NEA News

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2000 – No. 18.1

The *NEA Newsletter* is published twice yearly in English and French by the OECD Nuclear Energy Agency. The opinions expressed in the *Newsletter* are those of the contributors alone and do not necessarily reflect the views of the Organisation or of its Member countries. Material in the *Newsletter* may be freely used provided the source is acknowledged.

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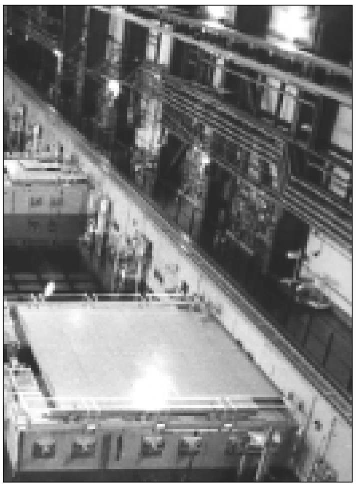
The OECD Nuclear Energy Agency (NEA) was established in 1958 as the OEEC European Nuclear Energy Agency and took its present designation in 1972 when its membership was extended to non-European countries. Its purpose is to further international co-operation related to the safety, environmental, economic, 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.

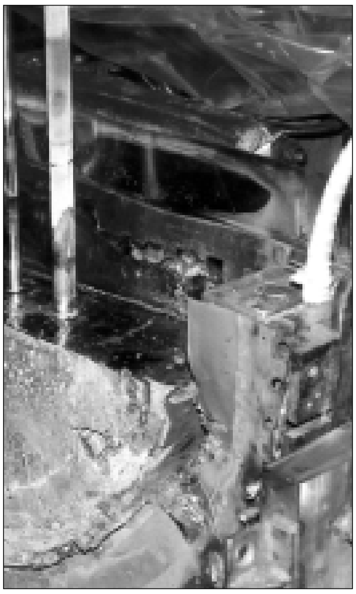
For more information about the NEA, see:

http://www.nea.fr

Cover page: Pickering nuclear power plant, Canada (AECL). Masurca critical assembly (Gonin, CEA, France). Marcoule research centre, France (Leindorfer/REA, CEA). Olympic dam uranium mine, Australia.

Facts and opinions





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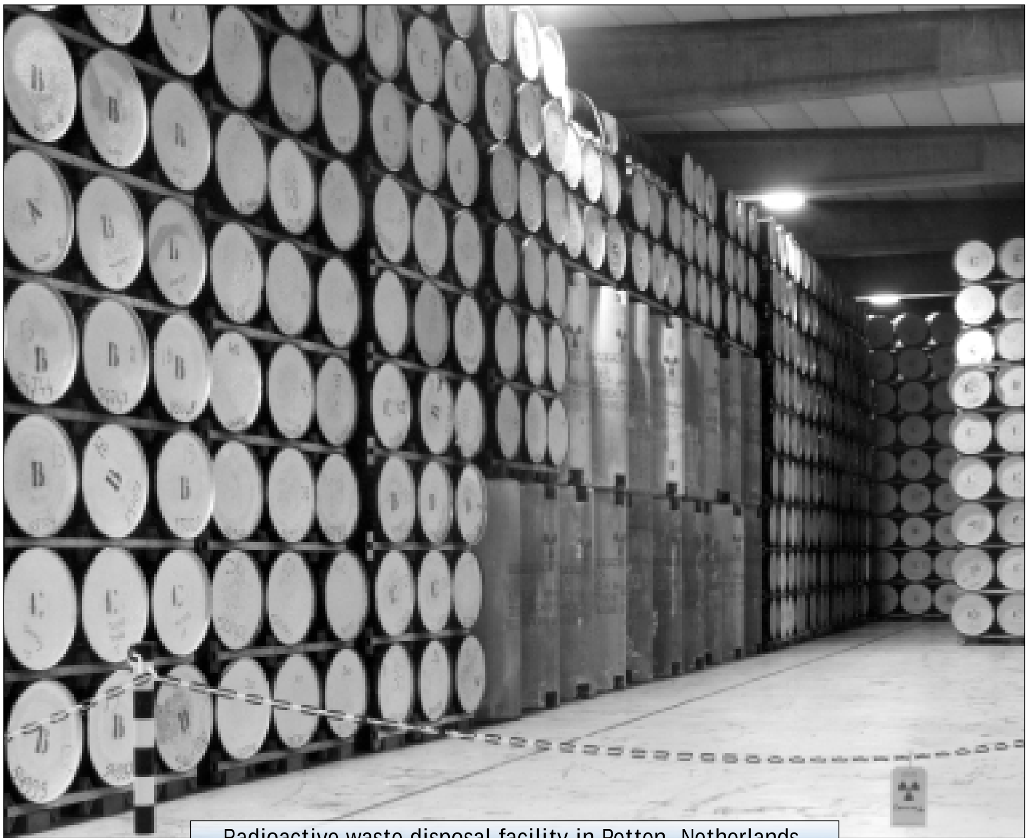

Radioactive waste disposal facility in Petten, Netherlands.

Confidence building and nuclear energy decision making

The political, economic and social challenges facing our societies at the beginning of this new century require informed and actively participating citizens. Increasingly, public authorities acknowledge their responsibility in ensuring transparency and clarity in policy making in all areas of concern to the citizen. Nuclear energy technology is a case in point because of its close connection with economic development, environmental protection and peoples' lives.

Governments of NEA countries that rely on nuclear energy as part of their energy mix are well aware of the need to develop or reinforce communication and consultation with broad segments of civil society. Opinion polls show a growing public awareness of the advantages and disadvantages of this energy source, including its economic, environmental, technical and social aspects, and unless there is adequate consultation with stakeholders, including the public, it will be difficult to make progress.

It is in this context that the NEA Strategic Plan *highlights the need for governments to take into account societal issues and concerns of the public, as they relate to nuclear energy, and to interact with stakeholders to create the necessary confidence in the decision-making process. Several programmes under way at the NEA address various facets of these issues, including stakeholder involvement in radiological risk assessment and management, the theory and practice of societal conflict resolution in difficult situations involving radiological risks, the issue of trust between nuclear regulators and the public, and stakeholder confidence in radioactive waste management decision making.*

These programmes take advantage of NEA capabilities to set up discussion fora which provide opportunities to exchange lessons learnt and to reflect, together with stakeholders, on useful consensual processes for decision making.

H. Yamagata*

Nuclear education and training: Cause for concern?

Many diverse technologies, currently serving nations worldwide, would be adversely affected if there was an inadequate number of nuclear scientists and engineers in the future with appropriate scientific and technical backgrounds and university curricula.

Mankind now enjoys many benefits from nuclear-related technologies. For example, advances in health care and medicine are increasingly dependent upon expertise in nuclear physics and engineering. The fabrication of advanced materials – from components the size of computer chips to the largest construction equipment – is dependent upon knowledge that stems from the nuclear industry. Nuclear technology is widespread and multidisciplinary: nuclear physics, mechanics, materials science, chemistry, health science, information technology and so on. Yet the advancement of this technology, with all its associated benefits, will be threatened (if not curtailed) unless the trend towards a declining number of courses in the field and the declining interest among students, is arrested.

Nuclear energy has played an important role in electricity production for the last half century. Today, over 340 nuclear power plants supply 24% of all electric power produced in OECD Member countries. Some countries, such as Japan and Korea, have plans to build new nuclear power plants. Even in countries not currently developing additional nuclear power, qualified manpower is still needed to operate the existing power plants and fuel-cycle facilities safely (many of which will operate for decades), manage radioactive waste, and prepare for future decommissioning of plants which have reached the end of their useful lives. Now and for generations to come, these activities will require expertise in nuclear engineering and science if safety and security are to be maintained and the environment protected.[1]

The human resource has long been identified as being one of the most important elements for engaging in the various types of nuclear applications. Major efforts must be directed towards attracting sufficient numbers of bright students to the field and pursuing research for both current and future nuclear technology utilisation. Such efforts are necessary to ensure the transfer of knowledge and know-how to the next generation. If we fail in the transfer, we stand to lose much valuable technology.

Although the number of nuclear scientists and technologists may appear to be sufficient today in some countries, there are indications (e.g. declining university enrolment, changing industry personnel profiles, dilution of university course content and retirement of many experts) that future expertise is at risk. A key concern is that future nuclear options will be precluded if governments, industry and academia fail to act.

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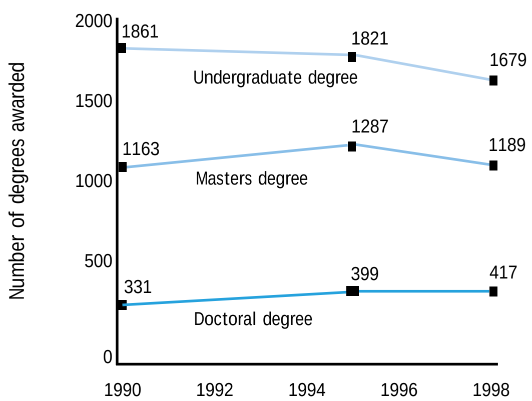
To clarify the extent of this international problem of declining nuclear expertise and to quantify the trends in nuclear education and training from 1990 to 1998, the Nuclear Energy Agency submitted a questionnaire in 1998 to almost 200 organisations in 16 Member countries (including 119 universities, and a range of research institutions, power companies, manufacturers, engineering offices and regulatory bodies). Some responses provided collective answers representing groups of organisations.

Emerging shortfall at universities

The number of universities that offer nuclear programmes, i.e. curricula that consist of a set of courses on nuclear subjects, is declining. In universities which try to appeal to a wider audience by offering nuclear programmes as options in more mainstream science programmes, nuclear programmes are being limited to the level of individual courses with a broadened, and hence diluted, content. A few new courses have been introduced, but the trend is for courses to be eliminated or merged.

While there was a 10% decrease in the number of nuclear-related degrees awarded at the undergraduate level between 1990 and 1998, the number awarded at the masters level remained fairly constant, and the number at the doctoral level increased by 26% (Figure 1). Of significance are the decreases observed between 1995 and 1998 at the undergraduate and masters levels. During this period, trends in the number of degrees awarded differ significantly from country to country, but sharp declines are observed in several countries.

Figure 1. Number of nuclear-related degrees awarded in 1990, 1995 and 1998



The number of full-time faculty members in nuclear fields has decreased in the United Kingdom and the United States, but has increased in France and Japan. In other countries, the numbers have remained fairly constant over the period in question. The number of part-time faculty members in the field is generally rising, especially in countries where the number of full-time faculty members is falling. The age distribution peaks at 41-50 and 51-60 in most countries. The average age of faculty members is almost 50 years and is construed as a risk to sustaining high-quality expertise.

Research facilities are ageing, with few replacements planned. Most university equipment and facilities are over 25 years old (Table 1). Many research reactors and hot cells have been decommissioned, and no replacements are planned. However, although three radiochemistry laboratories have been closed, four new ones have been opened, and laboratories for radiation measurement are regularly modernised. Generally, there is a decline in facilities, which will increasingly affect the capability of universities to do leading-edge research for industry. Because the industry is currently concentrating on operating existing plants more efficiently, it could be argued that this decline in facilities and universities is not important at present. However, such a decline erodes future capability and deters both students and faculty from working in the nuclear area.

By and large, at both the undergraduate and masters levels, only 20% to 40% of students chose to continue to study; at the doctoral level, between 30% and 70% of graduates, depending on the country, chose a career at an academic institution or nuclear research institute. The survey also showed that between 20% and 40% of graduates in nuclear fields (all degree levels) did not enter the nuclear industry. Some countries are already reporting that the number of students choosing a nuclear-oriented career is too low to respond to industry needs. It appears that this mismatch may grow.

Although the overall picture for the number of graduates during this period may seem reassuring, there are underlying causes for concern. The nuclear content of many undergraduate courses has declined. The pool of knowledge at the undergraduate level is therefore decreasing year by year. Doubts as to the quality of these graduates are already being expressed by industry. This will eventually have serious repercussions on the

Table 1. The average age, age range and expected lifetimes of nuclear facilities at universities in 1998

Facility	Average age (years)	Range (years)	Expected lifetimes
Research reactors*	32	13-47	2000 to 2040
Hot cells	28	10-44	2000 to 2030
Radiochemistry facilities	24	1-45	2010 to 2030
Radiation measurement facilities	25	1-44	indeterminate**

* Seven reactors were decommissioned between 1990 and 1998.
** The continuous upgrading of radiation measurement equipment keeps those laboratories operational and up-to-date.

masters and doctoral levels, where the situation is currently far more encouraging in terms of both quantity and quality of graduates. With fewer nuclear courses available there will be fewer students wanting to study nuclear topics for higher degrees, and with a broadening and hence dilution of courses there will be fewer students in a position to study for these degrees. Unless the situation is at least stabilised, in the next few years there will be a shortfall of quality graduates to cope with the existing concerns of the industry.

Industry programmes

Companies offer training programmes to support both broad-based knowledge and specific skill development. Training is designed for both new graduates and experienced staff with the aim of increasing the competence of the trainees in their specific function within the organisation.

With the nuclear industry consolidating in NEA Member countries, a decrease in training could have been anticipated. In reality, the opposite is true; increasing regulatory requirements and the need for more flexible workforces have led to an increase in in-house training, with a wide range of courses being offered.

Generally, in terms of facilities and trainers, the needs of the industry are being met. As the industry evolves, it may be expected that in-house training competence will evolve so that demand can be satisfied. Certainly, with the decline in university facilities and faculties, there will be little opportunity to outsource training there. Also, because the situation regarding nuclear education is roughly the same from one country to another, there can be no guarantee that what is no longer available at home can be obtained abroad. However, there is already evidence that companies are making places in courses available to other organisations, and it may be expected that this collaborative trend will continue.

Positive developments

Some positive developments are being noted in a number of universities. Many specific activities have had great success, as shown in the “Examples of best practices” (see Box 1). As an introduction to undergraduate nuclear engineering, universities provide basic and broad courses including general energy, environment and economic issues. Continuing efforts are applied to adjust the curriculum, develop new disciplines, and assess the situation in order to keep pace with the evolution of nuclear technologies, as well as to develop research areas that are attractive and exciting to students and meet the needs of industry. Information is being provided to potential students, such as university freshmen and high school students, who do not have appropriate and sufficient information on nuclear education in universities, so as to stimulate their interest in nuclear technology. University faculty members visit high schools, hold “open days” and work with the students. The latter can be reached by allowing them to “touch hardware” and learn more about challenges and opportunities through a highly “interactive web”.

Collaboration between industry and academia is widespread. Internship programmes, lectures by industry experts, scholarships from industry, and sponsored professorial chairs are common to many countries. Co-operative research between industry and universities, particularly at the doctoral level, is also widespread. This involves students in specific nuclear areas as well as in more general areas of importance to the nuclear industry, such as materials science, metallurgy, ceramics, etc. Students can be fully funded by a sponsoring company or funded mainly through government research initiatives with a lesser contribution from the company.

Conclusions

In most OECD countries there are now fewer comprehensive, high-quality nuclear technology programmes at universities than before. The ability of universities to attract top-quality students, meet future staffing requirements of the nuclear industry and conduct leading-edge research is becoming seriously compromised. Facilities and faculties for nuclear education are ageing, and the number of nuclear programmes is declining. The number of degrees with a nuclear content has generally decreased. As Figure 2 shows, student perception is affected by the educational circumstances: public perception, the industry's activities and reductions in government-funded nuclear programmes. This negative perception may be shared by many others, including a student's parents, teachers and friends. With an unclear image of the future, many young students now believe that job prospects in the nuclear field are poor and that there is little interesting research. Low enrolment directly affects budgets, and budgetary cuts then limit the facilities available for nuclear programmes. Unless action is taken to arrest these trends, the downward spiral of declining student interest and academic opportunities will continue. Human resources do not materialise instantly. It has become highly important to resume investment in nuclear education today.

Governments are responsible for doing what is clearly in their countries' long-term national interest, especially in areas where necessary actions will not otherwise be taken. They have an important multifaceted role in dealing with nuclear issues: managing the existing nuclear enterprise, ensuring that the country's energy needs will be met without significant environmental impact, influencing international actions on nuclear matters that affect safety and security, and pushing the frontiers in new technologies. Governments, therefore, should: 1) engage in long-term strategic energy planning and international collaboration necessary to sustain a healthy nuclear enterprise; 2) contribute to, if not take responsibility for, integrated planning to ensure that human resources are available to meet necessary obligations and address outstanding issues; 3) support, on a competitive basis, young students; 4) provide adequate resources for vibrant nuclear research and development programmes, including modernisation of facilities; and 5) foster "educational networks" among universities, industry and research institutes.

Universities should provide basic and attractive educational programmes; interact early and often with potential students; provide early research opportunities; and provide adequate information.

There currently appear to be enough trainers and qualified staff in industry and research institutes; however, industry must recognise its role and interest in assuring an adequate supply of capable students and vigorous research, as well as maintaining the high-quality training that is needed for staff in industry and research institutes. Industry should continue to provide rigorous training programmes to meet specific needs. Research institutes need to develop exciting research projects to meet industry's needs and attract quality students and employees.

Industry, research institutes and universities need to work together to co-ordinate more effectively their efforts to encourage the younger generation, through mechanisms such as grants, research

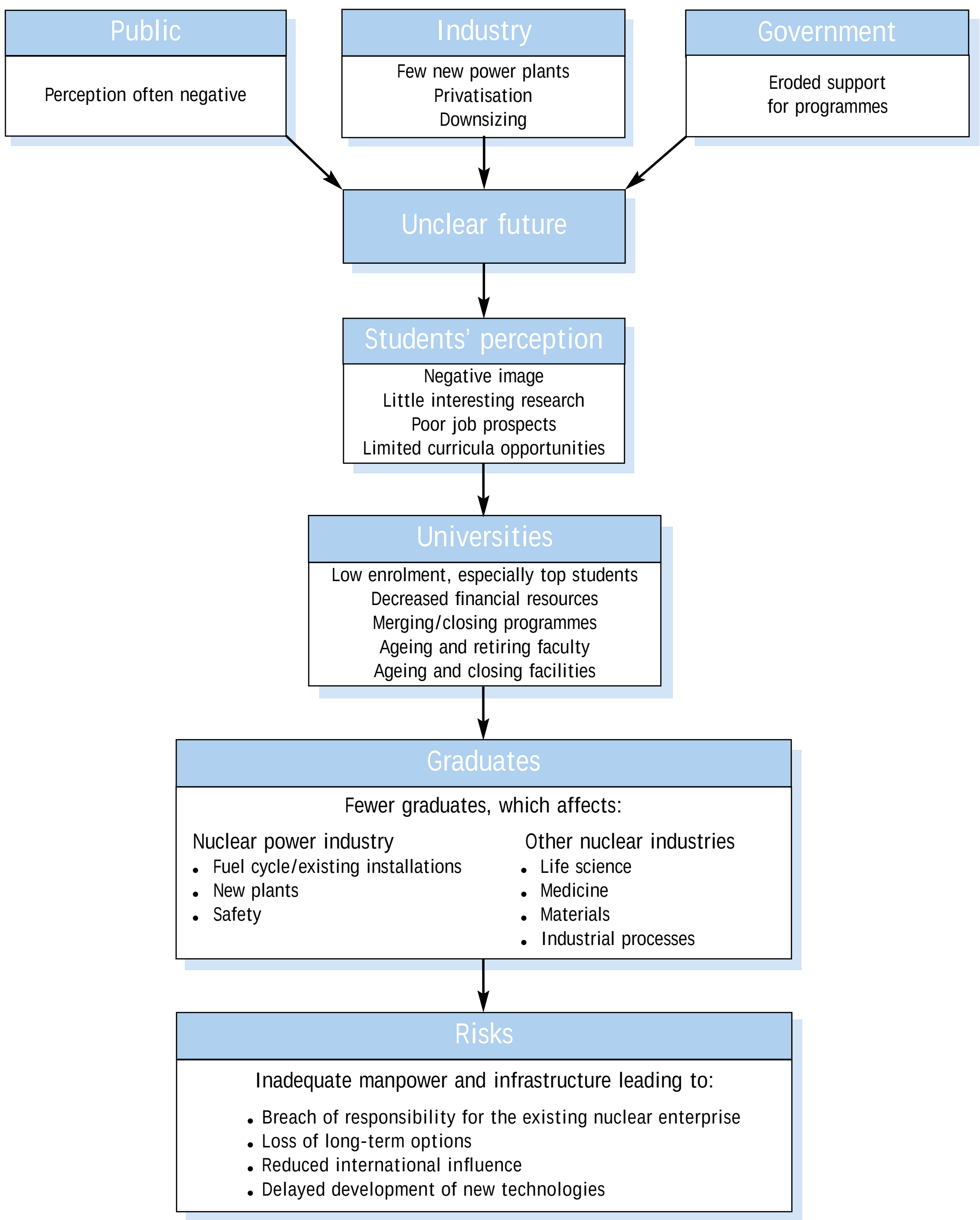
Box 1. Examples of best practices

- Create a pre-interest in the nuclear domain.
- Add nuclear content to courses and activities of general engineering studies.
- Change programme content in nuclear science and technology education.
- Increase pre-professional contacts.
- Provide scholarships and fellowships.
- Strengthen nuclear education networks.
- Provide industry employees activities that are professionally more interesting and challenging, and that pay more than those in the non-nuclear sectors.
- Provide early opportunities for students and prospective students to "touch hardware", interact with faculty and researchers, and participate in research projects.
- Provide opportunities for high school students and undergraduates to work with faculty and other senior individuals in research situations.

funding, partnerships and international collaboration. Collaboration between industry and academia varies widely. Where collaboration exists and works effectively, it is highly valuable, particularly when a university is involved in nuclear professional activities with industry. Collaboration keeps the academic subjects relevant to the actual problems encountered in industry – a key element for attracting students to the field. More collaboration and sharing best practices would be greatly beneficial.

1. See also the NEA update: "Assuring future nuclear safety competence".

Figure 2. The current situation for nuclear education



T. Lazo*

Evolution of the system of radiation protection

Debates on the various aspects of the "System of Radiation Protection", as recommended by the International Commission on Radiological Protection (ICRP), are becoming increasingly widespread, particularly outside the traditional radiation protection community.

It has been suggested that the "apparent incoherence" of the system of radiation protection should be addressed, particularly in light of the increased pressure by civil society to limit risks to human beings and to become more involved in radiation protection decision making. For several years, the NEA, through its Committee on Radiation Protection and Public Health (CRPPH), has been developing its experience in this field, devoting significant portions of its programme of work to interpreting the philosophical aspects of the system, and to providing guidance for its operational implementation. In conjunction with current debates concerning the system of radiation protection, the CRPPH has initiated its own critical review.

Controversy rising

Through the end of the 1970s, and even the beginning of the 1980s, the system of radiation protection was very largely accepted. This began changing, however, following the accidents at Three Mile Island (1979) and Chernobyl (1986), the latter of which deposited measurable amounts of radionuclides over large portions of the Northern Hemisphere. Worldwide interest significantly increased in the health effects of exposure to ionising radiation, and radiation protection terminology and philosophy found their way onto the centre stage of public debates.

The use of "collective dose", that is, the sum of the individual doses to all members of an exposed population, became much more commonplace outside the radiation protection community, notably in the media. This quantity was developed by the radiation protection community as an indicator to be used in selecting the optimum radiation protection for a given circumstance.

The "pure mathematics" of collective dose, however, can lead to the use of the quantity in other ways. For example, the calculation of collective dose from Chernobyl fallout to the population of the Northern Hemisphere resulted in the prediction of thousands of deaths from cancer. However, this did not prove to be the case and it is assumed to be unlikely that such figures will be attained, even in the next 20 or 30 years. Excluding the populations living in the highly contaminated zones in Russia, Belarus and Ukraine, the dose to any single exposed individual from the Chernobyl accident was very small.

The United Nations Scientific Committee on the Effects of Atomic Radiation estimated that individual lifetime doses in the Northern Hemisphere ranged from approximately 1 mSv (0.6% of lifetime dose from natural background) to approximately 0.001 mSv (0.0006% of lifetime dose from natural

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background). An individual would not normally be expected to contract a fatal cancer due to such a small dose, which is in fact only a very small fraction of natural background radiation. However, given that the population of that region was, for these calculations, estimated to be 4.9 billion people, the total collective dose calculated from the Chernobyl accident was estimated to be 600 000 man-Sv. Using a lifetime fatality probability coefficient (a dose-effect ratio based on epidemiological studies and extrapolation to low doses) of 0.05 cancer deaths per Sv of exposure yields an estimation of from zero to 30 000 excess cancer deaths due to the Chernobyl accident.

At the same time, some within the radiation protection community began to question the validity of the lifetime fatality probability coefficient estimated by the ICRP (0.05 per man Sv). Although carcinogenic effects are well documented at very high doses received very rapidly (Hiroshima and Nagasaki survivors), no such effects have ever been observed at the low doses and dose rates which are relevant to normal public exposures. However, the above coefficient is calculated assuming that the risk of cancer is linear with dose and therefore even the smallest dose carries, theoretically, some risk. Because no statistical increase in the number of cancers has ever been observed in populations exposed to low doses of radiation (nuclear workers, patients exposed to low doses of radiation for medical purposes, populations living in areas with elevated levels of background radiation, etc.) it is argued by some that there is a biological threshold, or at least a practical threshold, below which there is "no risk". Hence, some radiation protection professionals argue that too much is being expended on protection of the public and workers from the risks of exposure to ionising radiation.

Responding to the challenge

Professor Roger Clarke, Director of the UK National Radiological Protection Board and Chairman of the ICRP, has suggested that a new line of thinking might significantly improve the system. In an open paper on the control of radiation risks, he suggests that the "apparent incoherence" of the system of radiation protection should be addressed, particularly in light of the current social environment. By incoherence, he means such things as the lack of international guidance for the withdrawal of countermeasures, the difficulty in classifying certain situations as "practice" or "intervention". In a larger public perception context, dose limits for "normal" circumstances are often viewed by the public as the boundary between "safe" and "unsafe". However, public protection criteria under accident conditions (intervention levels) or under prolonged (chronic) exposure situations are much higher than the 1 mSv public dose limit, and this is seen by the public as incoherent.

In addition to Professor Clarke's new approach to the control of risk, the CRPPH is focusing on the concept of collective dose and a number of specific issues: When is this a relevant concept? When could and should it be used, if at all? What are the limitations and pitfalls? What are the experiences in NEA Member countries?

To address these issues, the CRPPH is preparing a critical review. The way forward will likely be the merging of two lines of thinking. The first line is that of Professor Clarke, that is, taking a fresh look at the philosophical and regulatory aspects of public and worker protection from ionising radiation, and developing a "new" system of radiation protection. The second line is more evolutionary in nature, beginning with the existing system of radiation protection and discussing how it could be simplified, made more coherent and applied in a more harmonised fashion.

The CRPPH review of the current system of radiation protection, which will be published this year, covers the following issues:

Clarity and coherence of the system of radiation protection

The system is very complex, and includes the use of many very precisely defined terms (e.g. risk, constraint, potential exposure, exemption, exclusion, clearance, practice, intervention, tolerable, acceptable, unacceptable, limit, justification, optimisation, guidance level, intervention level, action level). To make the system more clear and understandable, the CRPPH advises that the specificity of these terms should be revisited, and terms should be better related to common-usage definitions. In terms of coherence, it has been found that various numerical recommendations (public dose limit, intervention levels, action levels for radon exposures, action levels for prolonged exposure, etc.) are often not well understood by the public, regulators and decision makers. These numerical recommendations should be reviewed, and better explained in a framework which is easier to understand, particularly for the public.

Justification of activities

The CRPPH considers that the concept of justification as presented in ICRP 60 is in need of operational clarification. In particular, it believes that justification of a particular action is the result of a societal decision. The process for arriving at such a decision should be clarified. In addition, the relation between justification of an action, and optimisation of how to implement the action should be further explored.

Optimisation of activities

Optimisation is one of the pillars of the system of radiation protection, although in practice it can be difficult to apply. Some practical examples of optimisation, in detailed case studies, would be very useful to illustrate the application of this principle.

The use of collective dose

Although the example of the “misuse” of collective dose arising from the Chernobyl accident is relevant, the CRPPH deems this measure to be a very useful tool if applied to specific situations. The tracking of repetitive work activities, or the comparison of protection options for specific, well-defined populations, are two examples of the useful application of collective dose. The question of how collective dose should be used, particularly in these types of situations, should be discussed in the context of the new system of radiation protection.

Dose limits: presentation and numerical justification

As mentioned in the context of coherence, there is a need to review the numerical values the ICRP has chosen for its public and worker dose limits, as well as for various other levels. The justification of these values is clearly a modern societal concern and should thus be the object of broader public consultation.

Triviality: how necessary and useful is this concept?

Recent international guidance documents have defined trivial doses and risks. However, modern society is often in opposition to such institutional definitions of “imposed” risks. The utility of the concept of triviality, particularly in this societal context, should be revisited.

Public protection: science, regulation and public policy decisions

One of the current problems with the radiation protection system is that there is insufficient distinction between the various “elements” that define it. One specific problem concerns the science that supports the assessment of radiological risks; the regulations that have been developed using science as the decision basis; and public policy input, which must also be reflected in the development and application of regulations. Currently there is little distinction between these three separate elements, and the CRPPH considers that this lack of distinction has led to much confusion and apparent incoherence in the system of radiation protection.

Protection of the environment

Finally, the ICRP has for many years said that if the protection of man is assured, then the protection of nature and the environment will also be assured. This position is increasingly being questioned, and further discussion and research of this issue, particularly from the standpoint of input from society, and societal justification, is believed necessary.

The review should be considered as an early contribution to the debate over the future evolution and direction of the international system of radiation protection. It is hoped that, with this early beginning to discussions, there will be sufficient time to develop an appropriate international consensus, which would serve as a basis for the next round of ICRP general recommendations, probably in the 2005 to 2010 timeframe.

Further reading

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M. Takahashi, H. Riotte, B. Ruegger*

An overview of radioactive waste management

As waste is an inevitable byproduct of all industrial activities, radioactive waste is a byproduct of nuclear programmes. The main objective of radioactive waste management is to handle radioactive waste materials in a safe, environmentally acceptable, economical and responsible manner. In this article, the authors recall a number of factors which characterise the radioactive waste produced in the nuclear fuel cycle, and its management, and they describe the state of the art in this field, in the light of several recent NEA publications.

As in other industries, the final destination of radioactive waste is either dispersion or confinement. To achieve this goal, the four main procedures are:

- to separate as much as possible radioactive components from the main process stream and other less radioactive streams in order to facilitate later release or conditioning (*decontamination*);
- to release materials contaminated with radioactivity in compliance with regulatory requirements (*release, discharge or dispersion*);
- to stabilise the separated components in order to facilitate storage, transportation and eventual disposal (*conditioning*);
- to confine the conditioned products in an environment remote from human activity (*confinement or disposal*).

The NEA has been reviewing progress in reducing radioactive discharges from nuclear fuel cycle facilities in the framework of a generic study on comparison of the radiological impact of spent fuel management options. In this study all steps of the fuel cycle activities are reviewed. It is noted that radioactive discharges have been reduced significantly in all steps.

Current status

When nuclear programmes first began operation, little attention was given to waste. In contrast, waste generation has been significantly reduced since operators have been confronted with on-site storage shortages and delays in repository development, and operating experiences have led to cost estimates that are reliable enough to be used for decision making. Thirty years of experience in operating nuclear facilities have generated sufficient know-how to optimise

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plant design and operational practices. New technologies have been developed and introduced and better understanding of waste generation in nuclear facilities has resulted in the modification of operating modes. Good practices have been shared throughout the nuclear industry and increased competition in the electricity market has led to greater attention to waste management costs and influenced waste management practices. Future developments in waste management will involve selected strategic areas.

Various measures are applied in all steps of the fuel cycle to reduce waste generation and radioactive releases:

- The reduction of waste generation is achieved *inter alia* by reducing contamination levels, applying re-useable materials, gaining better understanding of water chemistry in power plants, introducing new low-cobalt materials, improving fuel cladding and using high burn-up fuel.
- Alternative processes, including the dry uranium hexafluoride conversion process, and new conditioning materials are being introduced.
- Good practices, such as waste classification, timely replacement of leaking fuel assemblies, and better decontamination techniques, are being adopted.
- Waste volume reduction is being sought through the incineration of combustible materials, the high concentration of liquids and the high compacting of solid materials.
- Radioactive releases are being reduced with the help of cryogenic charcoal filters and enhanced liquid stream treatment processes.

Efforts to reduce radioactive releases resulted in a short-term increase in waste generation and waste management cost. Since any new technique or process has to be tested in an operating environment and reviewed before being widely adopted, progress in improvements has been incremental rather than revolutionary.

Developments in separating long-lived gaseous or volatile radioactive nuclides have made possible the reduction of environmental releases and the further concentration of the radioactive nuclides. The resulting products nevertheless require proper storage and eventual disposal.

In applying these methods, an optimisation process is required since there may be a potential increase in radioactive doses to workers involved in waste management. This issue became important when the nuclear industry started to apply the as-low-as-reasonably-achievable (ALARA) principle. This process involves a number of factors: radiation protection aspects, operational safety of newly conceived methods, radioactivity involved, sources, volume, characteristicsh, disposal options, waste management and cost.

Characteristics of waste management in the fuel cycle

Mining and milling

Uranium is extracted from crushed rock in a process that generates above-ground mill tailings. Generally, open pit mining generates more waste material than cavity mining. Crushed rock and mill tailings contain small amounts of residual uranium, as well as radium, which have long-term effects, most notably the emanation of radon gas.

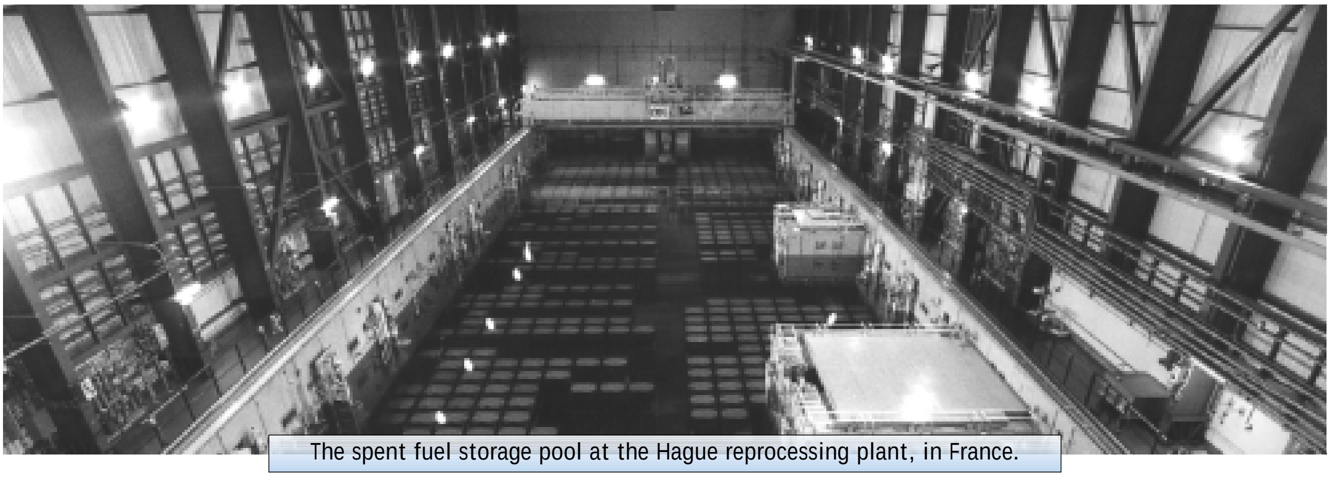
While the radioactive content of this material is very low, the volume is large and therefore tailings must be disposed of with due consideration for radiation protection. No special treatment is applied to these materials before disposal. They are stored on site, awaiting eventual disposal either by back-filling the mined cavities or in surface disposal areas. Usually, the surface disposal area is capped with clay to reduce gaseous releases, but other more sophisticated methods for long-term stabilisation are also applied.

Fuel fabrication

Conversion, enrichment and fuel fabrication are the processes needed to utilise uranium in most of today's power plants. With the exception of mixed-oxide fuel fabrication, the radioactive materials involved are naturally occurring or slightly enriched and their radiological significance is relatively low. The major waste arising is filter cake from the uranium purification process, prior to the conversion of uranium oxide into uranium hexafluoride, which is used for the uranium enrichment process. Various types of other waste are generated from different chemical treatment processes. The radioactivity content of all these wastes is low. A dry process to convert uranium hexafluoride into uranium oxide (so that it may be used as fuel) has been developed, and this process has contributed to the reduction of liquid waste from the fuel fabrication process.

Nuclear power generation

The waste stream in the power generation process is rather complex in terms of its chemical form, isotopic composition and radiation levels.



The spent fuel storage pool at the Hague reprocessing plant, in France.

The radioactive materials concerned are fission products and activation products. Most radioactive isotopes generated are confined in the fuel elements.

Due to either leakage from fuel elements or activation of component materials, a small proportion of radioactive substances can find its way into the coolant system. These are transported in the reactor system and finally removed, chemically or physically, through the purification processes. This process generates concentrated radioactive streams which are collected and stored for eventual treatment and conditioning into stable forms. The decontaminated water is recycled into the reactor system and liquid and gaseous effluents are released into the environment in accordance with national regulations.

Improvements in fuel design and fuel cladding materials and in the quality control of fuel fabrication have reduced the incidence of fuel leakage, which has resulted in less coolant contamination. Better understanding of water chemistry in the coolant system has also contributed to the reduction of activation products.

Each refuelling and maintenance outage generates additional waste; improvements in operating performance therefore have an immediate impact on waste reduction. Extended operating cycles with high burn-up fuel can be seen as contributing to waste reduction, particularly in those countries where spent fuel is considered as waste.

Reprocessing

Reprocessing separates uranium and plutonium from fission products in spent fuel. Temporary storage of spent fuel after removal from the core is common practice. It makes possible the decay of short-lived nuclides and facilitates the reprocessing process and radioactive waste management.

The waste stream in reprocessing is also quite complex in terms of its chemical and isotopic composition and the radiation level is very high. Most of the fission products are contained in the liquid stream from the first extraction cycle. This waste stream is highly radioactive and vitrification is the method used for conditioning the waste after an appropriate cooling period in storage.

The treatment of liquid effluents has been improved and this has contributed to a significant reduction of releases into the environment. The remaining radioactivity is conditioned as high-level waste. For conditioning metallic pieces, a super compacting method has been developed. A process to recover plutonium from waste containing trace amounts of this material has also been developed and is in operation.

Decommissioning and dismantling of nuclear facilities

Experience has been accumulated in dismantling small-scale research and development facilities as well as in dismantling large-scale facilities in some countries. To facilitate subsequent dismantling operations and to avoid the unnecessary spread of radioactivity, decontamination and immobilisation of radioactive contamination are used, and both chemical as well as physical processes have been developed and are applied.

Decontamination and dismantling operations generate large volumes of waste with low radioactive content. Decontaminated materials or components other than radioactive waste can either be released for other authorised uses or disposed of with less stringent regulatory requirements.

Off-site storage and disposal

A number of off-site storage and disposal facilities for low-level waste are in operation in NEA Member countries and new sites are being developed. Underground repositories for this type of waste are also operational in some NEA Member countries.

For disposal of long-lived waste, which includes spent fuel, vitrified high-level waste from reprocessing, and waste containing transuranium nuclides, development of underground repositories is the preferred option. Several national programmes have achieved significant progress in such areas as the construction of underground laboratories and the siting of repositories. In 1999, the US put into operation the first such facility, the Waste Isolation Pilot Plant. Further progress should help to convince the public that geological disposal of long-lived waste is feasible over the long-term.

Conclusions

A number of waste treatment and conditioning processes have been developed and are available for the handling of different types of waste streams. These processes have successfully reduced radioactive discharges into the environment and have contributed to achieving radiation protection goals for the public, workers and the environment.

Waste materials from mining and milling and low-level waste from nuclear facilities have been disposed of, after proper treatment or conditioning, in repositories licensed by the competent national regulatory authorities.

The volume of waste generated from nuclear programmes is relatively small and therefore it can be managed by means of temporary storage while awaiting disposal. While this is a satisfactory approach in the short term, in the longer term storing long-lived waste in this manner would not be acceptable in view of the long-term potential hazard of such waste.

Disposal of radioactive waste can be technically safe if all necessary safety and environmental precautions are taken and the system is passive. For low-level waste, disposal facilities are available in many countries. For long-lived waste, geological disposal is currently the preferred option in NEA Member countries. As national geological disposal programmes advance, in some NEA Member countries (e.g. Canada and the United Kingdom) decisions have been postponed in order to allow for wider public consultation. Alternative approaches (including extended storage before disposal and partial disposal for demonstration purposes) are also being considered.

No other industrial waste with long-term hazardous potential has been as strictly regulated as radioactive waste. This does not mean that regulation of nuclear waste should be relaxed, but that there should be a more consistent approach to regulating waste from nuclear and non-nuclear activities. In any case, the issues relating to geological disposal are complex since they involve technical, scientific, societal and environmental aspects. Nevertheless, regardless of how complex they are, the debates and decisions on these issues should be based on scientific and technological knowledge.

The decision-making process should be transparent and allow the active participation of stakeholders. Only through such a process can public acceptance be achieved.

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C. Vitanza*

Nuclear safety research at the NEA

The nuclear community has for some time been facing changing conditions in the industry as well as in governmental organisations. These changes have had, and will continue to have, profound impacts on the access to R&D funding and on the way research is organised and financed in most NEA Member countries.

On the industry side, utilities are faced with intense competition, and in order to compete efficiently they are looking for means to improve operational economics and flexibility and to reduce costs whenever feasible. The focus of utility-sponsored research is thus narrowing towards programmes devised to demonstrate more efficient means of running the plants, i.e. programmes that can provide a tangible economic return as convincingly and as quickly as possible.

At the same time, government funding has also been decreasing in most Member countries, affecting the grants made available for experimental work in facilities and R&D centres as well as the budgets of safety research programmes that are traditionally carried out by safety organisations.

This article provides an overview of the activities being carried out under the aegis of the NEA with a view to preventing irreversible losses of infrastructure and technical competence in critical safety research. It is apparent, however, that the reduction of both industry and government funds has put great pressure on all nuclear research centres, which as a result have been experiencing reductions in personnel and scope of work throughout the last decade. While significant differences exist from one country to the next, the overall trend has been in the direction of smaller and fewer safety-related programmes, a decrease in nuclear R&D expertise, and the closure or threat of closure of many facilities.

There are indications suggesting that this trend is likely to continue in the immediate future and possibly extend to countries that have so far been relatively immune to this process. Consequently, concerns have been raised as to the ability of individual NEA Member countries to maintain critical competence and focus on important safety areas, unless practical countermeasures are put in place. International co-operation can help provide a solution and makes economic sense.

The SESAR-FAP Initiative

For the past several years, the NEA Committee on the Safety of Nuclear Installations (CSNI) has commissioned studies by senior experts in safety research (SESAR), the last of which addressed technical priorities for facilities and programmes (FAP). The outcome of this study will be presented in a report focusing on research needs and priorities in the areas of: thermal hydraulics; fuel and reactor physics; severe accidents; human factors; plant control and monitoring; integrity of components and structures; and seismic behaviour of structures.

It emerges that in some areas specific follow-up is not needed at this time, either because sufficient infrastructure and programmes already exist or because the priority is low. The areas of

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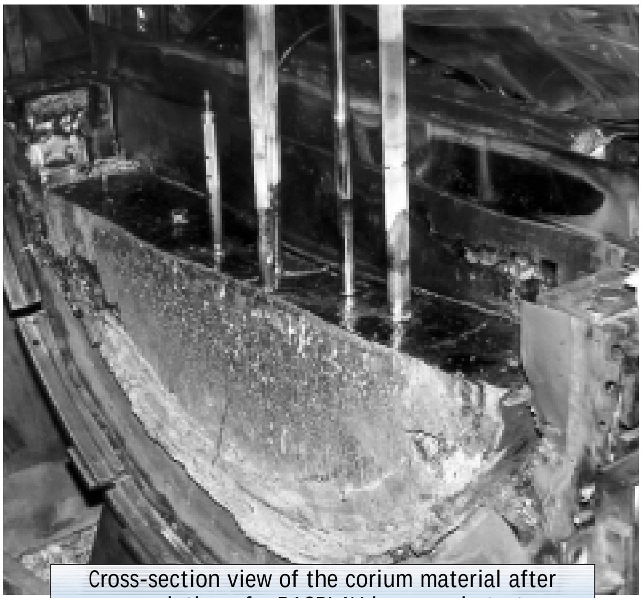
thermal hydraulics and severe accidents, however, were identified as requiring immediate attention. The CSNI is thus focusing its efforts on both of them, keeping in mind that certain other areas such as seismic behaviour may also need attention in the future.

The next steps must concentrate on the implementation of a convincing experimental programme for specific facilities. The intention is not to arrest a general process of downsizing, which largely depends on framework conditions that cannot feasibly be changed, but to provide a method and the means for preserving a meaningful technical infrastructure on nuclear safety research.

As a first step in this direction, the facilities identified in the SESAR-FAP report, operating in the thermal-hydraulic area, were requested to define a three-year programme of work consistent with the priorities indicated in the report. The facilities in question are PANDA in Switzerland, PKL in Germany, and SPES in Italy.

The PANDA tests address important containment 3-D flow distribution issues in a multi-compartment, two-phase configuration. The well-defined geometry of the facility makes the proposed tests particularly suitable for validating fluid dynamics codes and improving their accuracy. The tests intended for the PKL facility are to investigate two potential accident scenarios pertinent to existing PWRs. The first is the potential for reactivity insertion in the core due to ingress of low-borated water; the second addresses fuel uncoverage (an accidental condition that can occur in situations of plant shutdown). The SPES tests are to investigate phenomena related to station black-out and anticipated transients without scram, and can be used with modification to address the location of failures in PWR primary and secondary coolant systems.

Similar to what has been done in the thermal-hydraulic area, two research centres have put forward proposals for possible NEA research programmes in the severe accidents area. The two centres are the Kurtchatov Institute in Russia and the Argonne National Laboratory in the USA. Both proposals deal with phenomena occurring during a severe accident progression. The objective of the programme proposed by the Kurtchatov Institute (MASCA project) is to investigate in-vessel phenomena. In particular, it will address the influence of the chemical composition of the molten corium on the heat transfer to the pressure vessel environment. The tests will also investigate stratification phenomena of the molten pool and the



Cross-section view of the corium material after completion of a RASPLAV large-scale test.

Kurtchatov Institute, Moscow

partitioning of fission products within the different layers of the melt. The Argonne proposal focuses on ex-vessel phenomena and, in particular, on the molten core/concrete interaction, both in the case of a dry containment cavity and of the presence of an overlying water layer. Molten core coolability will also be investigated. The tests are to be carried out in the Argonne MACE facility.

The next step will be to form sufficient consensus around the FAP proposals such that formal agreements can be established with adequate financial support from Member countries, both in the thermal-hydraulics and severe accident areas. Efforts will be made to phase the programmes such that yearly costs to participants will be as low as reasonably possible.

Other ongoing safety projects

Considerable experience exists at the NEA in the implementation and execution of a variety of projects dealing with nuclear reactor safety and reliability issues. In general, results from these projects have been very good, and the NEA will build upon this experience when establishing the new FAP projects. An overview of NEA projects currently being carried out in the area of reactor safety is given below.

The Lower Head Failure Project is a three-year project dedicated to understanding key phenomena of vessel deformation and failure following an accident with core melt. The programme background resides in the inability of current models to predict adequately the failure of the vessel lower head. The programme of work contemplates a total of eight experiments carried out with prototypic materials at representative pressure conditions. The reactor pressure vessel mock-up will be heated from the inside to simulate the temperature conditions that might occur on the lower head. The experimental programme will be carried out at the Sandia National Laboratory in the USA and is planned for completion in mid-2001. It will be complemented by analyses, including a round-robin exercise to assess and harmonise modelling approaches in participating organisations. Organisations from eight countries participate.

The RASPLAV Phase-2 Project investigates the progression of a severe accident, and in particular the thermal loading imposed by a convective corium pool on the lower head of a LWR pressure vessel. It follows an earlier Phase-1 project dedicated mainly to building up experimental and analytical infrastructure. The project is carried out at the Kurtchatov Institute in Russia. Its objectives are to obtain relevant data on the physical and thermal behaviour of the corium in large-scale tests, to derive thermo-physical property data for various molten core materials, and to investigate the effects of stratification of molten materials. The programme of work uses facilities of different sizes available at the Kurtchatov Institute, is supported and co-financed by organisations in 16 countries, and is due to be completed by mid-2000. A proposal for a follow-on project (the MASCA project mentioned earlier) has been submitted to potential participants.

The CABRI Water Loop Project is investigating the ability of high burn-up fuel to withstand the sharp power peaks that can occur in power reactors due to rapid reactivity insertion in the core (RIA accidents). It involves substantial facility modifications and upgrades and consists of 12 experiments to be performed with fuel retrieved from power reactors and refabricated to suitable length. The project has just begun and will run for eight years. While the main lines of the programme of work and schedule have been defined, details of the scope and of the experimental conditions are still being discussed by participants. The experimental work will be carried out at the *Institut de protection et de sûreté nucléaire* (IPSN) in Cadarache, France, where the CABRI reactor is located. Programme execution can, however, involve laboratories in participating organisations (for instance, in relation to fuel characterisation or post-irradiation examinations). At present, organisations in ten countries have confirmed their intention to participate. Wider participation is expected as the project scope becomes more defined.

The Halden Reactor Project is the largest NEA project and constitutes a very important international technical network in the areas of nuclear fuel reliability, integrity of reactor internals, plant control/monitoring and human factors. The project has been operating by way of three-year renewable mandates over the past 40 years. The present mandate started at the beginning of 2000. The programme of work in the fuel and materials area includes fuel assessments in the high/very high burn-up range (both at normal operating conditions) and in transients, as well as embrittlement and cracking behaviour of reactor internals materials. These investigations are carried out experimentally at representative reactor conditions and with the utilisation of advanced instrumentation. The proposed programme on plant control and monitoring is intended to assess systems having the potential for improving plant performance and operational safety. The activities on human factors aim to extend the knowledge of human performance in a control room environment and to demonstrate how this knowledge can be incorporated in control room engineering solutions. The Halden Project is executed at the Halden establishment in Norway and is supported by approximately 100 organisations in 20 countries.

The PLASMA Project can be considered as a spin-off of the Halden Project in that it represents a practical utilisation and extension of the technology developed at Halden on plant monitoring. As in the case of a previous project (denominated SCORPIO VVER), it also represents a way to enhance interaction among Halden participants on practical plant applications. The PLASMA project is a collaborative effort among JAERI, Japan, the KFKI institute in Budapest, the Hungarian Paks power plant and Halden. The objective is to implement a system to monitor plant safety parameters in VVER power plants as part of VVER control system upgradings. Paks is the reference plant in which the system is first being implemented and demonstrated. The project has a duration of two years and is due to be completed during the course of 2000.

G.M. Frescura and T.E. Murley*

The NEA investigates safety culture

The Role of the Nuclear Regulator in Promoting and Evaluating Safety Culture and *Regulatory Response Strategies for Safety Culture Problems* are the first two publications[1] in a series produced by the NEA Committee on Nuclear Regulatory Activities on the subject of safety culture. They focus on early signs of declining safety performance, while discussing the role of the regulator in promoting and evaluating safety culture, and responding to problems in this area.

Safety culture clearly involves everyone whose actions, attitudes and decisions may influence nuclear safety, including not only the utility operators but also the regulatory body. *The Role of the Nuclear Regulator in Promoting and Evaluating Safety Culture* focuses on the dual role of the regulatory body in both a) promoting safety culture, through its own example and through encouragement given to operators, and b) evaluating the safety culture of licensees through performance- or process-based inspections and other methods.

Defining and establishing an effective safety culture and recognising related trends is still a recent initiative that is currently undergoing development and review within operator organisations and regulatory bodies. As more studies are performed and experience is gained in this area, the role of the regulator in promoting and evaluating safety culture will continue to evolve and mature. This NEA publication launches a clear framework for analysing regulatory response strategies, as well as the role of the regulator in evaluating and promoting safety culture in all aspects of nuclear power plant safety.

Understanding of the essential aspects of nuclear safety has evolved and deepened over the four decades of commercial nuclear power experience. In the early years, the primary focus was on basic physics and engineering principles, safety system design features, codes and standards, and general design criteria governing such matters as redundancy and diversity of the safety systems.

It was several years later, in the aftermath of the 1986 accident at Chernobyl, that the importance of safety culture came into clearer focus. We now know that a good safety culture is essential for overall nuclear safety. However it does not represent the whole of safety – a robust design, competent management of the technology and work processes, and compliance with regulations are also required for safety.

When discussing the concept of safety culture, the regulator should recognise that it is not really possible to measure it quantitatively. Instead the regulator can evaluate the outward operational manifestations of safety culture as well as the quality of the work processes, rather than the safety culture itself.

One of the most difficult challenges in assessing nuclear power plant safety performance is to recognise the early signs of declining safety performance, before conditions become so serious that regulatory sanctions must be imposed or, worse, a serious incident or accident occurs. Most nuclear plants collect and publish a standard set of performance indicators such as automatic trips, safety system failures, forced outage rate and

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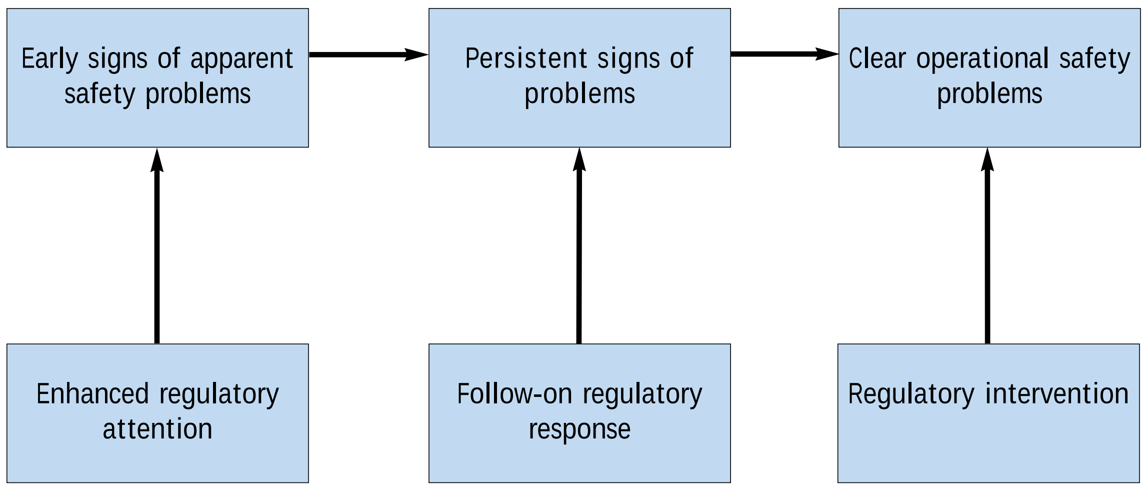
collective radiation exposure. Unfortunately, these are lagging indicators, and by the time negative trends in the performance indicators are evident, the plant is well into a stage of declining performance. Furthermore, the indicators are at such a high level that they give few clues regarding the underlying weaknesses causing the declining performance. For this reason, it is important that integral part of management planning in plants. Other programmes should be designed to address ineffective corrective actions and recurring problems. Quality assurance must be made a central part of plant activities, and audits of these programmes need to be made more effective. Formal programmes to analyse events, including activities in other plants, need to be created when

Pattern of declining safety performance



the safety regulator have the capability to inspect and recognise early signs of declining performance before it is too late.

Regulators must look for signs of a weak safety culture that may be the root cause for actual declining performance. All of the conditions described hereafter have their nexus in ineffective management of nuclear plants. This may take the form of misguided policies, weak leadership, or inadequate standards to guide employees' work. Some examples of early warning signs of potentially weak safety culture include lack of clear organisational commitment to safety, as well as lack of nuclear experience among top managers and their unwillingness to face problems and then correct them.

In order to solve these safety culture problems, training programmes must be designed as an reviews by safety organisations are found to be too superficial and management shows signs that it does not want to hear bad news regarding nuclear safety.

Clear accountability must be established in order for safety culture to progress. Problems arise when responsibility for fixing them is not assigned in advance, schedules are either not established or routinely missed, poor work performance remains tolerated, and decision making is too slow and inefficient. Regulatory reforms could be put in place to change these poor work habits, including discouraging the policy of minimal compliance with regulations, and ending the practice of delaying or deferring regulatory commitments.

Perhaps the most important, as well as most difficult thing to change is people's attitudes towards safety culture. Complacency, the "hypnosis of excessive self-confidence", and the provincialism of not having managers from outside, influence all players involved in nuclear safety. Self-satisfaction with current performance and a lack of receptiveness to outside suggestions do not help improve safety culture.

Accurate information and persistence remain essential in these safety scenarios. The regulator can promote safety culture in the operator's organisation by merely placing it on the agenda at the highest organisational levels. The operator's priorities are obviously influenced by those matters regarded as important by the regulatory body. Thus, the regulator can stimulate the development of a safety culture by providing positive reinforcement for good performance and high quality in plant work processes, encouraging good safety practices, promoting the examples of operators having a good safety culture, and recognising initiatives of industry organisations.

How the regulator deals with declining safety performance depends, of course, upon the laws, regulations and customs of each nation. A graduated approach of escalating regulatory attention has proven to be effective in dealing with declining performance in several cases.

When early signs of declining safety performance are observed, a graduated approach would be for the regulator to monitor the situation and document the inspection findings carefully so that trends can be seen. It is especially important that inspectors evaluate thoroughly all significant operating events at a plant. If the signs persist or new signs appear to be correlated, the regulator may decide to place the plant under special surveillance, which means special attention through focused inspections and requirements for periodic progress reports on technical and programmatic improvements. The regulator should meet with plant management to inform them of the reasons for the surveillance, areas where improvements are necessary, and the need for regular progress reports on improvements.

If the special surveillance and enhanced inspection programme over a period of several months continues to find signs of declining performance, further regulatory action will probably be required. These performance problems are rarely self-correcting without sustained outside intervention. The regulator may require further action for a meeting with the highest levels of the operator's management to stress the seriousness of the concerns and to describe the detailed basis for these concerns about declining performance. This meeting could be followed by an official letter describing the purpose and conclusions of the event.

If performance continues to decline, the regulator will likely be faced with the need for enforcement sanctions. The precise form of such sanctions depends upon the laws and regulations of each regulatory authority. Clearly, however, a regulatory body must have the ability to take enforcement actions, including the authority to order a nuclear plant to be shut down if judged necessary to protect public health and safety. *Regulatory Response Strategies for Safety Culture Problems* takes this topic a step further, describing response strategies available to regulatory organisations in addressing safety culture problems based on a simple model.

In this model, it is assumed that the early signs of safety problems may be ambiguous, but nonetheless may justify enhanced regulatory attention. If the problems persist, perhaps growing more frequent and more risk-significant, a follow-on response will be called for. Finally, if the root causes are not corrected, and clear operational safety problems are evident, the regulator will have to increase the level of intervention. Regulatory intervention in this context means action requiring the operator to take steps to improve specific performance problems – steps that the operator probably would not take without intervention by the regulator. Each of these steps is discussed in this publication.

Both of these reports illustrate that the regulator has to use careful judgement in diagnosing the root causes of apparent declining performance and in finding the appropriate threshold for regulatory intervention. If intervention occurs too early, the operator may not agree on the nature and extent of the problems, or the regulator may pre-empt operator initiatives to resolve his own problems. However, if intervention occurs too late, the threat of declining performance may not be arrested before serious safety problems become evident. In any case, the regulatory body need not wait for obvious signs of performance problems before giving attention to a nuclear power plant. Regulators will have to increase their level of intervention in order to assure proper safety culture is maintained. ■

1. These publications can be obtained free of charge by sending an e-mail to nea@nea.fr.

S. Griffiths, J. Royen*

Assuring future nuclear safety competence

Irrespective of the possible future evolution of nuclear power programmes, the long-term ability to maintain safety competence within the industry and regulatory bodies will remain a crucial objective. The nature of such competence may change, but the basic principle of safety remains.

In many countries, probably as a result of the growth of nuclear power approximately 30 years ago, nuclear safety competence is predominantly vested in the same age group. As a result, the age distribution for regulators is over 40 in most NEA Member countries. In countries with active programmes, this age is slightly lower; in those where programmes are in decline, it is higher. The time is rapidly approaching when this group will be retiring. The situation is similar in the nuclear industry. Furthermore, the number of enrolments in the fields of nuclear science and engineering are decreasing rapidly in most universities and engineering schools.[1] The recruitment rate is not matching current loss rates.

Even if a nuclear power programme was to terminate in the near future, an unwavering demand for a high degree of nuclear safety competence will remain for at least one more generation. To address the safety implications there will be a need for continued:

- maintenance of a "living" (regularly updated) safety case;
- safety of operating installations;
- safe decommissioning of nuclear installations;
- safe spent fuel and radioactive waste management.

These issues have implications not only for nuclear industry at large, but also for governments in maintaining an infrastructure to assure safety into the future. Governments – and industry – will have to take action, quickly, to continue to be able to fulfil their responsibilities. Programmes to initiate knowledge transfer to the next generation, suitable research and relevant competence renovation must be started as early as possible.

Workshop on "Assuring nuclear safety competence into the 21st century"

In a report on new future regulatory challenges published in 1999, the NEA Committee on Nuclear Regulatory Activities (CNRA) identified the human element "*as one of the most critical aspects of maintaining regulatory effectiveness, efficiency and quality of work*". There was consensus that "*Quality organisations require well-educated, well-trained and well-motivated staff. In some countries, national R&D programmes are being reduced to such a point that forming an independent regulatory position might be in jeopardy. If a significant problem occurred over the next ten years, there might not be sufficient knowledge and capability to deal with it in a timely manner if the current trend continues.*"

As a result of these concerns the NEA organised a workshop to consider the most efficient approach to recruiting, training and retaining safety staff, and preserving a critical mass of

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knowledge, both within industry and regulatory bodies. The meeting was hosted in Budapest by the Hungarian Atomic Energy Authority in October 1999.

Key areas of concern

Four key areas of concern were identified during the workshop:

- There are no new nuclear plants being built in the majority of countries.
- There is a lack of vitality in research.
- The nuclear industry is considered to be unattractive by potential new entrants.
- The workforce is ageing.

These issues are perceived differently in different countries, depending on the status of their nuclear programmes. Countries still developing their nuclear programmes such as France, Japan and Korea, and, for different reasons, central and eastern European countries, have less difficulty with recruitment to regulatory bodies and the industry. A strong government confidence in nuclear power tends to lead to a more favourable perception of this form of energy amongst the public, which facilitates the ability to preserve competence. At the other end of the scale, countries where nuclear programmes will be coming to an end in the next few years, with no prospect of extension, face increasing difficulty in maintaining competence. In the latter case there is a danger that once lost, the competence will not be recovered. Whilst these positions represent the extremes of the current situation, they show how different national attitudes and policies towards nuclear development will significantly influence the perspective of the problem.

Political factors also play an important part, as do public perceptions and the extent of opposition from pressure groups. These factors impact perceptions of young people, though again this varies greatly from country to country.

New areas of research are opening up and research is still being maintained in areas such as materials science and corrosion. Some research fields are directly transferable from other industry sectors; however, the traditional areas of research in nuclear fields such as reactor physics are declining. This is also true for several areas of safety research: large thermal-hydraulic facilities are being shut down and severe accident research programmes are being reduced or cut. These factors have a significant immediate impact on universities and education and on national laboratories. If the teaching and research facilities cannot be maintained then educational programmes will gradually close. Similarly, as people retire, the competence available to operate university-linked research facilities disappears. Both of these factors have a significant impact on the ability to transfer knowledge to future generations.

The factors discussed above are intimately linked. Teaching and research are required in order to provide the right sort of staff for the industry. However, teaching and research must be accompanied by on-the-job training and employment possibilities. There is also the need to regenerate lost academic teaching capability. Industry has a greater chance of recovering quickly as it may be able to recruit from the labour market; however, in academia, the time scales are much longer. Once lost there will be a substantial time lag before recovery of a specific level of competence is achieved. The time to recover will vary. Figure 1 provides a conceptual illustration of the time needed to develop competence, based on workshop deliberations.

Deregulation of the energy industry and liberalisation of the electricity market (often also called deregulation) are having a significant impact and will greatly add to the pressures to reduce staff. Paradoxically, there are preliminary signs that electricity market deregulation may require a stronger and more effective nuclear regulator (e.g. regulators need to say what is safe in terms of staffing for the long term). In the future this may place greater demands on regulators to examine in more detail organisational management issues and their impact on safety.

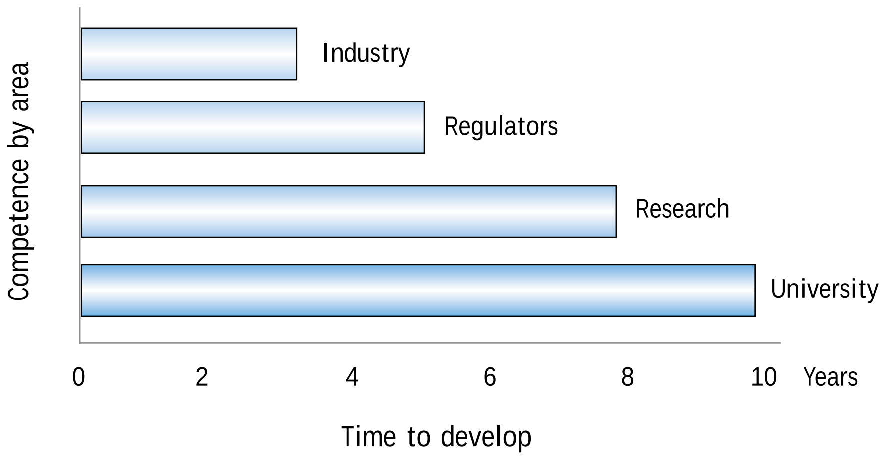
Trends regarding the need for future competencies

Common views expressed by the countries participating in the workshop have been identified, as well as trends regarding the need for future competencies.

Academic

There is a trend of undergraduate programmes in nuclear fields declining in most countries. Nuclear departments have been merged or eliminated. University teaching programmes have been broadened, masking the impact of the reduction in student numbers. As programmes close there is

Figure 1. Time required to develop competence in particular areas



less research support available to the industry, which further reduces the potential for attracting students and funding. Additionally, educators are ageing and, as they retire, further limitations appear in terms of availability of teaching courses and research programmes. In some countries, support for universities is in place to try to maintain key competencies and there are initiatives to look at human resource plans and better target competence requirements.

Future power programmes

The choices for future power programmes, and indeed existing programmes, depend on the status of available natural resources, and on economic and political considerations. There is an active lobby by anti-nuclear groups, but there appears to be an increasing awareness of CO_2 issues post-Kyoto. This provides both a threat and an opportunity. Some opponents are becoming far more sophisticated and use international pressure groups to disseminate their message. Regulators need to become more skilful communicators, and perhaps more aware of international interactions and collaboration.

Privatisation

Privatisation trends are increasing as the large state-run monopolies are broken up. The nature of the operators is changing. Their obligations are wider and they need to be confident and competent in their responsibilities and duties. There is a need for them to ensure that they have the right mix of skills for both today's technology and that of the future. This represents a challenge for the regulator and industry.

New challenges

New technological and intellectual challenges are providing attractive areas for work. Whilst these challenges tend to be short-term projects, they do help boost new recruitment with the opportunity for knowledge transfer and refreshment of present staff not only in terms of the age profile but also in motivation.

Plant life extension is of increasing interest to operators worldwide, particularly where there is no new construction foreseen. There is a range of economic and political reasons in each country which substantiate this interest. It calls for increased effort on living safety cases and relicensing, as well as on research capability to examine ageing issues. These aspects will require resources into the future.

An increasing number of plants will move into the decommissioning phase, shifting effort onto decommissioning activities, long-term storage, waste disposal, etc. This shift will require research and manpower to carry out decommissioning programmes. There will be a consequent impact on regulators and utilities.

A number of countries can be considered as exporters of design and expertise. However, as they are no longer designing new plants, the expertise could disappear while their indirect responsibility – or, at least, their direct interest – in maintaining or improving safety in importing countries will remain. Purchasers of existing technologies may have to become self-sufficient or buy services. The distinction between exporting and importing countries is becoming blurred.

Nuclear research

There is concern about the decreasing level of nuclear safety research resources. Some of the reasons are:

- Residual concerns remain regarding the safety of nuclear power plants and there is potential for further improvement.
- One needs to be able to address emerging safety issues, and to anticipate future problems of potential significance.
- Safety research contributes to establishing the independence of the regulator.
- Research attracts the most brilliant students and experts, and thus contributes strongly to the maintenance of nuclear safety competence.

Safety research can be the catalyst for dynamic and attractive education programmes as well as co-operation between industry and education, particularly as the nature of work changes and job mobility based on projects becomes more accepted.

International co-operation

International co-operation is increasing and globalisation is occuring at all levels. There is international liaison among plant operators (INPO, WANO). Regulators are co-operating increasingly. Problems are global, but mechanisms for solutions are being put in place. New skills are needed to take full advantage of emerging opportunities and to maximise areas of co-operation.

Use of the legal system

There is an increasing trend to look to the courts to settle issues, at the national level and between the regulator and the industry. Technical experts are being challenged more and more in a context of increasing distrust, leading to the need for a range of new, softer management skills for the regulator and the industry in addition to their technical skills. The problem is exacerbated by the decreasing number of technical experts available.

Economics

Increased liberalisation and pressure to cut costs are giving rise to requests for higher efficiencies from plants through extended operating cycles or reduced outage times. This will impact the regulatory role and create new pressure.

Wider challenges

Economics is not the only challenge. Increasingly there is concern over significant climate change due to the burning of fossil fuels, and over sustainable development constraints. Security of supply is another consideration. The regulator and the industry will need to have the right skills to meet these challenges.

Recommendations and actions

A number of common threads and themes, including short-term and long-term challenges, emerged at the Budapest workshop.[2] Several recommendations were made, some of them fairly specific and targeted. An action plan is being developed by the CNRA. One of the fundamental issues is to identify the competencies that are actually required. This identification provides a baseline for assessing current adequacy and investigating future needs. Several speakers mentioned the need for co-operation between education and research facilities, support for staff interchange and the pooling of resources. Nuclear expertise is ageing and there is a need to pass on knowledge. Modern communication techniques can assist (for example there is scope for utilising the worldwide web to disseminate knowledge). Better use should be made of young generation networks. An ad hoc task group will discuss these issues further, examine the recommendations, and develop them into an action plan. There is a clear need for a long-term strategic view to be taken in this area. The proceedings of the workshop will be published shortly.

Notes

1. For further details, see the article entitled “Nuclear education and training: Cause for concern?”.
2. Workshop on *Assuring Nuclear Safety Competence into the 21st Century: Budapest, Hungary, 12-14 October 1999, Summary and Conclusions*, NEA/CNRA/R(2000)1.

P. Lalieux, C. Pescatore, P. Smith*

Preliminary lessons from GEOTRAP

GEOTRAP is the NEA Project on Radionuclide Migration in Geological, Heterogeneous Media. In the framework of previous NEA initiatives[1,2] related to the analysis of the radiological impact and long-term safety of underground repository systems for high-level and/or long-lived radioactive waste, the following issues concerning the assessment of radionuclide transport in actual geological media have been considered the most important and provide the key challenges:

- the characterisation of the geological variability in the field;
- the theoretical and computational analysis of its impact on the prediction of flow and transport for the space and time scales of relevance in deep repository safety assessment;
- the extent to which site characterisation can provide site-specific data to build confidence that the required functions of the geosphere (in particular, the transport barrier function) will be realised; and
- the full evaluation of the potential errors and uncertainties associated with the use, in most safety assessments, of very simplified and/or idealised models of radionuclide transport in the geosphere.

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A more general observation from these projects is that there is a need to foster, both at national and international levels, co-ordination and exchange of information between disposal site characterisation and safety assessment. It is necessary to ensure i) that safety assessments properly take account of the data gathering, data interpretation, geological understanding, and first level of modelling that are carried out as part of any site-characterisation programme, and ii) that future phases of site characterisation can benefit from guidance from the findings of safety assessment.

Aims and structure of the project

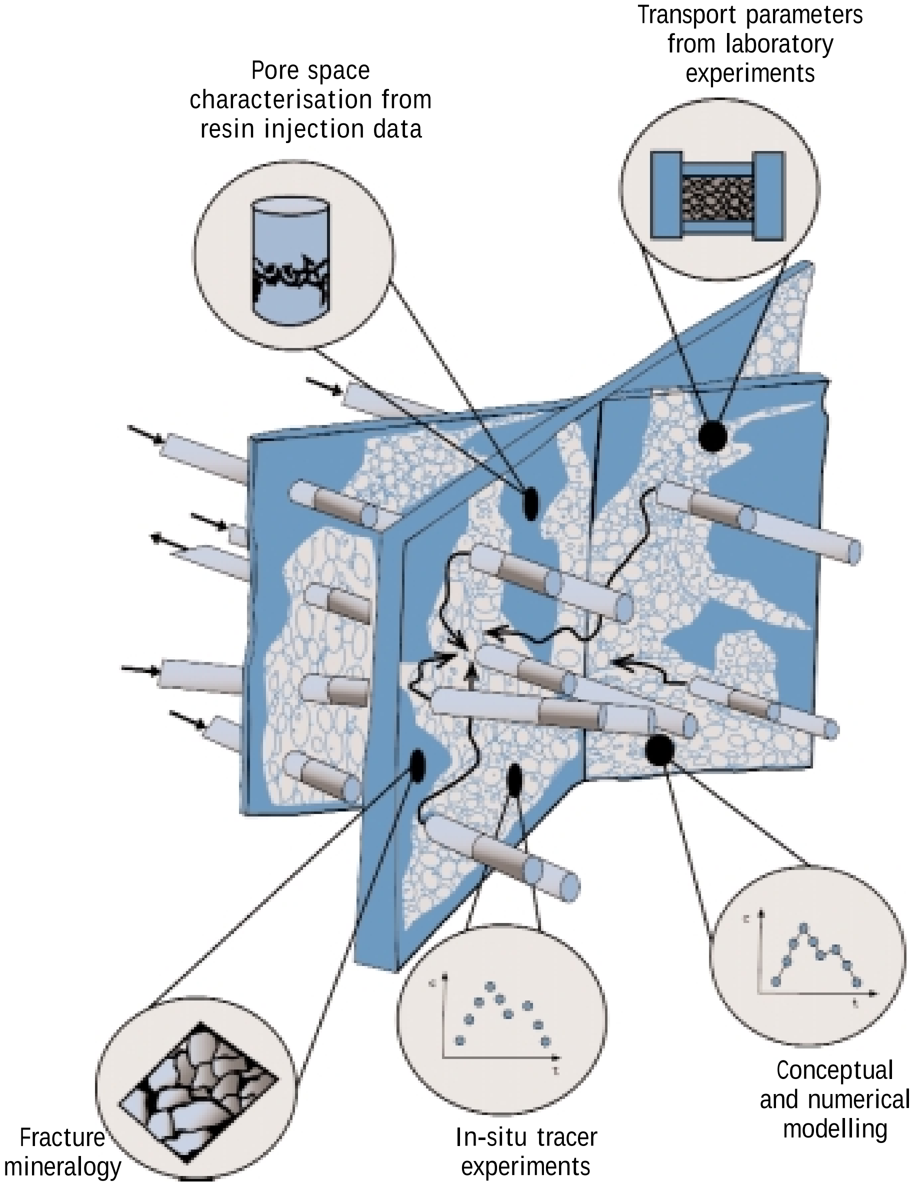
The GEOTRAP project is devoted to current approaches to acquiring field data, and testing and modelling flow and transport of radionuclides in actual (and therefore heterogeneous) geological formations for the purpose of site characterisation and safety assessment of deep repository systems for long-lived radioactive waste.

The project is articulated in a series of structured, forum-style workshops. The NEA documents the workshop by publishing proceedings which are complemented by a synthesis of the main outcomes and recommendations of each workshop.

The first four GEOTRAP workshops, respectively, addressed topics related to the:

- roles of field tracer experiments in the prediction of radionuclide migration[3];
- modelling of the effects of spatial (natural) variability[4];
- characterisation and representation of water-conducting features[5];

General scheme of the TRUE experiment at the Äspö laboratory in Sweden



SKB, Sweden

- confidence in models of radionuclide transport for site-specific performance assessment[6].

A fifth workshop, to be held in September 2000, will address the geological evidence and theoretical bases for radionuclide retention in heterogeneous, geological media.

Over 40 organisations – implementing waste management agencies ("implementers"), nuclear regulatory authorities ("regulators"), nuclear research institutes, universities, scientific consulting companies and the European Commission – are represented in the GEOTRAP project. The experimental and modelling work carried out under their auspices are the heart of the project.

Technical observations and recommendations

Up to now, the project has given rise to a number of technical observations and recommendations regarding the characterisation of heterogeneity (in particular, of water-conducting features) of geological media, as well as transport modelling (notably the development of models and confidence in the latter).

In the course of the presentations and discussions at the workshops, several additional observations and recommendations have been made that go beyond the scope of GEOTRAP itself and relate to wider issues of repository planning, implementation and regulation:

- Interaction between those involved in site characterisation and those involved in safety assessment is essential for efficient use of resources in repository development, as is clear communication between the implementing and regulatory organisations. More formal procedures may be needed to ensure that such interaction occurs. In particular, a regular exchange of views between regulators and implementers should be promoted in order to ensure clear communication on issues related to the characterisation and model representation of geological media.
- Communication between specialists can be hindered by problems related to terminology. These problems need to be addressed more formally, both to assist the work of specialists and to facilitate the transfer of confidence to external scientific audiences.
- There are significant benefits to be obtained by looking beyond the field of radioactive waste management, drawing on the knowledge of specialists in other fields of science and engineering.
- Since it may not be possible to retain key individuals for the life of a repository project, a process must be established for transferring working knowledge to new individuals.

Conclusions

Overall, the GEOTRAP workshops confirmed that a multidisciplinary approach is necessary in order to address more fully the issues relevant to transport modelling in a heterogeneous geological medium, in which coupled and, possibly, non-linear processes operate. Effective communication between the different groups involved is therefore essential.

Despite the difference in host rock, concepts and terminology, the GEOTRAP workshop series has been successful in developing a constructive dialogue between experimental scientists and modellers. In addition, both implementers and regulators have participated actively in the project. The project is thus helping bridge the gap between data acquired *in situ* and their uses for performance and safety assessment purposes.

The workshops have highlighted significant advances in the achievement of a depth of understanding in relation to geosphere heterogeneity and, in particular, water-conducting features, that is required for performance assessment modelling and for the compilation of a repository safety case that has defensibility and credibility. A depth of understanding implies the use of wide-ranging information to support the decisions that underlie transport-model calculations, even if not all of this information is incorporated directly in the models. Specific advances have, for example, been noted in the integration of methods used to characterise heterogeneity, over a wide range of scales, and in the incorporation of a wide range of qualitative data to constrain uncertainties in characterisation and to build an overall geological understanding of a site. Furthermore, external peer review, at all stages of a project, has an important role to play.

In spite of the efforts of the programme committees to achieve wide-ranging discussions, encompassing all aspects of geosphere transport, discussions at the GEOTRAP workshops have centred predominantly on the characterisation of hydraulic properties and on their representation in flow models. It is concluded that this reflects the weighting of current work internationally, and the relative maturity of hydraulic-characterisation techniques and flow models.

References

1. NEA/SKI (1996), *The International INTRAVAL Project – Final Results*, OECD, Paris.
2. NEA (1997), *Lessons Learnt from Ten Performance Assessment Studies*, OECD, Paris.
3. NEA/EC (1997), *Field Tracer Experiments: Role in the Prediction of Radionuclide Migration, Proceedings of the 1st GEOTRAP Workshop, Cologne, Germany, 28-30 August 1996*, OECD, Paris.
4. NEA (1998), *Modelling the Effects of Spatial Variability on Radionuclide Migration, Proceedings of the 2nd GEOTRAP Workshop, Paris, France, 9-11 June 1997*, OECD, Paris.
5. NEA (1999), *Water-conducting Features in Radionuclide Migration, Proceedings of the 3rd GEOTRAP Workshop, Barcelona, Spain, 10-12 June 1998*, OECD, Paris.
6. NEA (in preparation), *Confidence in Models of Radionuclide Transport for Site-Specific Performance Assessment, Proceedings of the 4th GEOTRAP Workshop, Carlsbad, New Mexico, United States, 14-18 June 1999*, OECD, Paris.

B-C. Na, C. Nordborg*

Recent improvements in reactor dosimetry calculations

With an increasing number of nuclear power reactors worldwide approaching the end of their design lives, decisions must be taken with regard to final shutdown or possible plant life extension. Accurately characterising the structural integrity of reactor components is of highest importance if correct decisions are to be taken regarding the validity of a reactor design over time, safety margins, and potential plant lifetime extension, and to avoid judgements that might lead to shutting down prematurely nuclear power plants that are still operational. This issue is thus important for both safety and economic reasons.

As many commercial light water reactors begin to approach the end of their licensed life spans of 30-40 years, nuclear utilities have started to investigate the possibility of extending their operating lives. Longer reactor operating times mean higher neutron and gamma fluence levels and hence smaller safety margins, in view of which reactor utilities/owners and regulators need to be able to ensure the continued integrity of reactor components and reduce still further the uncertainties in fluence estimation procedures. Because of the importance of this issue, the NEA Nuclear Science Committee set up a Task Force on the Computing of Radiation Dose and the Modelling of Radiation-induced Degradation of Reactor Components. The Task Force reviewed the computational techniques used in NEA Member countries to calculate neutron and gamma doses to reactor components. This work was then followed up by two benchmark exercises to verify the statements in the final report of the Task Force.

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Computing radiation dose in NEA Member countries

Even though the computational schemes for evaluating fast neutron fluence in the reactor pressure vessel (RPV) and reactor cavity are well-established, there are a number of uncertainties associated with the calculations. They are numerical approximations (quadrature sets, scattering cross-section expansion, spatial and energetic meshes, etc.), modelling approximations (capsule placement, RPV thickness variations, cavity streaming, 3D flux synthesis, peripheral subassembly source distribution, dimension and material uncertainties) and finally nuclear data uncertainties (transport cross-sections, dosimeter response cross-sections, fission spectrum, etc.). Recent studies have identified the needs for further improvements with respect to these uncertainties.

The NEA report on "Computing Radiation Dose to Reactor Pressure Vessel (RPV) and Internals"[1] provides a detailed overview of the computational methodologies currently used in the dosimetry programmes of NEA Member countries. Table 1 presents the different levels of precision reported for RPV dosimetry calculations in different NEA Member countries and information about the computational tools and data used.

Table 1. Levels of precision reported for RPV dosimetry calculations

Country	Uncertainty in fluence calculations	
Belgium	VENUS experimental results	<10%
	global uncertainties	<20%
	TIHANGE-2	
	unadjusted	<20%
	adjusted	4%
Finland	Loviisa VVER-440	
	Surveillance specimens	
	Fluence E>1 MeV	11%
	DPA and fluence E>0.5 MeV	13%
	Pressure vessel	20-25%
France	EDF power reactors RPV	
	Uncertainty in fluence E>1 MeV	12%
Germany	Siemens-KWU (general)	
	C/E* unadjusted	~20%
Japan	JMTR research reactor	
	Fluence E>1 MeV	~20%
	Thermal fluence	~40%
Korea	KORI 4	
	C/E	~23%
	Fluence E>1 MeV	15%
Netherlands	HOR research reactor	
	Fluence E>1 MeV	<15%
Sweden	General method	
	Fluence E>1 MeV	2-25%
Switzerland	Inner surface of PWR vessel	
	Fluence E>1 MeV	<15%
	Experimental uncertainty	10%
United Kingdom	Magnox reactors	
	Fast flux	0-35%
United States	Standard methods for LWR	
	Typical in-vessel E>1 MeV	<20%
	ex-vessel E>1 MeV	30%

*C/E: Ratio between calculated and experimental values.

Although the median of results reported in national calculations appears to have a precision of about 20% compared to measurements, significantly higher and lower values are also reported. The numbers reported are difficult to compare, since each country has its own methodology including different reactor types, computer codes, nuclear data sets and measurement procedures. Moreover, the accuracy of the analysis of one reactor system is often not valid for another system. Following this state-of-the-art report, the remaining questions are therefore:

- What is the current international level of accuracy in the pressure vessel calculations?
- What are the relative merits of various methodologies?

VENUS-1 and VENUS-3 benchmarks

As a follow-up to the NEA report, an international blind intercomparison exercise was launched to lead to consensus on:

- the level of accuracy of methods currently used in NEA Member countries in calculating radiation dose to reactor components;

- the relative merits of different calculation methods;
- possible improvement of these methods.

Specifications

For this purpose, two well-defined benchmark experiments VENUS-1 (two-dimensional geometry) and VENUS-3 (three-dimensional geometry) were chosen. The VENUS facility at SCK•CEN, Mol in Belgium represents a detailed mock-up of the outer core region and the pressure vessel internals of a Westinghouse three-loop reactor. Various computer codes using both the deterministic S_N and Monte Carlo methods were applied including the latest versions available. The transport cross-sections were based on ENDF/B-VI or JEF2.2, and dosimetry data based on IRDF-90 Version 2 or taken from the BUGLE-96 library. For comparing with measured data, equivalent fission fluxes of five different reactions [^{58}Ni(n,p), ^{115}In(n,n'), ^{103}Rh(n,n'), ^{238}U(n,f) and ^{237}Np(n,f)] in 34 positions at the core mid-plane were calculated in the VENUS-1 benchmark, and equivalent fission fluxes of three threshold reactions [^{58}Ni(n,p), ^{115}In(n,n') and ^{27}Al(n,α)] in 344 positions were calculated in the three-dimensional VENUS-3 configuration. Moreover, a comparison was made for theoretical quantities such as fast neutron fluxes above 1 MeV and above 0.1 MeV, as well as atomic displacement rates. All calculated equivalent fission fluxes were related to the measured values.

VENUS-1 results

The two-dimensional VENUS-1 benchmark calculations made it possible to clarify the capabilities and limits of two-dimensional neutron transport calculations. Over the past 20 years, two-dimensional transport calculations with corresponding synthesis methods have been the principal method used to determine the fast neutron fluence responsible for the neutron embrittlement of reactor pressure vessel walls. A relative difference between measurement and calculation of ±20% was observed, mainly due to the diffusion-based axial buckling correction. This was shown by about 20 independent calculations contributed to the VENUS–1 benchmark from around the world.

In determining the fast neutron fluence in the pressure vessel of large power reactors, the influence of the axial buckling correction is evidently smaller than in the VENUS-1 benchmark. However, in two-dimensional calculations, there still remains a problem in the treatment of axial core power variation. Furthermore, the axial coolant density changes in the reactor core have to be properly approximated (even more important in the case of boiling water reactors).

VENUS-3 results

In the three-dimensional VENUS-3 benchmark, the latest versions of three-dimensional transport codes such as TORT, PENTRAN and MCNP were validated in 14 contributed solutions. In more than 200 positions of threshold detectors the difference between measurement and calculation amounted to ±10%. This can be reached by three-dimensional routine calculations, even with a "few-group" data library such as BUGLE-96. As a typical example, the ratios between calculated and experimental values (C/E) of equivalent fission fluxes at indium detector positions in VENUS-3 are shown in Figure 1.

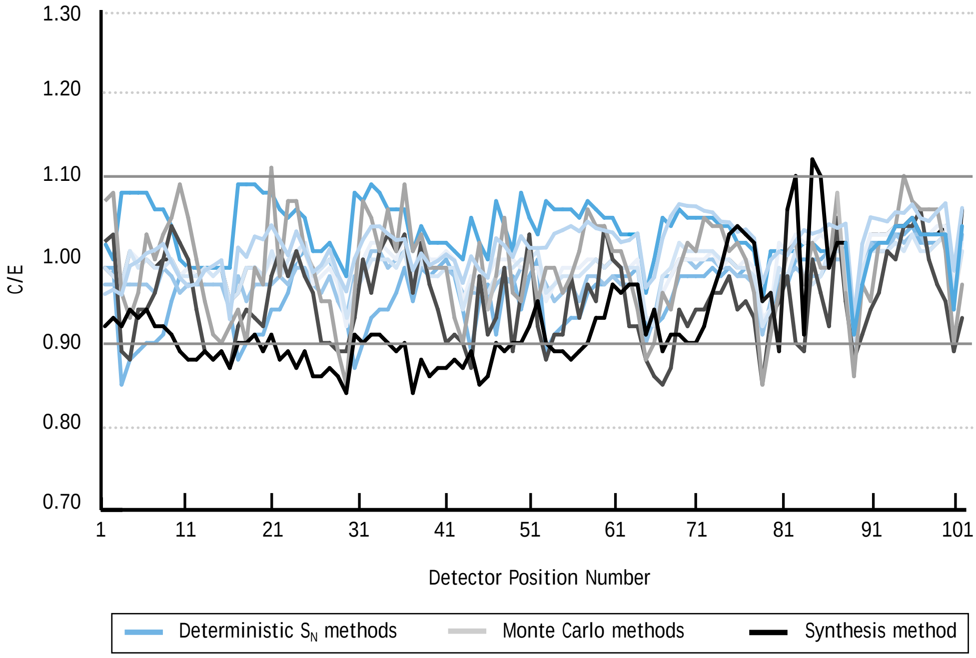
In the deterministic calculation results, except in a few positions where all calculations demonstrate a common underestimation (systematic errors of measurement), a scatter band of ±10% with relatively coarse spatial and energetic meshes, and better than ±5% with finer spatial and energetic meshes, were observed. Two Monte Carlo calculations and an improved synthesis method based on 1D/2D deterministic S_N calculations showed a scatter band of ±10%.

Summary of results

As a result of major advances in hardware and software development, it is now possible to carry out three-dimensional calculations with deterministic S_N codes for neutron fluence calculations in detailed energy group structures, e.g. VITAMIN-J (175 groups) or EURLIB (100 groups). In 77% of all detector positions in VENUS-3, the agreement between high-precision calculations and measurements was improved to better than ±5%, the figure quoted for the overall uncertainty of experimental results. The main finding is that the calculated results of the three-dimensional benchmark VENUS-3 are, in general, much closer to the experimental values than those of the two-dimensional benchmark VENUS-1. The powerful computers now available can easily perform full three-dimesional neutron fluence calculations, the results of which are significantly more accurate than those obtained from two-dimensional calculations. The detailed results of both benchmarks can be found in the NEA publication *Prediction of Neutron Embrittlement in the Reactor Pressure Vessel: VENUS-1 and VENUS-3 Benchmarks*[2].

After having performed a detailed analysis of the results of the two benchmark exercises, an

Figure 1. Ratios between calculated and experimental values of equivalent fission fluxes at indium detector positions in VENUS-3



international consensus was achieved on the current accuracy level of pressure vessel fluence prediction and the relative merits of different calculation methodologies.

Further studies needed

Although significant progress has been made in dosimetry calculations, further improvements are still needed. One of the biggest problems of current reactor dosimetry is to translate the computed fluences into metal damage. Basic physics models of material degradation, and estimated fluences, which aim to assess metal damage, often yields results of limited confidence. Generally only neutrons with energies above a certain threshold energy (e.g. 1 MeV) are considered to contribute to metal damage, but this threshold energy is different from country to country and between reactor types. Other parameters such as DPA (displacement per atom) and PKA (primary knock-on atom) are also introduced. However, there is still controversy with regard to damage parameters which are used to translate the computed fluence into metal damage. To make headway in this area, the NEA will establish a database containing experimental and theoretical data of displacement effects in irradiated materials. The database will cover data for both low and intermediate energy induced particles. These will later be used as a basis for the modelling of radiation damage in materials.

For some reactors, in which high thermal fluxes exist, thermal dosimetry is of importance. It is desirable to study the importance and magnitude of errors in thermal fluence estimation on metal degradation combined with that of fast fluence in, for example, D_2O reactors. In general, the uncertainty of computations in the thermal energy range is larger than in the fast energy range.

Gamma-ray dosimetry is clearly less well-established than neutron dosimetry. This effect becomes important for boiling water reactors or research reactors in which gamma flux levels are higher. Further validation of gamma transport codes, nuclear data, and gamma-metal interaction models for estimating metal damage will be needed.

Note

1. *Computing Radiation Dose to Rector Pressure Vessel and Internals* [NEA/NSC/DOC(96)5] is available free of charge by writing to the NEA (please indicate an e-mail address for electronic delivery).
2. *Neutron Embrittlement in the Reactor Pressure Vessel: VENUS-1 and VENUS-3 Benchmarks* can be ordered from the OECD Online Bookshop at www.oecd.org/publications/.

News briefs

Wrapping up Y2K

The Nuclear Energy Agency (NEA) had a comprehensive Y2K programme during the past three years as did a number of other organisations. Much of the NEA effort was led by its Committee on Nuclear Regulatory Activities (CNRA), a senior group of nuclear regulators. The CNRA programme included workshops, a network of experts that exchanged information via an electronic “mailbox”, and a Y2K Early Warning System (YEWS). This comprehensive and successful programme showed how nuclear regulators, nuclear plant operators and governments from both NEA Member countries and non-member countries could work together to achieve a common goal.

The key aspect of the programme was YEWS, a worldwide information exchange system set up between nuclear regulators, nuclear plant operators and governments, to provide timely accounting of the status of nuclear facilities during the transition to the new millennium. YEWS was developed by the US Nuclear Regulatory Commission as a secure, proprietary, Internet-based communications system and was given its international dimension by the NEA. Participation in YEWS was open to all countries, including non-NEA members.

The system, which commenced operation on 30 December 1999, monitored and exchanged nearly real-time Y2K information on nuclear facilities operations, receiving reports from some 300 nuclear facilities in 29 different countries. Average reporting time was 20 to 30 minutes following the date change in the respective time zones of each country. Over 38 countries and approximately 500 regulators and licensees took part in YEWS. The web site received over 100 000 visits and document requests between 30 December 1999 and 1 January 2000.

A total of 14 incidents, unrelated to safety, were reported during the first 24 hours of the rollover. It remains unclear, however, whether these problems were Y2K-related. YEWS continued to operate in a slightly modified version until 10 March 2000 as a precaution against minor follow-on degradation problems.

Following the successful operation of the Y2K Early Warning System over the millennium period, many participants noted that such a system for exchanging information about nuclear incidents would be extremely beneficial in the longer term. A similar, secure, proprietary, Internet-based communications system that allows for rapid transmission of information on the status of nuclear facility operations during nuclear incidents could provide a good foundation for establishing a Nuclear Emergency Warning System (NEWS). The main objective of NEWS would similarly be to provide a rapid, worldwide communication system to exchange information among national experts (regulators, operators and technical support organisations in particular) on nuclear incidents. Consensus on pursuing this proposal was reached at discussions held by the responsible bodies at the NEA, the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO).

NEWS would not replace existing reporting systems, but would supplement them by providing a lower reporting threshold than currently exists for emergency notification systems. Additionally, NEWS would not be limited to radiological incidents.

It is foreseen that, in general, NEWS would be used for any event or incident associated with radioactive material and/or radiation, and for any event or incident occurring during the transport of radioactive material. Industrial events or incidents that relate to or affect nuclear or radiological operations and are likely to attract media attention should also be included. As such, appropriate links would need to be made between NEWS and the international nuclear events scale (INES). ■

Nuclear power in NEA countries

Situation as of 31 December 1999

At the end of 1999, the total capacity provided by the 348 reactors now installed was 296.2 gigawatts (GWe). Another 10 reactors totalling 10.3 GWe were under construction and two reactors totalling 2.1 GWe were firmly committed. The total capacity of nuclear power plants in NEA countries in the year 2005 and 2010 is projected to be about 309.7 and 313.5 GWe respectively. The 8.3 GWe of capacity that is expected to be retired by the year 2005 is already deducted from these projections.

	1999 (Actual)		2000		2005		2010	
NEA Country	Net GWe	%	Net GWe	%	Net GWe	%	Net GWe	%
Belgium	5.7	36.3	5.7	35.6	5.7	36.5	5.7	36.3
Canada	10.0*	8.6	10.0	8.3	16.0	12.4	16.0	11.6
Czech Republic	1.6	10.5	2.5	16.4	3.4	19.9	3.4	19.9
Finland	2.6	16.0	2.6	15.8	2.6	15.6	2.6	15.6
France	63.2*	55.9	63.2	55.9	63.0	54.8	63.0	53.8
Germany	22.3*	23.5	22.3	23.0	22.3	21.4	22.0	21.0
Hungary	1.8	23.7	1.8	23.7	1.8	22.7	1.8	21.2
Japan***	43.5	19.8	43.5**	19.5	54.1**	22.9	63.5	25.2
Korea	13.7	29.1	13.7	28.0	17.7	28.1	22.5	30.2
Mexico	1.4	3.9	1.4	3.8	1.4	2.8	1.4	1.8
Netherlands	0.5	2.3	0.5	2.4	0.0	0.0	0.0	0.0
Spain	7.4*	14.4	7.4	14.9	7.4	14.4	7.3	13.8
Sweden	9.5	30.4	9.5	28.6	8.9	26.6	8.9	25.9
Switzerland	3.1	18.5	3.2	18.8	3.2	18.5	3.2	17.9
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.2
United Kingdom	13.0*	17.6	12.1**	14.9	9.3**	10.9	7.0**	8.2
United States	97.0*	12.2	97.0	12.1	93.0	10.8	84.0	9.1
NEA Total	**296.2**	**15.3**	**296.3**	**15.1**	**309.7**	**14.6**	**313.5**	**13.7**

	Connected to the grid		Under construction		Firmly committed		Planned	
NEA Country	Units	Net GWe	Units	Net GWe	Units	Net GWe	Units	Net GWe
Belgium	7	5.7	0	0.0	0	0.0	0	0.0
Canada	14	10.0	0	0.0	0	0.0	0	0.0
Czech Republic	4	1.6	2	1.8	0	0.0	0	0.0
Finland	4	2.6	0	0.0	0	0.0	0	0.0
France	59	63.2	0	0.0	0	0.0	0	0.0
Germany	20	22.3	0	0.0	0	0.0	0	0.0
Hungary	4	1.8	0	0.0	0	0.0	0	0.0
Japan***	53	43.5	4	4.5	2	2.1	13	13.7
Korea	16	13.7	4	4.0	0	0.0	8	9.6
Mexico	2	1.4	0	0.0	0	0.0	0	0.0
Netherlands	1	0.5	0	0.0	0	0.0	0	0.0
Spain	9	7.4	0	0.0	0	0.0	0	0.0
Sweden	11	9.5	0	0.0	0	0.0	0	0.0
Switzerland	5	3.1	0	0.0	0	0.0	0	0.0
Turkey	0	0.0	0	0.0	0	0.0	2	2.6
United Kingdom	35	13.0	0	0.0	0	0.0	0	0.0
United States	104	97.0	0	0.0	0	0.0	0	0.0
NEA Total	**348**	**296.2**	**10**	**10.3**	**2**	**2.1**	**23**	**25.9**

* Provisional data. ** Estimate established by the NEA Secretariat. *** Gross capacity data converted to net by the NEA Secretariat.

New publications

General interest and economic issues

Nuclear Energy Data – 2000

ISBN 92-64-05913-X – 47 pages – Price: FF 130, US$ 20, DM 39, £ 12, ¥ 2 050.

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

Methodologies for Assessing the Economic Consequences of Nuclear Reactor Accidents

ISBN 92-64-17658-6 – 112 pages – Price: FF 200, US$ 31, DM 60, £ 19, ¥ 3 250.

For practical reasons, the consequences of nuclear reactor accidents are often measured in economic terms. Figures currently available, however, show significant discrepancies. For this reason, the NEA created an expert group to investigate the methodologies used in calculating the economic consequences of accidents, and the bases for such methodologies. Calculation methods were assessed according to three end uses: for compensation and liability purposes; for accident preparedness and management purposes; and for making electricity-generation choices. The group concluded that comparing numerical results is very difficult, even for estimates made from the same perspective, as they are strongly dependent on "boundary" conditions (such as the accident scenarios used, plant characteristics and amount of radioactive material released). This book provides a summary of the group's findings and will be of interest to decision makers, experts and accident-consequence modellers.

Reduction of Capital Costs of Nuclear Power Plants

ISBN 92-64-17144-4 – 105 pages – Price: FF 240, US$ 38, DM 72, £ 24, ¥ 4 400.

The competitiveness of nuclear power plants depends largely on their capital costs that represent some 60 per cent of their total generation costs. Reviewing and analysing ways and means to reduce capital costs of nuclear power plants are essential to enhance the economic viability of the nuclear option. The report is based upon cost information and data provided by experts from NEA Member countries. It investigates the efficiency of alternative methods for reducing capital costs of nuclear units. It will provide stakeholders from the industry and governmental agencies with relevant elements in support of policy making.

Monitoring and Data Management Strategies for Nuclear Emergencies

ISBN 92-64-17168-1 – 96 pages – Price: FF 160, US$ 26, DM 48, £ 16, ¥ 2 850.

Since the accident at Chernobyl in 1986, many countries have intensified their efforts in nuclear emergency planning, preparedness and management. Experience from the NEA nuclear emergency exercises (INEX 1 and INEX 2) indicated a need to improve the international system of communication and information in case of a radiological emergency. To address this need, research was carried out by three NEA working groups, the findings of which are synthesised in the present report. This report defines emergency monitoring and modelling needs, and proposes strategies which will assist decision makers by improving the selection of data that is transmitted, and the way in which data and information are transmitted and received. Modern communication methods, such as the Internet, are a key part of the strategies described.

Radiation protection

Radiological Impacts of Spent Nuclear Fuel Management Options

A Comparative Study

ISBN 92-64-176578 – 122 pages – Price: FF 215, US$ 32, DM 64, £ 20, ¥ 3 400.

Given its potential significance for public health and the environment, the impact of radioactive releases during important steps of nuclear energy production must be considered when selecting among different fuel cycles. With this in mind, the OECD Nuclear Energy Agency (NEA) has undertaken a comparative study of the radiological impacts of two main fuel cycle options: one with and one without reprocessing of spent nuclear fuel. The study compares the respective impacts of the two options based on generic models and assumptions as well as actual data. It concludes that the difference between them is not significant. A wealth of recent data assembled and evaluated by an international expert team is provided in annex.

Radioactive waste management

Geologic Disposal of Radioactive Waste

Review of Developments in the Last Decade

ISBN 92-64-17194-0 – 104 pages – Price: FF 190, US$ 31, DM 57, £ 19, ¥ 3 300.

The concept of removing long-lived radioactive wastes from the human environment by disposal in deep geologic repositories was developed several decades ago. In the intervening years, research efforts worldwide have increased our knowledge and understanding of how underground disposal systems will function over very long periods of time. Significant progress has also been made towards implementation of such facilities. There have, however, been delays in the disposal programmes of several countries. This report is a review of developments in the past decade. The primary sources of information are the answers to a questionnaire provided by waste management organisations represented in the NEA Radioactive Waste Management Committee (RWMC). The latter is an international forum of senior specialists from safety authorities, waste management agencies, R&D institutions and policy-making bodies.

Regulatory Reviews of Assessments of Deep Geologic Repositories

Lessons Learnt

Bilingual – ISBN 92-64-05886-9 – 132 pages – Price: FF 210, US$ 32, DM 63, £ 20, ¥ 3 400.

Integrated performance assessments (IPAs) of radioactive waste repositories deep underground are made at different stages of repository development in order, for example, to allow full-scale implementation, to provide feedback to R&D, and to test and develop review capability. IPA studies must be acceptable to a wide range of stakeholders and are one of the bases for dialogue amongst regulators and implementers of disposal facilities. The goal of the IPAG-2 study was to examine the experience of regulatory reviews of IPAs, from both the implementer and regulator points of view. Ten implementer and seven regulatory organisations participated. This report presents the lessons learnt from their review experiences, and provides recommendations to aid future regulatory decision making.

Strategic Areas in Radioactive Waste Management

The Viewpoint and Work Orientations of the NEA Radioactive Waste Management Committee

Free: paper or web versions.

The NEA Radioactive Waste Management Committee (RWMC) is a forum of senior operators, regulators, policy makers, and senior representatives of R&D institutions in the field of radioactive waste management. The Committee assists Member countries by providing objective guidance on the solution of radioactive waste problems, and promotes safety in the short- and long-term management of radioactive waste. This report identifies some of the major challenges currently faced by national waste management programmes, and describes the strategic areas in which the RWMC should focus its efforts in future years.

Nuclear safety

Regulatory Response Strategies for Safety Culture Problems

Bilingual – ISBN 92-64-07672-7 – 25 pages – Free: paper or web versions.

Since 1998 the NEA Committee on Nuclear Regulatory Activities (CNRA) has been dealing with the issue of how a regulatory organisation can recognise early, and address safety performance problems that stem from, safety culture weaknesses. Following a report published in 1999 entitled *The Role of the Nuclear Regulator in Promoting and Evaluating Safety Culture*, this report explores regulatory response strategies for dealing with declining safety performance. It also discusses resumption of normal surveillance after a period of enhanced regulatory attention and intervention. The intended audience is primarily nuclear safety regulators, but government authorities, nuclear power plant operators and the general public may also be interested.

Nuclear Power Plant Operating Experiences from the IAEA/NEA Incident Reporting System: 1996-1999

ISBN 92-64-17671-3 – 44 pages – Free: paper or web versions.

Incident reporting has become an increasingly important aspect of the operation and regulation of all public health and safety-related industries. Diverse industries such as aeronautics, chemicals, pharmaceuticals and explosives all depend on operating experience feedback to provide lessons learned about safety. This report is intended to provide general information for senior officials in industry and government who have decision-making roles in the nuclear power industry.

Nuclear law issues

Nuclear Law Bulletin

No. 65 + Supplement (June 2000)

ISSN 0304-341X – 80 pages (+ 43 pages for the Supplement)
2000 Subscription (2 issues + supplements): FF 460, US$ 80, DM 140, £ 48, ¥ 9 550.
Single issues on sale on request.

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

Reform of Civil Nuclear Liability

Budapest Symposium 1999

Bilingual – ISBN 92-64-05885-0 – 675 pages – Price: FF 800, US$ 129, DM 239, £ 79, ¥ 13 850.

The International Symposium on the Reform of Civil Nuclear Liability, organised by the OECD Nuclear Energy Agency in co-operation with the International Atomic Energy Agency and the European Commission, was held in Budapest, Hungary, from 31 May to 3 June 1999. The event attracted over 200 participants from 50 countries, with a view to examining nuclear liability and compensation issues in the context of the recent revision of the Vienna Convention on Civil Liability for Nuclear Damage, the adoption of the Convention on Supplementary Compensation for Nuclear Damage and the current negotiations being carried out under the aegis of the OECD/NEA on the amendment of the Paris and Brussels Conventions. These proceedings reproduce all papers which were presented at the Symposium, and provide detailed records of the discussion periods.

Basic Studies on High-temperature Engineering

First Information Exchange Meeting – Paris, France, 27-29 September 1999

ISBN 92-64-17695-0 – 401 pages – Free: paper or web versions.

In response to increasing interest in high-temperature, gas-cooled reactors (HTGRs) and the need for improved knowledge of materials for nuclear applications that resist high temperatures, the NEA organised a first information exchange meeting on basic studies in the field of high-temperature engineering. The proceedings of the meeting cover studies on irradiation effects on advanced materials, safety-related behaviour of HTGRs and in-pile reactor instrumentation development. They also include recommendations for further promotion of international collaboration.

Calculations of Different Transmutation Concepts

An International Benchmark Exercise

ISBN 92-64-17638-1 – 157 pages – Free : paper or web versions.

In April 1996, the NEA Nuclear Science Committee (NSC) Expert Group on Physics Aspects of Different Transmutation Concepts launched a benchmark exercise to compare different transmutation concepts based on pressurised water reactors (PWRs), fast reactors and an accelerator-driven system. The aim was to investigate the physics of complex fuel cycles involving reprocessing of spent PWR reactor fuel and its subsequent reuse in different reactor types. The objective was also to compare the calculated activities for individual isotopes as a function of time for different plutonium and minor actinide transmutation scenarios in different reactor systems. This report gives the analysis of results of the 15 solutions provided by the participants: six for the PWRs, six for the fast reactor and three for the accelerator case. Various computer codes and nuclear data libraries were applied.

Chemical Thermodynamics of Technetium Volume 3

ISBN 0-444-50378-1 – 544 pages – Price: NLG 450, Euros 204.20, US$ 228.50.

The books in the “Chemical Thermodynamics” series provide comprehensive reviews and critical evaluations of experimental data available for the chemical thermodynamics of solid and gaseous compounds, as well as aqueous species and complexes, of selected elements of particular interest for nuclear waste storage performance assessment calculations. The objective of the reviews is to provide a set of reliable thermodynamic data that can be used to describe the behaviour of the elements reviewed under conditions relevant for radioactive waste disposal systems and various geochemical environments. Two volumes have already been published on the inorganic chemistry of uranium and americium. This third volume considers the inorganic chemistry of technetium. The data have been critically evaluated using thoroughly documented procedures, and references to the publications containing the original data are given. The reasons for the various selections are carefully documented. Data with uncertainty limits are recommended for the formation energies, enthalpies and entropies of selected aqueous complexes, solids and gaseous compounds containing technetium. The data are internally consistent and compatible with the CODATA Key Values, as well as with the data in the earlier volumes in the series. The resulting selected thermodynamic data for technetium are indispensable for nuclear waste storage programmes and academic researchers.

Published by: Elsevier. Also available:
Volume 1: Chemical Thermodynamics of Uranium, *ISBN 0-444-89381-4, Price: NLG 400, US$ 228.50.*
Volume 2: Chemical Thermodynamics of Americium, *ISBN 0-444-82281-X, Price: NLG 375 , US$ 234.50.*

Core Monitoring for Commercial Reactors

Improvements in Systems and Methods

ISBN 92-64-17659-4 – 291 pages – Price: FF 460, US$ 71, DM 137, £ 44, ¥ 7 450.

The opening of energy markets is leading to increased competition, and the nuclear power industry must adapt if it is to meet this challenge. Internationally discussions are taking place among government authorities and electric utilities and vendors on how to deal with the rapid technical development and optimisation of nuclear fuel and its utilisation under new, more aggressive fuel management strategies. Improving reactor core monitoring systems is an important part of this process. Participants in a recent NEA workshop discussed how instrumentation, methods and models used in core monitoring can be validated or, if needed, improved and further developed to provide more reliable and detailed information on local power in the core and on other parameters indirectly affecting fuel duty. This book shows how the core monitoring system can be used to support reactor operation in normal and anticipated transient modes and to supply data used to derive initial key core parameters for transient and accident analysis.

Prediction of Neutron Embrittlement in the Reactor Pressure Vessel

VENUS-1 and VENUS-3 Benchmarks

ISBN 92-64-17637-3 – 265 pages – Free : paper or web versions.

The OECD/NEA Task Force on Computing Radiation Dose and Modelling of Radiation-Induced Degradation of Reactor Components (TFRDD) launched two international blind intercomparison exercises to examine the current computation techniques used in NEA Member countries for calculating neutron and gamma doses to reactor components. Various methodologies and different nuclear data were applied to predict dose rates in the Belgian VENUS-1 and three-dimensional VENUS-3 configurations for comparison with measured data. This report provides the detailed results from the two benchmarks. The exercise revealed that three-dimensional neutron fluence calculations provide results that are significantly more accurate than those obtained from two-dimensional calculations. Performing three-dimensional calculations is technically feasible given the power of today's computers.

The JEF-2.2 Nuclear Data Library

JEFF Report 17

ISBN 92-64-17656-1 – 253 pages – Free: paper or web versions.

The JEF-2.2 library, the latest version in the Joint Evaluated File series, is composed of sets of evaluated nuclear data, mainly for fission reactor applications. It contains a number of different data types, including neutron interaction data, radioactive decay data, fission yield data, thermal scattering law data and photo-atomic interaction data. It gives detailed information on JEF–2.2, including the origin of evaluations, measures of typical biases (calculation-experiment discrepancies) for different applications and indications on the changes needed to nuclear data in order to improve the predictive power of the file. The feedback contained herein will be used to prepare JEFF-3 (the Joint Evaluated Fission and Fusion file). This report will be useful for scientists and engineers in national laboratories, universities and industry who use nuclear data constants. It is particularly suitable for those who work with computer codes utilising application libraries based on JEF-2.2.

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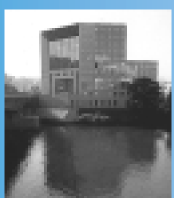
Employment Opportunities

OECD Nuclear Energy Agency



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

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

Qualifications:

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

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

Initial appointment:

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

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OECD PUBLICATIONS, 2 rue André-Pascal, 75775 PARIS CEDEX 16
PRINTED IN FRANCE
(68 2000 01 1 P) ISBN 92-64-17572-5 – No. 51319 2000
ISSN 1605-9581