide the opportunity for broader-based and more meaningful peer review.
5. Communication between implementers and regulators at all stages of the process of repository development is extremely important. Communication can allow the regulator to gain information and provide feedback on the technical direction being pursued by the implementer, as well as understand the limitations of data and models. At the same time, the implementer can gain an improved understanding of the expectations of the regulator and modify its programme as appropriate. This communication, however, should not, in any case, be allowed to compromise, or appear to compromise, the independence of the regulator.

These messages have applicability beyond issues relating solely to radionuclide transport through the geosphere. They pertain equally to almost all aspects of radioactive waste repository programmes. In this way, they provide guidance to all national repository programmes as well as to future NEA international collaborative projects.

News briefs

International peer review of a radioactive waste repository

The NEA conducts peer reviews as part of its mandate to help improve and harmonise the technical basis for dealing with nuclear waste issues in its Member countries. Over the years it has performed such reviews for national programmes in Japan, the Netherlands, Sweden, the United Kingdom and the United States. The most recent review was of the Total System Performance Assessment supporting the site recommendation process (TSPA-SR) of the Yucca Mountain Project in the United States.

The US Department of Energy (USDOE) has been studying the Yucca Mountain site in Nevada for more than 15 years to determine whether it is a suitable place to construct an underground repository for US spent nuclear fuel and high-level radioactive waste of commercial and military origins. In addition to site characterisation work and development of the system concept,the USDOE also carried out a number of performance assessments over the past decade.

The peer review of the TSPA-SR was requested by the USDOE and carried out over the period from June to December 2001. An independent team of ten international specialists, including two members of the Joint Secretariat formed by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), conducted the review. The team members represented several scientific and technical disciplines relevant to assessing the performance of underground radioactive waste repositories.

The primary objective given to the International Review Team (IRT) was to review and critically analyse the performance assessment methodology and rationale used by the USDOE in the site-recommendation decision process in order to:

- identify consistencies and inconsistencies between methods that were implemented by the USDOE and those being considered or developed in international recommendations, standards and practices;
- provide a statement regarding the adequacy of the overall performance assessment approach for supporting the site recommendation decision;
- provide detailed recommendations for specific technical and other improvements that would help performance assessment better support the next programmatic decision point, if the site is recommended and subsequently approved, which entails the preparation and submission of a license application.

The IRT has generally concluded that:

While presenting room for improvement, the TSPA-SR methodology is soundly based and has been implemented in a competent manner. Moreover, the modelling incorporates many conservatisms, including the extent to which water is able to contact the waste packages, the performance of engineered barriers and retardation provided by the geosphere.

Overall, the IRT considers that the implemented performance assessment approach provides an adequate basis for supporting a statement on likely compliance within the regulatory period of 10 000 years and, accordingly, for the site recommendation decision.

On the basis of a growing international consensus, the IRT stresses that understanding of the repository system and its performance and how it provides for safety should be emphasised more in future iterations, both during and beyond the regulatory period. Also, further work is required to increase confidence in the robustness of the TSPA.

The Peer Review is available for free download from the NEA website at www.nea.fr. Paper copies may be ordered at the address provided on page 32. ■

New publications

Economic and technical aspects of the nuclear fuel cycle

Externalities and Energy Policy: The Life Cycle Analysis Approach

Workshop Proceedings, Paris, France, 15-16 November 2001

ISBN 92-64-18481-3 – 240 pages – Free: paper or web versions.

Getting the prices right is a prerequisite for energy market mechanisms to work effectively towards the development of sustainable energy mixes. External costs of energy have been recognised and assessed in many studies, and the life cycle analysis (LCA) approach provides a conceptual framework for a detailed and comprehensive, comparative evaluation of alternative technology options. Despite this, results from analytical work on externalities and LCA studies are seldom used in policy making.

The International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) organised a workshop on "Externalities and Energy Policy: The Life Cycle Analysis Approach" to bring together policy makers and experts from governmental agencies and the industry to discuss key issues regarding the role and limitations of external cost evaluations and LCA results. The presentations and discussions reported in these proceedings will be of interest to senior analysts, policy makers and other stakeholders concerned with the sustainable development of the energy sector.

Environmental Remediation of Uranium Production Facilities

A Joint NEA/IAEA Report

ISBN 92-64-19509-2 – 350 pages – Price: € 70, US$ 63, £ 43, ¥ 7 050.

Environmental remediation activities in uranium mines and mills have become increasingly important in the last few decades due to the large number of facilities which have been taken out of operation, the growing interest in remediating previously abandoned sites and the increasingly strict environmental regulations that are being put in place. Remediation programmes are being implemented to ensure the return of affected areas to previously existing environmental conditions or to a land use that will be sustainable in the long term and acceptable to all stakeholders.

This report provides a summary of the most relevant issues and practices in remediation programmes or uranium production facilities and an overview of activities and plans in reporting countries. It covers the areas of site characterisation, dismantling and decommissioning, waste management facilities, water remediation, long-term stewardship and monitoring, policies and regulations, and costs. The country profiles of remediation activities and plans include information considered to be important by the country and are based on survey responses provided by 22 countries (12 OECD and 10 non-OECD countries).

Trends in the Nuclear Fuel Cycle

Economic, Environmental and Social Aspects

ISBN 92-64-19664-1 – 160 pages – Price: € 37, US$ 33, £ 23, ¥ 3 700.

The role of nuclear energy in a sustainable development context has multiple facets, a significant number of which relate to the nuclear fuel cycle. This report provides a description of the developments and trends in the nuclear fuel cycle that may improve the competitiveness and sustainability of nuclear generating systems over the medium and long term. It also presents criteria and indicators for future nuclear energy systems. Prepared by experts from the nuclear industry, government agencies and research organisations, this report will be of interest to those involved in nuclear energy policy and decision making.

Radiation protection

Better Integration of Radiation Protection in Modern Society

Workshop Proceedings, Villigen, Switzerland, 23-25 January 2001

ISBN 92-64-19694-3 – 280 pages – Price: € 60, US$ 54, £ 37, ¥ 6 050.

The societal aspects of risk governance are increasingly becoming a part of public decision-making processes. This tendency is particularly evident in matters dealing with the protection of human health and the environment. These proceedings address the roles of various stakeholders in the decision-making process, and their expectations regarding how a modern system of radiological protection should be integrated within the broader context of risk governance. Case studies are presented to illustrate good practice and as a basis for drawing conclusions regarding general lessons that can be applicable in many different national contexts. These proceedings will be of interest to policy makers, radiation protection experts and interested members of the public.

ISOE - Information System on Occupational Exposure

Ten Years of Experience

ISBN 92-64-18480-5 – 40 pages – Free: paper or web versions.

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.

Radioactive waste management

Radionuclide Retention in Geologic Media

Workshop Proceedings, Oskarshamn, Sweden, 7-9 May 2001

ISBN 92-64-19695-1 – 272 pages – Price: € 55, US$ 49, £ 34, ¥ 5 550.

Retention of radionuclides within the geosphere for prolonged periods is an important safety function of deep geologic disposal concepts for radioactive waste. In addition to the material presented during the workshop, this publication includes a technical synthesis reflecting the discussions that took place as well as the conclusions and recommendations made, notably during the working group sessions.

GEOTRAP: Radionuclide Migration in Geologic, Heterogeneous Media

Summary of Accomplishments

ISBN 92-64-18479-1 – 52 pages – Free: paper or web versions.

This report provides an overview of the project's main findings and accomplishments over its five-year life. This summary should help make the valuable information collected and generated by the GEOTRAP project accessible to a wide readership both within and outside the radioactive waste community. It is a reflection of the careful attention paid by this community to the question of radionuclide transport.

An International Peer Review of the Yucca Mountain Project TSPA-SR

Total System Performance Assessment for the Site Recommendation (TSPA-SR)

ISBN 92-64-18477-5 – 96 pages – Free: paper or web versions.

The Department of Energy of the United States of America (USDOE) has been studying the Yucca Mountain site in Nevada for more than 15 years to determine whether it is a suitable place to construct an underground repository for US spent nuclear fuel and high-level radioactive waste of commercial and military origins. A number of performance assessments have been carried out over the past decade by the USDOE, the latest of which is the Total System Performance Assessment supporting the site recommendation process (TSPA-SR) of December 2000. This report presents the results of the jointly organised NEA-IAEA international peer review of the TSPA-SR, performed upon the request of the USDOE. The review was carried out by a team of ten international specialists.

Nuclear law

Nuclear Law Bulletin

No. 68 + Supplement (Volume 2001/2)

2001 Subscription (2 issues + supplements) – ISSN 0304-341X – Price: € 71, US$ 80, £ 48, ¥ 9 550.

Nuclear Legislation: Analytical Study – Update 2001

Regulatory and Institutional Framework for Nuclear Activities

ISBN 92-64-19743-5 – 180 pages – Price: € 40, US$ 36, £ 25, ¥ 4 000.

The 2001 Update consists of replacement chapters for Australia, Canada, Hungary, Italy, Japan, Luxembourg, Norway and Spain. In addition, there is a completely new chapter for the Slovak Republic, which became a member of the OECD on 14 December 2000, and which was not previously covered by this publication. An information note is also provided on Poland, pending revision of this chapter upon adoption of legislation to implement the new Polish Atomic Law.

Nuclear regulation/nuclear safety

Nuclear Fuel Safety Criteria Technical Review

ISBN 92-64-19687-0 – 68 pages – Price: € 20, US$ 19, £ 12, ¥ 1 900.

In this report, brief descriptions of 20 fuel-related safety criteria are presented along with both the rationale for having such criteria and possible new design and operational issues which could have an effect on them. No attempt was made to categorise the criteria according to event type or risk significance. This report will be of particular interest to nuclear engineers working in the area of fuel safety and to all those interested in general aspects of nuclear safety.

Collective Statement on Major Nuclear Safety Research Facilities and Programmes at Risk

Joint OECD Projects and Centres of Excellence

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

Nuclear science and the Data Bank

Fission Gas Behaviour in Water Reactor Fuels

Workshop Proceedings, Cadarache, France, 26-29 September 2000

ISBN 92-64-19715-X – 564 pages – Price: € 120, US$ 107, £ 74, ¥ 12 100.

During irradiation, nuclear fuel changes volume, primarily through swelling. This swelling is caused by the fission products and in particular by the volatile ones such as krypton and xenon, called fission gas. Fission gas behaviour needs to be reliably predicted in order to make better use of nuclear fuel, a factor which can help to achieve the economic competitiveness required by today's markets.

These proceedings communicate the results of an international seminar which reviewed recent progress in the field of fission gas behaviour in light water reactor fuel and sought to improve the models used in computer codes predicting fission gas release. State-of-the-art knowledge is presented for both uranium-oxide and mixed-oxide fuels loaded in water reactors.

Comparison Calculations for an Accelerator-driven Minor Actinide Burner

ISBN 92-64-18478-3 – 200 pages – Free: paper or web versions.

In 1999, the NEA organised a benchmark exercise for an accelerator-driven minor actinide burner to check the performances of reactor codes and nuclear data for ADS with unconventional fuel and coolant. The benchmark model was a lead-bismuth-cooled subcritical system driven by a beam of 1 GeV protons. This report provides an analysis of the results supplied by seven participants from eight countries. The analysis reveals significant differences in important neutronic parameters, indicating a need for further investigation of the nuclear data, especially minor actinide data, as well as the calculation methods. This report will be of particular interest to reactor physicists and nuclear data evaluators developing nuclear systems for nuclear waste management.

PENELOPE – A Code System for Monte Carlo Simulation of Electron and Photon Transport

Workshop Proceedings, Issy-les-Moulineaux, France, 5-7 November 2001

ISBN 92-64-18475-9 – 250 pages – Free: paper or web versions.

PENELOPE is a modern, general-purpose Monte Carlo tool for simulating the transport of electrons and photons, which is applicable for arbitrary materials and in a wide energy range. PENELOPE provides quantitative guidance for many practical situations and techniques, including electron and x-ray spectroscopies, electron microscopy and microanalysis, biophysics, dosimetry, medical diagnostics and radiotherapy, and radiation damage and shielding. These proceedings contain the teaching notes of a recent workshop/training course on PENELOPE, with a detailed description of the physics, numerical algorithms and structure of the code system.

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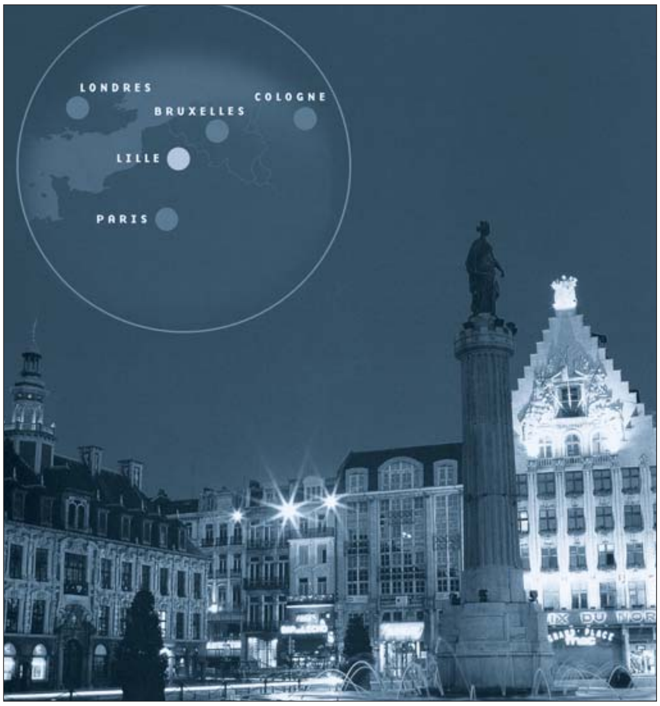

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