# NEA UPDATE

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## NEWS BRIEFS

### New NEA Report: Nuclear Liability and Compensation for Nuclear Damage

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## NEW NEA PUBLICATIONS
The first unit of the Laguna Verde nuclear power plant is in commercial operation since 1990.
MEXICO JOINS THE NUCLEAR ENERGY AGENCY

On 1 May 1994, Mexico joined the OECD, and became the 25th Member of the Nuclear Energy Agency. This major event, coming just one year after the accession of the Republic of Korea to the NEA, testifies to the desire of the Agency to widen its ties with emerging dynamic economies worldwide which share the views and principles of OECD Members regarding economic development and multilateral co-operation and, of course, are interested in sharing knowledge and experience in the safe use of nuclear power.

In the same way as the OECD helps like-minded nations to reinforce their own economic growth and social progress by working together on relevant policies, the NEA has as a major objective to further the development of nuclear power as a safe, economic and environmentally acceptable energy source, through co-operation among its Members.

It is therefore particularly significant that Mexico, which has become an important player in the international economic scene, has also turned its attention to the area of nuclear energy co-operation among industrialised countries. It is indeed not surprising that this new Member country, which has had impressive growth in its GNP in recent years, has included nuclear power in its energy strategy to help meet rapidly rising energy demand, and help minimise some of the important atmospheric pollution problems linked with high-population growth, a rapid rate of industrialisation, and significant migration to urban areas.

THE MEXICAN NUCLEAR POWER PROGRAMME

The current National Energy Plan issued in 1990 calls for a reduction in oil dependency, mainly through energy savings, rational use of energy and the development of other sources. Diversification of energy sources has been pursued through the electric sector, including geothermal, coal and nuclear energy for the generation of electricity. As regards nuclear energy, the National Energy Plan calls for the production of 3.0 to 6.9 megawatts electrical of nuclear origin by the year 2010; however, several factors, including changes in the national economic situation and shifts in public opinion regarding nuclear power, have led to postponing a new nuclear power plant order.

Currently Mexico has one nuclear power plant, Laguna Verde, located on the Gulf of Mexico, consisting of two units of 654 MWe each. The first unit has operated commercially since 1990 and started its fourth operating cycle in March 1994. Unit 2 is undergoing the last steps of pre-operational testing; commercial operation is expected in 1995.

Both units will operate in base load. Unit 1 has achieved capacity factors above 70% during the past three operating cycles; in the last operating cycle, it reached an availability of 90.3%, and its capacity factor came close to 85%.

FUEL CYCLE

Although Mexico has uranium resources of about 10,000 tU, all exploration and mining activities have been suspended, due to the low cost of uranium currently available on the world market. For the coming years the necessary uranium for reloads of Laguna Verde will be obtained in the world market since currently there are no current plans for producing uranium in Mexico.

Uranium is bought either as hexafluoride or as concentrates that are converted to hexafluoride by Comurhex in France, under a long-term contract. Enrichment services are provided by the U.S. Department of Energy, also under a long-term contract. Fuel fabrication is currently also done in the United States by General Electric. Four assemblies supplied by Siemens Corporation are being tested in the present cycle of Unit 1 of Laguna Verde and there are plans to test also four assemblies supplied by ABB-ATOM in the near future.

A fuel fabrication pilot plant is about to start operation at the Nuclear Research Institute (ININ) using technology provided by General Electric. This pilot plant could produce up to 20 fuel assemblies per year for the Laguna Verde reactors. However, after some experience is gained with the operation of the plant and the fuel produced, the plant will probably be shut down, as there are no sound economic reasons to sustain its continuous operation.

RADIOACTIVE WASTE MANAGEMENT

An interim repository exists in Mexico for all the low- and intermediate-level wastes produced in medical and industrial radioisotope applications. This repository will have to be replaced by a permanent one in the future.
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For the Laguna Verde plant, the high-level waste is being stored on site. As for the low- and intermediate-level wastes produced by the plant, detailed site studies are now underway at the plant site itself in order to determine the engineering design basis for a "triple-barrier" repository using a French approach. The repository is planned to have capacity for the wastes generated during the operating life of at least four nuclear reactor units, and could also include the waste generated by the medical and industrial radioisotope applications in the country.

As for the spent nuclear fuel, the current plans are to store it at the reactor pools, which have been re-racked to increase the original capacity in order to accommodate the spent fuel that the reactors will produce during their expected operating lives. This plan allows time to take a more definite decision, depending on future developments in uranium availability and price, expansion of the Mexican nuclear power capacities, new technologies, etc.

NUCLEAR RESEARCH AND DEVELOPMENT

For its nuclear R&D, the country relies mainly on two national research laboratories, namely the National Nuclear Research Institute (ININ) and the Institute of Electric Research (IIE). However, some minor efforts are devoted at the National Commission of Nuclear Safety and Safeguards (CNSNS – Comisión Nacional de Seguridad Nuclear y Salvaguardias) to specific issues in order to provide technical support to the decision process in matters related to licensing and regulation of nuclear and radioactive installations.

So far most efforts have been applied to developing the capability, first, to implement reliable tools of analysis, and second, to successfully applying them. Three main fields have received attention: nuclear thermohydraulics of boiling-water reactors (BWR), core neutronics and...
probabilistic safety analysis. A particular task was successfully completed by the IIE regarding the design and construction of a full-scope operational plant simulator for the Laguna Verde Nuclear Power Plant. Some preliminary consideration is also being given to projects on artificial intelligence and fracture mechanics, as applied to BWR nuclear power plants.

The main research facilities are located in a nuclear centre near Mexico City. The centre has been in operation since 1968 and has among its facilities a 1-MW research reactor, a 12-MeV Tandem Van de Graaf accelerator, a 500,000 curie gamma irradiator, a metrology centre for ionising radiation and the fuel fabrication pilot plant.

**THE REGULATORY STRUCTURE**

The utilisation of nuclear energy for power and heat generation is reserved by law to the Mexican State. The Secretariat of Energy, Mines and Parastate Industry (SEMIP) is in charge of regulating its use in the country through the CNSNS which is the specialised technical body in charge of regulating nuclear and radiological safety, physical security and safeguards for all nuclear and radioactive facilities in the country.

The CNSNS manages its own budget and personnel, and operates its own radiological environmental monitoring laboratories to verify independently the operation of the nuclear facilities in the country.

The radiological protection regulations of Mexico are based on the recommendations of the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP-26). Currently an evaluation is being conducted to determine what the strategies for implementing the ICRP-60 and the new *Basic Safety Standards* of the IAEA in the country, as well as the ensuing implications.

For nuclear safety, the CNSNS follows the NUSS Guides of the IAEA, and for Laguna Verde, it applies also the regulations of the U.S. Nuclear Regulatory Commission.

The Federal Electricity Commission (CFE – Comisión Federal de Electricidad) is the state-owned national utility and is the only entity in the country that can utilise nuclear materials to generate nuclear power. The policies for its use are defined by the SEMIP.

**NON-PROLIFERATION STATUS**

One of the principles of Mexican foreign policy is to support nuclear disarmament, and Mexico has taken a strong stand against the proliferation of nuclear weapons. In fact, Mexico is largely responsible for the existence of the *Treaty for the Prohibition of Nuclear Weapons in Latin America*, also known as the *Tlatelolco Treaty*, to which it is a party.

Mexico is also a party to the *Non-proliferation Treaty* (NPT) and is subject to IAEA safeguards under both treaties.

Currently, to strengthen the effectiveness and the efficiency of the IAEA safeguards system, Mexico has voluntarily agreed to notify the imports and exports of nuclear material and imports of equipment and non-nuclear material.
NUCLEAR POWER IN THE CONTEXT
OF THE IEA’S WORLD ENERGY OUTLOOK

Earlier this year the International Energy Agency (IEA) issued an update of its World Energy Outlook (1). This looks forward over the period to 2010 and suggests what might be the pattern of energy consumption if current trends and policies were to continue. The projections combine results of econometric modelling with a number of imposed assumptions about some trends. The aim was to illustrate one of a number of outcomes that could arise, in order to stimulate debate about energy policies.

The salient features of the latest update are that, under the conditions assumed, by 2010 the world will be consuming 47% more energy than it was in 1991. Electricity would be the most rapidly growing use of energy, exceeding Gross Domestic Product (GDP) growth in many countries, and particularly in non-OECD countries, the former Soviet Union (FSU) and Eastern Europe, labelled as “Rest of World” (ROW), where it is predicted on average to double. This is linked with a world GDP more than 70% higher than in 1991, and it is this which more than any other factor drives the increased energy demand of 28% overall in OECD countries and even higher growth, at 5.3% a year, in the ROW.

World consumption of coal would grow by 2.1% a year. Europe would become increasingly dependent on imports. In the ROW, coal demand would grow at 3.8% a year, with China accounting for half the incremental demand. Gas consumption would continue to rise at 2.1% in the OECD area (over half the increase going to the power generation sector), while in ROW countries the growth rate would be 5.6%. On these bases it is expected that the gas market in the United States would tighten after 2000 and Western Europe would require new infrastructure for the delivery of remote supplies late in the forecast period, although being able to count on North Sea, FSU and Algerian sources for the next 10 years. Oil demand in the OECD area would be some 18% higher than in 1991 but the OECD’s share of the world’s oil consumption would drop from 56% to 47%. One outcome of these predicted changes is an increase of 50% in the annual world emissions of carbon dioxide (CO2) by 2010. Emissions in ROW would more than double, and CO2 emissions in OECD countries would continue to rise. Under alternative low economic growth assumptions used by the IEA there would not be a fundamental change in the picture for CO2 emissions.

These reference predictions are associated with particular assumptions on price (oil rising to $28 by 2005 from $17; coal generally stable, although rising by 20% in the United States; gas rising to $3.30 per thousand cubic feet by 2005 in the United States, from $1.73 in 1991, and keeping pace with oil prices in Europe and Japan). Economic growth assumptions include 2.6% a year on average in the OECD Pacific, 2.3% in North America, and 2.2% in OECD Europe. For Central and Eastern European countries (CEE) and the FSU, GDP is assumed to increase by a third from 1990 to 2010. However, economic growth would be greatest in the ROW with China attributed 7.9% and East Asia 6.2%.

It is calculated that there would be an incremental demand of 620 GWe in the OECD area and 835 GWe in the ROW for power generation capacity. The picture is less clear in the FSU and CEEC in view of the great structural changes taking place in their economies. Overall, the share of non-fossil fuels is expected to decline. Certainly, for the world as a whole the expansion of nuclear, hydro, and other renewable sources of electricity generation is not expected to keep pace with the growth in demand. In line with the constraint of applying current policies, however, there is not much credence given in this Outlook to increases in nuclear capacity, and it is commented that the “prospects for nuclear power in the OECD are highly uncertain”. Nevertheless, there appears to be considerable scope for nuclear vendors to deploy their wares; note that the installed nuclear capacity in the OECD at 31 December 1993 was 281 GWe (2) and for the whole world, 338 GWe (3). The reference scenario used by the IEA, however, includes only 413 GWe for the world total by 2010, much of the growth coming in France, Japan and the Republic of Korea.

Setting aside for a moment the question of public acceptability of nuclear power, the main question for the future is whether the electricity generation companies will wish to continue to use and to invest in nuclear power plants. That is an economic question with the answers partly determined by views on the likelihood of obtaining a better return from a nuclear investment than from alternatives, and on the financial risk.

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The assumptions on prices built into the World Energy Outlook indicate that in pure cost terms there would be more rather than less scope for deployment of nuclear power during the forecast period. As was shown in the joint NEA/IEA study published in December 1993 on comparative costs of electricity generation (4), an increase in gas prices of 25% while nuclear fuel cycle prices remained constant would eliminate gas from competition with nuclear in all but one of the countries for which data was collected. The prospect of a significant rise in gas prices, at least in Europe, also emerges from a recent study by UNIFEDE (5). Their expert group suggested that stable gas prices were not compatible with the use of gas for electricity generation growing at a somewhat lower rate than that postulated in the World Energy Outlook.

A number of recent NEA studies bear on the question as to whether nuclear fuel costs will increase. The latest NEA Red Book (6) points out the large amounts of uranium reserves available at relatively low cost. It is possible that there may be some transitional upswings in uranium prices when the uranium markets tighten around the end of the century, if there has not been a reasonable and timely investment in reopening mothballed or starting up new mines and milling facilities. There are currently surpluses of capacity in some of the front-end industries that are concerned with the production of fuel from raw uranium. These may not persist over the period covered by the Outlook. The industries concerned, however, are fully mature; they invest in new plant and engage in material and cost improvement as part of their competitive strategies. The improvement of fuel burnup in reactors has contributed about a fifth of the 40% reduction in projected lifetime levelised fuel cycle costs for a large pressurised-water reactor that has been identified in the comparison of the latest report on the Economics of the Fuel Cycle (7) as compared with expectations reported in 1985. There are grounds for believing that a portion of this latter cost-reduction trend can continue, even if not at the same rate. While, therefore, there may be some increases in nuclear-fuel costs, there are market forces to constrain them. In any case, as shown in the comparative cost studies (4), nuclear fuel costs form a relatively small part of the overall electricity generation cost compared with generation using fossil fuels.

The major part of nuclear generation costs is attributable to investment in the reactors. Progress is being made in simplifying designs, reducing the number of components to be procured and assembled, as well as reducing the amount of construction material. Licensing processes have also been streamlined in some countries. All this goes to shorten construction time, which is itself a great advantage, given the high costs of interest charges for financing the projects.

The third major contribution to nuclear costs is the "operation and maintenance" (O & M) component. In some countries, notably the United States, the tendency in the 1980s was of rapidly rising O&M costs, driven in part by utility reactions to new regulatory requirements. There is some evidence to suggest that these trends have been halted or at least substantially weakened. Overall, therefore, there is a good prospect that nuclear generation costs will not be increasing.

The World Energy Outlook suggests that there will not be any significant penetration of renewables over the period considered, even though growth rates for some of the new technologies will be high. A brief look at other alternatives shows that, apart from the fuel-cost component, there has been and will be a trend for costs to come down with the adoption
NUCLEAR POWER IN THE CONTEXT OF THE IEA’S WORLD ENERGY OUTLOOK

of new technology. At the same time there will be some abatement of increases in the fuel cost per kilowatt-hour, as there will be a considerable improvement in efficiency. There can be no grounds for suggesting that the market will fall into the lap of the nuclear reactor-vendors purely on cost arguments. Furthermore, their share of the market will not be determined solely by the cost factors discussed so far.

Another main element in the thinking of the electricity producers will be their view on the risk associated with the investment. In addition to the technical risk, which in the case of nuclear is associated very largely with the potentially crippling economic impacts of very low frequency events, there are a number of other risks that utility executives can be expected to weigh very carefully.

There has been a history of markedly over-optimistic forecasts of electricity-demand growth that will predispose decision-makers to look for investments in small capacity additions. The change of ownership structure that is taking place in many OECD countries is leading to demands for higher returns on capital invested, and is a further incentive to look for small investments with quick returns. With the change in ownership, there has come, at least in some countries, a change in the economic regulatory regime, which in itself could be expected to induce caution over long-term investments. The effect of past uncertainty in nuclear regulation in some countries is certainly a cautionary tale that is likely to have its effect more widely. We should also pay attention to a demographic factor – the decision-makers are increasingly coming, not from a generation of engineers who, early in their careers, were exposed to the concept of nuclear power as an economic, reliable energy source for the future, but from a later cohort of engineers and other professionals who have been exposed to a number of difficulties related to nuclear power programmes. These include experience of coping with nuclear accidents or with the public reaction to them; of prolonged negotiations over siting proposals for power plants and waste repositories; and with public anxieties over provisions made to manage historic liabilities. This background can be expected to induce fairly cautious attitudes about nuclear energy.

Thus there is foundation enough for the postulated low nuclear expansion in the World Energy Outlook, even in the so-called “high nuclear” case. However these scenarios do imply a far from negligible nuclear construction programme, as over the next 15 years it can be expected that between about 110 and 50 GWe will be withdrawn, depending on whether a 30-or-35-year average life is assumed for reactors (8). To the extent that plant life management programmes succeed there will, of course, be less pressing need for construction of replacement capacity.

It should also be recalled that the scenarios assume that government policies remain unchanged. Given the large rises in oil use and CO₂ emissions that follow from the assumptions, both of which run counter to goals that are shared by the governments of the IEA, there is a considerable incentive to bring in new policies. Indeed the World Energy Outlook notes that there have already been significant policy changes since the 1993 edition of the World Energy Outlook was produced, and it is “highly unlikely that the same policies that are in place today will be in place in 2010”. The intriguing question then arises as to whether the policy changes will result in a greater recourse to nuclear energy.
There is no doubt that there is the physical possibility of constructing greatly increased nuclear capacity; the rate of construction achieved during the 1970s and early 1980s led to the connection to the grid of 33 reactors in 1985 and again in 1986. It would take a little time to work up to the same rate but the experience of the 1960s and 1970s suggests that it would be reasonable to assume that by 2000 orders for a capacity increment of at least 15 GWe/\text{a} could be accommodated by the industry, with that rate rising to 30 GWe/\text{a} by 2005 if not earlier. Achievement of these rates would be contingent on policy changes that gave confidence that there would be a continuing stream of orders.

Given the lead times for acquiring sites, licensing designs and for actual construction, however, it could be extremely challenging to approach the scenarios’ postulated nuclear capacities. For example, taking the assumptions that current reactors last on average 35 years, that current ordering plans do not change markedly before 2000, and that 54 GWe is ordered from 2000 to 2003 with lead times of seven years to grid connection, there would still be only about 383 GWe available in 2010, somewhat short of the World Energy Outlook’s reference case. Achievement of the postulated scenario would then require an intensive effort to manage nuclear plants to prolong their expected lives.

In this light the World Energy Outlook appears to be placing quite strong reliance on construction of new nuclear power plants. Perhaps this view is conditioned by the difficulties seen in adopting other means of reducing dependence on oil and of limiting carbon dioxide emissions. There is already built into the “Reference Scenario” an improvement in energy efficiency, leading to a decrease of energy intensity by a little over 1% per annum. An “Efficiency Case” is also presented that takes into account much greater penetration of the energy efficient technology that is already available, as well an allowance for further technological progress. While one outcome of this Case is that a fairly close approach to stabilisation of carbon dioxide emissions at the 1990 level would be possible, the report suggests that this would not be cost-free, requiring a “dramatic shift in capital stock, transportation means and household appliances at a considerably faster rate than would be achieved under ‘business as usual’ circumstances”.

Another case that is analysed is that of introducing a carbon tax at $100 or $300 per tonne of carbon. The models used suggest that the $300 tax, introduced in 1995 at $100 with subsequent annual increments of $13, have such an effect on the demand side that emissions of carbon dioxide in the OECD area would be held below 11 billion tonnes at least to 2010, compared with 1990 emissions of 10.4 billion tonnes. The report points out that the existence of “backstop technologies” would impose limits on the level to which a carbon tax would need to rise but this effect was not explored in the report.

It is relevant to note that one already available backstop technology is nuclear power. The potential for stimulating greater use of this source of CO$_2$-free energy is indicated by the impact shown in the World Energy Outlook of a $100 carbon tax on fossil fuel prices in 2010.

Depending on the OECD region considered, fuels for power generation would rise in price as follows:

- Heavy fuel oil: 33 to 56%;
- Natural gas: 25 to 46%;
- Hard coal: 92 to 185%.

Referring back to the comparative cost analysis presented above (4), it is clear that there would be considerable economic incentive to resort to nuclear power if this tax were included in the governments’ policy responses. It seems reasonable to suggest that, as an even greater change in energy use is required than would be provoked by this tax level, any set of government policies that is to approach the targets that have already been adopted will need to allow for a considerably expanded use of nuclear power.

The World Energy Outlook points out that the additional amount of nuclear power included in the “High Nuclear Scenario” does not make a significant difference to the increased level of carbon dioxide emissions (46% up between 1990 and 2010, rather than 47.6% up for the “Reference Scenario”). It also points out that even the Energy Efficiency and $300/tonne Carbon Tax Cases do not stabilise CO$_2$ emissions by 2010 and shows them rising at that time.

Nevertheless, the figures seem to imply that the 413 GWe of nuclear capacity included in the “Reference Scenario” prevent the emission of about 2.1 billion tonnes of CO$_2$ in 2010, and this is close to one tenth of the world’s energy related emissions of CO$_2$ in 1990. Thus the postulated use of nuclear power would be a significant factor in reducing CO$_2$ emissions, even without a major change of government policies.
It may already be too late for governments and industry to take decisions that would lead to nuclear power having a much greater impact by 2010 but there is a clear need to intensify efforts beyond that time to curb greenhouse-gas emissions and other environmental impacts of energy use. It is not too soon to be working on means to compare those impacts from different energy sources, to consider the many different ways in which nuclear expertise can be preserved and deployed, and to be preparing decisions on the role of nuclear energy in the next century. These topics will continue to be central to the work of the NEA.

REFERENCES


COLLECTIVE OPINION ON RADIATION PROTECTION

In 1993 the NEA Committee on Radiation Protection and Public Health (CRPPH) launched a major reflection exercise on the present status of radiation protection and its expected trends in the future. The initiative, considered particularly appropriate in the current climate of promising scientific developments and significant policy evolution, was strongly supported by Member countries. The result was a thorough review of the current situation and achievements in the scientific, conceptual and operational aspects of radiation protection, and a far-reaching appraisal of the developments anticipated in these areas in the short and medium term. The CRPPH published its collective opinion in 1994 as an OECD/NEA Report entitled Radiation Protection Today and Tomorrow. The Executive Summary is reproduced below.

EXECUTIVE SUMMARY

Radiation protection concerns the protection of workers, members of the public, and patients undergoing diagnosis and therapy, against the harmful effects of ionising radiation. In order to cope with the expanding radiation and nuclear practices, and in view of the particular character of the radiation risks, radiation protection has developed during the last few decades a unique and elaborate system of concepts, principles and techniques for the prevention and control of radiological risks.

A largely held view in the radiation protection community today is that the degree of scientific knowledge which serves radiation protection so far constitutes an acceptable basis for a conservative system of protection. For example, the current level of scientific knowledge resulting from the epidemiological study of the Hiroshima and Nagasaki atomic bomb survivors and other groups of people has allowed the protection experts to establish a number of assumptions about the dose-effect relationships (e.g., linearity of the dose-effect curve without a threshold) which resulted in a reasonable choice of a risk factor for effects such as cancer induction. However, there is a growing feeling that future scientific advances in biology might result in other breakthroughs in fundamental scientific knowledge capable of affecting radiation protection principles and doctrine. These advances could lead to changes in the dose-effect relationship and the risk models, and provide genetic analysis techniques capable of specifically identifying radiation-induced tumours above the general background of cancer incidence. Consequently, these scientific advances could have a profound effect on many aspects of radiation protection, e.g., the cost of protection.

The present conceptual framework for radiation protection, as proposed by the International Commission on Radiological Protection (ICRP), provides the basis for operational criteria and guidance, applicable to the various protection situations (e.g., nuclear power, medical applications of radiation, chronic exposure to natural radiation), which are developed by international intergovernmental organisations such as the International Atomic Energy Agency (IAEA) and other United Nations (UN) agencies, the Commission of the European Communities (CEC) and OECD/Nuclear Energy Agency (NEA). Essentially all countries incorporate ICRP concepts in their radiation protection regulations and operations.

Radiation protection concepts can only be implemented through an effective infrastructure which includes adequate laws and regulations, a well structured complex of experts and operational provisions, and a “safety culture” shared by all those involved with protection responsibilities, from the workers up through management levels. The OECD countries generally have well established infrastructures for radiation protection and the standard of protection across the OECD area appears good and sometimes excellent. This conclusion is supported by trends showing significant dose reduction in many practices through diligent application of the protection principles in several OECD Member countries. A similar conclusion can be drawn for some, but not all countries throughout the rest of the world.

A fundamental component of radiation protection is the availability of adequate measurement equipment and techniques as well as modelling and assessment methods and software. These are well developed for most situations. However, the evolution of radiation protection technology is expected to continue with gradual improvements in instrumentation, modelling, assessment methods and quality control, in parallel with developments in fields such as electronics, environmental studies and the nuclear industry in general.

Radiation protection is a dynamic field. Regardless of the general status of protection, there are a number of conceptual and practical issues which still remain open. Examples include: better adaptation of the protection...
COLLECTIVE OPINION ON RADIATION PROTECTION

concepts to cope with situations of chronic exposure resulting from natural radiation or contamination from accidents or past practices; developing practical methodologies for the assessment and regulation of situations where there is a potential for exposure, usually as a result of accidents, but with no certainty of occurrence; and satisfactorily addressing those radiation protection and long-term safety aspects of radioactive waste disposal which continue to be the subject of public controversy. Other issues can be expected to be raised by some new practices which are currently being developed or are expected to be introduced in the near future.

Moreover, the social dimension of radiation protection decisions, both in managing work force and in coping with the impact of large scale nuclear operations, including possible accidents, is now more fully recognised. It requires the development of better mechanisms for the involvement of social parties [labour and employers organisation, citizen groups, etc.] and the public in the decision processes and the search for a closer integration of the management of radiation risks with that of other hazardous substances or situations.

When considering current issues, the prospect of new scientific information which might affect important aspects of protection, the expansion of radiation and nuclear practices, and changing public attitudes toward risk, it is clearly important that the wealth of expertise and resources for protection and related fields which has been accumulated so far is preserved in order to continue to guarantee adequate and cost-effective protection.

Although speculative, there is a broad movement emerging that might influence radiation protection concepts and infrastructures. It is the search to find a common basis to manage risk, particularly risk from hazardous materials, including radioactive materials. It is being driven, in large measure, by a need to improve allocation of resources. How this will affect radiation protection is not clear. Radiation protection concepts and infrastructures often appear to be more advanced than are most other systems for protection from hazardous materials. Also, knowledge about the effects of radiation is substantially greater than for other hazardous materials in general. Therefore, the field of radiation protection might lead the way toward a more integrated system and better allocation of resources for protection. There are other possible consequences resulting from a more integrated system of risk management. Better allocation of resources might mean reduced funding for radiation protection. However, it would mean that radiation risk could be placed in a more realistic perspective to other risks when more closely coupled through integrated management.
LIABILITY FOR NUCLEAR DAMAGE IN EASTERN EUROPE AND INTERNATIONAL CO-OPERATION

Until the mid-1980s, the mere suggestion that the rules in communist countries on liability and financial security were perhaps inadequate to cover the consequences of a nuclear accident would have been greeted on the part of the countries concerned with incomprehension or possibly indignation. It would have been pointed out that in such countries, the State and the Party were responsible for the safety and well-being of workers in all circumstances, without any need for special measures to regulate the allocation of liability or ensure financial cover in the event of an accident. Thus, apart from the somewhat special case of Yugoslavia, no Eastern European country was, at that time, a Party to the Vienna Convention on Civil Liability for Nuclear Damage (branded as “capitalist”, as was the Paris Convention), nor had any special legislation in this field.

The accident at Chernobyl, in April 1986, was, in this sphere as in many others, to lead to a major change in approach and to the mobilisation of international cooperation.

In accordance with normal practice in communist countries, the victims of Chernobyl (i.e., mainly persons evacuated and those involved in clean-up operations who suffered injury or material damage) were not compensated by means of money payments but rather offered a new house or job, increased medical surveillance and other forms of assistance designed to improve their quality of life. The Soviet Union’s refusal to countenance any liability for the essentially economic damage caused in Western European countries by radioactive fallout from the stricken reactor, made the international community realise that there were shortcomings in the system of nuclear third party liability, starting with the fact that there are not nearly enough Parties to the Vienna Convention (by reason of its regional nature, the Paris Convention is in a somewhat different category). A first step to remedy the situation was the adoption, two years after the accident, of a Protocol1 introducing a link between the two Conventions; by means of the mutual recognition of the benefit of their provisions by their respective Contracting Parties, a broadening of the geographical application of the international system of nuclear third party liability was thus achieved. At the same time, this has made it more attractive for other countries to adhere to the Vienna Convention.

It was generally felt that the signature of the Joint Protocol was a first step only on the road to a fundamental review of the nuclear third party liability Conventions. There was general agreement that the Vienna Convention, designed for worldwide application and having remained unchanged since its adoption in 1963, should be the first to be brought up to date. This task was to be facilitated by the break-up of the Soviet Empire and the movement, in East European countries, towards a market economy, since this removed the objection of principle that communist countries had to a system of liability governed by private law.

THE VIENNA NEGOTIATIONS

As a result of these profound changes, the negotiations on the revision of the Vienna Convention, conducted within the IAEA Standing Committee on Liability for Nuclear Damage, involved many more countries than the still somewhat limited number of Parties to the Vienna Convention. In addition to NEA Member countries, naturally directly concerned by improvements to the international system of nuclear third party liability, many ex-communist States attended meetings and took part in the discussions more and more actively as their specific weight within the Group grew due to their increasing adherence to the Vienna Convention.

The purpose of this short article is not to give a detailed account of some five years of complex negotiations about the changes to be made to the Convention or about the thorny question of a supplementary financing mechanism for compensating nuclear damage. It may simply be noted in passing that on the first point, a reasonably detailed draft exists and could in theory be adopted in the near future, despite the fact that unanimity has not yet been reached on a number of amendments. It should also be pointed out that the key question of the future minimum amount of the nuclear operator’s liability has still not been settled since many countries are reluctant to commit themselves on this

1. Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention. The Joint Protocol, adopted on 21 September 1988, entered into force on 27 April 1992. There are 16 Parties, namely: Bulgaria, Cameroon, Chile, Croatia, the Czech Republic, Denmark, Egypt, Estonia, Hungary, Italy, Lithuania, Netherlands, Norway, Poland, Romania and Sweden. The great majority of these are European countries.

2. The NEA has just published a new study on this subject, entitled Liability and Compensation for Nuclear Damage: An International Overview.
point [the reference amount, however, remains that recommended by the NEA Steering Committee to the Parties of the Paris Convention, namely 150 million Special Drawing Rights (SDR) of the International Monetary Fund].

On the second point, the Standing Committee has worked successively on several types of international compensation systems but none has, so far, been found acceptable by all delegations concerned. A new proposal, from the United States, based on a somewhat different approach since it would take the form of a separate agreement instead of being joined on to the existing basic Conventions (Paris and Vienna), could perhaps represent a breakthrough or, on the other hand, complicate the negotiations still further.

Given these problems and the slow rate of progress, some countries were apparently tempted to "separate" the revision of the Vienna Convention from the drafting of an agreement on supplementary financing, thus making it possible to conclude the first of the tasks entrusted to the Standing Committee. It is interesting to note that in rejecting this option for the main reason that it would not be enough simply to amend the Vienna Convention, the Contracting Parties to this Convention adopted for the first time a concerted approach to the general direction the negotiations should take. This reaction may also be perceived as reflecting a certain distrust of the real intentions of the Western countries with regard to their participation in an international system of financial support in which, by the nature of things, they would be the main contributors.

It may also be noted that the original idea – based on nuclear legislation in some Western countries and also on the international system for compensating oil pollution damage – that the nuclear industry would be invited collectively to make a financial contribution in the event of an accident causing damage in excess of the capacity for financial cover of the operator liable, seems now to have been more or less abandoned. Should this prove to be the case, it would be for national governments alone to pay for any additional compensation for nuclear damage, thus increasing the contribution required from public funds. As they have pointed out, such a burden would be particularly difficult for those countries with limited finances, which is at present the case for Central and Eastern European countries.

No matter what difficulties were and still are being encountered in the work on the Vienna Convention, the fact remains that remarkable progress has been made in recent years; in particular, the all but doubling of the number of Parties to the Vienna Convention, due notably to the adherence of Central European and Baltic countries (see Table). Apart from Armenia, however, countries formerly part of the USSR (New Independent States: NIS) have not so far joined this movement. And yet it would be of capital importance to convince in particular Russia and Ukraine to adhere to the Convention (and the Joint Protocol), given the size of their nuclear power programmes. Another sector in which progress must absolutely be made in East European countries, is that of insurance.

**INSURING THE NUCLEAR RISK**

The main characteristic of the nuclear insurance market is that it is administered, in each country, by a "pool" bringing together the available financial capacity of national insurance companies. These pools, which thus co-insure nuclear risks (damage to the installation and third party liability), can then re-insure part of their commitments with foreign partners.

However, for the reasons explained at the beginning of this article, the countries of Eastern Europe had until
recently chosen not to insure their nuclear installations. This policy has changed, and on being asked to help insure these installations, Western insurers indicated that a necessary condition for any participation by them was the creation in the countries concerned of insurance pools modelled on those which have operated in the West for some 30 years. Given the present economic climate and the need to set up a general insurance sector, which also requires an appropriate legislative framework and the mobilisation of national financial resources, progress has been slow. However, several East European countries have recently acquired nuclear insurance pools, thus giving them the opportunity to access the international re-insurance market. It is to be hoped that this example will quickly be followed by the other East European countries, even though the creation of pools will not automatically resolve the problem of the insurability of certain installations deemed potentially dangerous.

At the same time, the reluctance of several East European countries to accept one of fundamental principles of the nuclear third party liability system, namely the channelling of all third party liability for nuclear damage to the operator in question, is causing serious difficulties which could compromise the endeavours of Western countries to help their East European partners to improve the safety of their nuclear installations.

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**NUCLEAR SAFETY AND QUESTIONS OF LIABILITY**

In countries which have adhered to neither of the nuclear third party liability Conventions nor adopted any internal legislation based on the provisions of these Conventions, liability for a nuclear accident is normally regulated by the ordinary law. Usually, this involves the concept of fault to determine who is liable for the damage caused, and it is always possible to attempt to demonstrate the liability of persons other than the nuclear operator directly concerned. This could be, for example, one of the suppliers, should equipment prove faulty, in accordance with the principle of product liability.

Given the complexity of the technological processes involved and the scale of the financial consequences at stake, it is easy to understand why the manufacturers of nuclear installations and equipment, and even the suppliers of nuclear services, have always insisted that nuclear operators should be held exclusively liable for any damage. Potential victims also benefit since the “channelling” associated with the objective liability of the operator simplifies and speeds up their legal remedies. This rule of law is thus one of the features of the systems established under the Paris and Vienna Conventions.
It is therefore not surprising that the firms concerned hesitate to sign contracts involving for them a potentially extremely high level of liability. This is particularly true of East European countries who benefit from numerous – bilateral and multilateral – programmes of co-operation and assistance regarding the safety of reactors and other nuclear installations but are neither Parties to the Vienna Convention nor possessing equivalent legislation. This situation prevents firms from being assured that they will be totally protected from any action which could be brought against them, on the basis of the ordinary law, by victims in the country concerned or even in a third country.

While agreeing that the only entirely satisfactory solution to this problem would be for the countries of Central and Eastern Europe all to adhere to the Vienna Convention, the Western countries – particularly within the G-24 – have endeavoured to find temporary arrangements that would convince business firms to accept the risks inherent in providing assistance. These arrangements have taken the form of government declarations or bilateral agreements between “donor” and “beneficiary” countries under which the latter undertake, in the event of an accident, to defend or compensate “donor” countries – or the firms concerned from these countries – with regard to any action or judgement engaging their liability.

The drawback to such arrangements, apart from their complexity, is that they normally only commit the government of the beneficiary country and do not therefore offer the same legal guarantees as an agreement duly approved by Parliament and having the force of law. In these circumstances, many Western firms have felt that they did not give sufficient protection. The situation becomes even more complicated when the countries bordering the country receiving assistance are not Parties to the nuclear third party liability Conventions either, since, in this case, victims of nuclear damage suffered in such countries would be free to try to bring a direct action for damages against the firm which had worked in the installation where the accident occurred.

International financial institutions, such as the European Bank for Reconstruction and Development (EBRD), which help finance these assistance programmes, as well as the Commission of the European Union which administers and funds them, are basically in the same situation as business firms. Indeed, victims may find it more advantageous to bring actions against parties with more funds behind them, and to choose countries with the most “beneficial” legal systems (forum shopping).

This deadlock is all the more frustrating in that all the parties involved have an interest in finding a solution: the authorities responsible for nuclear safety in East European countries, because they are anxious to see the promised aid materialise; the Western nuclear industry, which wants to be able to use its skills in this new market; and lastly, the “donor” countries, which are naturally anxious to demonstrate to their voters that, faced with the risk of a new nuclear catastrophe, they are doing something. It is in this context that the OECD Nuclear Energy Agency took the initiative of organising in Paris, in July 1994, with the help of the European Commission and of the IAEA, a conference to bring together all the parties concerned. The intention was not to propose an immediate solution to what is an essentially political problem (even if the starting point is a precise legal difficulty: the channelling of liability), which will take a long time to resolve. It did, however, serve as a forum in which deeply felt views could be exchanged with great frankness.

The conclusion reached at these discussions was that the problem can only be permanently and comprehensively resolved on the following three conditions:

- all the countries concerned must adhere to the Vienna Convention and Joint Protocol;
- since this would not, however, be sufficient, these same countries must promulgate legislation to implement in national law the provisions of these agreements;
national nuclear insurance pools must be set up so as to
give operators of power plants in East European countries
the financial guarantees corresponding to their legal
obligations as regards compensation of nuclear damage.

Meanwhile, every effort must obviously continue to be
made to agree on interim arrangements to protect firms
engaged in projects to improve the safety of nuclear
installations in Eastern Europe. In other words, long-term
and shorter-term objectives must be combined in the
framework of concerted programmes for action based on
the optimum use of available resources.

While the negotiation of agreements and compensation
declarations falls more particularly within the competence
of the governments concerned or of the European
Commission for the PHARE and TACIS programmes,
international agencies specialised in nuclear co-operation
certainly have an active role to play in promoting attainment
of the above-mentioned objectives. Such
measures would, moreover, fit into the more general
framework of their activities designed to develop laws and
regulations on the use of nuclear energy, to strengthen the
authority and improve the skills of regulatory bodies, and
to train lawyers in East European countries in nuclear law.

Having now reached the stage where both the West and
the East are impatient to see the introduction of international co-operation programmes to reduce the risk of
another Chernobyl, and in the knowledge that important
funds have been set aside for this purpose, it would be
regrettable if all these endeavours were to be compromised
because of this difficulty of liability. Everything should
therefore be done to overcome this obstacle as soon as
possible, especially as there is basically no disagreement
about the objectives in this sphere.

In the same way that assistance programmes to improve
the safety of nuclear installations are intended to ensure
increased protection for the public and the environment,
the promotion of a universal system of liability and
financial guarantees for nuclear damage shares the same
goal: the greater safety of nuclear energy, which is the best
way of ensuring its acceptance by the public. Thus, in this
sphere, governments and industry, in the East as in the
West, share the same interests as potential victims of a
nuclear accident.

THE PRINCIPLES INVOLVED

Drafters of the Paris and Vienna Conventions were concerned to safeguard the public against possible, though
unlikely, damage which was potentially very serious, while at the same time ensuring that the development of the
nuclear industry was not hampered by the obligation to shoulder the intolerable burden of liability for the consequences
of an accident. In order to reconcile these two requirements, the two Conventions are based on the following principles:

- Nuclear operators are exclusively liable for damage caused by an accident within their installations or in the course of
transport. This "channelling" of liability simplifies the bringing of proceedings by victims and avoids multiple actions
against the operator's co-contractors and the need for a chain of insurance policies.

- The liability of the operator is objective (no fault) which also facilitates the bringing of legal proceedings by victims.

- It is limited in amount (the NEA Steering Committee recommended that the Contracting Parties to the Paris
Convention fix liability at a level not less than 150 million SDRs). It is also limited in time (generally speaking, 10 years after the date of the accident).

- Liability must obligatorily be covered by financial security, in theory of the same amount, taken out by the operator in
question.

- There should normally only be one competent court, even where damage has been suffered in the countries of other
Contracting Parties.

- The Conventions' provisions - especially the conditions for compensating victims - must be implemented without any
discrimination based on nationality, domicile or place of residence.

Unlike the Vienna Convention, the system of the Paris Convention was expanded in 1963 by the Brussels
Supplementary Convention which added to the nuclear operator's insurance cover a tier of compensation payable by the
"State of the installation" and, above this amount, by another tier made up of contributions from the public funds of the
Parties to the Convention, up to an amount of 300 million SDRs.
NUCLEAR LAW AND CODE OF CONDUCT

The Hague Academy of International Law recently turned its attention to nuclear energy issues for the first time ever by deciding to choose “the hazards arising out of the peaceful use of nuclear energy” as the theme for the 1993 workshop by its Centre for Studies and Research into International Law and International Relations. The results of this workshop have just been published by the Academy in a report which, by addressing the issues from an international perspective, offers an original analysis of the problems currently confronting nuclear law. Some of the issues it explores are the new Convention on Nuclear Safety, the revision of radiological protection standards, current work on the civil liability of operators, and the prospects of extending the Non-proliferation Treaty. In his conclusions on the Centre’s work, Mr. Strohl stresses the need for nuclear law and any proposed code of conduct for the nuclear community to underpin each other. Excerpts from his conclusions are given below.

New technologies play such an important part in modern societies that their control poses major problems. The problems of “regulating” the means used by telecommunications, information technology, genetic engineering and the space industry, and the hazards arising from their use, are no less complex and their consequences no less serious than those posed by nuclear energy, although they differ in nature. The challenges for the legal profession are just as great as in the field of nuclear law. All are fraught with uncertainty and all assume the same international and political dimensions.

Whatever the new technology we are seeking to control, the central issue is, of course, man and his ability both to adapt to new technologies and to safeguard human values from the adverse effects of such technologies. The answer to these concerns, ultimately lies in society’s ability to control both the means and the ends of science and technology, which have now become, and doubtless irreversibly so, an integral part of that society’s infrastructure. This is by no means an easy answer and will call, as stated previously, for a multidisciplinary approach. Suffice to say, at this point, that the law is only one means of exerting such control among many others – science and technology itself, the market, information, private initiatives, political intervention, etc.

The regulation of the means and statement of the ends are normal components of any provision of law. The grey areas of human behaviour are familiar territory to the law and it has thus far managed to reach some accommodation with them. However, the far-reaching consequences of abstruse scientific and technological concepts are now putting legal experts in a very uncomfortable position; the heavier responsibilities they now bear, as they attempt to incorporate all these factors into the appropriate rule of law, are prompting them (and rightly so) to try new approaches – thus introducing a further element of uncertainty – while at the same time trying to establish firm safeguards. They have to be aware of both the limits and the incremental nature of research, leaving the way open for the developments that are bound to follow; it is difficult to reconcile this with the need for strict regulation, which is just as likely to produce stifling over-regulation as to be wide of the mark. But their situation is not so very unusual; after all, the law only ever attains perfection when the problem it was designed to resolve has effectively ceased to exist.

Nuclear law is a good example of the kind of innovation, flexibility, informal approach, and discipline which seem to be the essence of any legal framework for advanced technology.

In connection with the current legal reforms, nuclear industry involvement in the process of consolidating past experience is to be desired. Adopting a code of conduct (or code of practice) for the nuclear industry, agreed by its national and international representatives, would have two advantages:

- it would allay the ethical concerns that arise when exploiting virtually any modern technology: the invasion of privacy in information technology, the manipulation of public opinion through audiovisual techniques, the dangers that eugenics present in genetic engineering or that nuclear power presents to health and the environment;
- it would supplement legislation by imposing standards of conduct voluntarily accepted by nuclear agencies: industry executives and professionals, regulatory authorities, policy makers, etc.

If such a code of conduct is warranted from the safety culture standpoint, it is no less important to promote quality

1. The International Nuclear Law Association is currently drafting a code of conduct of this type.
Nuclear law is a good example of the kind of legal framework needed for implementing an advanced technology.

Standards in research and in the development of more reliable or more profitable techniques, objectivity in social cost/benefit analyses for nuclear power programmes, and the accuracy of economic analyses. The standards of conduct in international trade are also very pertinent to the future of nuclear power, especially as regards the attitudes of firms and authorities to publicising technology and to the observance of non-proliferation policies. Finally, among a host of other examples, the quality of information on industry projects and the transparency of the decision-making process concerning plant construction are ethical decisions which those responsible must take.

Substantive law, which establishes the generally accepted rules, is the main instrument governing nuclear technology, at national level, and is the ultimate safeguard against failures. The same applies to agreements between governments relating to the interests of the international community. In an area as complex as this, where the individual’s standards of conduct are a determining factor, the effectiveness of regulation through legislation is nonetheless limited. The call for standards of conduct arrived at by consensus between private operators, which will help to ensure the relevance of regulations to real situations, can only reinforce legislation or perhaps throw light on the measures it should take.
NUCLEAR POWER AND THE ENVIRONMENT: A SOLUTION?

Nuclear power is a proven technology that makes an important contribution to energy supply. Almost 24% of electricity within the OECD come from nuclear power plants (Ref. 1). Worldwide the proportion is 17% with more than 30 countries having nuclear power plants. Nuclear energy has proven attractive, if only for cost or security of supply reasons. But does it offer a long-term solution to environmental problems? One can argue that, notwithstanding problems such as Chernobyl, the use of nuclear energy for electricity production has several environmental benefits. When operated in a safe fashion – and every effort is made to ensure that this is the case – nuclear power has less environmental impact than most alternative technologies.

SITUATION IN THE NEXT DECADES

Given expected population increases, world total primary energy demand is expected to grow at 2.1% per year over the next 20 years, even taking into account energy intensity improvements of 1% per year. Additional electricity generation is projected to amount to around 8400 TWh (Ref. 2). Coal and nuclear power are the only discernible supply alternatives for responding to the bulk of this demand, while renewable sources have the potential to cover only a minor percentage of it (Ref. 3). Gas, while making an important contribution in the short term, is not seen as a long-term solution.

ENVIRONMENTAL PROBLEMS

Two long-term environmental problems are often quoted. The first is global climate change, often referred to as global warming. Is the production of carbon dioxide causing changes to the climate which will affect the quality of life, if not threaten life in some areas? The question is not resolved to everybody’s satisfaction. But there is a growing consensus that a path of “no regrets” should be taken5. Cost-effective measures should be taken to ensure that the threat of climate change be minimised, and that entails ensuring that use of fossil fuels, which generate carbon dioxide, be reduced as much as possible5.

The second problem is to develop or to use technologies that lead to sustainable development. Future generations should not have to pay for benefits that our current generation enjoys and should have the opportunity to have as “good” a life as we do.

POWER GENERATION AND THE ENVIRONMENT

Three important points can be made at the outset. First, the impacts associated with electricity generating sources are not confined to the generation stage. They extend backwards into fuel extraction and processing, and to materials extraction, conversion and fabrication, as well as the construction of the plant itself. They also extend forward toward reprocessing and final disposal of wastes. Second, the benefits and costs associated with individual options have to be measured against those of the alternative options. Third, these alternative options may include non-electricity options, such as conservation strategies or direct fuel combustion, which have their own environmental and health impacts.

All fuel cycles within the electricity generating systems involve some health risks and lead to some environmental impacts, with both nuclear power and renewable energy systems tending to be in the lower spectrum of health risks (Ref. 4). Nuclear power, however, is almost unique in having made considerable effort to tackle life-cycle issues from the very beginning.

GLOBAL CLIMATE CHANGE

Nuclear power contributes to global climate change (or global warming) only if used made of fossil fuels in the extraction and processing of uranium, in generating electricity for uranium enrichment (where this is not accomplished from nuclear or hydroelectric sources) or in the production of steel and cement for reactor and fuel plant construction.

In general the emissions associated with nuclear power are comparable in this regard to those associated with renewable sources and equivalent energy conservation measures (Ref. 5-6) requiring the use of materials to achieve their effect (e.g., loft insulation, cavity wall insulation). Table 1 (Ref. 7) shows relative carbon dioxide emissions. Other products of fossil-fuelled electricity generation (acid gases, hydrocarbons, etc.) would be in similar ratios.

1. This accident of major consequences was due to design and operational problems not encountered in OECD/NEA countries.
2. This is an approach proposed, among others, by the World Energy Council.
3. The IPCC has been studying the effects of global warming, and favours a reduction of 60% in greenhouse gas emissions.

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NUCLEAR POWER AND THE ENVIRONMENT: A SOLUTION?

Should there be no change in the present trends carbon dioxide emissions are expected to grow by 50% from 1990 to 2010 (Ref. 2). Total emissions in 1990 were 6,000 million tonnes of carbon (Ref. 8). In the United States, for example, it has been estimated that the annual damage, if carbon dioxide concentration were to double in the atmosphere, would be some 60 billion dollars (1990) or 1.1% of the gross domestic product (Ref. 9). However if nuclear power were to be used to provide 70% of the OECD electricity demand of 12 000 TWh, the avoidance of carbon dioxide emissions by 2030 would amount to about 1.2 gigatonnes of carbon annually at the end of the period as compared to using coal at 50% efficiency.

Table 1. Carbon Dioxide Release Versus the Technology
(Based on production or saving of 5 TWh/a of electrical energy)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Annual Average Total Carbon Dioxide Release (in 100,000 tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation options</td>
<td></td>
</tr>
<tr>
<td>Coal-fired</td>
<td>59.1</td>
</tr>
<tr>
<td>PWR</td>
<td>2.3</td>
</tr>
<tr>
<td>PWR</td>
<td>0.4</td>
</tr>
<tr>
<td>PWR (self-supplied)</td>
<td>0.2</td>
</tr>
<tr>
<td>FBR</td>
<td>0.2</td>
</tr>
<tr>
<td>Hydro/power</td>
<td>0.9</td>
</tr>
<tr>
<td>Wind/power</td>
<td>0.5</td>
</tr>
<tr>
<td>Tidal/power</td>
<td>0.5</td>
</tr>
<tr>
<td>Efficiency measures</td>
<td></td>
</tr>
<tr>
<td>Roof insulation (10-in fibre glass)</td>
<td>0.2</td>
</tr>
<tr>
<td>Cavity wall insulation (polystyrene foam)</td>
<td>0.2</td>
</tr>
<tr>
<td>Low-energy lighting</td>
<td>0.2</td>
</tr>
</tbody>
</table>

SUSTAINABLE DEVELOPMENT

Sustainable development has been a catchword intended to reflect concerns that future generations should have at least as good a life as we currently have — how ever one defines “good”. This has meant to some that sustainable development has to avoid significant (and irreversible) damage. A weak view would be that an economy is sustainable if it saves more than the depreciation on its man-made and natural capital. A stronger approach is to insist that there be no net damage to environmental assets (Ref. 10).

In the case of nuclear power, depletion of uranium fuel resources cannot be considered as a “damage” as the resources can only be used in nuclear power plants to generate electricity (apart from certain special uses). This assumes that full environmental restoration is done after the depletion of mines.

The question can therefore be limited to certain processing and power generation facilities. In the weak case does the economic advantage of using nuclear power outweigh the environmental impact? The question is academic if all environmental impacts are already internalised and included in the costs. This is basically the case for nuclear power where the impacts are internalised (Ref. 11). In the strong case, does nuclear power damage the environment? Most people would agree that during normal operation the impacts of civilian nuclear operations are benign.

If one ensures proper safety (and this can be argued to be the case within the OECD area) one would have to conclude that nuclear power is an environmentally benign technology that leads to sustainable development.

4. As a side benefit the use of nuclear power avoids other pollutants. France, which now has over 70% of its electricity coming from nuclear, produced 978,000 tonnes of sulfur dioxide and 208,000 tonnes of nitrogen oxides in 1979. This has been reduced to 83,000 tonnes and 34,000 tonnes (a more than ten-fold reduction and a six-fold reduction) respectively through the increased use of nuclear power. This has also cut carbon dioxide from 82 million tonnes (1980) to 13 million tonnes (1997) (a factor of 6) and dust emissions (particulate) from 77,000 tonnes to 1,900 tonnes (a reduction by a factor of 40) [Data provided by EdF.]

5. Pulverised fuel plant.
7. Using centrifuge enrichment (Europe).
8. Using nuclear electricity to power enrichment plants.
The benefits and costs associated with individual energy options have to be measured against those of alternative solutions.

IS THERE A CATCH?

It would seem from the above that nuclear power has only environmental technology. However, nuclear power is a demanding technology. If one looks at the accomplishments of nuclear programmes in different countries it becomes obvious that the nuclear technology adapts with difficulty to pure profit motives, market mechanism and fragmented organisations (Ref. 12). The need for a long-term view, given the long lead times for establishing the infrastructure and the generation capacity, the need for large resources given the capital costs, the need for standardised products to reduce costs, the need to put safety above profits, all those factors imply that centralised bodies with a critical independent safety organisation, supported by the governments, would have more success in developing a cost-efficient and safe nuclear programmes.

Nuclear power, to be operated safely, demands a certain social, technical and scientific environment. A safety culture must be present. There has to be a minimum number of technically competent personnel. Adequate research facilities must be present to support the research ensuring that nuclear power is used wisely and safely. A proper regulatory structure must also be in place.

CONCLUSIONS

Benefits from nuclear power can only be obtained if rigorous care is taken to ensure that safety is maintained, and that the concern for the environment, expressed in many ways including waste management, is ever present.

However, nuclear power will still have to surmount difficult problems in the next few years before it can deliver its full potential. There will be a period where short-term alternatives, such as gas, will be more attractive, and during which the industry will have to maintain its capability. The industry also has other difficulties to overcome, not the least of which are public opposition, the need for reduction of cost and financial risk of nuclear power.

Nuclear power does provide significant long-term environmental benefits. Several studies such as the joint U.S. Department of Energy/Commission of the European Communities project, the inter-agency joint project on comparative assessment (DECADES) and others are pointing to the environmental advantages of using nuclear power.

REFERENCES

NEEDS FOR AND AVAILABILITY OF NUCLEAR DATA

The design and operation of a nuclear power plant is very strongly dependent on computer use. Analysis and prediction of reactor behaviour depends on using complex computer programs to simulate the different processes at work. In turn, these calculations depend on high-quality data describing the nuclear reactions (in particular fission induced by neutrons) needed for energy release, and the many other physical phenomena concerned in safe operation of the plant.

WHY DO WE NEED MORE NUCLEAR DATA?

Fifty years after the first pile in Chicago, why should scientists still be measuring and evaluating neutron and other nuclear data to improved levels of accuracy?

During the early development of nuclear power, computer modelling of reactor neutronics was based on simplified mathematical presentations of the phenomena concerned, using group averaged data values whose uncertainties were too high to be directly acceptable within the required accuracy limits. These values were adjusted to reproduce correctly the results of measurement in partial replicas of reactor designs, and only then used in the design process. The adjustments were expensive to make, and of limited applicability.

Successive generations of “evaluated” data libraries since 1958 have used more accurate measurements, and improved nuclear models, in libraries of preferred cross-section values which are used for neutronics calculations in increasingly sophisticated computer programs. Such programs are then able to convert better and more complete data into more accurate predictions of heat production, neutron balance and other events within and beyond the reactor core.

Long-term efforts to reduce the uncertainties in nuclear data have contributed to refinements in reactor design, bringing improved operating safety and efficiency and making possible savings in engineering costs. New designs for nuclear fuel will allow for increased total energy output. The range of particle energies to be covered by the evaluated libraries at higher accuracy has also increased in recent years; new data are used and more data are needed in studies for nuclear fusion, but also for actinide burning and transmutation, plutonium recycling and accelerator/target design. Nuclear medicine, astrophysics and space studies are non-energy users, together with diverse industrial applications.

<table>
<thead>
<tr>
<th>Application</th>
<th>Needs</th>
<th>Problem</th>
<th>Improvement expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor fuel</td>
<td>Improved data for transuranic isotopes and fission products</td>
<td>Uncertainties in data limit effective fuel endurance</td>
<td>At present 5% allowance is made in design for uncertainties</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New fuel designs for extended burnup.</td>
<td></td>
</tr>
<tr>
<td>Reactor structures</td>
<td>Reduced data uncertainties for structural materials, from 1-5 MeV</td>
<td>Radiation damage; reactivity effects in the harder neutron spectrum of advanced reactors</td>
<td>Target accuracy 5%. At present 20% uncertainty in Fe (n,n’).</td>
</tr>
<tr>
<td>Fusion energy study</td>
<td>Data for low-activation materials, nuclear heating, radiation damage</td>
<td>Current data files have too large error margins</td>
<td>(New data evaluations and measurements needed)</td>
</tr>
<tr>
<td>Transmutation long-lived isotopes.</td>
<td>Reduce data uncertainties for transuranic isotopes. Data for accelerator-driven neutron sources</td>
<td>Improve efficiency of reactor transmutation, design studies for accelerator driven reactors</td>
<td>Higher transmutation rate mixed-fuel reactors</td>
</tr>
</tbody>
</table>

* MR. NIGEL TUBBS IS CO-ORDINATOR OF THE NEA DATA BANK.
FROM EXPERIMENTER TO END USER

The expression “nuclear data” covers several distinct phases in the production and refinement of the data used by reactor physicists and nuclear engineers in power reactor design and other practical applications. Starting from an identified need for new data, measurements may be carried out in several laboratories, then compiled and distributed by one of the neutron data centres. These data may then be incorporated into an “evaluated” data file, which will itself be tested in calculations against the results of reactor physics experiments. The timespan of each phase may cover years rather than months, and it is this long lead time between measurement or evaluation of data and their implementation which makes a strategic view of data needs so essential.

THE CHANGING EMPHASIS OF NEUTRON DATA DEVELOPMENT

If one examines the publication dates in the international database of nuclear reaction measurements, they show a sustained high rate of publications between 1957 and 1987, with a peak around 1970; the first evaluated data file to be widely used was developed in 1958, while an important later landmark was the first U.S. “reference file”, completed in 1973. The current generation of evaluations, released since 1990, is still largely based on data measured during this peak period. Continuing development of evaluated data for fission reactors is concentrated for OECD countries in the Japanese (JENDL), United States (ENNDF/B) and JEF files. The JEF file is a joint evaluation project between countries participating in the Data Bank. The improved consistency between these newer files results from important later high-precision measurements, painstaking reanalysis of some of the best older data, and improved mathematical and statistical techniques.

Before they can be used in most neutronics calculations, these data files must be transformed into so-called “group cross-section sets” for which the neutron energy range is divided into bands and an effective cross-section for each is determined, depending on the energy spectrum encountered in the application under study. Pictorially, they appear as histograms. These Group data sets are strongly dependent on the neutron energy spectrum and may also be specifically adjusted to different reactor types.

RESOURCES FOR SATISFYING DATA NEEDS

The experimental facilities in commission, qualified manpower and available funds have decreased to a point where it is difficult to maintain a coherent programme of nuclear data measurements in one country, and international coordination of the remaining resources may be the only way to continue operation and meet the data needs which have been identified. The risk of further decline is that with the programme itself, unique facilities will be lost and with them the know-how to build, run and produce data from such facilities in the future.

EXPERIMENTAL FACILITIES

Generally speaking, the existing database of cross-section measurements is sufficient for most current thermal reactor applications. The special problems which remain require high-precision differential data measurements; many of them are safety-related. The question of precision data for new reactor types, and for plutonium or actinide burning, remains open. Very few suitable pulsed neutron sources are still available for high-resolution data measurements for energy applications. Integral experimental facilities are likewise fundamental to validating the calculation methods and data used in different reactor applications. Though very many integral assemblies have been taken out of service, there are examples of good collaboration in using those which remain, in particular the AEA-CEA programme using DIMPLE (UK) and EOLE/MINERVE (France). This concerns fuel management “burn-up credit” in criticality safety, and more generally the validation of JEF data for wider use in reactor physics, fuel and criticality calculations.

Collaborative measurement series between European and U.S. laboratories have recently made indispensable contributions to resolving problems studied by neutron data evaluators, and the collaboration is now being extended to Russian laboratories.
NUCLEAR MODELLING AND EVALUATION

Nuclear model development is carried out in universities and national laboratories, and is not at risk as an activity. However, the practical application of nuclear models is an essential part of the art of nuclear data evaluation, together with the re-examination of important data measurements and revision of data values to take into account new standards data and modern techniques of error analysis. Such experience has in the past been acquired over a lifetime’s work in nuclear physics, and many evaluators have now passed retirement age. Despite its shrinking manpower, evaluation is the discipline on which current nuclear development depends for its data.

Improvements in nuclear theory and the associated modelling codes have made modelling an integral part of the evaluation process, and in areas such as Intermediate Energy where few experimental data are available, it has taken on major importance. NEA has a long-standing programme of international calculation exercises (“benchmarks”) for the validation of modelling software: most recent studies have covered the fission cross-sections of higher actinides, a blind intercomparison of models for charged particle emission, modelling parameters for iron data, and codes for predicting cross-sections at intermediate energies up to 1.6 GeV.

In a very crude approximation, an evaluated data file is built up by “intelligent averaging” of the best available experimental values, with theoretical calculations for interpolation when experimental values are insufficient. For reactor calculations, a complete file covering a wide range of isotopes is needed, and a measure of the file’s quality is obtained by benchmark testing it in calculations of the results of standard critical experiments.

Attempts over a twenty-year period to generate evaluated data which could be used without adjustment in reactor calculations have brought scientists close to success in the recent generation of OECD-area files. In calculations, using these files, the agreement obtained in predicting the results of criticality experiments and performance measurements in operating reactors, is now comparable to or better than that obtained with adjusted data. In order to secure further improvements, NEA coordinates a worldwide collaboration on nuclear data evaluation with a full exchange of information: new evaluations are made available to all the different evaluation projects, but as a unique combination of data sets each file keeps its own identity.

NUCLEAR DATA CENTRES

It is not enough to make new and more precise evaluated files of nuclear data. The most current data must be easily available to nuclear scientists and technologists in a form which they can apply simply in their work.

NEA Data Bank and the U.S. National Nuclear Data Centre together make nuclear data easily available in all OECD member countries. By their support for the development and qualification of new evaluated files, major national laboratories and the funding authorities behind them have contributed to improving the standard of data available. International collaboration is essential to this enterprise.

Scientists working on an evaluated neutronics data file need to draw on many different types of information: experimental data, standards for neutron flux measurement, computer codes for reanalysing some important data sets and for nuclear reaction modelling, results of benchmark experiments on criticality and radiation shielding, and measurements in operating reactors. Their task would scarcely be possible within a reasonable time unless this information can be acquired from data centres on other groups holding a reasonably complete collection of the data or programs needed. Moreover, the information is required in computerised form, and in a consistent format. It must be made easily accessible to all the scientists who need it.

A “Strategic View” document recently published by the OECD Nuclear Energy Agency considers in some detail the role and contribution of the two international nuclear data centres, the NEA Data Bank and the IAEA Nuclear Data Section, and

1. In 1993, the NEA published a report entitled “A Strategic View on Nuclear Data Needs”. The report considers needs for new and improved data in the short and long terms, for nuclear energy as well as other scientific and technical applications. It recommends measures to improve communication between users and producers of data, and to maintain an adequate level of research resources, by improved national and international collaboration.
the nine national data centres in processing and storing nuclear data, and making them available worldwide. Their work is completed by the distribution of computer programs for nuclear applications, from Oak Ridge for the United States and Canada, and from the Data Bank for other NEA and IAEA users.

Collaboration in the compilation of experimental data began with the exchange of data for neutron cross-section measurements through a “Four-centre network” of centres in the United States, Russia, OECD-NEA and IAEA, set up in the 1960s. It has been extended to include other national data centres, and topics which now include charged particle and photo-neutron reaction data, and contributions to the Evaluated Nuclear Structure Data File (ENSDF). This work is coordinated by IAEA as the Nuclear Reaction Data centres network (NRDC). The information contributed by each centre is available to all its members, but in practice user services are the responsibility of the original four centres, whose agreed service areas together offer worldwide coverage. Within OECD/NEA, service on nuclear data is provided for North America by the National Neutron Data Centre (Brookhaven, New York, USA) and for other Member countries by the NEA Data Bank.

THE CONTRIBUTION OF INDIVIDUAL CENTRES

Each of these data centres makes a specific contribution to the basic compilation work coordinated within NRDC. In general, this responsibility will absorb only a small part of its resources. Most of its efforts will be concentrated on other specialised tasks, which make up the main part of its programme: support to national nuclear activities, neutron data evaluation coordinated within the Agency’s Nuclear Science Committee (NSC), or nuclear structure and decay data (for the ENSDF project). Service work to users absorbs far less effort than building up and verifying the data bases on which the service depends, so that even in the larger centres distribution does not absorb more than 10 to 15 per cent of their effort.

The study concluded that the nature of data compilation and services to users allows few economies of scale to be won by concentrating them in a single location; sharing of compilation work is already very well coordinated by NRDC, as are the
specialist tasks such as neutron data evaluation (NSC) and ENSDF. Efficient service, as well as the willingness of scientific users themselves to prepare and submit data for compilation, depends on good contacts between staff and individual scientists. It seems preferable to continue these tasks on a regional basis.

It is also important that the value of the contributions by each of the centres, and their place in the overall picture, should be fully clear to the authorities funding them. It is planned to produce a joint NEA-IAEA document on this topic.

THE ESSENTIAL ROLE OF INTERNATIONAL COLLABORATION

Even with a worldwide effort, it might today be impossible to repeat more than a part of the neutron measurement programmes carried out in several parts of the world in the 1960s and 1970s. Likewise, an evaluation effort similar to that invested in the ENDF/B and JEF files in the 1980s would be very hard to reproduce. NEA countries have moved quickly to combine their interests in a single collaborative programme, which by now occupies a high proportion of the available nuclear physics effort in the countries taking part. The “Strategic View” document has proposed several measures which can help slow down the decline in capacity; increased funding would be needed to restore it.

• Data needs may be short or long term. Some short-term needs should be supported by industry, which must also consider contributing to data production for the long term. However, the ultimate responsibility for financing long term work must rest with governments.

• There is a need to strengthen contacts between data producers and users of all kinds, in order to identify the possible benefits from applying improved nuclear data to existing applications or where potential savings can be clearly identified.

• Resources in skilled manpower and equipment in nearly all NEA countries are falling below the minimal level needed to carry out an independent measurement programme. International cooperative effort would never replace national efforts, but could improve productivity from existing and future facilities.

• Data centres are an integral part of the process of data production, as well as data dissemination. They play a very important role within the nuclear data community, and the two international centres should continue to be strongly supported. While the maintenance of national centres is a matter for the countries concerned, their specialised contributions could not in fact be replaced.

In the framework of NEA, Member countries are responding to the problem by strengthening coordination (within NSC, the International Evaluation Cooperation has been reinforced by a new Working Party on Measurement Activities) and improved contacts with industry. This year new support from the nuclear industry has made possible a project on improved presentation of JEF data for use in PC programs, and a research mission of several months to the ORELA measuring facility in the United States. These early actions are necessarily limited, but it is intended that others will follow. A User-Producer Forum on nuclear data is planned, in order to achieve wider understanding of the needs for continued research in this field, and to promote increased direct support from industry.
NEW MAN-MACHINE INTERFACES IN NUCLEAR POWER PLANTS

The OECD Nuclear Energy Agency has just published a report showing how human factor considerations are now being taken into account in the control room at existing nuclear power plants and discussing current developments for future ones. This report is a synthesis of the work undertaken on various aspects governing the relationship between the operator and the installation whose safety lies in his hands, in other words, the man-machine interface.

Feedback analysis and, more specifically, the analysis of the incidents that occur at nuclear power plants as in every other industrial installation, reveal the importance of human factors in plant operation. The adoption of human factor principles in conjunction with the development of advanced digital technology has led to the introduction of computerised operator aids at most operating plants. These aids cover a wide range of means from the installation of safety parameter display systems to the design of fully digitised control rooms. This variety is largely due to the fact that in existing installations radically new improvements are difficult to introduce and for future power plants, they can only be included at the design stage.

Most operating plants are now equipped with safety parameter display systems which monitor a small number of essential functions while providing crucial support for the control room crew, especially in managing complex incident and accident situations and in making optimum use of procedures during emergency operation. Other operator aid systems have been introduced at some installations in the form of advanced reactor core parameter monitoring systems or even computerised process information systems. Finally a few countries seem to be opting for the design of fully digitised control rooms. France, for instance, has gone ahead with this design for the new units belonging to its N4 reactor set (140 MWe reactors).

EVALUATION OF MAN-MACHINE INTERFACES

The evaluation/validation phase is an important part of the implementation process for man-machine interfaces. It provides an opportunity to detect and solve errors, to measure discrepancies and deviations from expected performances and to ensure compliance of the interface with design requirements. Depending on the countries, various methods are applied, from verification of interface compliance with existing standards to intensive use of simulators and mock-ups.

ALARM PROCESSING AS A SUPPORT TO OPERATORS

One of the main difficulties encountered by the designers of man-machine interfaces is the need to define an alarm system that will act as a modern support tool for operators in their monitoring tasks without submerging them with information as they now are with current alarm systems. Modern systems divide alarms into functional groups, applying filtering criteria using priority codes, cut-out conditions and variable limits.

The adoption of an improved alarm system that, on the one hand, solves the problems related to the operator's cognitive overload and to the alarm avalanche during fast transients or accidents and, on the other, provides adequate support to the operator in relation to his enhanced supervisory tasks, typical of advanced control rooms, is crucial in plant design.

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**EXPERT SYSTEMS**

Modern digital technology provides an opportunity to use artificial intelligence in the form of expert systems. These can be applied to several areas of plant supervision and control such as real-time diagnostics, decision support, emergency response in order to enhance operator understanding of the plant status and therefore to take appropriate remedial action. The anomaly and accident management support function is warranted inasmuch as it provides operators with assistance based on ergonomic and cognitive principles, helping them to understand imminent plant conditions and to decide on what action to take without risk of error.

Such systems may also contribute to maintenance activities by bringing significant support to the preparation of plant maintenance work planning, thereby improving working conditions and making adequate maintenance procedures available. The maintenance support function is chiefly aimed at helping maintenance personnel in the planning and monitoring of their work.

**TASK ALLOCATION BETWEEN MAN AND MACHINE**

The allocation of tasks between man and machine is not just a matter of automation level even though this does provide indication of the extent to which the operator forms part of the control chain. The proper balance between automation and operator actions is one of the major issues in designing future nuclear plants. The safety and reliability of plant operation depend on the operator.

With advanced digital technology, the machine can be given increasingly complex functions and it is likely that the automation level in plant operation should increase in the future and may even lead to better plant safety, although this is hard to tell at this stage. The wide spectrum of solutions adopted in various countries reflects the complexity of this task. More time and resources should be devoted to the optimum allocation of tasks between man and machine, and in any case this task should be given to engineers in cooperation with human factor specialists. Experience shows that satisfactory solutions can be found with very different approaches even if the industry feels a need for a more systematic one based on the definition of operator role and capability. An example is advanced reactors with passive safety systems, where the role will change from that of a “fast actuator” as in traditional plants to that of an “intelligent supervisor”.

**ERGONOMIC EVALUATION/VALIDATION METHODS**

New technology using modern computer and display techniques is being introduced in control rooms. It must be effectively introduced in order to improve plant safety and reliability. This is a complex task because no current theory can predict whether any given interface or control room will operate as expected.

Consequently, licensing authorities as well as plant constructors and utilities feel a need to develop an ergonomic evaluation procedure for the systems using such new technologies. One method that is advocated in particular consists of operator testing on full-scale simulators under realistic conditions. The results of these evaluations, which may take several years to perform, will allow detailed analysis of all the advantages and disadvantages of the solutions adopted prior to introduction of the systems in the control room.

In conclusion, the concept of “advanced” control rooms is sure to be extensively developed in the nuclear industry both for future and existing power plants. The new control rooms will apply new man-machine interface technologies that will bring far-reaching changes in the role of operators, in their interaction with increasingly complex systems and in information modes, and will therefore influence overall plant safety. Consequently, adequate resources must be devoted to the study of man-machine interfaces to ensure that they have been designed in agreement with tried human factor principles whereby operators meet performance and reliability requirements for public health and safety.
probabilistic safety assessments (PSA) have become common tools in the nuclear field. The NEA’s Probabilistic System Assessment Group (PSAG) has provided timely support to several OECD countries seeking to develop a capability to conduct PSAs of potential radioactive waste disposal facilities. International co-operation can be used fruitfully to enhance confidence with regard to assessment philosophy, methodology, and tools.

Many decisions in everyday life are based on beliefs concerning the likelihood of uncertain events such as the outcome of an election, the guilt of a defendant or the future value of the Deutsche Mark. At times these decisions, although relying on actual data, do not recognise the limited validity of the data and rules which underlie the judgmental and decision process. For instance, the apparent distance of an object is determined in part by its clarity: the sharper the object is seen, the closer it appears to be. The rule has some general validity, but reliance on this rule only would lead to systematic errors.

Structured probabilistic analyses, otherwise known as “probabilistic safety assessments” or “probabilistic risk analyses” (PSA or PRA), are the scientific counterparts to the more practical decision-making processes of everyday life. In order to quantify the chance of an event, the relative validity of the data and the rules governing their analysis first need to be assessed before choosing the most appropriate mathematical tools. Although it is understood that PSAs can provide neither definitive answers nor rigorous solutions in a statistical sense, this disciplined approach fosters confidence and a better acceptance of the decisions being taken, so much so that PSAs have become common in the nuclear field and are used to support the claim of good engineering practice at, and safety of, nuclear installations.

The procedures and methodologies for PSAs have been perfected and widely implemented within the nuclear and aerospace industry only in the last 25 years. A 1975 study on reactor safety (WASH-1400), published by the USNRC, is justly famous both for its new method and its prediction of the Three Mile Island accident sequence. The PSA methodology is adequately described in the USNRC’s PRA Procedures Guide (1983), but there is as yet no standardised universal approach to PSA. Due to the increasing concerns raised by the impacts of human activities on the environment, PSAs are now being extended to numerous other fields.

**PSA COMPONENTS**

Safety analyses of the geologic disposal of long-lived radioactive waste can either be deterministic or probabilistic, depending on the relative weight and mathematical treatment given to specific combinations of possible events, also known as “scenarios”. In the former, scenarios are seen as totally independent and cannot be averaged with each other, thus generating a separate evaluation for each one; in the latter, scenarios have each a likelihood of occurrence and the “most likely” consequence can be assessed.

Probabilistic safety assessment is composed of qualitative and quantitative elements. Qualitative analysis identifies various failure modes, while quantitative analysis utilises available experience and knowledge of the system components and their interactions, in order to provide a numerical value of the probability that the system will perform as intended. The quantitative analysis would be meaningless without the qualitative one.

A qualitative reliability analysis is performed with one or more of the following objectives:

1. to identify weak points or imbalances in design;
2. to aid in the systematic assessment of overall system safety;
3. to document and to assess the relative importance of all identified failures;
4. to develop the discipline and objectivity of designers of safety-related systems;
5. to provide a systematic compilation of data as a preliminary step to facilitate quantitative analysis.
SAFE GEOLOGIC DISPOSAL OF NUCLEAR WASTE: THE DEVELOPMENT OF PROBABILISTIC ASSESSMENTS

The quantitative analysis calculates the performance of the system and takes into account the uncertainty analysis of parameters, models and degree of completeness of the implemented approach. Parameter uncertainties arise from the need to estimate parameter values from usually incomplete data from which the analyst must make inferences; model uncertainties stem from the inadequacy of the various models to represent reality and from the approach used to estimate probabilities and consequences; completeness uncertainties are related to the ability of the analyst to evaluate exhaustively all contributions to the unreliability of a system. According to the USNRC Guide, completeness and model uncertainties can never be quantified univocally. It is only discipline and a traceable, transparent and continuous record of ongoing and unsuccessful search for new failure modes or previously unforeseen interactions which foster the view that those uncertainties have been reduced to the maximum possible extent.

In order to quantify uncertainty, statistical methods are applied. However, because a combination of subjective and objective observations are used, the USNRC Guide recognises that “the theory of statistics [...] only provides tools and guidelines [...], but it is in general too restrictive to satisfy the needs of the uncertainty analyst”. Nevertheless, it also states that this lack of rigour is not as serious as it may seem, since the most important areas are covered and the most effective action is formulated to improve design reliability, thus reducing uncertainty.

Therefore, although quantitative methods cannot demonstrate absolute performance, they are useful in decision-making by providing a numerical measure of current knowledge and collective belief, based on multi-disciplinary references, and, fundamentally, confidence to the technical community. Indeed, nuclear power plants are not licensed based on PSA results, but a PSA is a mandatory requirement before any operating licence can be delivered and it is constantly reviewed during reactor operation.

THE COMPLEXITY OF THE DISPOSAL SYSTEM

Any geologic disposal system for high-level radioactive waste looks deceptively simple: three nested barriers (see figure 1) encompassing the waste form and its main container, a system of engineered barriers (the “near field”), as well as the host rock and shaft seals (the “far field”). The waste form and the engineered barriers are designed to contain radioactive elements and to prevent their transfer to the groundwater system. The host rock is meant to maintain a favourable environment for the performance of the engineered barriers, as well as to slow down and dilute the migration of any potential contamination. The longer the retention time is, the lower the radionuclide inventory will be, due to radioactive decay. The more dilute the plume, the more likely the environmental quality standards will be met.

In practice, each barrier is an heterogeneous system whose properties change slowly with time. Since barriers are not completely independent from each other, feedback effects must also be foreseen and accounted for, such as radioactive decay heat which affects the local properties of the near field. To that effect, the system is broken down over and over in subsystems and components until very fine details are included, such as the geochemistry of fracture fillings in the host rock. Changes are engendered not only by endogenous factors (e.g., groundwater attack on container materials), but also by exogenous conditions (e.g., tectonic uplift, erosion, glaciation, etc.), which may alter the current reference conditions. A safety analysis consists of the identification of all potential scenarios and associated processes, including human intrusions, and a performance evaluation of the system under their influence (see figure 2).
Figure 2. To understand the long-term safety of a waste isolation system a detailed assessment is needed of the performance of all its components and their interactions.

THE ROLE OF THE PSAG

In 1985 the NEA created a group which was soon to become the Probabilistic System Assessment Group (PSAG). The Group has applied itself mostly to analyse the propagation of the numerical uncertainties associated with the parameters of system models designed to predict radionuclide dispersal in the geosphere. Their implemented approach (see figure 3), known as “Monte Carlo”, assumes that uncertainty can be adequately described using probabilistic values for the model parameters. This yields different probabilistic outcomes, which suggests some degree of variability in the system performance. The statistical precision of the analysis depends upon the number of computer runs examined, and its accuracy, on the realism of the mathematical models and the correctness of the fundamental model parameters.

Most of the PSAG experience has been committed to paper in a set of reports on international code verifications and intercomparisons, known as PSACOIN exercises, available from the NEA. The specifications of some of these exercises have become benchmark problems in the PSA literature on radioactive waste. The history and achievements of the PSAG will be summarised in an NEA report under preparation.

DEEP REPOSITORY SAFETY

Through the PSAG, the NEA has provided important and timely support to its Member countries seeking to conduct safety assessments of potential radioactive waste disposal facilities. However, at the present stage, a final methodology suitable for licensing has not yet been demonstrated. In fact, although it is generally believed that a properly sited and designed repository will be able to meet the strictest safety standards, the road towards demonstrating and judging compliance with those standards appears to be long and full of potential detours.

The main intrinsic difficulty is that long-term safety will have to be demonstrated and judged according to circumstantial rather than direct evidence, that is, a “reasonable assurance” that the performance will be as intended. “Reasonable assurance”, however, is a term of law rather than a term of science, and it has its counterpart in the “adequate protection” (another term of law) of public health and safety that the safety agencies are called upon to ensure.

Because the concept of reasonable assurance is not entirely objective, it may entail a difficult licensing process whereby the “subjective” views of the regulator may not agree completely with those of the licence applicant, and more evidence is
continually requested. For radioactive waste repositories this difficulty is compounded by at least two additional aspects: (a) the fact that any deep disposal facility will be one of a kind in every country; and (b) the increasingly speculative character of any performance evaluation as it attempts to predict events which are to take place further and further in time, versus the strict and fixed-in-time nature of the safety standards. The latter problem is especially important in the case of PSAs, where there may be a temptation to take the predicted performance measures at face value.

Indeed, the statement is sometimes made that probabilistic calculations are necessary in order to avoid unrealistic pessimism in the choice of models, which may lead some to conclude that the PSA offers a realistic representation of reality in the sense that the predicted variability incorporates the real evolution of the system. However, it is as yet impossible to defend any narrow uncertainty band on any projected long-term performance measure which intends to be “realistic” because we lack a methodology to quantify model and completeness uncertainties, and future work should address this question.

In practice, because reasonable assurance is largely subjective, it is the whole case that will need to be taken into account, including non-quantifiable aspects, such as the transparency and openness of the implementing agencies’ case, the application of a methodology which strives to identify all decision points and accepted or discounted uncertainties, not to mention the overall logic of the argumentation. Thus, the demonstration of safety requires confidence building through a number of qualitative, quantitative, and even intangible steps which may depend on the specific culture of each country for building consensus.

Finally, it is fair to say that a ruling of reasonable assurance is not likely to be rendered until the technical community at large and the most prepared technical interveners feel comfortable with such a ruling. This may depend not only on the quality of the evidence as discussed above, but also on other extrinsic factors, such as future changes in the perception of risk, the increased utilisation of risk assessment methods for analysing societal choices with potential long-term impacts, and the end of the dichotomy between nuclear and non-nuclear, hazardous waste. Once again, this will need time. In order to speed up the process it would be helpful if the nuclear waste management agencies were to engage themselves into educational programmes aimed at raising the level of knowledge and expertise about nuclear waste and risk assessment. In fact, there exists as yet no specialized university curriculum in nuclear waste management and disposal. Direct dialogue and debate with the public and with the interveners are also needed in order to promote an emotion-free and rational approach to the issue of judging the safety of nuclear waste repositories. To some extent this is taking place already, but there is no royal road to proving safety.

1. Generally, the latter conform to or are more stringent than one of the following: a dose constraint of 1 mSv/a for members of the public or $10^{-7}$ as the upper limit for the annual risk of severe health effects by the affected individual. These criteria apply over 10,000 years or longer. Some regulations, however, require a strict quantitative analysis only up to 10,000 years after disposal.
RADIOACTIVE WASTE MANAGEMENT IN PERSPECTIVE

Radioactive waste management is an important step in the nuclear fuel cycle and raises various concerns in the public, often due to ignorance of basic scientific facts and the current status of implementation of national waste management programmes. With this in mind, the NEA will be publishing in early spring a generic study entitled Radioactive Waste Management in Perspective, which is intended to help a wide unspecialised readership take stock of the state of the art in this field.

Radioactive waste is commonly perceived at best as an unsolved problem and at worst as an insoluble one. Although only less than 1% of all toxic wastes generated in OECD countries each year is radioactive, nuclear wastes have received more attention and cause more public concern than most other types of potentially hazardous wastes, some of which are equally toxic and long-lived. Many people see the wastes as uniquely dangerous, and the need for long-term isolation as one that places unacceptable burdens upon future generations. There is little public awareness of the broad scientific and technical consensus that all categories of radioactive waste can be managed and disposed of in accordance with all regulatory requirements by the careful application of currently available technologies, or of the fact that many stages of waste management, including the disposal of some categories, have been safely implemented for many years. Consequently, the situation demands that the public be as fully informed as possible about the issues at stake, and take the greatest possible part in the decision-making process.

The primary objective of radioactive waste management is to protect current and future generations from unacceptable exposures to radiation from the wastes, in accordance with the three basic radiation protection principles recommended by the International Commission on Radiological Protection (ICRP): justification; optimisation of protection, and limitation of individual dose and risk. National regulations and standards also incorporate other internationally agreed criteria, such as the fact that the level of protection of future generations should be at least equivalent to that of the present generation and that safety should not depend on the maintenance of disposal systems by future generations beyond a limited period of surveillance.

The origin and nature of each category of low-level and medium-level radioactive wastes generated throughout the nuclear fuel cycle, whether gaseous, liquid or solid, are discussed. Various disposal options exist in each case, ranging from filtration and monitored release of low-level gaseous effluents to chemical treatment, compaction or incineration of low-level liquid or solid wastes, to near-surface or underground disposal after immobilisation in concrete or bitumen in the case of medium-level wastes, such as industrial and medical radioisotope sources.

The situation is somewhat different when it comes to high-level wastes which include spent fuel from nuclear reactors and wastes generated by the reprocessing of that fuel. Although no country has yet implemented a permanent disposal system, reprocessing wastes are currently vitrified and sealed in stainless steel containers, while spent fuel is stored in cooling ponds at reactor sites for at least several decades pending encapsulation. In both cases disposal will be deep underground in various stable geologic formations, such as granite or salt, where potential radioactive contamination will be contained by multiple barriers, including the conditioning of the waste itself, the engineered structures of the repository and the retentive power of the host rock between the repository and the surface. Extensive research is going on in this field, resulting in numerous physical, chemical, biological and hydrogeological studies which provide a more precise quantitative understanding of the complex processes that might affect the safety of waste repositories. Empirical studies of existing disposal facilities in underground laboratories are also under way.

Each potential underground disposal site is subject to a detailed safety assessment prior to disposal in order to demonstrate that a specific radioactive waste management operation at a specific site will satisfy the relevant safety requirements under all conceivable future circumstances. Assessment of the effectiveness of a long-lived waste disposal concept has to consider all the possible pathways by which radionuclides could be transmitted from the repository to people. Each pathway is assessed by the use of mathematical data from laboratory and field research programmes. Assessment of the overall safety of the disposal system draws together the analysis of the various possible pathways and the interaction between them. The outcome of the assessment is a prediction of the long-term radiological consequences of the disposal in terms of radiation doses to individuals or groups of people assumed to be living in the vicinity at some time in the distant future.
The NEA and the IAEA have recently reviewed existing methodologies for safety assessment and the practical experience gained from the wide range of assessments carried out by many national and international bodies. Their review resulted in 1991 in the publication of a collective opinion, entitled *Disposal of Radioactive Waste: Can Long-term Safety Be Evaluated?*, which recognises that there is now wide agreement on the engineering, physical and chemical principles of the design of a repository. It also registers real progress in setting up, testing and improving the conceptual framework and the technical tools necessary for long-term safety assessments.

Apart from issues related to environmental concerns and the protection of future generations, the financing of radioactive waste management, dominated by the cost of encapsulating and disposing of high-level wastes, is also a major concern. The fact that it costs 10 times more to manage radioactive wastes than other waste categories, may appear prohibitive, and most countries have adopted the "polluter pays principle" for financing their radioactive waste management and disposal programmes. However straightforward the application of this principle may appear in the case of short-term operations, such as effluent clean-up and temporary storage, its implementation becomes more complex when it comes to the differed disposal of high-level wastes, for example. Such long-term operations do require special funding provisions which will have to take into account uncertainties concerning the precise nature and timing of those activities. Generally speaking, though, the NEA recently compared the estimated costs for encapsulation and disposal of high-level wastes for a number of countries, expressed as the cost per unit of electricity produced, and concluded that radioactive waste management costs represented in all cases only a small fraction of the generation costs.

Last but not least, the risk of transboundary pollution by radioactive materials, the transport of spent fuel between countries and the possible smuggling of radioactive waste for use in nuclear weapons, emphasise the international dimension to the issue.

All of these factors necessarily influence public perception and opinion, and some progress is being made in increasing acceptance of radioactive waste management activities. This may be due to a growing awareness of the part that nuclear power can play in alleviating the problems of greenhouse gas emissions. Several recent public opinion polls in a number of OECD countries suggest that nuclear power, while not positively welcomed, is now seen by the majority of people as having an essential role in future energy supplies. As more people come to accept that there is a need for nuclear power, there is likely to be less opposition, at least in principle, to the disposal of the resulting wastes, but only insofar as people can be convinced that everything possible is being done to ensure safety.
At the end of 1993, the total capacity provided by the 339 reactors now installed was 281.1 gigawatts (GWe). Another 24 reactors (25.6 GWe) were under construction and three (2.8 GWe) were firmly committed. The total capacity of nuclear power plants in NEA countries in the year 2000 is projected to be about 307 GWe. The 1.5 GWe of capacity that are expected to be retired before the year 2000 are already deducted from these projections.

### NUCLEAR ELECTRICITY CAPACITY IN NEA COUNTRIES

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<th>COUNTRY*</th>
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<th>1995</th>
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<td>23.1***</td>
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<tr>
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<td>-</td>
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<tr>
<td>Japan</td>
<td>36.7</td>
<td>19.7</td>
<td>39.6**</td>
</tr>
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<td>7.6</td>
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<td>8.6</td>
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<tr>
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<td>3.0</td>
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**OECD Total**: 281.1 16.5 287.4 16.3 307.0 16.2

### STATUS OF NUCLEAR POWER PLANTS

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<th>COUNTRY*</th>
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<th>Firmly committed</th>
<th>Planned</th>
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<td>-</td>
<td>-</td>
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<tr>
<td>Japan</td>
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**OECD Total**: 339 281.1 24 25.6 3 2.8 50 53.5

* The NEA countries listed here included only those which currently have a nuclear power programme.

** Estimate established by the NEA Secretariat.

*** Gross data converted to net by the NEA Secretariat.
NEW NEA REPORT: LIABILITY AND COMPENSATION FOR NUCLEAR DAMAGE

The OECD Nuclear Energy Agency has just published a new report on the current status and future prospects of the international regime for the liability and compensation of nuclear damage.

The potential hazards of nuclear power have been recognised from the very beginning. Although the chances of an accident are small, the consequences may be both severe and widespread, affecting the population and environment of many countries. A special regime of liability and compensation for nuclear damage was therefore established as early as the 1960s, differing from the common law and accommodating the unique features of nuclear activities. This regime is embodied in several international Conventions which channel the liability to the operator of the installation causing the damage and require that he have financial coverage consistent with his potential liability.

The Chernobyl disaster put to test this international regime and revealed a number of weaknesses, notably due to the fact that several countries with reactors with insufficient safety levels were not parties to any of these international conventions, and that, in any case, not all the potential damage was covered under the conventions.

As a consequence, within the context of the IAEA and the OECD/NEA, States have begun a fundamental reappraisal of the international liability and compensation regime, and are studying at present the possibility of concluding a new convention or improving the old ones. However, there remain differences of opinion and approaches among the countries involved, and this revision process is likely to last for some time.

The new NEA report, aimed at a wide readership, describes the basic elements of the existing Conventions, the question of insurance coverage, and typical legislation in countries which are Parties — or not — to the Conventions. It discusses the need to modernise and to broaden the scope of the international liability system in response to the gaps and deficiencies revealed by the Chernobyl accident. In this context, the report outlines both the problems in the existing Conventions and the challenges for the future. Finally, there is a brief summary of the ongoing efforts to revise the Vienna Convention in order to arrive at a compensation system that will be acceptable to all States, and of the proposals to date for a supplementary funding scheme to provide additional compensation for the victims beyond the liability limit of the operator whose installation is responsible for the damage.

The texts of the major international nuclear liability conventions are reproduced in this book.
NEA ACTIVITY REPORT 1993
Free upon request

NUCLEAR ENERGY DATA 1994
Bil. - ISBN 92-64-04122-2

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.

NEW MAN-MACHINE INTERFACES IN NUCLEAR POWER PLANTS
ISBN 92-64-14329-7

The rapid development of advanced computerised technologies and the acknowledgment that human factors significantly contribute to abnormal events during nuclear power plant operation, underscore the growing importance of the interaction between man and machine.

This report presents the current thinking about this issue. In particular, it reviews those aspects of power plant operation related to the design, evaluation and licensing of new man-machine interactions, alarm computerisation as a support to operators, expert systems such as artificial intelligence, man-machine task allocation, and methodologies for the ergonomic evaluation and validation of advanced nuclear power plants.

THREE MILE ISLAND REACTOR PRESSURE VESSEL INVESTIGATION PROJECT
Achievements and Significant Results
Proceedings of an open forum sponsored by OECD/NEA and USNRC,
Boston, USA, 20-22 October 1993
ISBN 92-64-14134-0
Price: France FF 185 – Other countries: FF 240 US$ 42 DM 73.

The Three Mile Island Vessel Investigation Project (TMI-VIP) was an international research project undertaken by eleven Member countries of the OECD Nuclear Energy Agency from 1988 to 1993. The TMI-2 accident was a unique opportunity to study a severe accident in a commercial pressurised-water reactor (PWR). The TMI-VIP was set up when the damage was found to be more extensive than thought initially, in order to determine and assess the conditions of the lower head of the reactor vessel.

The TMI-VIP was successful in the difficult task of recovering vessel samples and has enabled both scientists and engineers to obtain a better understanding of reactor pressure vessel structural integrity under beyond-design-basis conditions. From this understanding, improvements in severe accident management and designs for future systems may be derived. The open forum presented the accomplishments of the project in the context of the overall evolution of nuclear safety and the benefits of international co-operation in nuclear research.

THE ECONOMICS OF THE NUCLEAR FUEL CYCLE
ISBN 92-64-14154-5

This study updates the 1985 NEA report and presents a comprehensive analysis of the individual and total costs of the nuclear fuel cycle for a pressurised water reactor (PWR) to be commissioned in the year 2000 for both direct disposal and reprocessing routes. Sensitivity cases are discussed and fuel cycles of other reactor types are also considered.

NUCLEAR WASTE BULLETIN – June 1994
Free upon request

PROCEEDINGS OF THE FOURTH INTERNATIONAL SYMPOSIUM ON THE OECD/NEA STRIPA PROJECT
Stockholm, Sweden, 14-16 October 1992
ISBN 92-64-14225-8 (66 94 02 1)

The International Stripa Project was launched in 1980 under the auspices of the OECD Nuclear Energy Agency at the disused Stripa iron-ore mine in Sweden to study the ability of crystalline rock to isolate radioactive waste. The project is now completed and the final symposium was held on 14-16 October 1992 in Stockholm. This is the fourth and final proceedings from a series of symposia held to review progress in the three main areas covered by the Project: (1) the development and improvement of site assessment methods and concepts; (2) characterisation of the Stripa granite and validation of concepts for groundwater flow and radionuclide transport through fractures; and (3) techniques and materials for the engineered sealing of possible groundwater flow paths through crystalline rock.

POWER GENERATION CHOICES: COSTS, RISKS ANDEXTERNALITIES
Proceedings of an International Symposium
Washington, USA, 23-24 September 1993
Organised by the OECD Nuclear Energy Agency and the Oak Ridge National Laboratory
ISBN 92-64-14236-3
Price: France FF 250
Other countries: FFE 325 US$ 60 DM 94.

Power generation choices depend on the costs, risks and externalities associated with the technologies under consideration. These proceedings present a comprehensive review of the total cost of electricity generating technologies, with particular emphasis on nuclear power.

Some papers concentrate on the political, economical and social aspects related to power generation choices in a number of OECD countries (Canada, France, Germany, Italy, Japan, Sweden, Switzerland, the United Kingdom and the United States). Other present the state of the art in economic analysis from a total cost perspective within a pragmatic decision-making context, including environmental and health issues, trade, security of supply, risks related to public acceptance, as well as the criteria to be used in economic comparisons.
NUCLEAR SAFETY RESEARCH IN OECD COUNTRIES
ISBN 92-64-14248-7
Price: France FF 120 – Other countries: FF155 US$29 DM47

There is currently a range of specific safety concerns which are broadly shared throughout the international nuclear safety community. Continuing research is necessary to address many of these concerns. In this report senior experts have reviewed the nuclear safety research currently being performed and set down their views on likely future needs and priorities: they have identified a number of research topics of outstanding importance to which priority should be given. The need for international collaboration will be strengthened in coming years as budget and manpower resource pressures grow.

INTERMEDIATE ENERGY NUCLEAR DATA: MODELS AND CODES
Proceedings of a Specialists’ Meeting
Issy-les-Moulineaux (France) 30 May-1 June 1994
ISBN 92-64-13278-9

This specialists’ meeting was organised as a follow-up to the recent exercise initiated by the NEA Nuclear Science Committee on an Intercomparision of codes and models used to calculate nuclear reaction processes from 20 to 1600 MeV. This study was initiated to help determine the predictive ability of current nuclear reaction and transport codes for future design concepts for transmutation as well as for other application areas, such as radiation oncology, accelerator shielding, astrophysics, radiation during space travel, etc.

The purpose of the meeting was to discuss the results of the two benchmark exercises which has been organised by the NEA. The first one on microscopic nuclear reaction calculations (thin target) for which the results has been published prior to the meeting. The second exercise, on transport calculations (thick target), is still in progress.

NUCLEAR LAW BULLETIN
Annual Subscription – France: FF 200
Other Countries: FF 220 US$42 DM 84.
No. 53 – June 1994
No. 54 – December 1994

RADIATION PROTECTION: TODAY AND TOMORROW
A collective opinion of the NEA Committee on Radiation Protection and Public Health.
Free upon request

ARAP: THE INTERNATIONAL ALLIGATOR RIVERS ANALOGUE PROJECT – Background and Results
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