The demand for qualified manpower in the nuclear field continues to be very high.
THE COSTS OF ELECTRICITY GENERATION

When governments or utilities make plans for their future sources of electricity supply, they have to take account of many technical, social, or economic factors. The cost of generating electricity from several technologies is one of the most important factors which should be considered in the choice of a generation technology. For instance, nuclear power has increased its generation capacity in many years and in many countries, mostly because it has been regarded as a cheap and secure source of electricity both for the short and long term. In fact, it was observed in past NEA studies that generation costs of future nuclear power plants would be cheaper than those of future coal-fired plants in many countries. Recently, however, there have been increasing arguments that nuclear power is not cheap any more if escalation of costs of construction, operations and maintenance (O&M), and decommissioning are taken into account. These claims are not generally true as shown by the NEA’s recent study updating its series of comparative studies on projected costs of generating electricity.

NEA STUDIES AND THEIR MAIN OBJECTIVE

The NEA has already conducted studies on electricity generation costs in 1983, 1986 and 1989, the last time jointly with the OECD International Energy Agency (IEA), and in all cases in close association with the International Union of Producers and Distributors of Electrical Energy (UNIPEDE). The new study was also performed jointly with the IEA and in co-operation with the UNIPEDE. Sixteen OECD countries participated in it as well as six non-OECD countries (notably China, Czech and Slovak Federal Republic (then), Hungary, India, Korea and Russia) which joined the study as part of the contribution of the International Atomic Energy Agency (IAEA).

The main objective of the study was to review and explain the costs that would be expected for base load electricity generation technologies which could be commercially available in the near future. The study did not aim to analyse current costs of generating electricity nor future generation costs of existing power plants. This objective influenced the choice of method of calculating electricity generation costs considered in the study and the scope of generation technologies to be analysed.

LEVELISED LIFETIME COST METHOD

During the first study in 1983, several cost calculation methods were discussed, and the constant-money levelised lifetime cost method was adopted because it was widely accepted and provided a useful basis for inter-technology comparison of generation costs from plants operating under similar conditions, e.g. base load plants from a specified plant commissioning date. The same method has been adopted in the subsequent studies.

The levelised cost of generation from a power plant is derived by dividing the total costs of building and operating the plant over its lifetime by the net electrical output over the same time period. The ideal calculation of this method will take account of the flow of money expended on constructing the plant, its fuel, its operations and maintenance and all subsequent stages including spent fuel management, radioactive waste management and disposal, and decommissioning of the plant. A standard economic discounting procedure with an appropriate discount rate related to the real return on capital is used in order to find a total cost in present worth terms. Then a levelised generation cost is obtained in constant money terms by dividing the total present worth cost by the sum of the discounted electricity output over the plant’s lifetime.

SCOPE OF PLANTS

As in the past studies, all costs which were analysed in the study were based on data provided by the participating countries either directly from utilities or through government agencies. They were asked to provide projected costs from power plants which could be commercially commissioned on 1st July 2000. The date was, however, only for guidance, and plants which were assumed to be commissioned before or shortly after the date were also analysed. The submission of cost data does not necessarily mean that there exist real firm plans for the construction of such plants.

In the previous studies, the submitted cost data were almost limited to those of large scale pulverised coal combustion plants (PCC) or large scale water-cooled nuclear plants (PWR, BWR and PHWR). However, other technologies have emerged recently as commercially available options, such as the combined cycle gas turbine system (CCGT), advanced coal-burning plants and some renewable technologies. Efforts were made to include these technologies in cost comparisons in the study. As a result,
Countries, like Japan, which intend to increase their electricity production through nuclear power, are interested in the development of new types of reactors. Here the Monju Fast Breeder Reactor.

many cost data were provided for CCGT as well as those for nuclear and coal-fired plants. However, cost data on advanced or renewable technologies were disappointingly limited, although a few estimates were provided for advanced coal-fired technologies, small-scale hydropower plants, wind turbines, etc. The reason for the lack of response could be that utilities and government agencies participating in the study had considerably less commercial experience with respect to the technologies, their performance and costs than for other, more established technologies.

**BASIC ASSUMPTIONS**

All cost data submitted to the study were calculated on a common basis of technological and economic assumptions. Operational lifetime and load factors of nuclear plants and conventional coal-fired plants for the reference case are assumed to be 30 years and 75 per cent (6600 hours at full load per annum (p.a.)) respectively. These technical assumptions for other types of power plants, including CCGT, were left open to be decided by countries as the previous studies did not provide sufficient guidance on values to be expected.

The discount rate is an important factor which could significantly influence levelised lifetime cost of generating electricity from capital intensive power plants such as nuclear plants. In the previous study published in 1989, a real discount rate of 5 per cent p.a. was adopted as the reference value because it was consistent with the values adopted in the majority of OECD countries. Five per cent p.a. still remains the most common value for OECD countries, but discount rates have been increased in some participating countries since the last study. In addition, the non OECD country values are somewhat higher at 8 per cent to 12 per cent. Thus, both 5 per cent and 10 per cent are adopted as reference discount rates for this study.

**COSTING BASIS**

The costs of generating electricity considered in the study cover all components of plant specific direct costs falling on the utility that would influence its choice of generation
THE COSTS OF ELECTRICITY GENERATION

technologies. The costs are calculated on the basis of net power supplied to the station bus-bar. The costs of transmission and distribution are excluded from the analysis.

In addition to the costs of construction and operation of the plants, nuclear generation costs include costs of decommissioning of the plants and management and disposal of operating waste (including low-level radioactive waste). For most countries, the fuel costs for a nuclear plant cover all necessary stages of the fuel cycle including spent fuel storage, reprocessing and the disposal of fuel wastes.

Costs which are not plant specific, e.g. taxes on income and profit charged to the utility, are excluded from the analysis, as they are not altered by the choice of plant. External costs are also excluded because these do not fall on the utilities themselves. These exclusions were considered in some detail in another NEA study.

All costs are expressed in constant money terms and have been converted to national currency of July 1st 1991 using appropriate national currency deflators; then they have been converted to US mills (0.001 US$) of the same date.

There are great difficulties in making international comparisons with costs expressed in US mills. Exchange rates do not accurately reflect purchasing power parities. Furthermore the apparent cost relativity between countries can be influenced significantly by the date adopted for inter-currency conversions.

RESULTS: COMPONENT COSTS

Investment cost is a dominant component of costs of nuclear power. The proportion of investment cost to total generation costs of nuclear power is 45 to 65 per cent at 5 per cent p.a. discount rate or 60 to 75 per cent at 10 per cent p.a. discount rate in most countries. On the other hand, fuel cost dominates generation costs of CCGT. The proportion of fuel cost to total generation costs of CCGT lies in the range 60 to 85 per cent at 5 per cent p.a. discount rate. The characteristic cost composition of coal-fired plants is also fuel intensive but less extreme than CCGT. The proportions of investment cost and fuel cost of coal-fired plants at 5 per cent p.a. discount rate are 25 to 45 per cent and 40 to 60 per cent, respectively, in most countries.

The base construction costs (i.e. excluding interest during construction and allowances for decommissioning) of nuclear power plants are projected to be in a range from 1 150 to 1 800 $/kWe in the majority of countries. The projected base construction costs of coal-fired and CCGT show a smaller range of variation from 1 000 to 1 500 $/kWe and 550 to 800 $/kWe, respectively, in the majority of the countries providing relevant data.

The cost differences can be explained by a number of factors. Designs used in different countries differ to match their own regulatory and siting requirements. The scale of plants, number of plants at a site, contractual arrangements and costs of construction are also different from country to country. If a plant is one of an established series, it will tend to be cheaper than a first of a new design.

Absolute ( undiscounted) values of decommissioning costs of nuclear power plants were estimated from 10 per cent to 15 per cent of total investment costs in the majority of countries. However, when discounted, decommissioning costs are less than 2 per cent of total generation costs in most countries. Thus it is obvious that decommissioning costs do not significantly influence generation costs of nuclear power plants.

The operation and maintenance (O&M) costs for nuclear and coal-fired plants are in the range from 30 to 110 $/kWe and from 25 to 100 $/kWe per year at 75 per cent load factor, respectively. These ranges essentially overlap, although the majority project O&M costs for coal-fired plants at 75 per cent load factor to be lower than those for nuclear plants. The O&M costs for CCGT plants are between 10 to 50 $/kWe per year at 75 per cent load factor, and are expected to be less than those for nuclear and coal-fired plants, generally by a significant margin.

The divergences of O&M costs for nuclear plants could be explained by varying coverage of the costs. For instance, some countries include mid-life refurbishment costs but some do not. The NEA is now conducting a new study in order to provide a clearer explanation of the differences in projected O&M costs.

Most countries project fuel costs for LWRs to lie in the range 5 to 11 mills/kWh at 5 per cent p.a. discount rate. The cost for unenriched PHWR fuel is expected to be lower at 1.8 to 7.1 mills/kWh. Fuel costs for coal-fired and CCGT plants are projected to be in the range from 8 to 50 mills/kWh and from 18 to 58 mills/kWh, respectively, at 5 per cent p.a. discount rate. All countries expect fuel costs of fossil plants to be significantly higher than those of nuclear plants.

Most countries project no significant escalation in nuclear or coal fuel prices during the early part of the next century. On the other hand, gas price projection is more difficult, and countries’ estimates of future prices lie in a much wider range than those of the prices of the other fuels.

RESULTS: OVERALL GENERATION COSTS

Any comparison between overall generation costs from nuclear power plants and coal/gas-fired plants depends highly on the level of discount rate. At a 5 per cent p.a. real discount rate, nuclear power is projected to be cheaper than coal-fired power in 12 of the 13 countries providing data for both. At this discount rate, CCGT plants are more expensive than nuclear plants in 8 of the 9 countries providing data for both. In other words, nuclear power will be the most economical base load generation technology around the year 2000 in most countries, if 5 per cent p.a. discount rate is adopted.

However, at 10 per cent p.a. discount rate, the conclusion is less clear-cut, as the position of the less capital intensive technologies is greatly improved relative to the more capital intensive ones. A CCGT plant is projected to be the cheapest base load option in 8 countries. Only 5 countries
Many factors have to be taken into account when calculating electricity generation costs.

project nuclear generation to be significantly cheaper than coal-fired generation, 3 countries show the two options about even and 4 countries project coal-fired plant to be the cheaper option. Nuclear power is only projected to retain its significant overall advantage in 2 countries, amongst the 9 countries supplying data for all three technologies.

The overall cost comparison is also sensitive to nuclear investment costs and fossil price projection. For instance, a 25 per cent increase of gas fuel cost makes CCGT more expensive than or equal to nuclear power in most countries when the 10 per cent discount rate is applied.

Although cost data about renewable technologies were quite limited, they show some aspects of generation costs from those sources. Wind turbines are projected to be more expensive than the major base load generation options, and the competitiveness of small scale hydroplants will depend on their locations.

TRENDS IN PROJECTED COSTS

For a number of OECD countries that have contributed to the NEA series of four generation cost studies, it is interesting to note the trends in projected costs. It is, however, necessary to take account of different technical assumptions adopted in the past studies. For this purpose, the data in the earlier studies in constant national currency terms have been converted to a common 75 per cent load factor and 30 year plant life, and compared to the results of the latest study.

When analysed on the basis of the real value of national currencies, projected overall nuclear generation costs have remained fairly stable over the past decade, as increases in capital and O&M costs have been offset by decreased nuclear fuel costs. On the other hand, the attractiveness of coal-fired plants has been improved due to a decline in projected overall generation costs. In fact, this is due to changed expectations of future coal prices, which are no longer expected to escalate, contrary to predictions made in the 1970s and early 1980s.

At present, nuclear power is not seen as having quite the same economic advantage as was thought in the early 1980s. Nevertheless, even at 10 per cent p.a. discount rate, 5 out of 14 countries providing nuclear and coal cost data project nuclear power to have a clear economic advantage over coal, and 3 out of 9 countries providing nuclear and gas cost data project nuclear power to be a cheaper option than CCGT. At a 5 per cent p.a. real discount rate, using the reference performance assumptions, most participating countries project nuclear power to be the cheapest source of base load power from plants to be commissioned around the year 2000.
AN OVERVIEW OF NATIONAL REGULATORY APPROACHES FOR HIGH-LEVEL AND LONG-LIVED WASTE DISPOSAL**

INTRODUCTION AND BACKGROUND

The development of regulatory approaches to the disposal of high-level and long-lived radioactive waste started to receive significant attention some 10 years ago. A great deal of experience existed already, from general approaches to nuclear regulatory issues. The general regulatory regime of prior authorisation for the construction, operation and decommissioning of nuclear facilities, based on formal licensing procedures and a convincing safety case, was applicable in principle, as well as the basic radiation protection standards for the protection of man and the environment. Furthermore, some experience was available from the management of low-level wastes since a few disposal centres were already operational in the years 1960-1970.

The early developments concerned the establishment of national legislation and institutional structures, defining overall management strategies and responsibilities at operational and regulatory levels for such types of waste. In particular, in the late 70s and early 80s, national agencies in charge of implementing disposal concepts at an operational and financial level were set up in many countries and it was possible to allocate clearly separate and independent responsibilities to the two main groups concerned: on the one hand, the implementing agencies which were often an emanation of nuclear electricity utilities and, on the other hand, the officially designated regulatory authorities.

Another important aspect of the long-term management of high-level and long-lived radioactive waste was the progressive build-up of a consensus in favour of multibarrier isolation systems, located deep underground in stable geological formations. Some national laws on the management of this type of waste refer to possible alternatives (such as seabed disposal in the United States) or the need to revisit the issue after a research period and before implementation of the concept is considered (such as in France). In some other countries, a formal debate is sometimes organised as to the acceptability of the geological disposal concept (as in Canada, where a review is being conducted by an Environmental Assessment Panel appointed by the Minister of the Environment). Nevertheless, geological repositories are regarded today as the most likely and favoured solution and regulatory frameworks are essentially centred around this long-term and final solution, whether for high-level waste from reprocessing or for unprocessed spent fuel.

The disposal of high-level and long-lived waste has always been regarded as a difficult environmental challenge because of the very high radiation toxicity and the extremely long life of some of the radionuclides present in the waste. The level of ambition which was suggested from the beginning for the management of such waste is accordingly very high. In practice, the widely adopted principle of protecting future populations at the same level as current ones, has far-reaching consequences and imposes isolation of the waste from the biosphere for tens or hundreds of thousands of years. The acceptance of such a long-term constraint is unique in man’s history. The resulting difficulty is not so much to set up technical or environmental protection objectives, but rather to ensure and, especially, to demonstrate compliance with them. Isolation systems cannot be expected to last indefinitely and must be assumed eventually to lose their integrity. How and when this will happen will always be somewhat uncertain. This is where the crux of the matter lies from the regulatory standpoint.

Finally, most countries are still two or more decades away from the opening of the first high-level and long-lived waste repositories. During the coming decades there will be a significant evolution with regard to scientific progress and the national regulatory situations in this field. Two main areas of regulatory policies will probably continue to dominate the scene: the safety criteria and the associated compliance issues. In this respect, site-specific or integrated performance assessment activities will remain the cornerstone of the regulatory review process. Such assessments of the long-term safety of radioactive waste repositories are also the subject of intensive discussions at the international level stressing the role of international cooperation.

SAFETY OBJECTIVES AND CRITERIA

The common objective of radioactive waste management practices is to provide an isolation period long enough to ensure that possible radiological exposure of current and future populations remains at an acceptably low level, in

*MR. JEAN-PIERRE OLIVIER IS HEAD OF THE NEA RADIATION PROTECTION AND WASTE MANAGEMENT DIVISION.

**Adapted from a paper presented at SAFEWASTE 93, an International Conference on the Safe Management and Disposal of Nuclear Waste, Avignon, France, 13th-18th June 1993.
conformity with the recommendations of the International Commission on Radiological Protection (ICRP) which are the basis for national regulations in this field. National authorities have developed their own radiological protection criteria for radioactive waste disposal with reference to ICRP recommendations and other international documents published by the OECD Nuclear Energy Agency and the IAEA. These criteria are expressed in quantitative terms following notably the ICRP principles of dose limitation and optimisation of protection. A second series of criteria dealing with the isolation system itself and the geological site properties is of a more technical nature and essentially qualitative.

**RADIOLOGICAL CRITERIA**

They are directly derived from the ICRP recommendations and generally expressed in terms of *individual dose levels or individual risks*, risk being defined as:

\[
[\text{probability of receiving a given exposure}] \times [\text{probability that the exposure will give rise to a deleterious health effect}]
\]

In addition, there is usually a requirement that all exposures should be kept as low as reasonably achievable, economic and social factors being taken into account (the optimisation of protection or the ALARA principle).

The use of a dose or risk criterion is largely debated at international level and countries are divided as to which criterion they should adopt. For “normal evolution scenarios” which would involve a gradual and slow degradation of the barrier system, the probability of individuals of a hypothetical critical population group receiving an exposure at some future date can be regarded as one, although there is some uncertainty as to how far in the future the exposure is going to be received. A dose criterion is then relatively logical. Furthermore, it is a convenient measure of the impact of radiation exposure.

For uncertain or even unlikely scenarios, which may result from relatively rare events with a probability of occurrence *much less than one* over very long periods, a risk criterion may be more appropriate to describe *potential exposure situations*. In addition to the uncertainty which will always exist in assessing the radiological consequences—in this case, the potential dose—a real difficulty is to estimate the probability of the rare events at the origin of the degradation of the barrier system and the possible exposure of future populations. This is a significant obstacle in the use of fully probabilistic approaches to safety assessments.

In fact, dose and risk are both valid *safety indicators* and are directly comparable, a risk level of $5 \times 10^{-4}$ per year corresponding to an annual dose of 1 millisievert (1 mSv) (according to the latest ICRP recommendations for individual members of the public). This is why hybrid systems, using both dose and risk, have been suggested by the ICRP itself and also by some countries.

The Table below attempts to summarize the current situation, in a number of countries, concerning radiological criteria used as safety indicators for long-term waste management situations. The information given in this Table should be used with great caution, since a short summary cannot represent a fair description of each national situation, and because several national regulations are expected to be revised soon to take into account the emerging experience in this field. In addition, from a *safety standpoint*, the differences which may be noted in the figures adopted for national radiological criteria do not in practice correspond to different isolation requirements. In spite of the various formulations used, *radiological criteria are therefore essentially equivalent in all countries and promote similar long-term safety levels*.

The US criteria represent the exception compared to the approaches used in all the other countries which consist essentially of a *simple individual dose or risk indicator*. These countries have practically no other quantitative measure formalised in their regulations to assess future
<table>
<thead>
<tr>
<th>Country</th>
<th>Main Criterion</th>
<th>Other Main Feature(s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANADA</td>
<td>Max. indiv. risk obj. 10(^{-6})/year</td>
<td>Period of time for demonstrating: 10(^{y})</td>
<td>AECB regulatory document R-104 (1987)</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Individual dose &lt;0.25 mSv/year (for normal evolution scenarios)</td>
<td>Period of time for demonstrating: at last 10(^{y})</td>
<td>Règle fondamentale de sûreté N°III.2.f (1991)</td>
</tr>
<tr>
<td>GERMANY</td>
<td>Individual dose &lt;0.3 mSv/year for all reasonable scenarios</td>
<td>Calculations limited to ~10(^{y}) but isolation potential beyond may be assessed</td>
<td>Section 45, para 1. of Radiation Protection Ordinance (1989)</td>
</tr>
<tr>
<td>THE NORDIC COUNTRIES</td>
<td>Individual dose &lt;0.1 mSv/year for normal scenarios (0.1 mSv/year risk equiv. used to assess unlikely disruptive events)</td>
<td>- Calcul.up to reasonably predictable time period - Additional constraint based on natural &quot;activity inflow&quot; considerations for very long term</td>
<td>(see Ref.8) in this paper</td>
</tr>
<tr>
<td>SPAIN</td>
<td>Individual dose &lt;0.1 mSv/year Individual risk &lt;10(^{-6})/year in any situation</td>
<td>-</td>
<td>Statement by Nuclear Safety Council (1987)</td>
</tr>
<tr>
<td>SWITZERLAND</td>
<td>Individual dose &lt;0.1 mSv/year at any time for reasonably probable scenarios</td>
<td>-</td>
<td>Regulatory document R-21 (1980) (to be revised)</td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>Individual risk &lt;10(^{-6})/year without ALARA OR Individual risk &lt;10(^{-6})/year if ALARA</td>
<td>- Simpler reference calculations after 10(^{y}), possibly constrained by radionuclide release rates from the geosphere to avoid biosphere modelling - Overall prob. limit of 10(^{y}) for scenarios likely to cause doses &gt; 0.5 Sv</td>
<td>Radiological Protection Objectives for Land-based Disposal of Solid Radioactive Wastes, NRPB 1992</td>
</tr>
<tr>
<td>UNITED STATES</td>
<td>Limits of cumulative releases of radionuclides over 10(^{y}) years based on health impact on population</td>
<td>Other requirements on individual dose and drinking water contamination</td>
<td>40 CFR Part 191 (1985) (to be revised)</td>
</tr>
<tr>
<td>EPA</td>
<td>Limits of cumulative releases of radionuclides over 10(^{y}) years based on health impact on population</td>
<td>Other requirements on individual dose and drinking water contamination</td>
<td>40 CFR Part 191 (1985) (to be revised)</td>
</tr>
<tr>
<td>NRC</td>
<td>Minimum level of performance for - waste package - engineered barrier system - groundwater travel time</td>
<td>Other requirements on individual dose and drinking water contamination</td>
<td>10 CFR, Part 60</td>
</tr>
</tbody>
</table>
exposures and they have no derived sub-criteria. In the USA, the approach was for the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) to develop a system based on primary containment standards/requirements to limit projected radionuclide releases to the accessible environment for 10 000 years. The main objective was to limit the collective adverse health impact of given quantities of spent fuel or high-level waste, or alpha-emitting transuranic radionuclides. The US National Academy of Sciences is currently involved in a study to provide findings and recommendations on reasonable safety standards for high-level radioactive waste disposal, as a basis for the revision of EPA standards and NRC regulations.

One significant element of this discussion concerns the timescales to be considered in a radiological assessment. Official regulatory policies are relatively careful in this respect, reflecting in this area also the ongoing discussions at the international level. Formal requirements for quantitative assessments exist up to at least 10 000 years. However, at certain times, the level of uncertainty becomes so large that quantitative assessments in terms of dose or risk are becoming less and less meaningful and it is recommended that they should be replaced by qualitative evaluations or the use of different reference safety indicators.

About the use of different indicators, the recent recommendations adopted by the Nordic countries8 include the following principle mainly designed to cover situations after 10 years: “The radionuclides released from the repository shall not lead to any significant changes in the radiation environment. This implies that the inflows of the disposed radionuclides into the biosphere, averaged over long time periods, shall be low in comparison with the respective inflows of natural alpha emitters”.

The Nordic recommendations give some guidance as to the practical application of this principle which is not really straightforward. A reference to inflows of natural radioactive elements may nevertheless assist regulators in obtaining a useful indication or perspective of possible changes in future environmental radiation fields due to waste management practices.

Finally, it is also necessary to mention the ICRP optimisation principle, or ALARA, and its significance in regulatory requirements for long-lived waste disposal. While it is specifically quoted in every regulatory document and remains valid in theory, the ALARA principle seems to be of limited practical use for long-term situations. Detailed quantitative optimisation attempts are always severely constrained when they deal with the long-term and they do not usually provide reliable information for decision-making processes on high-level and long-lived waste disposal, mainly because of the existence of significant uncertainties. Rather than the application of the ALARA principle, in a strict radiological protection sense, what is often advocated is a judgemental and qualitative optimisation in the development of detailed repository design options and in the selection of repository sites, showing that reasonable efforts have been made to consider the various means available to reduce potential exposures in the long term.

**TECHNICAL CRITERIA**

Another and complementary way to promote long-term safety is to include technical design and site selection requirements in regulatory documents. All national approaches do include such requirements focusing on the isolation requirements. However, they are essentially qualitative, expressing the need to consider each design and geological setting on the basis of its own merit. They also preserve a certain degree of flexibility for the implementing agency to develop what it may consider as the most appropriate isolation system, given a broad range of conditions. The approach is therefore not prescriptive, except to some extent for the particular set of containment criteria adopted in the USA. Even in the USA case, which includes sub-system requirements for the waste canister and the underground water travel time to the nearest accessible environment, such constraints are not supposed to be completely rigid. In fact, it is perhaps more appropriate to talk about guidance and procedures to be followed in this area to achieve safety, than about strict regulatory requirements as such.

Technical criteria usually cover:

- *the selection of an appropriate site*, with basic, and sometimes more, requirements concerning geological stability, hydrology, geochemistry, depth and dimensions of formations, possible presence or proximity of minerals or other resources, etc.;
- *the design of the multibarrier system* and the characteristics of its various components: the waste form, the waste canister, the buffer and the near-field materials;
- *redundancy and quality assurance aspects*.

All regulatory approaches recognize the absolute need for site-specific and integrated safety assessments and, therefore, for a fundamental and detailed understanding of the proposed disposal systems. They are actually designed through the procedures foreseen for systematic checks and independent reviews at all stages of the development, construction, operation and closure of disposal facilities, to promote the building-up of specific safety cases corresponding to the state-of-the art in the many scientific disciplines involved.

---

104
In conclusion, the analysis of existing radiological and technical criteria for waste disposal reveals somewhat different choices at national level in their formulation. However, all criteria share the same general basis and correspond to a more or less identical safety approach: no exposure for very long timescales and future potential exposures at levels which would be compatible with today’s radiological protection standards.

![Multiple Barriers](Credit: US DOE United States)

**MULTIPLE BARRIERS**

Multiple barriers help prevent radioactive material from ever reaching man or the environment.

**COMPLIANCE ISSUES**

In a final licensing exercise, the results of an assessment describing the expected performance of the proposed repository have to be evaluated in the context of the established regulatory criteria. In general, the basic approach used to assess the long-term behaviour of an underground repository is largely independent of the type of safety criteria used. It consists in a critical and systematic review of a licence application file provided by the implementing agency and submitted to the regulatory authority about a specific radioactive waste disposal system. The application file should be based on a detailed quantitative assessment showing that performance predictions meet safety criteria, including:

- a documentation of methods, models and data used in calculations;
- a description of inherent limitations (e.g., model validation) and uncertainties (e.g., on data) and, when possible, relevant quantitative estimates of their possible impact on the partial or overall results of the assessment;
- a critical discussion and clear presentation of the results, using experimental and natural evidence (analogues) whenever possible, with the purpose of building confidence.

Clearly, an implementer has to be as specific and exhaustive as possible in his attempt to establish a convincing safety case and in following the formally agreed procedures. But, he cannot be expected to provide unchallengeable evidence on every choice made for data sets, models, expert judgements, design options, and on full correctness of all the assumptions made. The long-term evolution of the disposal system is inevitably associated with a certain degree of uncertainty and the regulator is faced with it, just the same as the implementer. The development of the regulator’s own technical and scientific expertise in performance assessment is therefore important.

Regulatory approaches have to cope with this difficult situation and the following needs, which are common to all countries, have been identified in this respect:

- development of guidance for the preparation of a licence application, including operational and post-operation aspects;
- regulators’ participation in the different phases of a repository development, interactively and iteratively, notably during:
  - site selection and evaluation
  - repository design
  - licence preparation and application;
- development of an in-depth understanding of the proposed system at the regulatory level;
- transparent and easily understandable regulatory review procedures, to assist in conveying results to non-experts;
- peer review processes and quality assurance mechanisms.

In practice, the regulatory review process is expected to start at the initial stages of a national programme, to follow R&D progress, to enable interim technical or policy orientations/decisions during the course of the programme, to allow for a certain flexibility in dealing with technical alternatives, and to be as objective and rigorous as possible in the evaluation of the long-term risk assessment provided by the applicant agency. Based on the experience already available in a few countries, the complexity of the regulatory process militates in favour of a continuing dialogue between the implementer and the regulator. Without losing its independence and its credibility, the regulator should be in a position to satisfy himself with the quality of the work presented by the implementer, both directly by following it through very closely, and indirectly by doing his own verifications, using, for example, “robust” models and conservative assumptions.

Considerable help in this area comes from international co-operation. In particular, in 1991, following extensive reviews at the international level, the NEA, IAEA and CEC published a joint statement, called an International Collective Opinion, on the state-of-the-art concerning the evaluation of the long-term safety of radioactive waste.
disposal). This Collective Opinion, which was endorsed by the competent committees of the three organisations composed of both implementers and regulators, put the problem in perspective and concluded with the necessary precautions that "appropriate use of safety assessment methods, coupled with sufficient information from proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations".

A recurrent theme throughout this Collective Opinion was the constant need for interpretation and judgement in the safety evaluation of waste repositories. This is a significant complication, in particular when legal arguments are made and have to be reconciled with technical realities. The joint Collective Opinion and other international documents, which put a large body of peer-reviewed information at the disposal of national authorities, may help them, not only at the technical level, but also in their dealings with politicians and the general public, as objectivity, transparency and good communication are essential prerequisites for progress in this area.

**FINAL REMARKS**

In spite of their relatively recent and evolving character, national regulatory approaches for the isolation of high-level and long-lived waste in deep geological structures offer already today well-established licensing frameworks. Criteria exist in most countries which promote safety levels in the long-term comparable to what we would expect for ourselves. They are relatively general, but use the same radiological protection basis, and are consistent in their objectives. They appear flexible enough to make it possible to implementers of waste disposal systems to select the options which they consider the most suitable. Several countries have announced that they would soon review their respective criteria. The main reason for such revisions seems to be the desire to adopt criteria that may be better suited to the long-term safety evaluation context and the compliance demonstration process, without, of course, reconsidering the safety level to be achieved. Forthcoming revisions look, therefore, more a matter of presentation than a question of substance and safety.

The regulatory process itself is well understood and structured in advanced countries, with many steps and independent reviews foreseen. As in other nuclear safety areas, a performance assessment and safety culture has rapidly developed and the methodologies available are now relatively reliable. A key element is the conduct of well-structured and documented site-specific safety assessments. Whereas long-term safety assessment techniques are available, an important part of future work is the collection and interpretation of field data for the characterisation of potential repository sites. Safety assessors and regulators do need such site-specific data to come up with results which are sufficiently representative and credible.

Inevitably, the safety of long-lived waste disposal will have to be demonstrated by predictive modelling. This may be considered as a handicap as no direct evidence of compliance with safety objectives can be provided. In addition to this challenge, the regulatory requirements established for nuclear waste have been made extremely stringent. The current indications are, nevertheless, that they can probably be compiled with. The continuation of R&D programmes and the study of pending issues, such as the question of human intrusions at disposal sites and various aspects of institutional control, are expected to contribute to reinforce the feeling of confidence which is already widely shared in this field by specialists at the international level. Hopefully, the example of the regulatory approaches developed for the disposal of nuclear waste will eventually trigger a similar professional and responsible approach in other environmental protection fields, where long-term issues have not yet been recognized to the same extent.

**REFERENCES**


TEACHERS AND NUCLEAR ENERGY: A NEW DEAL?

Two years have elapsed since the Seminar which the OECD Nuclear Energy Agency (NEA) organised in Engelberg (Switzerland) on the topic of Education and Nuclear Waste. This meeting, the first of its kind at international level, was the starting point of several international follow-up activities, notably the setting-up of the International Alliance for Education in the field of radioactive waste management, under the sponsorship of the US Office of Civilian Radioactive Waste Management, and the International Seminar on Teachers and Nuclear Energy, which the NEA organised in June 1993 in Oxford, in the United Kingdom, in co-operation with the British Nuclear Industry Forum.

This article focusses on highlights of the meeting, which was attended by some 60 specialists (teachers, curricula developers, teachers’ associations, information specialists from governmental nuclear agencies and the nuclear industry) from twelve OECD countries.

TECHNOLOGY AND SOCIETY

Today’s society has become highly dependent on increasingly complex technologies, and no one is capable of knowing and understanding all the implications of this phenomenon. Knowledge has now been split into a multitude of individual competences and, although ways of exchanging it between groups have been considerably diversified, it is becoming more and more difficult for individuals to recombine this split knowledge in order to synthetize its scientific, technical, social, economic and ethical implications.

Modern society is combatting ignorance as a way to minimise misunderstandings between social groups which can ultimately affect national decisions on key issues. Individuals need to learn so as to be able to understand, pass judgment and, finally, play their part in the decision-making process. Individuals themselves show increasing motivation for understanding issues which concern them directly in their personal lives. Dr. Brian Wynne, of the University of Lancaster in the United Kingdom, says that: “The public uptake of science is not based upon intellectual capability as much as socio-institutional factors having to do with social access, trust, and negotiation as opposed to imposed authority”. This is a point to be kept in mind because nuclear energy does have a number of implications for our daily life, and has precisely to do not only with science and technology, but also with trust and social access.

These broad considerations highlight the central responsibility of the education system and the teachers, in particular, for preparing younger generations to deal with the complex issues of modern society, for stimulating their search for facts and developing their sense of critical analysis. What is said in schools, by whom and how, is vital in forming views on the role of science and technology in society. This is the case, of course, for nuclear energy which has been - and continues to be - a matter of intense debate in public circles, due to the scientific complexity of the phenomena involved and the strong emotional connotation of the subject in the public mind. School is therefore a privileged place where the subject of nuclear energy may first be encountered, not only through teaching of individual scientific disciplines such as physics, but also through the convergent teaching of other complementary disciplines, such as economics, or social sciences.

An international survey conducted in 1992 by the Japan Atomic Energy Relations Organization (JAERO) has cast some light on the part education plays in Europe and Japan regarding energy and environment for students in upper secondary schools, as compared to other sources of information. The Table shows that the United Kingdom, Sweden and Switzerland are leading in this respect. But, of course, teachers themselves must be willing and adequately prepared to play this key role. Regarding nuclear energy, we can only note that, today, teachers’ training in OECD countries is insufficient both as regards basic knowledge and methods to come to grips with the subject.

Except for science teachers, little or no information on nuclear energy is given to secondary school teachers during their initial professional training. It is therefore only through additional training during their professional life and through information provided, inter alia, by the nuclear industry that teachers can be sufficiently prepared to deal with nuclear energy in the classroom. In addition, global, synthetic information is seriously lacking, which would help teachers to approach a discussion on nuclear energy from a wide perspective and do justice to its many interrelated aspects: scientific, technical, economic, social, historical or ethical.

Faced with this challenge, it is clear that the role of the teacher is quickly evolving, if only because “the context of teaching is as important as the content”.

*MR. JACQUES DE LA FERTE IS HEAD OF EXTERNAL RELATIONS AND PUBLIC AFFAIRS OF THE NEA.
Several decades ago, civic education was taught routinely in secondary schools. While the background has changed, the need to prepare tomorrow’s citizens to act in a responsible way when a choice of policies is put to vote remains strong indeed. This mission continues to fall essentially on the teacher, also when various aspects of different technological options such as nuclear energy must be weighed and their multiple impacts on society discussed.

In such cases, and the subject of nuclear energy first comes to mind, the role of teachers is changing. The teacher must now be prepared to act rather as the moderator of a group discussion, where pupils will assert their ideas and debate their points, sometimes leading to controversial positions, than as a traditional source of knowledge. The teacher’s role is to encourage pupils to investigate, to debate, to put facts together with ideas, and help them to reach a well-founded conclusion. As to the search for information, it is now customary for pupils to collect it essentially on their own with little assistance from others.

RAISING THE MOTIVATION OF TEACHERS

To assist teachers in fulfilling this new role, their training and information must first aim at raising their own interest level and motivation for approaching the subject of nuclear energy in their classrooms. In other words, their training must enable them to identify more clearly the relationship between nuclear energy and their own social and cultural environment in their day-to-day lives. The Oxford Seminar offered several interesting examples in this respect. One of them puts in parallel the level of complexity of nuclear energy technology with that of other more familiar technologies such as radio, television, personal computers, and the role of electricity in day-to-day life. In another example, the attention and interest of teachers is drawn to the fact that nuclear fission is based upon natural phenomena which find their place in man’s every day environment, and the sun is a kind of “nuclear fusion reactor” and a source of radiation. The incentive to open a discussion
on nuclear energy at school is, of course, very high when it coincides with the development of a nuclear project in the local area, where technical, but also economic and social issues are at stake. In each of these examples, the topic of nuclear energy may find its place in the broader scope of the discipline for which the teacher is responsible.

INTER-DISCIPLINARITY: A NECESSARY APPROACH

Beyond the accommodation of a specific aspect of nuclear energy in individual teaching, the development of a nuclear energy education package that can be incorporated wherever appropriate in the school curriculum presupposes that teachers of all disciplines are prepared to co-ordinate their action. Removing barriers between disciplines, especially for a subject that, in OECD countries, is usually approached only from a scientific standpoint and chiefly in physics courses, should lead to interdisciplinary education. Several experiments with this type of co-ordinated approach have already turned out to be very positive, especially in secondary schools in the State of Nevada, in the United States, where a deep geological repository for high-level radioactive waste is being excavated, and is actively debated. Also of particular interest in this respect is the recent initiative taken by the JAERO to promote the development of a cross-curricular model for environmental and energy education, which includes social studies, natural science and economics.

TRAINING AND INFORMING TEACHERS

To be able to face the challenge of discussing broad societal issues in the classroom, teachers require an appropriate pedagogical training and access to necessary information. There are today a variety of sources available to teachers for this purpose. These sources have different characteristics and their respective contributions are not evenly distributed.

Firstly, there are teachers' supervisory authorities such as Education ministries, which must logically be at the root of any training and information programmes for teachers. At present, however, they do not seem to be the most active regarding nuclear energy. At best, they will delegate their responsibilities in this field to associations and other non-governmental bodies which have programmes to offer.

Teaching material can be very sophisticated, for example the tool kit developed by Électricité de France.
Secondly, there is the nuclear industry, which plays a prominent role as information source and conducts teachers’ training programmes.

Thirdly, let us also mention the specific action of international organisations (OECD Nuclear Energy Agency, Commission of the European Communities, International Atomic Energy Agency, ...), which tends to become increasingly relevant, not only by encouraging exchanges of experience about education on nuclear energy at school, and for coordinating national thinking and action, but also through the development of teaching material. The Commission of the European Communities has just completed a Teachers’ Manual on Radiation and Radiation Protection which contains information and teaching plans and has been pre-tested already in five Member States of the European Communities.

FOR TEACHERS, BY TEACHERS

But beyond these more or less formal sources of training and information, there is evidence that it is the teachers themselves, those who have experience and knowledge, who can best teach other teachers. The formula “for teachers - by teachers” strongly reflects the desire of teachers to keep their own control of the process, to remain independent, critical, and to avoid the domination of imposed external inputs. In addition, self-training and information through members of the profession allows the possibility of a debate among teachers, which is considered to be a more attractive formula than that of a formal teaching. The role of teachers’ unions is important in this respect.

The Oxford Seminar noted also that it seemed important to involve in this training process teachers who are at the same time researchers in scientific or technical areas, who are in close contact with the real world of research. Similarly, frequent interchange among teachers and research circles is necessary for the former to understand the scientific and technological world in which they live.

THE ROLE OF THE NUCLEAR INDUSTRY

What has just been said should not diminish in any way the role played by industry, be it in terms of financial resources invested in teachers’ training and information, or in terms of source of knowledge provided. It seems that the interface between teachers and the nuclear industry is at present evolving towards a balanced partnership, whereby teachers are closely associated from the very beginning in the development of teacher training and information programmes, pedagogical material and methods proposed by the nuclear industry.
It will remain essential, however, to carefully check that it is industry which will adapt to teachers’ needs and not the contrary.

**TYPICAL TRAINING AND INFORMATION ACTIVITIES**

Activities intended to train and inform teachers on the various aspects of nuclear energy may be categorised into three groups:

A first group of activities involves information transfer to teachers through conferences, debates, exhibitions and site visits, organised by the nuclear industry, electric utilities and major R&D institutes. A second group includes development of supporting material to assist the teacher: teachers’ guides and manuals, video games and interactive softwares to be used on personal computers at school. A third group includes activities implying an active participation by the teachers themselves, such as think-tanks, workshops, training periods at industrial plants, theoretical and practical training, summer universities, etc.

Obviously, it is the combination of two or more elements of the three groups which will provide the appropriate mix depending on the cultural environment of the teachers, with greater or lesser emphasis being placed on the theoretical aspects of radioactivity, on explaining nuclear technology, and on evaluating its impact on day-to-day life.

In parallel, we can observe that teaching material is also evolving rapidly in line with general progress in information and communication techniques. Priority is given to “user-friendly” handbooks and teachers’ guides, interactive material using PCs and audio-visuals. Greater prominence is also given to practical, hands-on, demonstration and experimental kits to be used by the teacher as well as the pupils (e.g. to show the existence of radioactivity and the means to detect it).

**NATIONAL INFORMATION CENTRES**

In fact, there is already a substantial amount of information and teaching material available in OECD countries in a variety of forms and for a variety of objectives, mostly developed by industry, but also by other sources (e.g. teachers’ professional associations). Unfortunately, teachers are not often aware of their existence. Hence the suggestion made at the Oxford Seminar that national information centres or reference points be established with a complete collection of available material for consultation or loans, and that exhaustive data bases, which could be easily consulted by teachers, be set up to allow a quick selection.

**CONCLUSION**

While secondary school systems differ from country to country, they all share a common objective to improve the flow of information to students and teach them ways of opening their minds to all the implications of technological reality. To meet these objectives in the nuclear energy field, there is no single pedagogic method than can be applied throughout. Each country, each school and even each teacher must adopt the most appropriate strategy and adjust it to the field, the curriculum and the class. The need for this flexibility must be emphasized in the course of teacher training.

The role of teachers at school is constantly evolving to adapt to the need for an inter-disciplinary approach to broad societal issues at schools.

It is encouraging to note from the Oxford Seminar that a balanced partnership already exists in some countries between teachers and the industry to develop teaching material and methods, and that, in general, teachers have already begun to rise to the challenge of tackling nuclear energy in the classroom.

To support its action, and on the basis of the lessons learnt from this international seminar, the OECD Nuclear Energy Agency is preparing a video intended for teacher trainers and teachers to encourage them to become acquainted with the education experiments that have been conducted in various countries to tackle the topic of nuclear energy at school in a broad context.
LONG-TERM SAFETY OF NUCLEAR POWER PLANTS

Nuclear Power Plants (NPPs) are getting older. How to maintain and, where possible, improve their safety when compared with the requirements set for modern power reactor systems, are questions that have been asked by both operators and regulators for some years. It seems an appropriate time and it is the purpose of this article to review how, at an international level, these questions are being addressed.

Age statistics for nuclear power plants around the world are shown in Figure 1. There are a number of reactors which have now had over 30 years of operation and many with over 10 or 20 years operation. It is therefore not surprising there is world-wide interest in the safety level of NPPs of the older generation. They were designed and built to different standards and safety concepts when compared with the current standards which are applied to a modern plant. That is not to say, however, that such plants are unsafe, but continued operation can only be justified if it can be demonstrated that safety margins remain acceptable.

In recognition of this situation, many initiatives have been taken by operators and regulators. These have been reflected in the activities of international organisations and in particular those of the OECD, CEC and IAEA can be summarised as follows:

1. OECD Nuclear Energy Agency

Under the NEA Committee on Nuclear Regulatory Activities (CNRA), one of the first tasks was to undertake a survey of the approaches by member countries to periodic safety reviews (PSRs) of the safety of NPPs. It was recognised that there are changing regulations, advances in technology, plant backfits and upgrading and component ageing - all of which point towards the need for some form of fundamental review of the safety status of each plant. The CNRA was, however, aware that there was a wide variation in the current practices for evaluating the safety status of each plant.

Figure 1

World Wide Operating Nuclear Power Plants
Distribution By Age at 1993

©M R. JO H N T URNE R IS DEP UTY C HIEF I NSPECTOR AT HER MA JESTY'S NUC LEA R I NSTALLATIONS I NSPECTORATE IN LO ND ON, U NITED K INGDOM. HE WAS ALSO THE CHAIRMAN OF THE CNRA T ASK F ORCE ON S AFETY EVAL U A TION OF AGE ING NUC LEA R P OWER P LANTS.
The objective of the survey was to obtain information which would allow each Member country to compare its approach to periodic safety reviews with those of the others.

Aspects addressed in this review covering 13 countries representing 357 NPPs included statutory basis, objectives, scope, and relationship to other regulatory activities.

The survey confirmed that there was a wide variation in the scope and depth of PSRs undertaken by Member countries, but it concluded that appropriate objectives might be:

- to verify that the initially envisaged level of safety is maintained;
- to periodically assure that the operational experience is taken into account to improve safety;
- to evaluate the design of the plant by comparison with the latest safety requirements.

The review also recognised that most PSRs were already a legal requirement either as a condition of the operating licence or as requirement for its extension or renewal, and that the scope of PSRs often included a review of the plant status and operational feedback. Frequency of reviews varied but, on average, was around 10 years.

2. Commission of the European Communities

At its plenary meeting (December 1991), the CEC Working Group on Safety of Thermal Reactors, agreed to a work plan concerning periodic safety re-evaluations in operating NPPs in CEC countries.

The first phase of the work plan was to gain an understanding of Member countries’ approaches, and a report on their findings (based on a survey of 7 CEC countries) was subsequently published in 1990 [Report Ref: EUR 13056]. All these countries were found to be implementing programmes of safety reviews for their ageing NPPs.

The second phase of work was to undertake a wider review of current practices (in 10 European countries) building on the experience of the earlier review. The OECD survey report was used as a major source of information. This work is now complete and will be published by the CEC at a later date. The need for a best practices Document to be developed for use by both licensees and regulators with EC countries is being evaluated.

3. International Atomic Energy Agency

Based on the experience of assessing the VVER 440 model 230 NPPs, the IAEA developed general guidance for undertaking safety re-evaluations of operating NPPs (endorsed at the IAEA's Safety Conference in 1991).

Declarations agreed at the 1991 IAEA General Safety Conference included:

- The IAEA should initiate a process to develop a Common Basis on which the acceptable level of safety of all operating NPPs built to earlier standards can be judged
- to ensure the completeness of reviews”
- to ensure implementation of measures to achieve an acceptable level of safety”

The IAEA is currently pursuing work at several levels through its Divisions of Nuclear Safety and Nuclear Power and under the auspices of the International Nuclear Safety Advisory Group (INSAG).

CURRENT NEA ACTIVITIES

The NEA has now taken the work a stage further by making the “Regulatory Approach to Maintaining the Safety Case for Ageing NPPs” the subject of a special topical meeting held in June 1993 under the auspices of the CNRA. The CNRA considered it important and timely to bring senior Regulators together to review progress on this increasingly important topic, in particular:

- to evaluate the extent to which there is a consensus among member countries on the safety evaluation strategies, building on the earlier OECD work;
- to reach a consensus between members on what are the key aims and objectives of safety evaluations of ageing NPPs;
- to reflect on work being undertaken within the framework of other international initiatives and to conclude whether there is now a need for the NEA (CNRA) to encourage member countries to draw up Regulatory Guidelines in the context of safety evaluations of ageing NPPs.

In preparation for this review the CNRA established an ad hoc task force with representatives from six member countries under the chairmanship of a representative of the UK regulatory authority to identify whether there are basic aims and objectives for the safety evaluation of ageing nuclear power plants. These can then be used in any particular country according to their own legal and administrative arrangements.

It was generally agreed that the safety case for the continued operation of a NPP is maintained by the combination of two activities, namely:
a) Ongoing Inspection and Assessment

Operators and regulators assure themselves on a continuous basis that adequate safety standards are being maintained by means of routine inspections and assessments. Procedures for plant operation, maintenance, inspection, radiological protection, emergency provision and staff training are also reviewed and good compliance with these procedures by the NPP operating staff has to be assured.

In addition to these continuing routine safety checks, regulators in some countries also require annual, biennial safety reviews by the operators which usually consider operational experience and problems since the last such review.

b) Special Reviews

These are normally reactive, prompted by some event. Special reviews are carried out by operators and are often required by the regulator following any NPP incident leading to a potentially dangerous situation. Operators are required to implement lessons learnt from such incidents. Specific examinations are also performed following significant events at NPPs on a world wide basis. The events at TMI and Chernobyl were particular examples of this process. Some Regulators also undertake generic reviews on the analysis of specific topics such as operator training, quality and safety of maintenance operations.

The evaluation of the safety case for a NPP can be seen to fall into two parts. Firstly, the assembly of base line data, then the evaluation of this information.

THE EVALUATION OF BASE LINE DATA

This covers the extent and availability of information relating to the plant, for example:

- plant drawings and specifications, manufacturing and construction records, plant modifications;
- current operating rules and limits;
• results of maintenance and inspections;
• staff qualifications, experience and training;
• radiation dose records; and
• plant performance.

THE SAFETY EVALUATION

This can be divided into three aspects, namely:

- the evaluation and trending of operational data;
- the safety analysis of the plant; and
- the evaluation of current management systems.

In support of this work, an operator must ensure that the process of feedback of experience continues to be well applied: that the level of safety as initially envisaged is, at the very least, not impaired; and that the plant concerned is thoroughly re-evaluated by comparison with the evaluation of current safety requirements and technical goals and that effective programmes are in place to maintain safety.

At the meeting held in June 1993 the members of CNRA were supportive of the general approach outlined above. It was noted that there were a number of ways in which the safety evaluations could be met dependent upon individual countries’ approaches including a combination of a number of methods, e.g.:

• Continuous Reviews (on-going surveillance, routine inspections and audits, reviews of operating events, annual performance reviews).

• Periodic Reviews (comprehensive assessment of plant design, operation and safety analysis carried out at regular intervals, PSRs).

The work on long-term safety of ageing NPPs is continuing with the objective of producing guidance which will be helpful to both operators and regulators dealing with the safety requirements of ageing Nuclear Power Plants.

CONCLUSION

Looking ahead, it is clear that the work on long-term safety of ageing nuclear power plants will have to be pursued further, with the objective of producing guidance useful to both operators and regulators. However, already today an international consensus is emerging regarding technical and regulatory requirements necessary for the safe maintenance and continued operation of nuclear power plants.
TOWARD A NEW NEA INTERNATIONAL VENTURE: THE RASPLAV PROJECT

Under severe accident conditions, it is important to cool the debris of the reactor core to avoid any weakening of the remaining fission product barriers. One step of the so-called “defence-in-depth” is the retention of core material in the pressure vessel. The Three-Mile-Island (TMI) accident demonstrated that this objective could be attained by water remaining within the reactor vessel, combined with long-term water injection to cool down the debris and remove the decay heat, and reduction of pressure. Under even more severe accident conditions, this water would boil off and the absence of cooling would thus contribute to the slumping of the core debris to the lower plenum of the vessel, as happened to some extent during the TMI accident. In this case, external cooling of the reactor pressure vessel is a way to remove heat and maintain the primary circuit integrity.

Bilateral negotiations between the U.S. Nuclear Regulatory Commission and the Russian Research Center “Kurchatov Institute” regarding a joint research project to investigate in-vessel core debris cooling through external flooding of the reactor pressure vessel began in 1991. Given the broad interest in this question among OECD countries, an international Project (RASPLAV) to carry out experiments under the auspices of the OECD Nuclear Energy Agency is currently under development. The research to be covered is of interest with respect to both VVER reactors and certain operating Pressurised Water Reactors and Boiling Water Reactors, as well as advanced light water reactors. The proposed Project will be the first NEA International Joint Project to be conducted in a non-OECD country, namely Russia, with partnership of that country on an equal footing with interested OECD countries. The tests will be carried out at the Russian Research Centre “Kurchatov Institute”, with theoretical analysis at the Institute for Safety Development of the Russian Academy of Science. Both the Kurchatov Institute and the Academy of Science are located in Moscow.

There is an obvious connection between this Project and the joint research performed within the OECD TMI Vessel Investigation Project (TMI-VIP) which examined the nature and extent of the damage to the lower vessel structure with a view to determining the margin to failure of the reactor pressure vessel. The TMI-VIP started in 1988 and finished this year.

The RASPLAV Project uses prototypical materials (real corium components and vessel steel) in quantities and at temperatures representative of reactors. This assists in understanding the chemical reactions, which are very complex, and contributes to understanding the natural convection processes. The main experiment will involve 200kg of corium and there are supporting smaller scale experiments to study material properties and chemical interactions.

Several molten fuel structural experiments are planned and the technical objectives include:

- determining material properties such as emissivity, viscosity, and density to aid predictions of the volume, the composition, and the temperature of the core melt;
- evaluating the interaction of molten core material with the lower head of the vessel and determining the heat fluxes imparted to the lower head;
- exploring the effect of scaling, in order to assure that the experimental data will be suitable to validate existing codes.

Measurements made in conducting the experiments will include melt temperature measurements in the RASPLAV furnace and in the vessel lower head as well as heat flux measurements.

The information from the RASPLAV Project will complement the database obtained from other experiments and projects that provide information related to reactor vessel failure, such as the Swiss PSI CORVIS experiments, the OECD TMI Vessel Investigation Project and the FARO experiments at Ispra.

It is believed that there are substantial benefits in expanding the current programme of the Kurchatov Institute into an OECD project, for the following reasons:

- the OECD countries participating in the Project will obtain important experimental data on the behaviour of core debris in vessel lower heads, and on cooling of core debris by external cooling of the vessel;

*DR. ALEX MILLER IS A MEMBER OF THE NEA NUCLEAR SAFETY DIVISION.*
the technical programme will be significantly improved by involving the international community of experts;

increased financial resources will allow a better experimental programme that can be done on a reasonable schedule;

the Russian experts will gain substantial experience in dealing with OECD countries;

the OECD countries will obtain benefit from the expertise available in Russia.

Preparatory meetings have been held at OECD in April and July 1993 with Russian experts and all OECD countries with Pressurised Water Reactors. The NEA secretariat has been charged with the setting up of the project, which is intended to be started at the beginning of 1994. The budget will be US$5.45 million in total, over a three year period.

The research to be covered by the Rasplav Project is relevant to both western type light water reactors and VVER reactors, such as that at the Paks nuclear power plant in Hungary.
VALIDATING ACCIDENT CONSEQUENCE ASSESSMENT CODES

INTRODUCTION

Increasing use is being made internationally of quantitative risk assessment as an input to the evaluation and improvement of safety, both for nuclear and other types of installations. The nature and extent of the risk assessment performed may vary considerably according to its intended purpose. At one extreme it may be limited to quantifying the probability with which major damage may occur to a facility; at the other extreme a comprehensive assessment may be made of the health and environmental risks presented by an installation. Assessments of the latter sort are more common in those countries which have developed quantitative guidance or targets for nuclear and/or other installations that are expressed in terms of risk to health.

With such an increasing use of quantitative risk assessment in the evaluation of safety, greater attention has been given to, and demands placed on, the reliability of the methods used and the inherent uncertainty associated with their predictions. In this context, the Commission of the European Communities and the OECD Nuclear Energy Agency (NEA) initiated in 1991 a study to compare the predictions of probabilistic consequence assessment (PCA) codes which are used in certain probabilistic safety analyses and are concerned with the estimation of the health and environmental risks from postulated accidents at nuclear installations. The initiation of this comparison was particularly opportune in that a number of new PCA codes had been developed in the late 1980s and early 1990s.

OBJECTIVES

The main objective of the study was to compare the predictions of participating codes for a range of postulated accidental releases and to assess the significance of any differences observed. However, a number of other key objectives were established. It was considered important that the exercise should contribute to code quality assurance programmes and guide future research and development. It was also expected that the study would facilitate interaction between code developers and code users, including regulators, and as such would enhance the general appreciation of the usefulness of PCA codes and perhaps encourage the harmonisation of methods where appropriate. A final objective was to prepare a report on the study which would represent a major landmark in the risk assessment field.

TECHNICAL SPECIFICATION

In order to perform the study, a detailed specification was drawn up. Population, agricultural production and economics data for the region of interest were constructed. Information on various countermeasures were also prepared: four different measures were considered: sheltering, evacuation, relocation and food banning. This information included criteria for countermeasures implementation, e.g. thresholds for food bans. Data characterising a nuclear reactor were also prepared. This included the inventory of radionuclides of the system and the characteristics of the postulated accidental releases (e.g. the amounts of each radionuclide released, the release duration, the energy content of the release, the physico-chemical forms of the released material). The characteristics of the postulated releases covered a wide range and were chosen to provide a rigorous and comprehensive test of the main features of the participating codes. For example, some of the postulated releases are characterised by a very short release duration, around one hour, others are spread over much longer timescales, up to one day, while some comprised a few discrete phases.

RESULTS

Seven codes from various countries participated in the exercise: ARANO (Finland), CONDOR (UK), COSYMA (Cec), LENA (Sweden) MACCS (USA), MECA2 (Spain) and OSCAAR (Japan). They calculated a wide range of consequences, for example: collective doses, early and late health effects, economic costs and the effect of countermeasures on people and agriculture. In each case, the probability distributions predicted by the codes were compared.

As expected, in view of known modelling and other characteristics of these codes, there were differences between the consequences predicted by the various codes. The magnitude of the variations between code predictions

depended on the particular consequence endpoint being considered. However, with few exceptions, the spread of predictions was within a factor of a few. This spread is small in comparison with the overall uncertainty associated with the estimation of risk from postulated accidents at nuclear installations (i.e. including the estimation of the probability of a release, the characteristics of the released material and the resulting consequences). While of scientific and technical interest, the observed differences are not, therefore, central to decisions on the acceptable use of any of the participating codes within a complete risk assessment. Additionally, the spread observed between predictions provides little, if any, insight into the magnitude of the inherent uncertainties associated with the predictions of the participating codes. These inherent uncertainties were not addressed in this exercise.

Two of the code systems, COSYMA and MACCS, are used by several institutes and, in a parallel exercise, a comparison was also made between the predictions of users of the same code. Differences were observed between the respective predictions and these were either resolved or explained; they arose, mainly, from differing interpretations and simulations of the specification. As a direct outcome of this exercise, international user groups have been established for COSYMA and MACCS, which should greatly enhance their reliable application and provide an effective forum for exchange between PCA code developers and users.

CONCLUSION

This major exercise has provided a valuable opportunity to compare approaches and methods for probabilistic consequence analysis from many organisations and countries throughout the world. The principal aim of comparing the predictions of these codes and assessing the significance of differences observed under a wide range of conditions has been achieved through the development of comprehensive technical specifications.

As noted earlier, the results from the comparison process, where spreads of predictions covering a factor of a few are typical, are considered to represent acceptable agreement, in the light of general uncertainty levels in the overall assessment of risks.

Through the development of comprehensive benchmark specification, the exercise has served to enhance the quality assurance aspects of the participating codes. The exercise has also provided a valuable forum for discussion on various approaches to PCA model and code development. This has increased the general awareness of the applicability of these methods and has facilitated the process of international harmonisation.

The results of the exercise, along with the interactions between the various participants, have also led to a number of suggestions for future developments in the field. The developments suggested include: obtaining a better understanding of uncertainty, extending the relatively simple agricultural countermeasures currently modelled, improving the estimation of economic costs and clarifying an ambiguity in the current modelling of early health effects. Additionally, with the increasing use of PCA codes by many institutes and organisations, it is recommended that greater attention be given to providing appropriate documentation and training to ensure the proper use of the codes. The creation of user groups for particular codes will assist in this respect.

The results of the study have been compiled in four reports: an overview report which is intended for non-specialists in PCA who may use the results from such assessments as an input to their decisions on safety; a detailed technical report which is intended for specialists in PCA and which contains the detailed results of the comparison; and, two reports, intended for PCA code users and specialists, which contain the results of comparisons between multiple users of the same code. These last two studies, while strictly not comparisons between codes, were particularly important given the wide distribution of some PCA codes and the extensive use being made of them by many organisations.

This comparison has made an important contribution to enhancing the quality assurance of the various participating codes and has provided many insights into their strengths and limitations. It will continue to provide a valuable benchmark for some time to come against which new or improved codes can be measured.
STEAM GENERATORS: CLOSELY-MONITORED EQUIPMENT

Within the OECD Nuclear Energy Agency (NEA), an international working party is specifically responsible for exchange of information about events relating to the safety of the nuclear power plants in operation in OECD countries. The information is exchanged chiefly through the IRS (Incident Reporting System) set up by the NEA in 1980 for the purpose of notifying safety-related events and thereby contributing to the overall improvement of nuclear plant safety in Member countries. Experience with the IRS soon led the working party experts to examine the behaviour of steam generators (SG); these components being specific to pressurised water reactors (PWR): the information contained in the IRS reports showed that steam generator tubes were subject to various types of degradation on an unexpected scale and frequency.

Two international meetings held by the NEA in 1984 and 1991 had revealed the many different origins of the mechanisms causing damage to these components, as well as their continued increase in spite of the improvements in inspection techniques and in our understanding of the faults and fault management.

In June 1992, the members of the NEA Committee on Nuclear Regulatory Activities (CNRA) held a broad exchange of views on regulatory issues and experiences relating to SG's and in particular on aspects concerning the various types of degradation, inspection techniques and fault acceptance criteria, preventive and corrective action and, finally, surveillance by the safety authorities. The discussions showed that although opinions converged on many points concerning the nature of the degradation, inspection techniques, the corrective measures to be taken and the role of the safety authorities, it was probably too early to draw up joint practices and rules, especially since inspection techniques and regulatory policies were rapidly evolving.

What does a steam generator look like, what forms does the damage to these components take, what are the risks entailed and what are the implications for the general public and power plant workers and finally, what steps are being taken to remedy such damage?

THE STEAM GENERATOR: COMPLEX AND SENSITIVE EQUIPMENT

As at 1st January 1993, there were 350 pressurised water reactors (PWR), heavy water reactors (HWR) and water-cooled, water-moderated reactors (VVER, in Eastern European countries) throughout the world (of which 79 were under construction). 220 of these (including 17 under construction) are installed in OECD countries (180 PWR, 21 HWR, 2 VVER). Depending on their capacity, ranging from a few tens of electrical megawatts (MWe) to 1 400 MWe for the newest facilities, these reactors are equipped with 2, 3 or 4 steam generators. The SG's concerned here chiefly consist of a heat exchanger usually having a height of over 20 metres, weighing more than 400 tonnes and containing over 5 000 tubes shaped like an upturned U, which are made of Inconel 600. These are to be found in most PWR's operated in OECD countries.

During reactor operation, the tubes (diameter approximately 2 centimetres and thickness about 1 millimetre) are subjected to a wide pressure differential of approximately 80 bars and to temperatures in excess of 300°C. The pressurised water in the primary circuit is heated in the reactor core then passes through the U tubes,

*MR. J.P. CLAUSNER IS A MEMBER OF THE NEA NUCLEAR SAFETY DIVISION.*
releasing the heat to the water in the secondary circuit, which flows around the tubes and is thus converted into steam. The steam then drives the turbine, which drives the alternator to generate electricity. In other words, the two functions of heat exchange and separation between the radioactive hot water in the primary circuit and the non-radioactive water in the secondary circuit feeding steam to the turbine are performed by the tubes, which represent a considerable surface area and are very thin.

These tubes are a specific feature of PWR design under the "barrier" concept defined by nuclear safety experts. This concept is based on the containment of radioactive products in the installation in order to limit their dispersal under all circumstances, especially in the event of an accident, and thus protect the public against the consequences of any such release. It consists of erecting a series of leak-proof barriers between the source of radioactive products (nuclear fuel) and the public. As a rule, there are three such barriers: the fuel cladding, the primary system pressure boundary and the reactor containment. Consequently, steam generator tubes provide both the second and the third barriers since the steam produced in the SG directly actuates the turbine located outside the containment.

### STEAM GENERATOR AILMENTS

The main tube degradation mechanisms in Inconel 600 steam generators, which may lead to piercing and even steam generator tube rupture (SGTR), include corrosion phenomena and mechanical damage caused by vibration, wear or migrating foreign bodies (loose parts).

### RISKS ARISING FROM SUCH AILMENTS

The largest risk relating to safety is the SGTR (steam generator tube rupture). This accident, which is taken into account in studies on design basis accidents, shows a number of specific features.

It consists of a break in the primary system causing primary coolant, which contains some radioactivity, to enter the secondary.
circuit instead of flowing into the containment. Because of the high pressure differential between the primary and secondary systems already mentioned above, an SGTR produces a large primary coolant leak into the secondary circuit of up to 180 cubic metres/hour at the start of the accident. The primary coolant leak into the secondary circuit can lead to direct release of radioactive products into the atmosphere. The SGTR triggers automatic reactor shutdown and start-up of the safety injection system. The SG concerned by the tube break receives water from the auxiliary feedwater system, which is started up as soon as the safety injection begins, and also fluid from the primary leak. This causes the level to rise faster than in the other steam generators. If no further action were taken, the water level would continue to rise inside the SG until it was full and would then lead to the direct release of contaminated water via the safety valves to the outside.

**TUBE RUPTURE DIAGNOSIS**

The management of a SGTR does not present any special difficulties especially as far as limiting the radiological consequences is concerned, provided the operator makes the right diagnosis without delay. He has several parameters or criteria at his disposal, including the increased activity in the secondary system.

Worldwide experience acquired from incidents has shown that monitoring secondary circuit activity is highly important since it gives an early clue for diagnosing a tube leak. Consequently, a system has been developed for measuring steam activity due to nitrogen 16, which is now used in most OECD countries. High-performance sensors fitted to the steam pipes at the containment exit ensure early detection of SG tube leaks. This method also has the advantage of monitoring changes in leakage rates and anticipating any sudden break, so that it is in fact a highly reliable diagnostic tool.

**CONTROLLING A PRIMARY/SECONDARY LEAK**

After identifying which steam generator has sprung a leak, the operating team takes immediate steps to minimise any subsequent discharges by isolating the steam generator concerned. The operators do this by closing the main steam valve thus cutting off the steam generator from the turbine. The next step is to limit any direct releases to the atmosphere as soon as possible. The water supply to the steam generator is cut and the blow-down system is restarted so that the water level rises more slowly.

Next the primary coolant leak into the secondary system must be stopped while ensuring reactor core cooling. To stop the leak, the operator brings the primary pressure down as soon as possible to remove the pressure differential between the primary and secondary circuits and prevent the

<table>
<thead>
<tr>
<th>Unit</th>
<th>Date</th>
<th>Origine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Beach (US)</td>
<td>26/2/75</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Surry 2 (US)</td>
<td>15/9/76</td>
<td>Small bend corrosion</td>
</tr>
<tr>
<td>Doel 2 (Belgium)</td>
<td>25/7/79</td>
<td>Small bend corrosion</td>
</tr>
<tr>
<td>Prairie Island (US)</td>
<td>2/10/79</td>
<td>Loose part</td>
</tr>
<tr>
<td>Ginna (US)</td>
<td>25/1/82</td>
<td>Loose part</td>
</tr>
<tr>
<td>North Anna (US)</td>
<td>15/7/87</td>
<td>Vibration fatigue</td>
</tr>
<tr>
<td>North Anna (US)</td>
<td>25/2/89</td>
<td>Burts plug</td>
</tr>
<tr>
<td>Mac Guire (US)</td>
<td>07/3/89</td>
<td>Manufacturing fault</td>
</tr>
<tr>
<td>Mihama 2 (Japan)</td>
<td>09/2/91</td>
<td>Fretting fatigue</td>
</tr>
<tr>
<td>Palo Verde 2 (US)</td>
<td>14/03/93</td>
<td>Corrosion</td>
</tr>
</tbody>
</table>
primary coolant from leaking. Reactor cooling continues via the steam generators not affected by the fault then via the residual heat removal system until the conditions are right for opening up the primary system and repairing the faulty steam generator.

Thanks to this procedure, the release into the atmosphere of low radioactive steam, mainly containing iodine 131 and rare gases, is minimised. As shown by the table below, all major tube ruptures or leaks to date have entailed very low releases.

**EXPERIENCE WITH SGTR**

Since 1975 about ten major tube ruptures or leaks at nuclear power plants have been reported. By the end of 1992, the experience acquired with the different PWR systems in OECD countries represented approximately 2 890 production years. This is the only design-basis accident where feedback has been successfully used to compare an observed frequency with an a priori estimated frequency on the one hand, and measured releases with conservative evaluations calculated in accident studies on the other, and to draw lessons for both existing and future installations.

**REMEDIAL ACTION**

On the basis of the analyses conducted following tube ruptures and leaks, lessons have been learnt and measures drawn up for the purpose of preventing future degradation but also of limiting the consequences of any actual leak for the general public. These measures cover both preventive and corrective action, monitoring and incident management during operation, in-service inspection programmes and activities of the regulatory authorities.

Preventive measures are taken during and after equipment manufacturing. One of the most widely applied measures for both new and replacement steam generators consists of selecting a different material for tube fabrication. Experience has also shown that a small reduction in primary coolant temperature can also limit the rate of propagation of degradation phenomena, and several countries have already opted for such a reduction. Another major parameter is primary coolant and secondary chemistry, both the subject of strict control. Finally, chemical cleaning of the secondary side of steam generators is also a very widespread practice, both as a preventive method and as a corrective one.

Corrective measures, which tend to cover unacceptable faults and severe failures, chiefly include plugging, tube
sleeving and the replacement of steam generators. Electrolytic nickel coating is used preventively and correctively. Tube repair techniques are based on safety criteria defined by the safety authorities and on the technical analyses performed by plant operators. These criteria and analytical results govern the choice of a suitable solution. Steam generator replacement is a very expensive operation in technical and in economic terms but it offers a viable option for extending nuclear plant life. Over the next decade more than a hundred steam generators are to be replaced in Belgium, France, Japan, Spain, Sweden, Switzerland and the United States.

**PLANT OPERATION**

Monitoring during operation is based on continuous surveillance of tube leak tightness. The purpose of this surveillance is to prevent contamination of the secondary system by detecting tube degradation before the tube is ruptured (concept of the leak prior to rupture) and in the event of a tube rupture, by identifying the steam generator affected as soon as possible. Leak control is therefore a major component of in-depth defence. During operation, the maximum acceptable leakage rate is set by the criteria in technical operating specifications. These specifications also require a very low level of primary coolant activity so as to limit radiological consequences in the event of release into the atmosphere.

**OPERATOR TRAINING**

It is essential for operators to be well prepared for handling any accident. Prompt operator response determines the extent of any release of radioactive products into the atmosphere. Nuclear licensees have therefore held information sessions for their operators and have developed specific forms of operator training for tube rupture accidents. As in all accident situations where a procedure for handling the accident has been drawn up, SGTR is...
systematically included in basic training modules using simulators and also in refresher courses.

**IN-SERVICE INSPECTION**

Shutdown monitoring measures also form part of the requirements under the basic preventive maintenance programme, to enable licensees to maintain equipment reliability and availability. This maintenance strategy allows licensees to anticipate potential damage and then to define suitable action, both preventive and corrective. Checks are performed during in-service inspections according to principles which take into account the various types of degradation identified during checks or from feedback.

In-service inspections involve hydraulic or helium leak tightness and eddy current testing performed on a large number of tubes (several hundred thousand each year). The progress made in automation and computer processing means that all tubes can now be checked without extending plant outage and workers are less exposed to radiation in the course of the work. Among the other improved techniques that are being increasingly used ultrasound tests and video inspection methods should be mentioned.

Finally, improved understanding of degradation phenomena is a very important aspect for licensees and safety authorities. Licensees therefore have to conduct many different expert evaluations and destructive tests on an ever increasing number of tube samples from steam generators.

**DESIGN**

Feedback can be used to study further measures in order to limit the consequences of steam generator ruptures in steam generators now being operated as well as in new models: use of different materials, improvements to internal steam generator components and adjustment of certain operating parameters.

**CONCLUSION**

Very early on, the precursor problems observed on steam generators in nuclear power plants alerted licensees and safety authorities in OECD countries to the possibility of an SGTR occurring and to the need for preventive action, although it was not yet possible to draw up joint practices and regulatory policies. During exchanges of views between licensees, constructors and safety authorities, divergences of opinion were observed. The technical approaches, which can be difficult to reconcile, are further complicated by regulatory aspects and sometimes also by the influence of public opinion. Nevertheless, there are many points of convergence among the various participants concerning ways of reducing the probability of such an accident and of limiting its consequences for the general public. Some of these points include the need for the various parties to share operating experience more fully and to ensure that this experience is adequately taken into account, as well as for regulatory authorities to draw up rules and requirements that will take this experience into account.
PALEOHYDROGEOLOGY TO HELP EVALUATE WASTE DISPOSAL SITES

Paleohydrogeology can be broadly described as “a combination of observations on hydrochemical and isotopic differences in various groundwater zones or bodies, mineralogical data on the rock formations and the hydraulic properties of the same formations, which are then compiled to allow interpretation of the evolution of the rock-water system over long time periods in the past”.

In the process of evaluating sites for the construction of radioactive waste repositories, it is essential to gain a detailed knowledge of the hydrogeology of the site and its surroundings so as to be able to predict the transport of any uncontained radionuclides from the repository to the environment accessible to man. These predictions have to be made over time periods of thousands to millions of years. One of the keys to a successful assessment of the performance of the site is to assess the variability of hydrogeologic processes that could occur at the site over the long time periods. Unfortunately, hydrological testing, in the form of pump tests and pressure head measurements are done over a matter of days or months. This only samples a snapshot of the hydrogeology in geologic terms. Therefore, other ways to investigate the variability of the hydrology of the site had to be found. One method consists in using evidence of paleohydrogeology to assess the past geologic record of the hydrology of an area. In this way the variability of the hydrology over long periods of time can be established. Figure 1 illustrates some of the physical and chemical processes that paleohydrogeological studies can address.

A workshop on paleohydrogeological studies and their applications to radioactive waste disposal was organised in Paris in the autumn of 1992 under the sponsorship of the NEA Radioactive Waste Management Committee with the following objectives:

- to describe methods of deriving paleohydrogeological evidence and discuss applications of this evidence to help develop strategies for the characterisation of sites for radioactive waste disposal;
- to exchange information and experience in the collection, analysis and application of paleohydrogeological evidence among Member countries; and
- to explore the needs and desirability of future work in their area.

Using the concept of a paleohydrogeological study, the information that can be derived from a site characterisation programme includes:

- major categories or bodies of water present in different regions of the geologic environment;
- the residence times (“ages”) of these different bodies of water;
- the degree of mixing between the bodies of water and the rates at which the mixing occurs; and
- the principal pathways for water movement and the extent to which these have influenced the overall evolution of the groundwater regime.

There are two ways to incorporate this information into performance assessments. The first is to use the information in a contextual sense by demonstrating through a paleohydrogeological study that there exists a well-founded understanding of the hydrology of the site. This understanding must be based on a description of the evolution of the hydrological regime supported by the evidence acquired. With this knowledge, predictions of the future evolution of hydrogeology can be made with confidence and can support the simplified analysis done in a total performance assessment.

The second way of using paleohydrogeological evidence in performance assessment is more direct, more quantitative and more challenging. It consists in using the information to test predictive models, ideally under “blind” conditions. It requires that the modellers receive a limited data set to construct and run the model to predict certain parameter values. These values are then compared to the actual measured values derived from the paleohydrogeological studies. This type of exercise allows validation of the predictive capabilities of the performance assessment models.

Methods of collecting paleohydrogeological evidence include:

- the use of microfossils as indicators of paleohydrogeology and paleoclimate;
- natural tracer isotopes such as Sr, Nd and Pb isotopes;
- stable isotopes such as deuterium and "O;
- inorganic geochemistry.

There is a continuing debate among experts as to whether paleohydrogeological studies provide the kind of
information and understanding of hydrogeologic systems that is necessary. Some experts express the opinion that current studies are not yet able to describe how sites have evolved over long time periods. It is recognised that this is still an infant science and for it to mature and provide the kind of information expected, performance assessment modellers will have to develop more refined questions.

Much discussion also centres on what methods should be used and how should the data be collected. There is general agreement that careful sampling programmes should be planned. For example, to obtain representative samples, hydrochemistry must be done rapidly, including gaseous samples for noble gas analyses. Many agree that a variety of methods should be applied to solve these problems because of the highly complex nature of hydrochemical information coupled with other types of analyses. By using multiple methods the ambiguity of the results can be reduced. In addition, careful quality assurance has to be applied to data collection and the tools for interpreting results. Care must also be taken to look at entire systems such as understanding all of the sources and sinks for isotopes of interest.

Another major point of discussion concerns the role of communications. It is recognised that most paleohydrogeological studies are being carried out independently from performance assessment modellers, and from hydrologists. The need for improved communications and careful planning between the scientist carrying out these studies and the end users is of course desirable. In addition, as the general public has difficulties to understand the language of isotope geochemistry, efforts must be undertaken to enhance the communications and thus the understanding of science in the public.

Among the major conclusions drawn from the workshop, it is worth mentioning that:

• paleohydrogeological studies should be a central theme within site characterisation programmes, and should be carefully planned and integrated with the other investigations from the beginning;

• evidence from paleohydrogeological studies are perhaps the only way to validate long-term hydrological predictions used in performance assessments;

• many ambiguities and problems in data interpretation remain, which can be reduced by using as many methods as possible;

• communications between scientists performing paleohydrogeological studies and the performance assessment modellers hydrologists, and the general public need to be improved.
ACHIEVING NUCLEAR SAFETY

The NEA recently published a report entitled "Achieving Nuclear Safety, Improvements in Reactor Safety Design and Operation" which was prepared by Mr. S. Rippon, a scientific writer.

Intended for the non-specialist reader, this report reviews the significant efforts that have been made in recent years to enhance the safe design and operation of nuclear reactors in OECD countries. The reactors in operation today in these countries have widely benefited, in large part through international co-operation, from the lessons learned from past experience and from the pooling of resources in safety research and development.

The report shows how these efforts have led to a more coherent and consistent approach to safety, which has gone a long way to minimising the risk of major problems with the operation of today's reactors.

Over the past forty years, nuclear power plants around the world have clearly established their capability of producing large amounts of electrical energy from remarkably small quantities of uranium fuel. This means that they have opened up a very large energy resource which can meet many of our needs for the foreseeable future. Since the uranium fuel needed for nuclear power plants is readily available from many different regions of the world, there are also few worries about the security of supplies. If properly controlled, nuclear power plants produce very low emissions and certainly have much less impact on the environment than more conventional fossil-fuelled power plants.

How then do we ensure proper control of nuclear power plants so that we can enjoy the benefits? First and foremost, the answer is attention to safety of the nuclear reactors at the heart of the plants. Exceptionally high standards of safety must be applied to the design, building and operation of nuclear reactors. This is an obvious necessity because of the potentially very dangerous nuclear process and the accumulation of radioactivity in the core of any reactor.

The most widely used types of nuclear reactors are water-cooled designs. This book examines the safety of water-cooled reactors in operation in OECD countries, and in particular the progress that has been made in improving their safety in recent years. Of the three main types of water-cooled reactors, we will be talking a good deal about pressurised light-water reactors (PWRs) since these are more numerous, but the information presented also generally applies to the other types of water-cooled reactors in the OECD. All these reactors are much safer today because of a better understanding of problems and improved solutions applied over the past decade.

The paramount importance of safety was, of course, recognised from the earliest days of the peaceful development of nuclear energy. Safety was a major element of national and international programmes of research and development. The nuclear industry made significant efforts to anticipate and prevent everything that might go seriously wrong without having to learn lessons from major accidents.

COOLING UNDER ALL CONDITIONS

One of the essential considerations for maintaining the safety of a reactor is to ensure the removal of heat from the reactor core. In water-cooled reactors, the method of removing heat with a flow of pressurised water pumped through the core is very effective and in principle quite simple. But understanding exactly what could happen if there is an upset, or transient, in the cooling system can be quite complicated. During the development of water-cooled reactors, a tremendous amount of research work was devoted to characterising the behaviour of the pressurised water systems under different conditions. Extensive computer codes were developed to model this thermal-hydraulic behaviour over a wide range of conditions, from normal operation through to extreme conditions of postulated accidents.

A feature of this work in recent years has been greatly increased international participation. This not only helps to pay for some of the more expensive programmes of experiments, but also brings a greater body of expertise to the task of analysing the results. It has also made it possible to test the ability of computer codes developed in different countries to predict the results of experiments on a wide diversity of different test facilities. Scaling factors, which are inevitably involved with some of the physical parameters of experimental tests, can also be checked on a wider range of facilities. As a result, all those involved in this work have a better understanding of the strengths and weaknesses of different computer codes and know how and where to use them to best effect.

*MR. SIMON RIPPON IS A SCIENCE WRITER IN THE UNITED KINGDOM.

Cooling systems for reactors are much more effective today as a result of all these studies. This is not due to any radical change in the basic design of the systems for either normal or emergency cooling, but rather to important insights into how they should best be operated over a wide range of different circumstances. These are clearly set out improved operating procedures and are regularly practised on training simulators. Programmes for backfitting specific plant modifications have also been completed to strengthen the weak links that were identified from the testing and analysis. For example, the reliability of the auxiliary pumping systems, which supply feedwater to the secondary side of steam generators, has been upgraded to the full safety standards of the primary side equipment in recognition of their importance in supporting the main route for removal of heat from reactors.

Better Barriers

An overriding objective in reactor safety is to prevent the escape of radioactivity. A multiple barrier approach has been adopted. The safety features already discussed are mainly aimed at protecting the first of these barriers, namely the nuclear fuel and its cladding, which are very effective in retaining all the intensely radioactive by-products that result directly from the nuclear fission reaction. Coolant water and the primary coolant circuit, as well as helping to protect the fuel barrier, provide an effective second barrier for retention of any radioactivity that might escape from the fuel if it were to be damaged. As a final barrier, a large single-walled or double-walled containment building is provided around the whole reactor plant and is designed to withstand the worst conceivable rupture of the primary coolant circuit.

From the earliest days of reactor development, efforts have been devoted to the first barrier through careful design, testing and quality control of nuclear fuel fabrication. Exceptionally good performance has been obtained, with typically less than one failure in every 100 000 fuel rods irradiated in water-cooled reactors. Work has nonetheless been continued to study the likely performance of fuel under the most severe conditions that might result from postulated accidents.

The second main barrier for keeping in radioactivity is provided by the primary coolant circuit. Obviously, if this circuit can retain the highly pressurised water coolant, then it will also be an effective barrier for keeping in radioactivity. The high integrity of this barrier depends in the first place on very high standards of quality in manufacture of the steel components, especially the large reactor pressure vessels used for light-water reactors. An important area of progress in the early 1980s was the development of greatly improved non-destructive testing techniques for pressure vessels and other high-pressure steel components, both during their manufacture and periodically during the service life of a plant. But there was still a need to say just how good the testing was in order to ensure that the smallest crack that might grow to a critical size could be detected well within the periods of in-service inspections.

The final barrier is provided by large containment buildings completely enclosing the nuclear components of water-cooled reactors. Such a containment saved the day at TMI by preventing any significant release of radioactivity into the environment.

Thinking about the Unthinkable

Improved assurance of containment integrity is one of a number of practical outcomes from a great deal of theoretical study of severe accidents. Most of the safety features on water-cooled reactors are intended to prevent any damage to the fuel in the reactor core. To assess their ability to do this, designers and regulators pose some challenging "what if" scenarios, which are known as design basis accidents. Even before TMI, some serious consideration was also being given to extreme situations that might go beyond the design basis accident, and since this actually happened at TMI, more-
extensive work has been undertaken on the study of more severe accidents.

Most of these severe accident scenarios start with the assumption that the reactor fuel has been damaged, and postulate the progression of accidents to melting down into the bottom of the reactor vessel and even through the vessel into the basement of the containment building. The important thing is to realise that all is not lost. Quite a lot could still be done to halt the progression and limit the consequences of such an accident using the existing safety systems, as long as they are used in the right way. Improved emergency procedures are being developed by the operators of nuclear plants, and they are expected to form an important part of the regular training of staff.

Another important aspect of severe accident analysis has been a determined effort to specify more precisely and realistically just what sort of mixture of radioactive species might be expected to escape to the environment if all the barriers were eventually breached. These so-called source term studies seek to characterise the complex mechanisms of escape of different radioactive fission products from damaged or melting fuel, and to assess the potential for subsequent retention within the primary circuit or the containment.

**ALWAYS MORE TO LEARN**

Learning from each other is arguably one of the most important ways of avoiding accidents in any sphere of activity. In the case of nuclear power plants, the feedback of operating experience can take place at many levels: within an electric utility that operates several nuclear power stations; between groups of operating utilities and the manufacturers who supplied them with particular designs of plant; to national and international associations of utility operators; and to national regulatory bodies and international nuclear agencies.

International reporting of nuclear operating experience has been greatly expanded, providing a wider body of experts for analysis. With more than 420 nuclear power reactors of all types now operating around the world, the wealth of operating experience is growing rapidly year by year. Entering 1992, the accumulated total of operating experience was in excess of 6 000 reactor years. The majority of this experience is very good and makes an important contribution to assuring safety for future operation of nuclear power plants. Another encouraging development among the operating organisations in recent years has been an increase in the sharing of both good and bad experiences, so that others can emulate good practices as well as learning from the mistakes.

At a more technical level, international co-operation on safety research and development has always been a feature of the nuclear industry, especially among the many countries that have adopted similar designs of water-cooled reactors. Co-operation has taken place between many different organisations at bilateral and multilateral levels. International agencies such as the OECD Nuclear Energy Agency, the International Atomic Energy Agency and the Commission of the European Communities play an important role in co-ordinating and encouraging such work. In particular these agencies provide a forum for the review, intercomparison and interpretation of the results of safety research work in different countries.
Overall safety of a plant is assured by applying a defence-in-depth approach, with several levels of backup systems and several protective barriers. They act as safety nets, and extend even to safety systems to prevent holes developing in the safety nets. Redundancy and diversity are used to provide appropriate levels of reliability for the various safety systems.

Traditionally, engineers determine the safety of nuclear plants by considering postulated accident sequences – referred to as design basis accidents – and by making conservative assessments of the safety margins built into each of the layers of protection that are designed to halt the accident sequence. This deterministic approach is supported by knowledge of the engineering codes of practice that have been used, the quality control that has been applied and a great deal of testing.

Techniques for assessing the safety of nuclear plants have made significant progress in the past ten years. Notably, the techniques of probabilistic safety analysis (PSA), in which the statistical chance of success or failure at each step in a chain of events is assessed for all identified accident sequences to provide an overall probability of serious consequences, have been greatly refined and are now used as a tool for detailed assessment of specific plants or sections of plants.

PSA complements, but does not replace, the deterministic approach to safety review which has been adopted by the regulatory bodies that are responsible for licensing nuclear power plants in different countries. These regulatory bodies require the designers and operators of nuclear plants to adopt a defence-in-depth approach and support it by the application of the best engineering standards, redundancy of safety systems, multiple containment barriers, and comprehensive quality assurance and inspection at all stages of design, construction and operation of a plant.

While regulatory bodies preserve their national independence, they have increasingly recognised the great mutual benefit of international exchange of information. Here again the international nuclear agencies are fulfilling an important role in providing the forum for exchanges and in facilitating expert analysis on common issues. Out of this have come international standards, codes of practice and safety principles which can be adopted by countries embarking upon nuclear power programmes as well as being a constant measure against which existing national standards can be measured. It is a step on the road to international harmonisation of nuclear safety standards.

Water-cooled reactors operating around the world are certainly safer today as a result of developments during the past decade. There have, however, been no radical changes in the design of reactors. Rather, the exhaustive analyses of safety have tended to confirm the basic design concepts and safety philosophy that had been adopted from the outset of the civil development of nuclear power. Programmes of backfitting on plants have been mainly confined to strengthening safety systems at any weak points identified by the improved methods of analysis. There has also been some extension of protection systems to cover more severe potential accidents.

Human performance and the man-machine interface were identified as suspect areas and much has been done to improve this situation. This includes more exhaustive training of operators to increase their basic understanding of plant functioning, improvements in control and instrumentation systems to give better support to operators, and increased automation of essential safety systems. In addition there has been a widespread promotion of the concept of a safety culture which should be practised by everybody involved in the design, construction, operation and regulation of nuclear power plants.

For future nuclear power plants, it is reasonable to ask whether we should start anew with reactors designed to offer greater inherent safety, with passive protection systems that require minimal mechanical and human actions to bring them into play. On the other hand, it may be better to pursue the evolutionary development of existing water-cooled reactor designs, which have the benefit of drawing on the growing fund of worldwide operating experience. Designers are actively working on both approaches and the end result may not be so very different – evolution of existing reactor designs are expected to incorporate some additional passively operated safety systems, while new designs may still be expected to favour the basic water-cooled reactor technology.
At the end of 1992, the total capacity provided by the 320 reactors now installed was 267.2 gigawatts (GWe). Another 19 reactors (20.0 GWe) were under construction and two (2.1 GWe) were firmly committed. The total capacity of OECD nuclear power plants in the year 2000 is projected to be about 296 GWe. The 1.7 GWe of capacity that are expected to be retired between 1993 and 2000 are already deducted from these projections.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>5.5</td>
<td>39.0</td>
<td>5.5</td>
<td>36.4</td>
<td>5.5</td>
<td>34.2</td>
</tr>
<tr>
<td>Canada</td>
<td>13.8</td>
<td>13.2</td>
<td>15.5</td>
<td>13.5</td>
<td>15.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Finland</td>
<td>2.3</td>
<td>18.3</td>
<td>2.3</td>
<td>16.9</td>
<td>3.4</td>
<td>21.9</td>
</tr>
<tr>
<td>France</td>
<td>57.7</td>
<td>54.6</td>
<td>58.5</td>
<td>4.4</td>
<td>64.3</td>
<td>54.4</td>
</tr>
<tr>
<td>Germany</td>
<td>22.5</td>
<td>19.2</td>
<td>23.1 (a)</td>
<td>19.7</td>
<td>23.1</td>
<td>19.6</td>
</tr>
<tr>
<td>Italy</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Japan</td>
<td>33.9</td>
<td>19.1</td>
<td>39.6 (a)</td>
<td>20.3</td>
<td>47.5</td>
<td>21.3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.5</td>
<td>2.9</td>
<td>0.5</td>
<td>2.5</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Spain</td>
<td>7.0</td>
<td>15.9</td>
<td>7.0 (a)</td>
<td>15.3</td>
<td>7.0</td>
<td>13.7</td>
</tr>
<tr>
<td>Sweden</td>
<td>10.0</td>
<td>29.7</td>
<td>10.0</td>
<td>28.7</td>
<td>10.0</td>
<td>28.4</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3.0</td>
<td>19.4</td>
<td>3.2</td>
<td>20.3</td>
<td>3.2</td>
<td>18.8</td>
</tr>
<tr>
<td>Turkey</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>12.0</td>
<td>16.0</td>
<td>13.0 (a)</td>
<td>16.9</td>
<td>12.2 (a)</td>
<td>14.8</td>
</tr>
<tr>
<td>United States</td>
<td>99.0</td>
<td>13.3</td>
<td>101.0</td>
<td>13.4</td>
<td>104.0</td>
<td>13.2</td>
</tr>
<tr>
<td>Total OECD</td>
<td>296.2</td>
<td>16.0</td>
<td>267.2</td>
<td>16.1</td>
<td>279.2</td>
<td>16.2</td>
</tr>
</tbody>
</table>

(a) Secretariat estimate.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>Connected to the grid</th>
<th>Under construction</th>
<th>Firmly committed</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units</td>
<td>Capacity</td>
<td>Units</td>
<td>Capacity</td>
</tr>
<tr>
<td>Belgium</td>
<td>7</td>
<td>5.5</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Canada</td>
<td>20</td>
<td>13.8</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>2.3</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>France</td>
<td>56</td>
<td>57.7</td>
<td>4</td>
<td>5.7</td>
</tr>
<tr>
<td>Germany</td>
<td>21</td>
<td>22.5</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Italy</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Japan (a)</td>
<td>44</td>
<td>33.9</td>
<td>9</td>
<td>7.7</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2</td>
<td>0.5</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Spain</td>
<td>9</td>
<td>7.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sweden</td>
<td>12</td>
<td>10.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>5</td>
<td>3.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Turkey</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>United States</td>
<td>109</td>
<td>99.0</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>31</td>
<td>12.0</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>OECD Total</td>
<td>320</td>
<td>267.2</td>
<td>19</td>
<td>20.0</td>
</tr>
</tbody>
</table>

(a) Gross data converted to net by the Secretariat.
COST ESTIMATES FOR REPOSITORIES FOR SPENT FUEL AND HIGH LEVEL WASTE

A group of national experts convened by the NEA published in June a new report on cost estimates for the engineering, construction and operation of repositories for the disposal of spent fuel or reprocessing waste (i.e., high level vitrified waste and alpha-bearing waste from reprocessing). Twelve different estimates were used from eleven countries. The objective of the study was to provide a better understanding of the origins of variations in the cost estimates and to discuss to what extent technical, political, social and economic factors could explain the variation.

Rather detailed engineering studies and cost estimates have been made in Member countries to provide adequate support for planning purposes and for establishing a relevant cost for disposal to be factored into the charge to the electricity consumer. Many of the cost components are based on well-established experience in other nuclear and non-nuclear fields and a high contingency factor is normally applied. Nevertheless the estimates are based on design studies and must be used carefully.

The cost of disposal of spent fuel or waste from reprocessing is only a small fraction of the total electricity generation cost. The uncertainties in the disposal costs will therefore have only a marginal effect on the cost of electricity production from nuclear power. However, the absolute value of the cost for disposal is expected to be substantial. Some development costs will occur appreciably before disposal, but most will appear long after the corresponding electricity generation. In most OECD countries with a nuclear programme, funding schemes have therefore been established to make provision for these costs. Fairly accurate estimates of the costs are thus required.

There is surprisingly good agreement between the estimates when they are normalized with regard to total electricity production, and the remaining differences can be explained at least qualitatively. This indicates that the disposal costs are reasonably well understood in the OECD countries even though some wide variations are apparent.
Observers from seven countries of central and eastern Europe attended the most recent meeting of the NEA Group of Governmental Experts on Third Party Liability in the Field of Nuclear Energy, from 28-30 June 1993. It was only the second time that such countries had participated in a meeting of the Group. Hungary, Poland, Romania and the former Czechoslovakia had sent observers to the Group’s meeting in September 1992. That experience was very positive, and in June 1993 the observers from Hungary, Poland and Romania were joined by representatives of Bulgaria, Russia and the Ukraine as well as the new Czech Republic.

The attendance of observers at meetings of the Group of Governmental Experts is one aspect of a programme of cooperation between NEA and the countries concerned. The invitation issued to the observers, following approval by the NEA Steering Committee and by the OECD Council reflects the concerns of the parties to the (OECD) Paris Convention. That Convention, which covers western Europe, and the very similar (IAEA) Vienna Convention, together comprise an international regime of civil liability for nuclear damage, to which, however, few of the countries of central and eastern Europe yet adhere. Paris Convention countries consider that the success of the effort currently underway to modernise the regime will depend largely on its ability to attract Central and Eastern Europe. The Group of Governmental Experts can provide a pan-European forum for the exchange of information and negotiation to this end.

Besides their contribution to that debate, the participation of the observers was especially valuable in the Group’s discussion of a specific practical problem concerning civil liability. It has arisen out of the involvement of companies from NEA member countries in the international effort to improve the safety of nuclear power stations in several countries of central and eastern Europe. A number of companies have expressed the fear that they might be exposed to litigation if an accident were to occur during or after their work on a nuclear installation.

In a host State which is party to the Paris or Vienna Convention, this would not be a danger, since those Conventions provide for all liability for a nuclear accident to be “channelled” to the operator of the installation concerned. That is to say, in the case of an accident in a nuclear installation, only the operator of that installation is liable, and not outside contractors or suppliers. This is the rule in the member countries of the NEA which have nuclear industries, including those which are not parties to the Paris or Vienna Convention.

However, many of the central and eastern European countries concerned not only are not parties to either Convention, but also have no national legislation providing for channelling of liability. Neither is the amount of liability limited. In addition, it appears that private insurance would not be available to contractors to cover the risk of liability.

Under these circumstances, fear of litigation has led to reluctance on the part of western companies to undertake work in the countries concerned. Indeed the Group of Governmental Experts heard that for this reason certain national and international agencies, although they have funds available to finance work on safety improvements, are unable to allocate the necessary contracts.

Ultimately, the solution to this problem appears to be ratification of the liability Conventions by the host countries and establishment of appropriate legislation, but this will necessarily take a considerable time as well as political will. An interim solution is therefore being sought urgently in a number of fora, including an expert working group established by the G-24, as well as through bilateral negotiations. The exchange of views between east and west within the Group of Governmental Experts was a worthwhile contribution towards this process.
The NEA has just completed a 10-minute video introducing its activities and the role of international co-operation for the development of peaceful nuclear energy.

The video is intended as a public information tool to be used by the staff of the Nuclear Energy Agency for briefing the national delegates to the many working Groups and Committees that NEA convenes at its Paris Headquarters and in Member countries on the Agency's role and work programme.

The film will also be shown routinely to the numerous groups visiting the OECD mother Organisation and the NEA, representing a broad cross-section of interested public groups (students, trade-unionists, industrialists, diplomats, teachers, etc.).
NUCLEAR ACCIDENTS - LIABILITIES AND GARANTIES
Proceedings of the Helsinki Symposium organised by the OECD Nuclear Energy Agency and the International Atomic Energy Agency
ISBN 92-64-03872-8 - 1993
Price: France FF 480
Others countries: FF 620  US$105  DM 190
The 1992 Symposium on Nuclear Accidents - Liabilities and Guarantees, organised by the OECD Nuclear Energy Agency in collaboration with the International Atomic Energy Agency, discussed the nuclear third party liability régime established by the Paris and Vienna Conventions, its advantages and shortcomings and assessed the teachings of the Chernobyl accident in the context of that régime. The topics included the geographical scope of the Conventions, the definition of nuclear damage, in particular environmental damage, insurance cover and capacity and supplementary compensation by means of a collective contribution from the nuclear industry or governments, and finally, the international liability of States in case of a nuclear accident.

NUCLEAR LAW BULLETIN No. 51 - June 1993
Annual subscription (2 issues and supplement)
ISSN 0304-34X
Subscription price: France FF 200
Other countries: FF 220  US$42  DM 84

NUCLEAR ENERGY DATA 1993
Bil : ISBN 92-64-03871-X  ISSN-1017 9402
Price: France FF70 – Others countries: FF 90  US$17  DM29
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 find quick and easy reference to the present status of and projected trends in total electricity generating capacity, nuclear generating capacity, and actual electricity production, as well as on supply and demand for nuclear fuel cycle services.

QUALIFIED MANPOWER FOR THE NUCLEAR INDUSTRY
An Assessment of Demand and Supply
ISBN 92-64-13932-X
Price : France FF 130
Others countries: FF 170  US$30  DM54
There is growing concern, in OECD countries and elsewhere, that it might be difficult for nuclear industries to secure or to keep qualified personnel in the future. This study by the OECD Nuclear Energy Agency presents the results of a pioneering survey of the demand for and the supply of qualified manpower in various sectors of the nuclear industry, and in the related areas of regulation and education in 12 OECD countries. The current manpower situation is presented and the future demand is reviewed. Present and future activities of OECD countries to ensure a balance between supply and demand of qualified manpower are discussed.

SPIN-OFF TECHNOLOGIES DEVELOPED THROUGH NUCLEAR ACTIVITIES
ISBN 92-64-13965-6
Price: France FF 90 – Others countries: FF 115  US$ 20  DM 37
Given the changing role of government research establishments and the interest in maximising return on capital and intellectual investment, determining the best way to apply or "spin-off" technologies from the nuclear field into other industrial and commercial sectors is of increasing concern.
This study by the OECD Nuclear Energy Agency draws on expertise from numerous countries to determine what the spin-offs are, where they come from, and how they can best be fostered. It looks both at the results and process of spin-offs, and helps decision-makers in government and project leaders and managers in industry to maximize their benefits.

THE COST OF HIGH-LEVEL WASTE DISPOSAL IN GEOLOGICAL REPOSITORIES
An Analysis of Factors Affecting Cost Estimates
ISBN 92-64-13913-3
Price: France FF 150 – Others countries: FF 200  US$36  DM 60
Many different estimates for the cost of radioactive waste disposal in geological repositories have been published. This study, aimed at the general reader, illustrates why the published
cost estimates for packaging and geological disposal of spent fuel or reprocessing wastes vary so widely, and examines to what extent various political, institutional, technical and economic factors could explain the variation.

The study shows that despite the differences in the various systems being considered, there is a surprisingly good agreement between the estimates when compared to total electricity production costs.

**PALEOHYDROGEOLOGICAL METHODS AND THEIR APPLICATIONS FOR RADIOACTIVE WASTE DISPOSAL**
Proceedings of an NEA Workshop, Paris (France), 9-10 November 1992
Bil. ISBN 92-64-03892-2
Price: France FF 200
Others countries: FF 260 - US$ 48 DM 83

Groundwater is the primary medium for transporting radionuclides from geological waste repositories to the accessible environment. Investigating hydrogeologic settings at potential sites for radioactive waste disposal is therefore particularly important for reconstructing their past hydrologic regimes. The use of such studies will increase confidence in understanding a present-day hydrogeological setting and in predicting its future state.

This volume presents the proceedings of a workshop organised by the OECD Nuclear Energy Agency to discuss the methods of gathering paleohydrogeological evidence and to review examples of studies already under way or completed in this area.

**LONG-TERM OBSERVATION OF THE GEOLOGICAL ENVIRONMENT: Needs and Techniques**
Proceedings of the Helsinki Workshop, Finland, 9-11 September 1991
Bil. - ISBN 92-64-03970-8
Price: France FF 150 – Others countries: FF 195  $ 34 DM 62

For site characterisation programmes aimed at determining the suitability of sites for the disposal of radioactive waste, attention must be given to collecting data over long periods of time for adequate understanding of certain processes in the geological environment (hydrologic conditions, seismicity, etc.). It is important for all national projects to carefully plan and implement programmes to observe the long-term behaviour of the geological environment in order to secure high-quality, reliable data for use in safety assessments. These proceedings present the results of a workshop organised to discuss the needs and techniques related to the planning and implementation of such programmes.

**RADIATION PROTECTION ON THE THRESHOLD OF THE 21st CENTURY**
Proceedings of an NEA Workshop, Paris, 11-13 January 1993
Bil. ISBN 92 -64-03971-6
Price: FF 250
Others countries: FF 325 FF 325 US$ 56 DM 100

Radiation protection is currently going through a period of evaluation and debate in several different fields. One major milestone is the recent publication of the new recommendations of the International Commission on Radiological Protection. The elements of novelty contained in the recommendations and other recent scientific and technical developments led the NEA Committee on Radiation Protection and Public Health to organise a workshop to review the current status of radiation protection and its perspectives as we approach the year 2000. These proceedings include the papers presented at the meeting and a summary of the conclusions and recommendations that emerged from the discussion.
Communications strategies in the nuclear field are often based on the setting-up of visitor centres at nuclear facility sites.

Today, the design, as lay-out and management of such centres has become a specialised function, and its role is closely complementary to that of the nuclear operator. It also uses the latest technology in the field of audio-visual, experiment and interactivity.

This publication contains the proceedings of an international seminar organised by the OECD Nuclear Energy Agency on the role of visitor centres at nuclear facility sites. It includes the main papers presented at this seminar.

**A STRATEGIC VIEW ON NUCLEAR DATA NEEDS**

September 1993
Report by NEA Secretariat

This report examines the present and future needs for scientific nuclear data and discusses ways of meeting any such needs.
Free on request

**NEA PUBLICATIONS CATALOGUE**
March 1993
Bil. - Free on request.

**Proceedings of an International Seminar on VISITORS CENTRES AT NUCLEAR FACILITIES SITES**
Madrid, 2-5 November 1992
Bil. ISBN 92-64-03972-4
Price: FF 180
Others countries: FF 235 $41 DM 75

**Proceedings of a Specialists' Meeting on EVALUATION AND PROCESSING OF COVARIANCE DATA**
Oak Ridge National Laboratory, Oak Ridge, USA, 7-9 October 1992
Free on request

**NEUTRON NUCLEAR DATA EVALUATION NEWSLETTER**
Free on request

**Issue brief N°9 BROAD IMPACTS ON NUCLEAR POWER**
Free on request

**PSACOIN Level S Intercomparison**
**PSACOIN Level 1B Intercomparison**

The PSACOIN Level B and Level S reports are the latest in a series of exercises designed to contribute to the verification and advancement of probabilistic codes and methodologies that might be used for assessing the safety of probabilistic disposal systems.

The focus of Level 1B is on biosphere modelling and implements a biosphere model which is used in several Member Countries to estimate the consequences of potential radionuclide releases to inland terrestrial and aquatic systems. The report compares results and draws conclusions with regard to the use of different codes, routines, and modelling approaches.

The focus of Level S is on sensitivity analysis. Given a common data set of output and input values of a model previously implemented for the Level E exercise the participants were asked to identify the model's most important parameters (deterministic sensitivity analysis) and the link between the distributions of the input and output values (distribution sensitivity analysis). The report finds agreement where it was expected but it also identifies several outstanding issues in sensitivity analysis.
Free on request

**NUCLEAR WASTE BULLETIN No. 8 - July 1993**
Update on Waste Management Policies and Programmes
Free on request

**ISOE**
(NEA Information System on Occupational Exposure)
Free on request