Nuclear Development

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

Several years ago a number of studies were undertaken to examine the concern that nuclear education and training is decreasing, perhaps to problematic levels. The NEA study *Nuclear Education and Training: Cause for Concern?* concluded that a failure to take appropriate steps immediately would seriously jeopardise the provision of adequate expertise in the near future. Several recommendations were proffered to governments, academia and industry to help ensure that crucial present requirements for highly qualified manpower are met and that future options are not precluded.

This study is a follow-up to the earlier NEA study. It identifies mechanisms and policies for promoting international collaboration in the area of nuclear education and R&D. The present study aims to address the question of infrastructure as a whole in order to identify good practices and help governments in the process of integrating nuclear R&D and education in an international setting. It was launched by the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) in collaboration with the NEA Nuclear Science Committee (NSC).

The publication was prepared by a group of experts listed in Appendix 1, and comprising representatives from academia, government agencies and research organisations. The report is published under the responsibility of the OECD Secretary-General.

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EXECUTIVE SUMMARY

The life cycle of the nuclear industry is no different to that of any other industry, indeed to most forms of human activity: birth, growth, maturity, decline, rebirth and renewal or death. The nineteenth century industries such as railways, chemical manufacture, steel production have experienced the full cycle whilst newer industries such as space, aviation and nuclear are only part way through. Economic development and economic needs depend where any industrial sector of a country is found on the life cycle. For the nuclear industry, some countries are at the stage of maturity; some have entered the stage of decline and are contemplating whether to favour renewal or to close the industry; others are just starting out with new build.

Although the life cycle might be a common factor of industrial activity, each industry has its own distinguishing, unique features that set it apart from the others. The nuclear energy sector is characterised by long time scales and technical excellence. The early nuclear plants were designed to operate for 30 years; today the expected lifetime is 50-60 years. When a nuclear plant is closed, decommissioning and decontamination may last as long as its operational lifespan, possibly longer. From cradle to grave may be in excess of 100 years. The rapid technical evolution of the industry would not have been possible without myriad high-quality research and development programmes. Through such programmes and through the associated links with universities and research institutes have come not only technical knowledge but also the technically competent staff necessary for the safe running of the industry.

As a result of the twin facets of long time scales and essential technical competence the industry now faces two problems: how to retain existing skills and competences for the 50 plus years that a plant is operating when the industry in that country may be in a position of maturity or decline on the life cycle and no further build is imminent and how to develop and retain new skills and competences in the areas of decommissioning and radioactive waste management when the latter are seen as "sunset" activities and are unappealing to many young people.

These problems are exacerbated by the increasing deregulation of energy markets around the world. The nuclear industry is now required to reduce its costs dramatically in order to compete with generators that have different technology life cycle profiles to its own. In many countries, government funding has been dramatically reduced or has disappeared altogether while the profit margins of generators have been severely squeezed. The result has been lower electricity prices but also the loss of expertise as a result of downsizing to reduce salary costs, a loss of research facilities to reduce operating costs and a decline in support to the university in order to reduce overheads.

All of which has led to a reduction in technical innovation and a loss of technical competences and skills. However, because different countries are at different stages of the nuclear technology life cycle, these losses are not common to all countries, either in their nature or their extent; a competence that may have declined or be lost in one country may be strong in another. And therein lies one solution to the problems the sector faces – international collaboration.

Progress made in the field of education and training

The OECD/NEA report *Nuclear Education and Training: Cause for Concern?* published in July 2000, quantified, for the first time, the status of nuclear education in member countries. It confirmed what many had long suspected: that, in most countries, nuclear education had declined to the point that expertise and competence in core nuclear technologies were becoming increasingly difficult to sustain. Although the overall situation appeared bleak, some encouragement could be gained from the diverse range of initiatives that were identified. If they were not responsible for an expansion in nuclear education and training, they were at least arresting its rate of decline. With the objective of building on these existing initiatives and stimulating new ones, the report made a number of recommendations to government, universities, industry and research institutes.

The reaction of governments has been varied. Some have launched, or supported, a variety of initiatives, often based on their own further studies of nuclear education and manpower requirements. Others have not undertaken any initiatives at all. This may be because they prefer to let the nuclear sector respond to market forces, or because there is a moratorium on nuclear power or simply because adequate programmes already exist.

There is considerable evidence to indicate that the two recommendations made to universities, namely that they should provide basic and attractive programmes and that they should interact early and often with potential students, are being pursued. How much of this impetus is directly attributable to the NEA report and how much is a reaction to market forces is unclear but it is indisputable that the outcome of the many initiatives currently undertaken by universities is an increase in the number of students undertaking nuclear education.

The report made two recommendations to industry: to continue to provide rigorous training programmes and to work together better with universities and research institutes to attract the younger generation. There is no doubt that the first is being pursued, although it would seem to be more out of self-interest and in response to regulatory requirements than by the recommendation of the NEA report. As regards the second, there is clear evidence that the industry, universities and research institutes continue to work together but whether more effectively than before is not apparent from the information received.

Research institutes are facing similar recruitment problems to those of the industry. In addition, the financial situation of research institutes is deteriorating in many countries due to cuts in public funding and to tough competition in the niche market in which they sell their services and products. This makes it difficult for the research institutes to fulfil the recommendation that they should attract the best students and employees by developing exciting research projects of relevance to the industry.

Human resources

Faced with possible demographic downturns in their nuclear industries, many NEA member countries have undertaken studies to define the extent of the problem. In spite of the myriad initiatives underway in the area of nuclear education and training, these national surveys show that more engineers and scientists having nuclear knowledge are required than are graduating.

The continuing antipathy of students in many countries towards science, engineering and technology subjects has meant that the proportion of those graduating in these areas has fallen in recent years. As fewer and fewer high quality technical graduates become available, the competition for them is ever greater and there are signs already that the nuclear industry is losing out. This is of concern to the nuclear industry as the majority of the scientists and engineers working in it do not have nuclear specialist education.

As well as losing out directly the industry loses out indirectly because this also means that the ability of organisations to circumvent the shortage of graduates with a sizeable nuclear component to their degree by hiring good quality technical graduates and training them in house is compromised.

As it has reached maturity, the nuclear industry has developed areas of expertise that are transferable to other industries. There has thus been a flow of personnel from the nuclear sector into other sectors. This was convenient when the industry was consolidating and wished to reduce staff numbers. Now that it cannot afford any further reduction in existing competences and needs to develop new ones in the areas of decommissioning and clean up, attracting young blood, retaining staff and attracting experts from other sectors in the face of competition from industries perceived as more attractive is proving problematic in many countries.

Many of the aforementioned problems can be countered through diverse and dynamic R&D programmes. Within companies R&D is as important for training staff as for technical advancement. Where industry collaborates with universities and research institutes it is also an important source of recruits. In addition, such collaborations provide a reservoir of qualified and experienced personnel, which can service both the industry and the regulatory bodies on an ad hoc basis. Further, R&D performed in universities revitalises the education system by paving the way for new courses, providing topics for theses, and encouraging academics to become positively engaged with the industry.

To some extent, the human resource situation can be ameliorated through the mobility of researchers and experts. This is often viewed as an important part of the education and training of the individual on the one hand and an effective way of coping with a temporary peak in workload or effecting knowledge transfer on the other. However, in reality the mobility of researchers may be rather limited. It seems that some research organisations are more prepared to accept researchers than to part with their own.

Research and development

Measured in terms of man-years, all responding countries devote significant resources to radioactive waste management. In contrast, although R&D in decommissioning is pursued by all the countries responding to this study, it is an area that generally attracts few R&D resources. Plant design is an important area of research activity in many countries. This is usually aimed at improving both the safety and the efficiency of operation of existing plant rather than innovative plant design. Perhaps as a consequence, in the majority of countries, research in material development is not a leading area of activity. The commitment to research in the nuclear fuel domain varies considerably from country to country and the studies cover a wide range of uses: improving the economics of existing plant, facilitating waste management and commitment to innovative plant design.

Trends common to all countries are difficult to discern in respect of industry funded R&D. Overall, though, it would seem that there is more emphasis on operating reactors than future systems. National projects predominate over international ones. Projects embrace the short, medium and long-term; there is no common denominator. As might be expected of industry funded research, economic drivers are important but in no country are they more important than safety. The nuclear industry in most countries funds open research and very often this complements the public funding of research. Whilst the acquisition of technical knowledge is important, there is no doubt that supporting open research is a way of ensuring the continued availability of experts in key areas at universities and research centres: such experts being crucial to the independent assessment of important issues such as the reliability and safety of plants.

In recent years, publicly funded nuclear R&D has experienced a dramatic reduction in most countries. The main focus has been, and continues to be, the safety of existing nuclear power plants and waste management issues. However, in a few countries, programmes for innovative, future reactors are becoming evident. Public funding is not confined to supporting domestic R&D; increasingly it is being used to fund international collaboration. In all countries there is recognition of the need to maintain core skills and competences and this is an underlying theme of public funding. However, given that it has decreased in most countries in recent years, this responsibility is increasingly falling to the industry.

International collaboration

The decline in recent years of many nationally funded nuclear research programmes and the associated loss of facilities and expertise has encouraged countries to seek international collaboration. Although bilateral arrangements continue, increasingly multi-lateral programmes between many countries and research institutes are favoured in order to maximise the use of facilities and expertise as well as to share costs. Agencies such as the NEA, EC and IAEA play an important role in both promoting and co-ordinating this type of collaboration and, moreover, ensuring that collaboration is open to as diverse range of participants as possible. The NEA has adopted a strategy aimed at maintaining essential types of research facility through these collaborative arrangements.

While nuclear research centres can look back over a long history of international collaboration, the same is not true for universities. It is only recently that some regional collaborative networks have been created in both Europe and Asia. The same principles apply to maintaining teaching expertise on nuclear related topics as to maintaining research capabilities, especially in those countries where such expertise may be in short supply. In this area, more can be done at the national level to develop co-operation between universities; at the international level the recognised agencies have a key role in promoting and co-ordinating co-operation between countries.

Naturally, collaboration between industrial companies is limited by commercial interests. Some companies have merged and their internal activities are, as result, no longer restricted to national boundaries. However, overall, it is necessary to recognise that industrial collaboration will always be subject to limitations.

Collaboration, information exchange and even exchange of personnel have always been an integral part of the development of nuclear power – inasmuch as political constraints have allowed. It is largely as a result of international collaboration that nuclear power has become a reliable energy source within a single generation, accounting for a significant proportion of the electricity produced in many countries today. That it may continue to do so in the future will depend even more on international collaboration but as long as there are initiatives such as the NEA Halden project and the Generation IV International Forum there will be grounds for quiet optimism.

I. INTRODUCTION

While previous NEA (Nuclear Energy Agency) studies have focused on nuclear competence and infrastructure in specific areas of activity, such as nuclear safety or nuclear education, this study, launched by the Nuclear Development Committee (NDC) in collaboration with the Nuclear Science Committee (NSC), addresses the issues of nuclear infrastructure and competence more generally. The study identifies:

- Progress against the recommendations presented in an earlier study, *Nuclear Education and Training: Cause for Concern?* [1]
- Human resource issues and R&D.
- Mechanisms and best practice regarding international collaboration.

The life cycle of the nuclear industry is no different to that of any other industry, indeed to most forms of human activity: birth, growth, maturity, decline, rebirth and renewal or death. The nineteenth century industries such as railways, chemical manufacture, steel production have experienced the full cycle whilst newer industries such as space, aviation and nuclear are only part way through. Depending on economic development and economic needs depends where any industrial sector of a country is found on the life cycle. For the nuclear industry, some countries are at the stage of maturity; some have entered the stage of decline and are contemplating whether to favour renewal or to close the industry; others are just starting out with new build.

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As a result of the twin facets of long time scales and essential technical competence the industry now faces two problems: how to retain existing skills and competencies for the 50 plus years that a plant is operating when the industry in that country may be in a position of maturity or decline on the life cycle and no further build is imminent and how to develop and retain new skills and competencies in the areas of decommissioning and radioactive waste management when the latter are seen as "sunset" activities and are unappealing to many young people.

These problems are exacerbated by the increasing deregulation of energy markets around the world. The nuclear industry is now required to reduce its costs drastically in order to compete with generators that have different technology life cycle profiles to its own. Consequently, in many countries, government funding has been drastically reduced or has disappeared altogether and the profit margins of generators have been severely squeezed. The result has been lower electricity prices. The result has also been the loss of expertise as a result of downsizing to reduce salary costs, a loss of facilities to reduce operating costs and a decline in support for the university sector to reduce overheads.

All of which has led to a reduction in technical innovation and a loss of technical competences and skills. However, because different countries are at different stages of the nuclear technology life cycle, these losses are not common to all countries, either in their nature or their extent; a competence that may have declined or be lost in one country may be strong in another.

This study was undertaken by an Expert Group, established under the auspices of the NEA, consisting of representatives from 11 member countries: Belgium, Canada, Finland, France, Germany, Italy, Japan, Korea, Sweden, the United Kingdom, the United States as well as from the European Commission (EC) and the International Atomic Energy Agency (IAEA).

Information on the three aspects cited above was obtained by means of a questionnaire prepared and issued by the NEA in 2002. Members of the Expert Group took responsibility for distributing it within their own country and for collating the responses. Where a country was not represented on the Expert Group but wished to participate in the study, the NDC collected information on its behalf.

Responses were received from 15 countries: Austria, Belgium, Canada, Finland, France, Germany, Hungary, Italy, Japan, the Netherlands, Slovenia, Spain, Sweden, the United Kingdom, the United States and from the European Commission. However, some of them contained very limited amount of information and, in general, the responses to the R&D section of the questionnaire, whilst providing a lot of factual information, failed to adequately quantify either human resources or facilities engaged in this activity.

II. EDUCATION AND TRAINING

Introduction

The data gathered for the OECD/NEA report, *Nuclear Education and Training: Cause for Concern?* [1] confirmed that, in many countries, nuclear education and training had been in decline for a number of years and were approaching a parlous state. It was evident that unless that decline was arrested and education and training were revitalised, both the supply of suitably qualified personnel to the industry and the adequate and appropriate support for the industry through research and development would be seriously jeopardised. Given the inherent time lag of the education and training process, immediate action was required and to help stimulate it a number of recommendations to governments, universities, industries and research institutes were made in the report. These are listed in Chapter V.

Three years after their publication, with the objective of sharing good practice, a questionnaire (see Appendix 5) was issued to identify the initiatives that had been undertaken in response to these recommendations. The findings are summarised below. The country reports in Appendix 4 provide national contexts into which they may be placed. It should be noted that details of international collaborations are given separately in Chapter IV.

Government initiatives

For various reasons, some governments have not undertaken any initiatives at all. The Italian government still has a moratorium on nuclear power. Nonetheless, researchers from the Italian Agency for Technology, Energy and Environment (ENEA) continue to attend nuclear meetings, collaborate with national and international partners in nuclear areas of investigation, and participate in international projects. However, students cannot be formally directed toward nuclear training. The Spanish government has taken a non-interventionist approach by letting the nuclear sector respond to market forces. Sweden is also without government initiatives and is looking to the Swedish Nuclear Power Inspectorate (SKI) to assume responsibility for issues on national competence in the nuclear sector. SKI have set up, in co-operation with industry, the Swedish Centre for Nuclear Technology, which provides funds for university research, supports positions for senior researchers and organises a national graduate school. Public money is not involved; the funds are raised by a tax on utilities. France has no need for urgent action since she has a long history of supporting nuclear training including in the field of safety, primarily through post-graduate training. The relative importance of the nuclear industry in France, with its corporate engineering services, CEA nuclear research, and the Institute for Nuclear Science (INSTN), ensures the continued success of such an approach.

The reaction to the recommendation that governments should engage in strategic energy planning, including consideration of education, manpower and infrastructure, has been varied. The Korean government amended its Atomic Energy Act as long ago as 1995 so that there was a legal basis for reviewing the Comprehensive Nuclear Energy Promotion Plan (CNEPP) every five years. The CNEPP includes long-term nuclear policy objectives, investment plans and budgets. While most other governments have undertaken or encouraged some action with regard to nuclear energy, only a few have quoted their strategic energy plan in respect of their commitment to addressing nuclear energy issues. In 2003, the UK government outlined its energy policy in a White Paper. It is evident that it intends to keep the nuclear option open but since the energy sector in the United Kingdom has been deregulated for some time, any decision to proceed with new build would rest with the commercial sector and would need to meet the criteria of private investors. In the United States, a National Energy Policy was adopted in 2001, which called for the wider use of nuclear power. The Department of Energy (DOE) currently has a draft Strategic Plan that also endorses the expansion of nuclear energy. Other governments are addressing the future of nuclear energy but not in a way that can be defined as strategic planning, while, as already noted, a few have taken no action at all.

That governments should contribute to, if not take responsibility for, integrated planning to ensure that human resources are available to meet necessary obligations and address outstanding issues is the recommendation to governments that appears to have attracted the most attention.

Faced with possible demographic downturns in their nuclear industries, a number of governments have commissioned studies to define the extent of the problem. In the United Kingdom, in September 2001, the government formed an ad hoc group to conduct a study into the provision of suitably educated and trained people to satisfy the needs of the nuclear energy sector, including health and environment as well as power generation, over the next 10-15 years. The study found that 50 000 new entrants would be required over this period to meet anticipated demand. In early 2004, a permanent body, supported by industry and government, the Sector Skills Council, took responsibility for addressing such strategic issues. The UK government is also establishing a non-governmental agency, the Nuclear Decommissioning Authority, to meet the environmental challenges arising from legacy wastes, spent fuel management and decommissioning of nuclear power stations and it is anticipated that this will have considerable influence on future training and education needs. The Korean government has sponsored a survey study of the number, age and qualifications of nuclear engineers in the country's nuclear organisations. Together with the warning given by the Korean Nuclear Engineering Department Heads' Organisation about the decline in nuclear courses, this has resulted in the expansion of the manpower development programme to include undergraduate students who major in nuclear engineering. In Germany, an analysis of the personnel structure of and future demand for nuclear technology experts in utilities, manufacturing and service industries, regulatory and licensing authorities, as well as the education capabilities in universities, including the number of students taking nuclear courses, has shown that education and training have thus far met the demand from industry. However, if the current trend continues, a severe lack of nuclear competence is expected to occur within the next 10-20 years. Hungary is another country conducting a review that was completed in 2003, so that it too will be able to address the issues of human resources in the nuclear industry.

The reaction of other governments shows a diversity of approach. The Japanese government, through the Ministry of Education, Culture, Sports, Science and Technology (MEXT), is actively promoting the teaching of energy and nuclear power. It provides teaching guidelines as well as subject content appropriate to each level and, since 2002, has begun to subsidise the cost of a range of measures from providing materials for teachers to teacher training. MEXT is also expanding the training of research personnel by providing substantial support to research institutes. The Belgian government has stated the need to keep the nuclear option open by maintaining the scientific and technological potential needed to ensure optimum conditions for safety and performance. This will be achieved by preserving national nuclear know-how and by participating in R&D on future reactor designs, most of which is private sector funded. Meanwhile, Finland's Ministry of Trade and Industry has published a report on nuclear knowledge management to which all nuclear organisations contributed. The Canadian initiative for providing the necessary human resources to their industry is unique in that it crosses traditional government, university and industry boundaries. The University Network of Excellence in Nuclear Engineering (UNENE) is an alliance of universities, nuclear power utilities, research and regulatory agencies. UNENE is a not-for-profit corporation established by the Canadian industry with the purpose of assuring a sustainable supply of qualified engineers and scientists to meet the current and future needs of the Canadian nuclear industry through university education, university-based training, and by encouraging young people to choose nuclear careers. Also in North America, the US government has been very active in the last three years in instituting new programmes. The US DOE has implemented programmes for high school science teachers; a university partnership programme that is designed to increase the number of minority students engaged in nuclear-related education programmes; a programme in radio-chemistry aimed at graduate students, post-doctorates, faculty enhancement and research; a new programme of fellowships for those interested in becoming involved in the naval nuclear propulsion programme; and the Innovations in Nuclear Infrastructure and Education (INIE) programme which encourages universities to make new investments in their research reactors and their nuclear engineering academic programmes while establishing new strategic partnerships with other universities, national laboratories, and the nuclear industry. The INIE programme currently supports activities at 32 universities throughout the United States.

Of those countries reporting their efforts to support young students, R&D and facility modernisation – the third recommendation to governments – a number of initiatives have already been cited that also relate to this recommendation: the Japanese support through MEXT for teaching nuclear subjects; the Belgian government's commitment to participate in R&D on future reactor designs; the Canadian UNENE initiative; the Swedish Centre for Nuclear Technology; and the long-established infrastructure in France.

In the United States, both the DOE and NRC have implemented programmes to attract and support students. The DOE has increased the number of government funded scholarships and fellowships available to students while the NRC has undertaken an internship programme designed to recruit students to work for the NRC, with particular emphasis on technical issues related to power plant performance. At DOE, programmes have been underway for three years to attract minorities into the nuclear arena and to increase research through the previously mentioned INIE programme that builds partnerships among universities, national laboratories (government), utilities and the private sector. Much of the INIE funding goes toward research and a large amount is designated by the recipients for modernising facilities, including research reactors, laboratories and computer labs. In Finland, the government contributes funds for nuclear safety and management research and the regulatory authority seconds younger staff with other regulatory bodies as part of international training initiatives. In Germany, the government has announced a fund to support several PhD students in nuclear safety research for operating reactors. The Korean government has established a nuclear research infrastructure development programme, accompanied by increased research funding, so that universities will have more opportunities for pursuing independent research as well as for participating in large-scale national research projects. In addition, as part of the manpower development programme, over 50 undergraduate students majoring in nuclear engineering received substantial grants in 2002 and over 70 in 2003.

For the most part, implementation of the recommendation that governments should provide support by developing "educational networks or bridges" between universities, industry and research institutes has not occurred. There are indications that progress toward this goal has been initiated but not yet achieved, for example the formation in the United Kingdom of a Nuclear Sector Skills Council, the alliance of competence in nuclear technology in Germany, the Finnish study on nuclear knowledge management and the Swedish Centre for Nuclear Technology. Perhaps the nearest to this network approach has been achieved by Canada through UNENE and the United States through the INIE programme. In contrast, France with her highly developed infrastructure does not have a formalised network.

University initiatives

There is considerable evidence to indicate that the two recommendations made to universities, namely that they should provide basic and attractive programmes and that they should interact early and often with potential students, are being pursued. How much of this impetus is directly attributable to the NEA report and how much is a reaction to market forces is unclear but it is indisputable that the many initiatives currently undertaken by universities are to the benefit of nuclear education and training.

Previously poles apart, the nuclear industry and academe are now very often found working closely together to address the crisis in nuclear education that prevails in many countries. At the masters level, British universities have preserved existing courses, and even introduced new ones, as a result of discussions with the industry and responding to identified needs. At one university, a partnership of the university, the regulatory body and a number of companies have preserved a long-standing nuclear course that would otherwise have closed due to withdrawal of government funding. The UNENE initiative in Canada will see new nuclear professorships established in six Ontario universities and increases in funding for nuclear research in selected universities. After extensive consultations with all sectors of the nuclear industry, including the state Electricity Company, the regulatory bodies and the research agency, to determine precisely what its needs were, a French university has introduced a master's degree in radioactive waste management. The degree content is unique in France and will contribute significantly to the education and training provision for the industry.

It is often said that research stimulates teaching. At several universities in the United Kingdom, raising the profile of research in the nuclear area, through the formation of industry-university research alliances, has aroused an interest in nuclear subjects among undergraduates. The result has been an increase in the number of students attending existing nuclear options and the introduction of new ones. This experience augurs well for the recommendation made to the Canadian industry that it might address its demographic downturn by strengthening its research links with universities and in so doing stimulate nuclear courses. In Germany, a number of universities have formed an alliance of competence in nuclear technology. The ones that belong to the alliance are linked to a research centre. Scientists from the research centres give lectures in the universities and students have the opportunity of internships and of studying for diploma or doctoral theses at facilities near to their homes.

Raising the profile of nuclear courses and making them attractive to students is fundamental to their success. Some German universities have done this by including inter-disciplinary components, using up to date teaching materials and Internet based resources. Students are encouraged to broaden their knowledge base by being given the opportunity to edit nuclear journal and review nuclear papers. Two main technical universities in Sweden have created a competence centre for nuclear technology in order to coordinate education and research in nuclear science and technology at different departments. In some Japanese universities, new professors have been employed to strengthen the teaching staff and thereby increase the attractiveness of curricula in undergraduate schools. To increase the attractiveness of graduate schools, some Japanese universities have initiated a system of two majors. The student studies a subject from the field of nuclear engineering together with another subject from other engineering fields. This allows nuclear specialists to broaden their knowledge and those who may not seek a career in the nuclear industry to have some knowledge of it. As well as hiring new faculty members and up dating the curriculum, some American universities have also invested in new facilities and equipment in order to attract students. The prospect of studying overseas appeals to many students. At a Belgian university, students spend a year in a foreign nuclear institution as part of their graduate training in nuclear engineering. Representatives from that and other foreign nuclear organisations contribute to the courses through, for example, tutorials and seminars. In Korea, the nuclear manpower development programme supports a one or two week visit to a foreign nuclear facility for those students who have achieved excellent result, as well as long-term training programmes of more than six months. In recent years, a Hungarian university has developed links with other European universities and research institutes, thereby giving its students the opportunity of pursuing part of their studies abroad. However, the flow of students is not all one way. The fact that the university has a training reactor, which is unique in Central Europe, is an encouragement for overseas students, as well as students from other Hungarian universities, to study there.

As in so many areas of modern life, the Internet is becoming increasingly important. In the United Kingdom, a web site that lists all of the university courses with a nuclear content and provides direct links to the university web sites has been successful in attracting students. In Germany, the young professionals interact with students through their web sites. This also happens in the United Kingdom. The use of Internet based resources by German universities has already been mentioned. In Italy, the universities that deal with nuclear or nuclear related subjects have been active in maintaining interesting and topical courses. The main contact with students is via the Internet and many professors have their own Web pages by which they inform students about courses. In US universities, distance learning is well established. Students can study courses not available at their own university or pursue ones that are during a semester when they may not be taught. Korea has also established web-based education and training programmes and, working with the IAEA, has proposed expanding them to form ANENT (Asia Network of Higher Education in Nuclear Technology).

Amalgamating under subscribed courses is an effective way of preserving nuclear teaching. Five universities in Belgium, in collaboration with the Belgian Nuclear Research Centre, have merged two post-graduate programmes into a single programme, taught in English. The initiative organises the degree of MSc in nuclear engineering. Five substantial grants a year are available for this purpose. In Sweden, nuclear centres have been established at two universities to promote co-operation between nuclear departments and to monitor both the nuclear courses being delivered and the number of students attending them.

The prospect of new build can stimulate teaching. In Finland, one university is currently modifying its curriculum in the light of new reactor build. Another has recently separated nuclear power plant technology from power plant technology as a major subject area in order to raise its profile with students. At the same time, this university received a nuclear safety research unit from the Technical Research Centre (VTT) and recruited additional members of staff.

Some American universities have hired recruitment specialists who are responsible for increasing the number of students applying for courses. This appears to be the main reason for the considerable increase in undergraduate enrolments for nuclear engineering that many faculties have seen over the last three years.

A number of universities organise summer schools, lasting anything from a few days to several weeks, to give secondary school students an insight into nuclear courses. In Japan, some universities promote nuclear subjects in their neighbouring schools; others open up lectures to the public. Visits to the Hungarian training reactor are encouraged and the university welcomes some 5 000 visitors a year, many of them secondary school students.

Industry initiatives

The NEA report made two recommendations that involved the industry: to continue to provide rigorous training programmes and to work together better with universities and research institutes to attract the younger generation. There is no doubt that the first is being pursued, although it would seem to be more out of self-interest and in response to regulatory requirements than by the recommendation of the NEA report. As regards the second, there is clear evidence that the industry, universities and research institutes continue to work together but whether more effectively than before is not apparent from the information received.

In many countries, recruiting high quality technical staff into the nuclear industry has become increasingly challenging and companies have to use every means at their disposal to meet their requirements. The United Kingdom is typical in that nuclear companies offer attractive salaries and benefits and use a divers range of methods to attract recruits: conventional advertising, specialist agencies and the Internet. The use of the latter is growing rapidly: in Japan, it is commonplace to use company websites to promote recruitment. Specialist agencies need not necessarily be directly related to advertising. In Spain, a training company has been used for the last three years to recruit licensed operating personnel. Understanding why many students are antipathetic to the nuclear industry or to science and engineering subjects in general, may help overcome recruitment difficulties. The American industry has gone further than most by trying to determine the motivational characteristics of young engineers who are making a decision on whether to enter the industry or not. It has also identified the good practice and common contributors to successful recruitment and retention programmes. To attract those with the highest potential, several countries report that companies have taken steps to improve their image. For example, a Korean electric utility, together with the government, has established the Korean Nuclear Energy Foundation to promote the understanding of nuclear energy and its contribution to society. However, one of the most effective ways of persuading students to enter the nuclear industry is to let them experience it first hand. As well as showing people around their sites many companies offer internships and scholarships.

Interactions between industry and universities and technical high schools occur in many ways. A Belgian company works with local universities and technical high schools on specific projects. In addition, it offers an annual prize for the best master level thesis on a nuclear subject. Such involvement by companies is quite common and alerts students to the industry in a positive manner. When it comes to attracting high quality staff the nuclear industry faces fierce competition from other technology sectors and the American industry is not alone in seeing more extensive and formalised involvement, partnering, as a way of recruiting both degree and non-degree personnel. Industry and academe often work together to devise and to deliver courses specific to the needs of the industry. As well as supporting the few remaining nuclear courses British companies have helped to introduce new ones. Very often company personnel lecture on courses. This also happens in Belgium, where representatives from one company not only deliver lectures but also help students with their theses. In Sweden, a university organises and provides courses as specified by the industry. A Canadian company has gone further and is working with universities to turn technical commercial material into educational material. Industry may help financially. A Belgian company contributes to the Belgian Nuclear Higher Education Network. In Sweden, the industry, together with the regulatory body, contributes to the funding of the Swedish Nuclear Technology Centre in order to ensure that there is adequate financial provision to replace retiring professors. Informing a broad audience of students of the needs and challenges of the industry is as important as delivering courses to a minority. In Germany, in 2002, two symposia were held to inform students of the opportunities in the nuclear industry and to motivate them to study nuclear subjects. In addition to those from industry and academe, these were attended by representatives from government and research centres. A third such symposium took place in 2003.

Organisations pursue research and development primarily for technical information but very often R&D projects are seen as an important route for recruiting young scientists. This may be through funding post-graduate students at universities, through internships or through collaborations with research institutes. Faced with a demographic downturn, the Canadian nuclear industry commissioned a report to better define the problem and propose ways of addressing it. The principle recommendation was that nuclear R&D funding be reviewed in order to improve collaboration between Canadian universities and the industry and by so doing stimulate an increase in the number and attractiveness of nuclear courses.

Recruitment is commonly driven by succession planning and integral to that is the need for continuing training. Japanese nuclear manufacturing companies, for example, consider succession planning to be of prime importance in order to preserve and develop nuclear competencies and skills. In all countries the industry continues to provide rigorous training programmes, not only to meet its own specific needs but also very often as part of career development. In many companies, training is still done in house. A German company has established a nuclear education centre to improve in house education and training capabilities in order to assure the safe operation of power plants. In France, power plant operators are recruited from general technical staff and are trained internally by the state Electricity Company. The relative importance of the nuclear industry, with its research organisations and the institute for nuclear science, is a warranty for the continuing provision of experienced trainers. However, the use of outside companies to help deliver training is quite common. In Spain, a training company is not only used to recruit licensed operating personnel but also to standardise the training process. To meet the specific theoretical training needs of engineers with a more general background, the Swedish nuclear industry has developed applied nuclear training courses, provided to the industry as in house training by a jointly owned company. In Korea, a power company has established mid and long-term training and education programmes, covering managerial as well as technical issues that make use of both domestic and foreign institutes.

Many companies are investing in knowledge management systems, usually as a way of retaining information as experienced staff leave. One example is in Hungary where, because of the age profile of the employees and the lifetime extension of the power plant, knowledge management has become a prime issue. In Finland, organisations have contributed to the government report on nuclear knowledge management as a result of prospective new build. A working group has been established to develop and organise professional post-graduate training on nuclear safety for new recruits and existing staff changing post as well as for the new generation replacing retiring staff.

Although government policies are generally intractable, this does not prevent the nuclear industries in most countries from lobbying for increased government support, particularly in the areas of research and educational programmes.

Research institute initiatives

Research institutes are facing similar recruitment problems to those of the industry. In addition, the financial situation of research institutes is deteriorating in many countries due to cuts in public funding and to tough competition in the niche market where they sell their services and products. This makes it difficult for the research institutes to fulfil the recommendation of the NEA report that they should attract the best students and employees by developing exciting research projects of relevance to the industry.

Although the extent of public funding for research institutes may be declining, in most countries it is still substantial. The exceptions are the United Kingdom, where there is no longer a research institute, and Sweden where the research institute now has to operate almost entirely on a commercial basis.

In most countries, the research institutes have links with universities. These can take the form of promoting or delivering courses, awarding prizes, grants and fellowships, offering internships and allowing students to do research in well-equipped laboratories. Such activities bring undergraduate and graduate students into contact with the research institutes in a manner that can only encourage employment in the industry if not the research institute itself. One example is in Korea where there is a long-standing internship programme between a research institute and a university. Students undertake research at the institute and follow lecture courses at the university. The objectives of the programme are to develop the next generation of researchers and to encourage the co-ordination of research between the institute and the university. The internships are often linked to employment.

University contacts can have varying degrees of formality. In the United States, there are alliances between national laboratories and selected domestic or foreign universities. In France, the specialist nuclear education and training institutions have been working closely with the research institutes and the industry for many years. The recent initiative by Canada to create a national alliance between universities, nuclear utilities, research institutes and regulatory agencies will naturally be of great benefit to the research institutes in that country.

As with any other nuclear organisation, in most countries research institutes need to project a positive image in order to overcome student and public antipathy. This can often be achieved by raising the profile of work that has a wide appeal or is non-controversial, such as nuclear applications in medicine or fundamental research in physics, for example. Organising visits to the research institutes is another effective way of creating good will. For students, whether at school or university, this can also trigger an interest in doing research in the nuclear field.

Examples of best practice

- **Collaboration between national universities**

  In Germany, a number of universities have formed a network of competence in nuclear technology. In Belgium, five universities, in collaboration with the Belgian Nuclear Research Centre, have merged two post-graduate programmes into a single one, taught in English.

- **Use of the Internet**

  In the United Kingdom, a web site that lists all of the university courses with a nuclear content has been successful in attracting students. In Germany, and several other countries, the young generation interacts with students through their web sites. In Italy, many professors have their own web pages by which they inform students about nuclear courses. In US universities, distance learning is well established and the Internet is but one way of delivering courses in a flexible manner. In Japan, it is commonplace to use company websites to promote recruitment.

- **Training existing staff and recruiting new staff**

  R&D is an important way of training staff as well as effecting knowledge transfer. Collaboration with universities and research institutes not only encourages an interchange of staff to mutual benefit but also is a conduit for recruitment. One British company has established a number of research alliances with universities that support a university skill base of some 150 people.

III. HUMAN RESOURCES

Introduction

Faced with possible demographic downturns in their nuclear industries, many NEA member countries have undertaken studies to define the extent of the problem. In spite of the myriad initiatives underway in the area of nuclear education and training, these national surveys show that more engineers and scientists having nuclear knowledge are required than are graduating.

The continuing antipathy of students in many countries towards science, engineering and technology subjects has meant that the proportion of those graduating in these areas has fallen in recent years. As fewer and fewer high quality technical graduates become available, the competition for them is ever greater and there are signs already that the nuclear industry is losing out. This is of concern to the nuclear industry as the majority of the scientists and engineers working in it do not have nuclear specialist education.

As well as losing out directly the industry loses out indirectly because this also means that the ability of organisations to circumvent the shortage of graduates with a sizeable nuclear component to their degree by hiring good quality technical graduates and training them in house is compromised.

As it has reached maturity, the nuclear industry has developed areas of expertise that are transferable to other industries. There has thus been a flow of personnel from the nuclear sector into other sectors. This was convenient when the industry was consolidating and wished to reduce staff numbers. Now that it cannot afford any further reduction in existing competences and needs to develop new ones in the areas of decommissioning and clean up, attracting young blood, retaining staff and attracting experts from other sectors in the face of competition from industries perceived as more attractive is proving problematic in many countries.

Many of the aforementioned problems can be countered through diverse and dynamic R&D programmes. Within companies R&D is as important for training staff as for technical advancement. Where industry collaborates with universities and research institutes it is also an important source of recruits. In addition, such collaborations provide a reservoir of qualified and experienced personnel, which can service both the industry and the regulatory bodies on an ad hoc basis. Further, R&D performed in universities revitalises the education system by paving the way for new courses, providing topics for theses, and encouraging academics to become positively engaged with the industry.

To some extent the human resource situation can be ameliorated through the mobility of researchers and experts. This is often viewed as an important part of the education and training of the individual on the one hand and an effective way of coping with a temporary peak in workload or effecting knowledge transfer on the other. However, in reality the mobility of researchers may be rather limited. It seems that some research organisations are more prepared to accept researchers than to part with their own.

Supply and demand

In recent years, a number of NEA member countries have undertaken manpower studies to assess their future requirements and their ability to meet them. The main findings of the national reports from Finland, Germany, Korea, Sweden, United Kingdom and the United States of America, complemented with data collected in the current study, are presented here. These countries are particularly interesting since, between them, they represent the three principal stages of the nuclear power lifecycle: building more, undecided and phase-out.

Table 1. **Status of nuclear energy in some NEA member countries**

Building more	**Undecided**	**Phase-out**
Canada, Finland, France, Japan, Korea and United States of America	Czech Republic, Hungary, Mexico, Netherlands, Slovak Republic, Spain, Switzerland and United Kingdom	Belgium, Germany, Italy and Sweden

In the autumn of 2000, the Finnish Ministry of Trade and Industry published the report of a study on nuclear knowledge management in Finland, the objective of which was to identify actions that would help to maintain nuclear competence at a high level both currently and in the future. As part of the study, the demand for and the supply of newly qualified personnel were estimated. All the relevant organisations, such as the regulator, research centres, universities and power utilities, contributed to this work. At the time of the study, the decision to construct a new NPP had yet to be taken. When it was, in autumn 2002, the power companies and the regulator re-evaluated the situation together and some new short-term actions were initiated.

According to the report, the age distribution in most organisations is such that the number of retirees will double or even triple over the next 5-10 years. However, the current education and training capacity is estimated as being sufficient to replace those who leave. This is because the research centres, the regulator and the power companies closely collaborate with the universities so that supply and demand are as evenly matched as possible. One course recently organised in Finland is a good example of this collaboration. The power companies, the safety authority STUK, the technical research centre VTT and the Ministry of Trade and Industry, all of which are involved in the project to licence and to construct a new NPP, organised a six-week full-time further education course for all those recently recruited into their organisations. The course was co-ordinated by a university and most of the lecturers were experts from the participating organisations. The structure and the general content of the course was developed by the IAEA, but adapted to the needs of Finland.

An alternative source of specialist personnel is to re-employ those who have a nuclear education but who have left the sector. This is illustrated by the experience of the Finnish Power Company TVO in connection with a new NPP. Seeking to employ 24 people, they received 658 applications. Amongst them were 15 who had a nuclear degree, had previously worked in the nuclear sector and who were willing to return to it. This is a significant number, matching as it does the number graduating each year in nuclear engineering.

In Germany, an Alliance of Competence in Nuclear Technology (*Kompetenzverbund Kerntechnik*) was established in March 2000 that included the main nuclear research centres and their neighbouring universities. As its first step, the alliance carried out a study of both the future requirement for, and the personnel structure of, nuclear technology experts working in utilities, manufacturing and service industries and the regulatory and licensing authorities. At the same time the educational capabilities of universities, including the numbers of students studying nuclear subjects, were also assessed.

It is estimated that the number of engineers working in the nuclear sector in Germany will decrease by around 10% over the next 10 years. The estimated requirement for new engineers, largely to replace those who retire, is around 25% of the total working in the sector – based on the current policy of decommissioning all NPPs after 40 years operation. In the light of these estimates, it is encouraging that, latterly, the number of degrees awarded annually in mechanical and electro-technical engineering has slightly increased in Germany. Also, that the number of nuclear engineering degrees awarded currently corresponds to the average annual need. However, if the present trend continues, a severe lack of nuclear competence can be expected before all the units have been shutdown.

Every year the Korean Ministry of Science and Technology (MOST) carries out a routine survey of the status of the nuclear sector. Whilst this is primarily to get an overview of the sector, it does include manpower and nuclear education and training. In 2003, MOST broached this subject specifically by sponsoring a study of the manpower status of Korean nuclear industries, research institutes and educational organisations.

The study showed the age distribution in Korean organisations in the nuclear sector to be particularly narrow: the age range 36-40 forms by far the largest group and that between 41-45 the second largest group. Because of the economic recession in recent years, organisations have cut back on recruitment, which has accentuated this picture.

Because of this age profile, only a small fraction of nuclear experts will retire in the next 10-15 years. But with the very low recruitment rate of the last 5-10 years set to continue, replacement could become a major issue beyond this time frame. As regards specific competences, the study revealed that during the next five years about 20% of nuclear engineers would retire. As a consequence, other engineers will most probably replace nuclear engineers.

In 2001, the Swedish nuclear power inspectorate (SKI) undertook a survey of strategic competence areas to quantify present needs and those in 10 years time. The survey also assessed the extent to which specific nuclear competence needs were currently being met by universities and institutes of technology. Eleven competence areas, such as reactor and core physics, fuel technology, nuclear engineer and process control, were defined. The power utilities, the other major industrial companies and the regulator were involved in this survey.

According to the report, the age distribution of personnel in the participating organisations is such that the risk of losing a large proportion of competence through retirement during the next 5-10 years is low. In addition, the changes in needs of personnel in different competence areas are generally small. Total annual recruitment is estimated to be about 50 people and the current educational capacity of universities in Sweden is estimated as being sufficient to meet this requirement. However, initiatives such as those described in Chapter II are needed to maintain this education capacity in the future.

A report commissioned by the UK government in September 2001 and published a year later, concluded that the recruitment demands of the power, fuel, defence and clean up sub-sectors of the nuclear industry were being satisfied but that the problem of finding suitable candidates was becoming increasingly difficult. The report identified a number of skill areas which gave cause for concern, including: radiological protection, radiochemistry, safety case writing, criticality assessment and nuclear safety research.

The power, fuel, defence and clean up sub-sectors were estimated as requiring approximately 1 000 graduates a year for the next 15 years; currently they recruit around 560. Of these, some 700 would be replacements for retirements and 300 in response to the growth in nuclear clean up. By virtue of the knowledge and skills required, the majority of these new entrants would be drawn from the engineering and physical science disciplines.

Yet, the antipathy of students towards these subject areas has meant that enrolment in them fell by 26% in the eight years prior to 2001. If this trend is not reversed, the nuclear and radiological sector may be seeking to recruit the equivalent of 10% of all UK engineering and physical science graduates in 10 years' time, even though the nuclear sector constitutes less than 1% of the national labour market engaged in engineering activity.

Furthermore, nuclear education in British universities is in an extremely fragile state. There is not one university undergraduate course with any significant nuclear content to it. At the postgraduate level, only four master courses with an entirely nuclear curriculum survive, producing just over 40 graduates a year. The industry is thus dependent upon recruiting good quality technical graduates and training them in nuclear topics in house.

In addition to graduates, some 8 000 people with trade skills will be required over the next 15 years, highlighting the need for apprenticeships. Yet, the United Kingdom does not currently have a strong apprenticeship system. In total, it was estimated that over the next 15 years the power, fuel, defence and clean up sub-sectors of the nuclear industry would require some 28 000 new entrants, excluding potential demand from new build. This figure rises to around 50 000 if the health sub-sector is included.

A significant reaction of the nuclear industry to the challenge of ensuring an adequate supply of suitably qualified and experienced staff has been to join forces with the oil and gas extraction, chemicals manufacturing and petroleum industries, which also face similar problems, to form a Sector Skills Council (SSC). The SSC will promote collaborative action by employers in the nuclear industry to define job requirements at a national rather than company level and to identify current skills gaps and latent skills shortages. Educational and training institutes will only have one organisation with which to deal and the unambiguous messages coming from it should facilitate the development and implementation of appropriate courses. Provision will be demand-led, not supply-driven.

Given the UK emphasis on clean up, it is likely that the requirements of the new non-Governmental Agency, the Nuclear Decommissioning Authority, will have a major influence on nuclear skills development in the United Kingdom.

In 2000, the Nuclear Energy Research Advisory Committee (NERAC), advising the US Department of Energy (DOE), published a report on the future of university nuclear engineering programmes and university research and training reactors. According to this report, the number of nuclear engineering degrees awarded annually in the United States fell by almost 75% between 1980 and 1998. As a consequence, demand for nuclear engineers exceeded supply. The report put forward several recommendations aimed at maintaining human resources in the nuclear sector.

In the last few years the DOE has launched several initiatives to address the questions raised by the NERAC report. The decline in nuclear engineering has since been reversed, with enrolment at least doubling in the last five years. However, this trend of increasing enrolments might not be sufficient to meet the manpower requirements of a new build programme. Encouragingly, the number of PhD degrees awarded annually has remained fairly constant but the number of engineering degrees in general has fallen slightly, as is the case in many other OECD member countries.

These national surveys show that employers require more engineers and scientists having a nuclear component to their education than those graduating. The proportion of nuclear engineers and scientists graduating each year expressed as a percentage of the number of mechanical engineers graduating each year in countries such as Finland, Germany, United Kingdom and the United States of America, is less than 1%. In Korea, it is much higher at 13%. Yet, the estimated required mix of new engineers and scientists working in the nuclear sectors of these countries is about 30% nuclear to 70% non-nuclear.

The fact that the majority of the experts working in the sector do not have nuclear related degrees emphasises the importance of in-house training and further education. Collaboration between industry and academia to deliver these aspects can be to mutual advantage. Indeed, in the last few years the extent of industry involvement in scientific education and training has increased.

The earlier NEA study indicated that the age distribution of faculty members was rather high in many countries. This situation, together with the decreasing number of students taking nuclear courses, raised a concern that when senior staff members retire, they would not be replaced. Recently, some encouraging examples, for example Sweden, have been reported, where the posts of the retiring professors have been maintained and successors have been nominated. In most cases, this would not have been possible without industry-academia collaboration.

Countries, which have in their defence sector nuclear naval propulsion and nuclear weapon programmes, e.g. France, United Kingdom and the United States of America, have an additional source of nuclear education. The characteristic of the military is a continuous turnover of manpower creating a constant need for new recruits and generating a steady source of trained and experienced personnel. The civilian nuclear power sector may profit from the defence sector activities in several ways: those educated by the defence sector can form an important source of educated and trained workers; the military education and training organisations can share resources with their civilian counterparts to deliver courses; civilians can take up spare capacity on military courses and vice-versa.

Mobility

The international mobility of highly skilled workers, in particular human resources in science and technology, is currently an important policy issue in most OECD member countries. To mitigate possible shortages, an increasing number of countries are implementing measures to facilitate the recruitment of skilled foreign workers. The positive effects for the host countries are the stimulation of innovation capacity, an increase in human resources and the international dissemination of knowledge. For the donor countries, the loss of human resources can be at least partially offset by the return of migrants and the development of networks facilitating the circulation of skilled workers between their host countries and their countries of origin. The mobility of skilled workers can also promote investment in training in both the donor and host countries.

According to the responses received for this study, the mobility of researchers is rather limited (Table 2). It seems that while research organisations are reluctant to send their own experts abroad they welcome foreign researchers. For example, in Spanish organisations, Spanish researchers are not sent abroad yet there is a high proportion of foreign researchers in some disciplines. Similarly, the number of Swedish researchers sent abroad is nominal, but in some disciplines, such as waste management, there are a considerable number of foreign researchers.

The data obtained were limited solely to researchers who stay abroad for a limited period, a maximum of a few years. Without any data on those who emigrate permanently, it is impossible to draw any conclusions about the total mobility of researchers or its significance. However, it can be estimated that overall mobility is no different in the nuclear sector to other technology sectors, i.e. migration is mainly from less developed countries into OECD member countries, rather than from one OECD member country to another.

Table 2. **Mobility of researchers*** (%)

Discipline	Germany	Japan universities	Japan research	Spain
Reactor design	–	0	3	10
	10	10	8	0
Material studies	5	0	0	0
	25	33	3	0
Fuel studies	–	0	1	20
	–	13	1	0
Waste management	1.5-5	0	1	10
	3-26	0	3	0
Decommissioning	–	0	0	0
	29		0	5
Radiation protection	–	0	0	15
	–	0	2	0
Others	3	0	–	–
	5-10	2	2	–

* The upper value indicates the share of researchers temporarily working abroad; the lower value the share of foreign researchers (% of person-years).

Examples of best practice

- **Education and training integral part of R&D**

  Education and training (E&T) is one of the thematic areas of the 6th Euratom R&D Framework Programme. The aim is to develop a harmonised approach to education in nuclear sciences and engineering and to provide support for fellowships, training courses networks and grants for young researchers. E&T is also one of the main objectives of the Finnish national research programmes.

- **Collaboration between industry, universities and research institutes**

  A Belgian company works with local universities and technical high schools on specific projects. British companies work with universities to develop new courses and support both new and existing courses through visiting lecturers and by providing work placements for students. The Canadian initiative UNENE – University Network of Excellence in Nuclear Engineering – crosses traditional boundaries to ensure a sustainable supply of appropriately qualified engineers and scientists to meet the needs of the Canadian nuclear industry. In Sweden, industry together with the regulatory body contributes to the funding of the Swedish Nuclear Technology Centre in order to ensure that there is adequate financial provision to replace retiring professors.

- **Encourage mobility of young generation**

  At a Belgian university students spend time in a foreign institution as part of their graduate training in nuclear engineering. In Korea, outstanding students are supported so that they can visit an overseas facility. A Hungarian university has developed links with other European universities and research institutes, thereby giving its students the opportunity of pursuing part of their studies abroad.

- **Preserving independent expertise and facilities**

  The funding of R&D by the private sector helps through private funding the continued availability of experts and facilities in universities and research centres. Joint funding is more efficient than single company funding. In the United States, members of EPRI and the Owners Group agree on jointly funded projects. Industry funding for R&D can complement public funding, as is the case in Germany, Hungary, Japan, Korea, Spain and the United States. Where there is little or no public funding, industry can act alone. In 2000, the nuclear industry of the United Kingdom had some 250 research contracts with universities worth about GBP 10 million. Since 2004, Finnish nuclear power companies have had to finance national nuclear safety and waste management research programmes to ensure the availability of the expertise for public authorities.

IV. INTERNATIONAL COLLABORATION

Introduction

The general trend towards a more global economy has been accompanied by a closer integration of the knowledge economy and an expansion of knowledge transactions. As a consequence, the production and application of scientific and technology knowledge has become a more collective effort. Virtually all forms of collaboration, such as co-operative research and international strategic alliances, show signs of increasing.

International research collaboration, excluding industrial collaboration, can take a number of different forms. Some examples, in increasing order of complexity, are:

1. Research collaborations between individual scientists. Formalities can be relatively simple, for example an exchange of letter, with little or no funding implications.
2. Collaborations based on agreements between research institutions. Usually a more formal approach is required, particularly if funding for the participants comes ultimately from government or from its associated agencies.
3. Collaborations requiring significant capital or operational funding. Even if funds do not cross national boundaries, a formal approach is usually inevitable, with correspondingly more complex arrangements. Such collaborations can be based on an existing facilities or organisation or may require the establishment of new arrangements.
4. Collaborations designed to provide a new capital facility, for example a facility that would not be within the capability of a single partner country, necessitating formal agreements.

The involvement of policymakers and governments will vary depending on circumstances. At the simplest level (1) no involvement is usually required. Beyond this, government is responsible for maintaining a general framework within which international collaboration can take place. For the provision of a new large-scale facility at considerable cost (4), government involvement is inevitable.

Financial support by national government is only given if the international programme objectives align with the national nuclear strategy. None of the countries responding to this questionnaire reported that participation in any international programme was explicitly forbidden. However, government funding is seldom available to support any involvement in work programmes which conflict with national policy.

Collaboration of research institutes

Nuclear research has never been a solely national activity. Collaboration, information exchange and even exchange of personal resources have always accompanied the development of nuclear power, as far as the political constraints of the day have allowed. It is largely as a result of international collaboration that nuclear power has become a reliable energy source within a single generation, accounting for a significant proportion of the electricity produced in many nations today. It is, therefore, not surprising that excellent links still continue e.g. between European countries, the United States, Korea and Japan.

The history of civil international nuclear collaboration in Europe goes back to 1957, when Belgium, France, Germany, Italy, Luxembourg and the Netherlands signed the Euratom Treaty with the intention of creating the conditions necessary for the development of a strong nuclear industry in Europe. Today, the Treaty still offers the basis for joint European research programmes for nuclear fission and fusion, having more partners today to support it. The member countries make their financial contribution to the organisation, which, in turn, supports financially the joint research programmes of their members.

In the United States, the NERI programme is funding national laboratories, universities and industry. However, international collaboration is welcome and organised within the framework of International-NERI programmes on a leveraged, cost shared quid pro quo basis. Each of the International-NERI collaborating partners provides funding for their respective project participants and a 50:50 matching contribution is provided by the United States.

In Japan, JAERI is financially supporting international programmes on a case-by-case basis. An "a priori" assessment and a retrospective evaluation are carried out in common with the practice for domestic collaborators. JNC actively co-operates with France, the United States and other advanced nuclear countries in the area of advanced nuclear technology and disposal of high-level radioactive waste.

Other opportunities for international collaboration are provided by the IAEA Co-ordinated Research Programmes and OECD/NEA Working Groups, Joint Projects (JP) and Information Exchange Programmes (IEP). The JPs and the IEPs enable interested countries to pursue research, scientific inter-comparison exercises or share data with respect to particular areas or problems. The projects are carried out under the auspices, and with the support, of the NEA secretariat, but the participants cover all the costs. Such projects, primarily in the areas of nuclear safety and waste management, are one of the NEA's major strengths. The Halden-Project is often cited as one of the best examples of a long-lasting JP. Approximately 100 organisations from seventeen countries participate in this Project.

Back in the 1960-70s, the object of international collaboration was primarily to find answers to those many questions which emerged during the development of this completely new technology. Information exchange and temporary exchange of personnel, accelerated by the new means of communication and transportation, enabled a rate of development to be achieved that had never been experienced before.

The accidents at Three Mile Island and, later, at Chernobyl created a new emphasis on nuclear safety research in the 1980-90s. A large, worldwide community was already trying to minimise the residual risks of nuclear power and to quantify assumptions about severe accident phenomena; international collaboration was a kind of quality assurance process. Codes and experimental data were benchmarked against each other to check their validity and the safety performances of individual plants were published.

Today, an important area of international collaboration is nuclear waste management. In Europe, almost 50% of the public research programmes are dedicated to nuclear waste management. International collaboration is needed to identify the alternative options and to find the optimum, to identify the risks of each option, or to explore innovative, new approaches such as partitioning and transmutation.

Nuclear safety research for existing installations, although still a high priority in some countries, has tended to decrease in international programmes. For example, in the 6^{th} European Framework programme the nuclear severe accident research programmes for existing installations will have a share of only about 3% of all nuclear fission programmes.

The development of future nuclear power plants still plays a minor role in European public organisations, with the exception of France perhaps. The priorities of new research topics are different, however, Japan, South Korea and the United States. In these countries, a significant or even predominant portion of the R&D resources is used for advanced, innovative plant development and design. International collaboration allows resources to be shared, an important aspect since some nuclear research facilities have been closed and R&D manpower has been significantly reduced.

In the next decade, there will be a new challenge for international collaboration. Those scientists and engineers who developed and built nuclear power plants are going to retire within the next few years; a new, young generation of nuclear engineers needs to be motivated, educated and trained to keep the nuclear option open for the future. Irrespective of whether individual countries are to phase out the nuclear option, there is a consensus that the expertise in nuclear technology needs to be maintained. There is no doubt that only a joint, concerted, international effort can succeed in forming a critical mass of young researchers having the spirit to revitalise an endangered technology.

The Generation IV International Forum (GIF) is an initiative which will help to solve this problem. It is composed of Argentina, Brazil, Canada, France, Japan, Korea, South Africa, Switzerland, United Kingdom, the United States and Eurotom, which are interested in jointly developing the future of nuclear energy. NEA has been invited to provide technical secretariat services for the R&D phase of the GIF activities. By selecting six candidate concepts for future nuclear power plant technology, they have sketched a clear vision for future research and development. A Roadmap helps to structure the envisaged R&D into its various disciplines, and defines milestones and tasks. GIF is a formal, government-sanctioned organisation committed to collaboratively pursuing R&D on Generation IV systems. The objective of GIF is to develop future nuclear energy systems that can be licensed, constructed and operated in a manner that will provide competitively priced and reliable energy products which satisfactorily address nuclear safety, waste and proliferation concerns which are expressed by society. The objective is to have them available for international deployment before 2030.

The European Commission intends to spend EUR 190 million from their Euratom budget for international collaboration of their member countries during the five years of the 6th Framework Programme (FP-6), started in 2003. Nuclear fusion covers by far the largest part of the programme. Almost half of the resources in the field of nuclear fission are directed to management of radioactive waste, including research on geological disposal as well as partitioning and transmutation or other waste reducing concepts. The nuclear technologies and safety, and radiation protection represent around equal parts of the programme.

Collaboration of industries

Collaboration of industries with industries is limited, of course, by the constraints of the competitive market. Nevertheless, international industrial companies have had to rationalise their structures by merging and by acquisition in response to the decreasing market for nuclear power plants, e.g. Westinghouse with BNFL and parts of ABB or Framatome with parts of Siemens. The new synergies have enabled manpower to be reduced while still maintaining a minimum level of nuclear competence, which will enable them to be a viable supplier in future. Indeed, recent decisions to proceed to construct EPRs in Finland and France are evidence of the value of this approach.

The pre-competitive research, on the other hand, has never been restricted, so that industries have collaborated with research centres in most of the research programmes listed above. Several worldwide industrial companies have an interest in GIF. They may provide financial support in addition to national funding, offer their test facilities for the common use of the forum, and conduct research projects using their own resources.

The aim of the FP-6 is to intensify and deepen the collaboration at programme and project level in order to make better use of resources (both human resources and experimental facilities) and promote a common European view on key problems and approaches, in accordance with the needs of the European research area. Also the networking is promoted with third countries, in particular Canada, Japan, the Newly Independent States of the Former Soviet Union (NIS) and the United States.

Collaboration of universities

Whereas nuclear research centres have a well-established acceptance of international collaboration and the nuclear industry is international, the opportunities for universities to collaborate with international partners tends to be more fragmented.

Students go abroad for part of their curriculum to become specialised in a particular topic or to get a different perspective and broaden their experience. This trend has strongly increased during the last 15 years. However, it is mostly done on the basis of individual initiatives, encouraged by scholarship systems and not the result of formal agreements and understandings between universities.

The situation seems not to be very different for researchers in universities. However, it should be noted that very little information was provided on international collaboration by universities in the answers to the questionnaire. One reason might be that in most countries having, or having had, a nuclear programme, organisations specifically devoted to nuclear research exist, draining the major part of public funding, so that universities were not so much involved in nuclear research.

As regards education and training, the need of the nuclear sector to recruit young engineers and scientists and the decrease in young people interested in science and engineering, recently resulted in a new approach, the creation of university networks. Examples exist in several countries such as Belgium and Canada. These networks aim at putting together the efforts to provide high level education programmes and to encourage students to choose nuclear careers. The programmes also involve the nuclear industry.

Euratom FP-6 contains an specific action on “Education and Training”, with the aim to better integrate European education and training in nuclear safety and radiation protection to combat the decline in both student numbers and teaching establishments, thus providing the necessary competence and expertise for the continued safe use of nuclear energy and other uses of radiation in industry and medicine. This approach has been implemented by setting up the European Nuclear Engineering Network (ENEN): it involves 22 universities or institutes from 17 countries of the EU or candidate countries. ENEN aims to harmonise nuclear curricula in Europe and intends to deliver an ENEN Diploma which would be recognised by all participants. In the near future, ENEN expects to extend its field to cover both education and training.

Other international arrangements were recently agreed in Europe on nuclear engineering education: bilateral agreements (French INSTN with Belgian ULB or Spanish UPM), multilateral agreements (Hungarian INT BUTE, Netherlands TU Delft, German University of Dresden and Forschungszentrum Rossendorf).

Following the IAEA senior meeting on “Managing Nuclear Knowledge” in June 2002, a meeting was organised in Korea to initiate the establishment of a regional Asian Network for Higher Education in Nuclear Technology (ANENT). The objectives of the ANENT are to promote, manage and preserve nuclear knowledge and to ensure the continued availability of talented and qualified manpower in the nuclear field in the Asian region. It also intends to enhance the quality of the human resources for the sustainability of nuclear technology and to facilitate co-operation in higher education, related research and training in nuclear technology in the Asian region.

Finally, the networking approach has also been adopted recently at a worldwide level with the launching, in September 2003, of the World Nuclear University (WNU): the initiative came from the World Nuclear Association.

Examples of best practice

- **International university networks**

  Regional initiatives such as The European Nuclear Engineering Network and the Asian Network on Education and Nuclear Training bring together universities in different countries to provide degrees in nuclear subjects that are beyond the capability of any individual university. The World Nuclear University is an example of government, industry and academia collaborating to support education and training. The mobility of students, teachers and experts is an integral part of such initiatives.

- **Securing access to nuclear expertise via international organisations**

  Many European countries encourage their nuclear organisations to participate in the Euratom Framework Programmes in order to enlarge the pool of expertise. International projects, such as NEA Joint Projects, offer a cost efficient option way of obtaining experimental data and of retaining and developing the competences necessary to keep the nuclear option open. Collaboration can also be effected through international organisations such as the NEA – the NEA Halden programme being just one example.

- **International collaboration**

  R&D can be accelerated through international collaboration. The Euratom Framework Programmes cover most aspects of nuclear activity from new reactor systems to decommissioning old ones. GIF, relevant for long-term development of innovative reactors, and INPRO, focused on users requirements are two examples of collaborative R&D.

V. CONCLUSIONS AND RECOMMENDATIONS

In spite of the ambivalent situation vis-à-vis nuclear energy, where and some countries have decided to build new reactors, some countries hesitate and some others avow their intention to phase out nuclear facilities, nuclear energy still accounts for a significant proportion of capacity throughout the world and particularly in OECD member countries. In so doing it saves precious fossil fuels and reduces greenhouse gas emissions. Furthermore, nuclear technology is far wider than electricity production. It covers a wide range of applications from medical diagnosis and treatment to the examination and testing of materials. With this holistic view in mind, the following recommendations are made. They are intended to help preserve and develop nuclear competences, no matter what their ultimate peaceful applications may be.

Nuclear Education and Training

Conclusions

Countries have recognised the issues and there has been good progress against the recommendations of the report but more needs to be done.

Three years after its publication, it is clear that, in most countries, there is a high level of awareness of the report *Nuclear Education: Cause for Concern?* More importantly, it is clear that it has been the catalyst for action. There is strong anecdotal evidence to suggest that without it some existing initiatives would have atrophied and that there would not have been the necessary impetus to start new ones. Certainly, the report has prompted a number of countries to conduct surveys in order to quantify more accurately their future manpower requirements. The benefit of these surveys is not limited to the national initiatives that they in turn have prompted. Taken together, they give a much clearer picture of the global situation and have already been the spur for international collaborations. Initiatives are starting to improve the situation but it is still early days and more needs to be done.

While there is a wide range of activities in all countries, there is no evidence of a breakthrough in addressing the demographic down turn; nevertheless, such activities have begun to ameliorate the situation.

The number and diversity of initiatives currently underway suggest that the situation is beginning to improve. However, in spite of the wide range of activities being undertaken by member countries, where demographic studies have been undertaken, they still indicate a shortfall of qualified personnel in the near future. Recruiting and retaining those with specialist nuclear expertise, such as reactor core physics for example, is a particular concern. All the more so if the ability of universities to teach nuclear subjects continues to decline.

The provision of necessary specialist nuclear education is under threat.

Because of its maturity, the demand for specialist nuclear education is lower now than it has been for many years and as a consequence the number of academics delivering nuclear courses has declined considerably. Yet the need for specialist education remains if the safe operation of plants is to be guaranteed.

Recommendations

Countries should seek to borrow good practice from other countries to enhance their domestic programmes.

While all countries have made progress, very often this has been through the logical extension and development of existing activities. One of the objectives of this study is to identify initiatives with the view to sharing good practice. Borrowing ideas from other countries could well be the route to both complementing and maximising the effectiveness of domestic activity.

Countries should widen their knowledge base through national and international initiatives.

There is a limit to the number and diversity of initiatives that countries can undertake on their own. While specific skills and competences might be under threat in one country, they may be far more secure in another. To retain all the necessary nuclear skills and competences of which the industry has need will require a greater degree of international collaboration than has occurred before.

Government, academia, industry and research organisations should collaborate both nationally and internationally to secure access to essential nuclear expertise.

The safe and efficient use of nuclear power demands a certain number of experts in nuclear specific areas: nuclear reactor engineering, reactor physics, radio-chemistry and radiation protection, for example. Since the required number of experts in these essential disciplines may be small in some countries there is a danger that the educational provision to supply them may disappear. There is, therefore, a need for government, academia, industry and research organisations to collaborate together in order to secure sustainable groups of expertise. Governments need to provide the strategic direction which ensures that sufficient education resources in critical nuclear specific areas are secured. Where essential expertise is in short supply or unavailable in one country, then access to its provision should be sought within another country.

Human Resources

Conclusions

Conducting manpower surveys is an important way of assessing present and future competence requirements.

Prior to the report *Nuclear Education and Training: Cause for Concern?* few, if any, countries had a clear understanding of their present or future manpower needs. The report confirmed what many had suspected for some time, that nuclear education and training had been in decline for a number of years and there was a serious risk of skill shortages in the near future. The potential insecurity of supply prompted a number of countries to accurately assess their needs and take steps to guarantee that they could be met.

Attracting high quality technical graduates into the nuclear sector is a challenge.

Being a mature industry, the nuclear sector has developed areas of expertise that are transferable to other industries. As a result, the sector has lost personnel to fast expanding sectors such as information technology. Replacing them should not be a problem given that many of the engineers and scientists working in the sector do not have a nuclear qualification and the numbers required represent only a small fraction of the total number of graduates in these fields. Yet, attracting high quality technical graduates into the industry in the face of competition from other industries perceived to be more attractive is increasingly problematic.

Recommendations

To ensure that supply and demand are as evenly matched as possible, it is worthwhile carrying out a manpower assessment every few years.

In a changing world it is evident that the manpower and competence requirements of the nuclear sector of any country will gradually change. Manpower surveys help to ensure that supply will meet demand. Simply identifying areas in which recruitment is proving difficult by talking to recruitment officers in nuclear companies and organisations would help universities and training institutions to develop the appropriate courses.

Industry and research organisations should increase their interaction with university science and engineering departments in order to raise the profile of the nuclear industry so that more students consider it when deciding on career choices.

With the nuclear industry facing fierce competition from other science, engineering and technology industries, it is incumbent upon those working within it to present the challenges and opportunities that the sector has to offer. A particularly important target group is those at university and on the brink of making career choices.

Research and Development

Conclusions

In recent years, publicly funded nuclear R&D has experienced a drastic reduction in most countries.

It is a natural consequence of a maturing industry that the public funding of research and development should decline. In some countries that decline has been accelerated by the decision to let market forces prevail, in others by the decision to phase out nuclear power. Increasingly, industry funds open research as a means of ensuring the continued availability of experts and facilities in universities and research centres.

The main focus of R&D is the safety of existing nuclear power plants and waste management issues. Commitment to innovative, future reactors is far from pre-eminent in most countries.

With the decline in public funding, the burden of R&D has fallen to the industry. Not surprisingly, this has been focussed on issues of immediate importance such as safety and waste management. In an increasingly competitive environment, it would seem only limited funds are available to support longer-term issues such as new reactor systems.

Recommendations

Publicly controlled funding of nuclear R&D should not be allowed to decline to the point that the retention of skills and competences are jeopardised.

The underlying theme of public funding or publicly controlled funding, in all countries, is the need to maintain core skills and competences. Yet, given that public funding has decreased in most countries in recent years, this responsibility is increasingly falling to industry. The danger is that the industry will narrowly focus on those skills and competences that it needs for the near-term. Strategic planning is needed to accommodate longer-term needs and this can only be effected in the absence of commercial pressures.

Those responsible for funding nuclear research and development should seek to ensure that education and training aspects are an integral part of activities.

In some countries, funding for nuclear research is dealt with in isolation from funding for nuclear teaching within the same university. In other countries, it is recognised that good teaching and good research go together and a more integrated approach to funding is taken. Although there would be benefit in increasing the funding of nuclear teaching to cover research as well, it is more likely that good research will beget good teaching rather than vice versa.

If nuclear power is to continue to evolve, commitment to developing innovative new plant is required. A mix of industry and public funding would seem an appropriate way forward.

Countries cannot take their nuclear programmes forward, or even merely keep their nuclear option open, without some commitment to innovative plants. Given that the benefits will be both on a national basis and a company basis, it seems appropriate that a mix of industry and public funding should support endeavours in this area.

International Collaboration

Conclusions

International collaboration in nuclear research and skills provision is well established and has become an essential way in which countries are able to meet their responsibilities.

International collaboration among civilian nuclear research organisations dates back to the birth of the industry and links made in the 1950s still exist today. Both bilateral and multilateral collaboration continue to operate effectively but increasingly the nuclear agencies are playing an important role in co-ordinating international activities on both research and skills related issues.

The recent Generation IV International Forum (GIF) is a good example of how countries and organisations can come together to collaborate on an issue in which they have a common interest. In this case the development of future nuclear power plants. However, collaboration by industry beyond the early research stage can be limited by commercial interests.

***Large, high profile international R&D programmes enhance the image of the nuclear sector and encourage recruitment*.**

Innovative nuclear research programmes in the area of Partitioning and Transmutation and future power reactors (GIF), for example, are tangible evidence that nuclear technology continues to be challenging, innovative and considered a long-term option in some countries. As such, research programmes have the potential to influence topics taught at university and to present a dynamic image of the industry to those making career choices.

Collaboration is as important to the industry as it is to the universities. Not only are shortages of expertise averted but so also are the closure of courses. There are good examples both in Europe (ENEN) and Asia (ANENT) where universities are collaborating to establish common platforms for education at the Masters level. Although collaborations need to be driven by the universities themselves, government and industry do have a role in clarifying the educational needs and in providing financial support.

Recommendations

Government, industry and academia should work together to create a functional framework to support education and training through national and international collaboration.

The teaching of nuclear related subjects at universities has declined considerably over the last decade or so. Consequently, a high and comprehensive standard of nuclear education can no longer be guaranteed in all countries using nuclear technology. Whilst national and international collaboration between universities can provide the means whereby the collapse of nuclear education may be avoided unfortunately such collaboration is weak or non-existent in many countries.

The NEA and other international agencies should facilitate transferability of education and skills between member countries especially in critical nuclear specific disciplines.

The strength of international organisations such as the NEA, IAEA and EC lies in their ability to create and secure frameworks in which member countries can work together and collaborate. Much progress has already been made in the areas of nuclear education, training and research and if it is to continue the responsibility of these organisations to facilitate collaborations must be maintained.

Appendix 1

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Appendix 2

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Appendix 3

Summary of Responses to R&D Section of Questionnaire

Current R&D programmes and projects

In order to achieve a commonality of approach for grouping the information on the myriad R&D programmes and projects being pursued by the countries participating in this study, five disciplines were defined (see questionnaire, Appendix 5): plant design, material development, fuel studies, waste management and decommissioning.

In the wake of the accidents at Three Mile Island and Chernobyl, the safe operation of the nuclear industry has gone from being a major preoccupation to being of paramount importance. As a consequence, the industry has had to meet far more stringent expectations from the public and politicians than the statutory legislation often demands. In many cases, these expectations have been realised through research and development. Although safety was not identified as a separate entity in this study, there is no doubt from the information received that the safe operation of nuclear facilities is of utmost importance in all countries and is being underpinned by extensive research and development, either in dedicated programmes or as an inherent component of others. Whilst reference is made to safety elsewhere in this chapter, the following few examples serve to illustrate the importance and commitment accorded to this most important aspect. In Germany, safety research for operating reactors accounts for over one third of those engaged in R&D. Areas of interest include simulated core melt experiments, coolant mixing in PWR and hydrogen combustion processes. In Belgium the national research centre focuses on reactor safety through optimisation of the fuel configuration and the degradation of reactor internals. In Spain there are programmes on containment, severe accidents scenarios, including the behaviour of liberated fission products and human factors. All countries reported research programmes in radiation protection. Areas include environmental and population monitoring, analysis of low-level radionuclide concentrations and dosimetry studies. Commitment to safety related research is also evident from expenditure: between 1998 and 2002, the Paks Nuclear Power Company in Hungary quadrupled their budget for safety related R&D for their sole power station (from 62.9 to 245.1 million HUF) and in Finland, which has two nuclear power stations, the volume of the national reactor safety research programme in 2003 was four million euros.

Plant design is an important area of research activity in many countries, often aimed at improving both safety and efficiency of operation. This is typified by Hungary, where, measured in man-years, it is the most significant area of research and is focused on improving the safety, and to a lesser extent, the efficiency of the country’s sole nuclear power station. In the United Kingdom, there are more people engaged in R&D for plant design than all the other research areas combined. Japan follows this trend with plant design being the most significant area of research, accounting for just over one third of R&D workers. Plant design covers both existing and new plant. For example, in Spain three safety projects relating to existing plant design are underway, two supported by the research programme of Euratom and one by the Spanish regulatory body. Regarding new plant, there is a project on the concept of an isotope transmutation facility in relation to nuclear waste. Despite the nuclear moratorium in Italy, there are 120 researchers, just over 10% of the total involved in nuclear R&D, engaged on plant design including that for new concepts and advanced reactors. In the United States, about 20% of those engaged in nuclear R&D do so in connection with reactor safety and reactor design. New technologies for future reactor design are also being addressed in Finland. By the decision to build a new LWR of the third generation, the EPR, Finland has clearly demonstrated its adherence to nuclear power. But in other countries, such as Germany and Sweden where it is the intention to phase out nuclear power, there is no commitment to innovative plant design. Any effort is directed at the safe running of existing plant.

In the majority of countries, research in material development is not a leading area of activity. In the United Kingdom, Japan, Germany, Spain and the United States, R&D in this area accounts for less than 10% of those engaged in nuclear research. Italy also has a comparatively small commitment to materials development: less than 5% of nuclear researchers being engaged in this area. The main fields of study are related to Pb-Bi systems, also of interest in Germany. In contrast, in Hungary it is the third most significant area of activity, in terms of manpower. As in other areas of nuclear R&D in Hungary, work is restricted to current reactors; there are no studies for new reactor types. Belgium possesses one of the most powerful materials testing reactors and this is used in the examination of materials for different reactor types and for the European fusion programme. In Spain, work is aimed at supporting the lifetime management programmes for operating nuclear power plants, particularly in respect of the integrity of the components, irradiation effects and crack corrosion phenomena.

The commitment to research in fuel studies varies considerably from country to country. In the United Kingdom and the United States it accounts for around 10% of those involved in nuclear research. In Japan, for around 20%, where it is the second most important area of activity after plant design. In Hungary, too, it is the second most significant area after plant design. Whilst there is no fuel development activity in the country, experiments with spent fuel are performed at a research institute. In Italy, the commitment is negligible, as it is in Germany. Spain, like a number of countries, has a range of projects supported by the utilities. Typical areas of interest are high burn up and fuel behaviour in normal and accident situations. In addition, some 13% of those working in research organisations are committed to fuel studies. Sweden has a fuel test facility. In Belgium, a research reactor is used for testing fuels for different reactor types. Many countries use the OECD/NEA Halden reactor project to conduct fuel studies.

If they are convinced that the nuclear industry is safe and that it operates efficiently, then both the public and politicians are often sceptical about its ability to manage its waste. It is, therefore, not surprising that all countries devote significant resources to R&D in waste management. In Germany, measured in man-years, it is the most important area of activity: about 50% of the resources of public research organisations are involved in waste management programmes. These are concerned primarily with final disposal in deep salt repositories and to, a lesser extent, research into alternative options such as partitioning and transmutation. In the United States, R&D in waste management accounts for just over 30% of research workers and in this respect is by far the most significant area of activity. Understandably, the regulator, the NRC, is involved but so too are universities and the DOE. Italy, too, has some 30% of its nuclear R&D personnel committed to waste management issues and again it is the most resourced area of activity. Although ranking second in the United Kingdom, after plant design, waste management still accounts for some 30% of researchers. In Spain, more than two thirds of the available research resources in publicly funded research organisations are engaged on waste management programmes. These include characterisation and conditioning of low and medium activity wastes and the storage of spent fuel, in particular in deep repositories. Waste management is becoming increasingly important in Hungary: work has been ongoing since 1993 to determine the site of a LLW/ILW repository and a research project for the final disposal of HLW commenced in 2004. In Japan, R&D in waste management ranks third, after plant design and fuel studies, and accounts for some 17% of researchers. Both Sweden and Belgium possess underground laboratories; in Sweden, it is in rock formation, in Belgium in clay. Finland, though, is the first European country to decide on the location of a final repository. It already has two ILW/LLW repositories at the sites of the two power stations and work commenced in 2004 on the construction of an underground research laboratory as part of the programme for a spent fuel repository at the same site.

Whilst R&D in decommissioning is pursued by all the countries responding to this study, it is an area that generally attracts few resources. Italy is a notable exception, with nearly 30% of researchers engaged in decommissioning activities. In the United Kingdom, whilst decommissioning ranks third in terms of manpower commitment, after plant design and waste management, it only accounts for some 10% of researchers. Programmes support the decommissioning of a fast reactor, a prototype PWR and also Magnox units. In other countries the commitment is less. In the United States and Japan it accounts for only 3% of research resources, in Spain 5% and Germany 7%. In Spain, programmes include those related to a fuel manufacturing plant, a plant for storing radioactive liquid wastes, hot cells, a reprocessing plant and an experimental reactor. Germany has programmes related to decommissioning not only a prototype reprocessing plant and prototype light water reactors but also a sodium cooled fast reactor. In Belgium, an important aspect of research on site restoration is the dismantling of a prototype PWR. In Hungary, where decommissioning the sole power plant and sole research reactor are not envisaged in the near future, there is little activity in this discipline.

Trend of industry R&D

Trends common to all countries are difficult to discern. Overall, though, it would seem that there is more emphasis on operating reactors than future systems. National projects predominate over international ones. The length of projects varies with research area and from country to country: they can be short, medium or long-term; there is no common denominator. As might be expected of industry funded research, economic drivers are important but in no country are they more important than safety.

In Hungary, industry funded research is mainly safety driven with projects relating to operating reactors; those relating to future reactors are not significant. Long-term projects predominate over short-term ones. In the United Kingdom, the nuclear generators participate in a collaborative programme of reactor safety research in response to issues raised by the regulator. All work relates to operating reactors, which, other than one PWR, are designs unique to the United Kingdom. Most projects are medium to long-term. As stations close, and in the absence of new build, it is expected that this R&D will progressively decline and be replaced by that into radwaste and decommissioning. In addition, utilities as well as the principal service company pursue in-house safety programmes. In Japan, there are some collaborative safety programmes with a research institute, although the level of industry funding appears quite low. These are diverse and include programmes for operating reactors, the next generation of BWR and fuel safety studies. The number of long-term and short-term projects is about the same. As in Japan, the level of industrial funding for safety studies carried out at research institutes is quite low in Germany. Most programmes are short-term and are related solely to existing power plants. In Finland the extent of industry funding has remained fairly constant in recent years although there has been a slight shift in emphasis from nuclear safety towards waste management.

Apart from safety, industry research is economics-driven, either to increase the performance of existing plant or as a speculative investment in new plant. In the United Kingdom, the in-house programmes of the nuclear generators are operational support programmes and address short, medium and long-term issues. Since the completion of the last reactor in the United Kingdom, a PWR, the level of R&D in support of future reactor systems has been much reduced. The principal service company continues to undertake in-house R&D associated with the fuel cycle, decommissioning and waste management, but this is largely focused on the needs of existing plants. Over the last 5-10 years, industry funded research in Belgium has shifted towards short-term and projects increasingly take into account economic aspects. However, the R&D remains safety driven. Gradually, research activity has moved towards future reactors systems, but projects on the safety of operating reactors are equally important. Over the last five years more focus has been put on decommissioning. About half of the R&D projects are conducted with partners, mostly European, and this trend is growing. In Spain, projects range from short-term to long-term. Economic drivers are recognised as being important but a balance is sought with safety issues; the project selection process always considers power plant safety. In respect of power plants, there are projects on future reactor systems as well as operating reactors but the preference is towards the latter. The industry participates in national and international programmes. The focus of industry funded R&D in Italy is very much on the next generation of advanced reactors embodying a high degree of inherent and passive safety. There are also projects on the accelerator driven system for the transmutation of long-lived radioactive waste. Following the decision by the German government to phase out nuclear power, there are now relatively few industrially funded projects at the research institutes. As already mentioned these are mainly short-term and relate to the safety of existing reactors. R&D for future systems is predominantly performed in-house by the industry. In Japan, industrial funding of projects at the research institutes is quite low – most R&D programmes are publicly financed. However, in addition to safety, there are projects on reactor design, material development, enrichment, reprocessing and MOX fuel fabrication. In the United States, private sector R&D is primarily funded by the nuclear utilities and related companies that own and operate nuclear power plants. Most of this R&D investment is managed by the Electric Power Research Industry (EPRI), a collaborative R&D organisation that conducts some R&D in-house and contracts the remainder with other R&D specialists. The budget is currently USD 90 million per year. Other utility R&D investment is managed by Owners Groups of which there are three at USD 5-10 million per year each for applications and regulatory/licensing work.

Industry funding for open R&D

The main reason that industry funds open R&D is common to most countries, namely to ensure the continued availability of experts in key areas at universities and research centres. Without them the independent assessment of high profile, important issues such as the reliability and safety of nuclear power plants is impossible. They are also the means whereby industry can access specialist facilities that are only available in universities and research institutes. Apart from such technical aspects, the role of the experts from industrial companies is becoming increasingly significant in education and training. This may be through the provision of courses for existing staff, in collaboration with industry to provide new courses or as a conduit for recruitment. All of which are becoming increasingly important, given the antipathy shown by students in many countries towards science subjects and the need to replace specialist personnel retiring from the industry.

Funding for open R&D is provided by utilities as well as by reactor manufacturers. Usually, the organisation provides direct funding to the university or research institute through a bilateral contract. Joint funding is more efficient and this approach is well established in the United States: members of EPRI and the Owners Group agree on jointly funded projects, although it is primarily EPRI that funds open R&D. In all countries, the nuclear industry usually funds national universities; instances of international contracts are rare.

The extent of industry funding varies significantly from country to country. In 2000, the United Kingdom nuclear industry had over 250 contracts with universities, worth about GBP ten million per year. BNFL, in particular, has established a number of research alliances with universities. It is estimated that these initiatives alone support a university skill base of some 150 people. In comparison, some countries, for example Italy and Belgium, do not fund any open R&D at universities at all.

In most countries, industry funding for open R&D is intended to complement public funding. For example, Germany, Hungary, Japan, Korea, Spain and the United States report that additional funding by industry can amount to a significant contribution in some cases. Japanese companies fund open research to the extent of about 390 man-years per year, on average, in addition to publicly funded research.

Trend of public funded R&D

From being one of the largest R&D sectors in the 1970s and 1980s, nuclear R&D has experienced a drastic reduction in public funding in many countries since the 1990s. One exception is Korea, where the decision to adopt nuclear energy is comparatively recent and for this reason public funding is still increasing. At the other extreme is the United Kingdom, where government policy has been to withdraw both from the direct operation of nuclear power plants and also from research; the United Kingdom no longer has a national nuclear research institute. In Italy and Germany, the situation is only slightly better: R&D budgets from the public purse are now only a fraction of what they were and even these are gradually being run down. Other countries, such as Hungary for example, report a constant but fairly low level of public funding in recent years. It is exceptional that the public funding of nuclear research at Japanese universities is reported to be slightly increasing.

The main focus of publicly funded R&D in the 1990s was the safety of existing nuclear power plants and waste management issues. Indeed, these are still the main elements of nuclear R&D in some European countries e.g. Germany, Sweden, Hungary and Spain. However, a new trend is emerging: R&D programmes for innovative, future reactors. This is particularly evident in Japan and the United States but some interest in future reactor design is also visible in Italy, Spain and Sweden. Whatever the topic, in most instances public funding is spent on addressing basic or generic issues rather than on plant development.

Public funding is not confined to supporting domestic R&D. European countries receive a significant fraction of their public funding through Euratom international framework programmes. As the European Commission shares only part of the total R&D costs, it encourages its Euratom member countries to contribute some of their domestic public funding to international programmes. As a consequence, public funding for international collaboration is showing an increasing trend in Europe today.

A similar trend has been reported in the United States, where the new Generation IV programme is an excellent example of an integrated, strategically planned and mission focused R&D programme involving extensive international collaboration. The International Nuclear Energy Research Initiative (INERI) should also be mentioned in this context. In Japan, JNC actively collaborates with other countries in the area of advanced nuclear technology and waste disposal.

Public funding and expertise

Every country responding to this survey question cited the need for funding to maintain core skills and competences for manpower in the nuclear industry. Even where public funding of research and development no longer exists, such as the United Kingdom, there is recognition of the need to maintain the infrastructure. While the United Kingdom does this through industry and its regulator, the Health and Safety Executive, working together in other countries it is the government and industry that work together. In Korea, the government collaborates with the private sector to ensure the availability of knowledge and future manpower.

Much of the support is directed toward nuclear regulation and safety. In Hungary, public funding supports the national regulatory body and academic research institutions. In Germany, maintaining expertise and R&D capabilities at universities and research centres, as well as building new test facilities and maintaining existing ones, is paramount. In Spain, public funding supports the conservation of nuclear expertise both in the short and long-term. In Italy, the sole nuclear group of ENEA participates in research activities with national and international partners to develop and improve concepts in the areas of safety and accident management.

The two countries where government actively pursuing new research beyond that needed for regulation and safety are Japan and the United States. Both countries support R&D in areas where, traditionally, industry cannot bear the associated burden of uncertainty. Further, as in other countries, resources are directed at retaining manpower and technical capability so as to support safety regulation. Both countries also stress the need for the support of longer-term research at research laboratories and in the United States there is a great reliance on universities for experimental research. This also provides support for faculties and graduate students and thus stimulates education and training.

Public versus industry funding

Somewhat surprisingly, in only two of the eight responding countries there is no significant public funding of nuclear research and development. However, the United Kingdom and Belgium still manage some public funding: the United Kingdom provides research support to universities through the Research Councils and in Belgium, public funding for R&D is obtained from the Framework Programmes of the European Union.

In the other countries, public funding ranges from about 20-25% in Sweden to over 80% in the United States and Germany and almost 100% in Italy. One discordant note in the United States public funding of energy R&D is that the ratio of public to private funding for the nuclear sector is significantly smaller than that for the non-nuclear sector. In addition, the research programme of the Nuclear Regulatory Commission is entirely funded by the private sector through user fees. Overall, among the eight reporting countries, the message is that three-quarters of them still have public funding for nuclear energy R&D.

R&D funding for long-term development

The common thread of long-term R&D in respect of long-term development is participation in the Generation IV International Forum designed to develop future generations of nuclear energy systems. The partners in the ten Nation Gen IV Forum are: Argentina, Brazil, Canada, Euratom, France, Japan, South Africa, South Korea, Switzerland, the United Kingdom, and the United States. While several countries do not conduct research for long-term development, others who are not Gen IV members participate through various means. German industry and research organisations get access to the GIF program through Euratom. Outside of Gen IV, German research organisations obtain funding for the long-term development of partitioning and transmutation of nuclear waste. Likewise, Belgium through Tractebel Engineering has access to Gen IV information and is involved in R&D related to High Temperature Reactors.

Spain participates in INPRO. The main objective is to collaborate with other interested countries and the IAEA in new developments in nuclear reactors and innovative fuel cycles with the objective of minimizing proliferation and environmental risks. Italy, while interested in future reactor concepts from Gen IV, has a strong focus on fission-fusion conceptual systems in an effort to appease public apprehension about existing nuclear power plants.

In comparison, the Japanese and the United States approaches to long-term nuclear development are fairly aggressive. In Japan, it is felt that the development of innovative nuclear power systems can be accelerated by international cooperation and also that, as the construction of new power plants slows down, it is important that research and development continue steadily through international cooperation so as to maintain technical competences. Long-term nuclear development is Japan's strategy and that of the United States as well. The United States, in addition to Gen IV is pursuing INERI and AFCI. The former is concerned with advanced nuclear energy systems and the latter, which is being pursued internationally, supports fuel development and fuel cycles associated with future concepts. In addition, there is NP 2010 which is designed to assist industry in overcoming barriers to new build in the near-term. United States industry is investing in NP 2010 but not Gen IV.

Appendix 4

Country Reports

Belgium

- Inhabitants (2001): 10.3 million
- surface: 30.825 km^2
- primary energy consumption (2001): 64 million tonnes of oil equivalent
- nuclear energy consumption (2001): 10.7 million tonnes of oil equivalent

End 1999, the installed net electricity capacity was 15 569 MW, 5 713 MW nuclear, 8 327 MW fossil, 1 404 MW hydraulic or pump stations and a small fraction waste valorisation and wind turbines. The net production was 80.85 TWh of which 57.8% nuclear.

Partly due to its industrial past, the nuclear activities started early in Belgium. The first research reactor reached criticality in 1956. Seven PWR's, totalling 5.8 GWe, were sequentially connected to the grid between 1974 and 1985. Although the reactors are operated with a magnificent track record, on 1 March 2002, the government approved the bill to bring the nuclear reactors to a standstill after 40 years of operation i.e. between 2015 and 2025. One year before, an international peer review group endorsed a main recommendation of the so-called AMPERE Commission: "to keep the nuclear option open by maintaining the scientific and technological potential needed to ensure optimal conditions for safety and performance, by preserving the national know-how on nuclear energy and by participating in mostly private-sector R&D on future reactor types". At state level, the legal and regulatory rules were fixed in laws voted in 1955 and 1963. In 2001, the Federal Agency on Nuclear Control became operational and a European directive on qualification for radiation expert was implemented as Belgian law. Uranium and plutonium fuel fabrication started in the late 1950s. In 2001, 36 t MOX fuel was produced. Early 2000, vitrified high level waste returned from Le Hague. It is stored at the Belgoprocess site. Belgoprocess is a daughter company of ONDRAS-NIRAS, the company since 1980 in charge of nuclear waste management in Belgium.

Nuclear education

For a long period, the high demand for nuclear engineers combined with the attractive power of the sector allowed all universities and higher technical institutes to offer their nuclear curricula to a sufficient large number of students. When the nuclear expansion ceased and the societal image of the nuclear sector declined, the number of students progressively decreased. Presently, the fact that nuclear installations operating licences require nuclear higher education diplomas, guarantees a minimal number of students.

Recently, major universities, together with the Belgian Nuclear Research Centre, and with sponsorship from Belgian nuclear industry merged the nuclear programmes into a single programme, highly modular and taught in English. The Belgian Nuclear higher Education Network has five grants (EUR 10 000 each) available to follow the postgraduate programme. Some universities organise five-year master courses with nuclear finality.

Further three Belgian institutes organise four-year master courses in nuclear technology, medical nuclear techniques and radiochemistry.

Contacts with European colleagues resulted in the European Nuclear Engineering Network. ENEN was launched as a European project in the 5th R&D Framework Programme on 1 January 2002, with SCK•CEN as project co-ordinator. The project contributes to the creation of the European education area in the field of nuclear engineering. The approach is based on a commonly agreed accreditation process for mutual recognition of education activities across Europe, i.e. promotion of student mobility, ensuring equivalence of university curricula based on the European Credit Transfer System described in the “Bologna Declaration on the European Space for Higher Education, June 1999”.

To demonstrate the feasibility of the concept, pilot courses are organised. The course on Nuclear Thermal Hydraulics and on Nuclear Reactor Theory, organised within the Belgian Academic Postgraduate Programme on Nuclear Engineering are organised in a highly modular way and taught in English to facilitate and enhance participation of European students. The courses make full use of the laboratory facilities and infrastructure of the Belgian Nuclear Research Centre.

More, the ENEN partners organised themselves in a non-profit-making legal entity pursuing the preservation the preservation and the further development of higher education and expertise. The association is composed of effective and associated members. The effective members are academic institutions providing high level scientific education in the nuclear field. The associated members have a firmly established tradition of relations with members in the field of nuclear education, research and training. New members are elected by the general assembly on recommendation of the Board of Governors. The first general assembly met on 11 November 2003.

Within the 6th European R&D Framework Programme, the NEPTUNO project widens the ENEN approach to professional training in the nuclear field. The expected result is an operational network for training and life-long learning schemes, underpinning: sustainability of Europe's excellence in nuclear technology; harmonised approaches for training and education in nuclear engineering; harmonised approaches to safety and best practices, both operational and regulatory; preservation of competence and expertise for the continued safe use of nuclear energy and other uses of radiation in industry and medicine.

Also within the 5th European R&D Framework Programme, a consortium of main decommissioners developed the European Nuclear Decommissioning Training Facility. EUNDETRAF's goal is to disseminate the European decommissioning knowledge by performing training courses. A course consists of one week theory and one week practice. Thirty persons participated in the theoretical part of first course, 18 to 29 November 2002. Nine participants had a practical training. Preliminary contacts are made to organise similar training courses in Russia.

In 2002, SCK•CEN staff organised for the tenth time the training course: “Off-site Emergency Planning and Response to Nuclear Accident”. The course is supported by the European Commission and is already planned for 2004, 2006 and 2008.

Thanks to its more than 40 years of experience in the field of nuclear science and technology, radiological protection and radiobiology, SCK•CEN a few years ago established the international school for Radiological Protection (isRP), www.sckcen.be/isrp/. The courses are primarily directed at the centre's own personnel. But, they are not limited thereto. The isRP primarily addresses the safety and emergency services within the frame of missions from the ministries of the Interior, Public Health, Social Affairs and the Environment, Labour and Employment. In the private sector, the courses are mainly aimed at personnel of the Belgian nuclear power stations and of external companies providing nuclear services, and at medical personnel working with radioactive radiation and requiring recognition by the government. By contributing to the training of Euratom inspectors, ALARA experts and responsibles for international transport of radioactive material, the isRP is steadily building up a relationship based on mutual trust with organisations such as the European Commission, the IAEA and various international organisations engaged in any field associated with radiological protection.

The *Hogeschool Limburg* and SCK•CEN organises the course underlying the qualification for radiation expert, as defined in the EU-directive 96/29/Euratom. It is a 120 hour course on nuclear physics, radiation physics, radiochemistry, applied dosimetry, radiation biology, principles of radiation protection, applied radiation protection, including European and Belgian regulation and legislation. The course is taught in Dutch. The *Institut supérieur industriel de Bruxelles* together with the *Institut national des radio-éléments* organise the course in French.

SCK•CEN staff lectures in the postgraduate European Radiation Protection Course. The ECRP transmits the knowledge needed for recognition as a qualified expert in radiation protection. The ECRP is hosted by the French *Institut national des sciences et techniques nucléaires*.

In a conscious desire to increase our pool of highly specialised young researchers and to tighten our links with universities, SCK•CEN hires yearly PhD candidates or postdoctoral researchers. In 2002, we selected six researchers to prepare a PhD thesis or perform a post-doctoral research project.

Keen to encourage high quality research, SCK•CEN allocates the biennial professor Roger van Geen award, worth EUR 12 500, to the best Belgian nuclear research work. SCK•CEN also allots yearly prices of respectively EUR 1 500 and EUR 1 000 to the best university and college final year theses carried out in its laboratories.

Given the criticality of knowledge management for the entire nuclear environment and the fact that knowledge is a primary and natural asset, SCK•CEN started in 2002 a new approach. To ensure better retrieval and access of existing data and documents, to elicit tacit knowledge and to enhance internal communication, as a first pilot project, an interactive community through a web-based portal became operational. The library services and concept are also placed in the wider concept of knowledge management.

Finland

Overview

Nuclear energy has played a major role in Finnish electricity production since the beginning of the 1980s. The present share of nuclear electricity is 27% of the total electricity production. The nuclear power plants have had very high load factors, competitive electricity production price, and low levels of radioactive emissions. The average annual load factor has been over 90% since 1983 almost without exception. The operation of the four Finnish reactors has been undisturbed and safe. Commercial profitability has been boosted further by the extensive modernisation, including considerable power uprates (see Table 3) carried out on all units, most recently in late 1990s.

The Finnish Parliament ratified in May 2002 the government's earlier favourable decision-in-principle on the fifth nuclear power plant unit. The decision-in-principle means that the construction is considered to be in line with the overall benefit of the society. The main reason to increase nuclear power capacity is the effort to restrict the greenhouse gas emissions. Good experiences of the existing nuclear power plants, the steady price of nuclear electricity and Finland's small indigenous energy resource were also contributing factors.

Table 3. **Finnish nuclear power plants**

Plant unit	Type	Net capacity (MWe)	Commercial operation
Loviisa 1	VVER-440	440 → 488	1977
Loviisa 2	VVER-440	440 → 488	1981
Olkiluoto 1	BWR	660 → 710 → 840	1979
Olkiluoto 2	BWR	660 → 710 → 840	1982

The power company Teollisuuden Voima Oy (TVO) is now continuing the preparation for the construction of the new nuclear power unit. TVO decided in October 2003 that the new unit will be sited in Olkiluoto and signed in December with the Framatome ANP consortium a contract concerning the construction of a new nuclear power plant unit with a pressurised water reactor of about 1 600 MWe. In January 2004, TVO submitted an application to the government for the construction licence. In favourable conditions the new unit could begin commercial operation by the end of the decade. The technical operating lifetime of the plant unit will be around 60 years. Thus the long-term assuring of nuclear competence in Finland is highly important.

Radioactive waste and spent fuel management

Nuclear waste management and disposal of spent fuel are progressing according to long-term plans under strict regulatory control. The financial arrangements for waste management are clearly defined in the legislation and sufficient funds have already been collected.

The Finnish Parliament ratified on 16 May 2001 with clear majority (votes 157 versus 3) the decision-in-principle of the government on the final disposal facility for spent nuclear fuel in Olkiluoto, Eurajoki. The decision is valid for the spent fuel generated by the existing Finnish nuclear power plants. An additional decision-in-principle ratified by the Parliament in 2002 extended the final disposal facility to accommodate the spent fuel generated by the new NPP unit. The total amount of spent nuclear fuel that can be disposed of in the final disposal facility is 6 500 t of uranium.

The site selection enables Posiva, the joint spent fuel management company of TVO and Fortum Power and Heat Oy, to focus the confirming bedrock investigations at Olkiluoto where during the next few years an underground rock characterisation facility, ONKALO, will be constructed. According to the plans, the construction of ONKALO will start in summer 2004; investigations at the final disposal depth can commence around 2006.

In June 2001, Posiva and the Swedish nuclear waste management company SKB concluded co-operation and information exchange agreements on research and technology for spent nuclear fuel.

Public opinion

Finns have shown an increasing support of nuclear power. A survey made in October 2003 showed that 45% of the Finns were in favour of nuclear power in general while 28% were opposed to it. In contrast, the numbers ten years earlier were 29% for and 43% against. Also the public acceptance of the final repository at Olkiluoto, Eurajoki is high. According to a recent poll, a distinct majority of about 60% of the inhabitants in the municipality of Eurajoki accepts the siting of the disposal facility in Olkiluoto.

During 2002, there were heated debates in the media concerning the construction of the new nuclear power unit in Finland. The interesting process culminated in the parliamentary vote on 24 May 2002 when the application for a decision-in-principle was approved with 107 votes against 92.

R&D

Finnish nuclear energy research has been decentralised into several research units and groups, which operate at different State research institutes, universities, utilities and consulting companies. The focus of nuclear R&D is on the safety and operational performance of the power plants, on the management and disposal of wastes, and on fusion. The funding between these three major areas is: nuclear power plant safety 40%, waste management 50%, and fusion 10%. In nuclear power plant safety nearly 40% of the research is done within public research programmes. In waste management only around 8% of research is in the public research programmes. The annual total volume of Finnish research into nuclear fission and fusion is estimated to be 200 person-years, and the total funding about 27 million euros.

The number of full-time nuclear experts has always been very small in Finland. Therefore, in the beginning of the nuclear era in Finland each expert had to learn a relatively large share of the nuclear field, at least to some extent. If the R&D funding will continue its gradual decrease in the future, it will be more and more difficult to guarantee the adequate expertise in the whole nuclear field.

Publicly funded nuclear energy research provides impartial expertise in nuclear energy issues. It contributes to maintaining the necessary personnel and equipment for research and development and has established the framework for international collaboration. The Finnish public nuclear energy research is organised into national research programmes. The objectives of the national research programmes have been largely aligned with the research fields and priorities of major international programmes, both within the European union, the OECD Nuclear Energy Agency (NEA) and the Nordic countries. In Finland it is seen important that work on future development of nuclear power plants involves both research on long-term goals and on evolutionary types.

The FINNUS national programme (1999-2002) concentrated on the themes of ageing, accidents and risks and was co-ordinated and mainly conducted by the Technical Research Centre of Finland (VTT), with significant contributions from the Lappeenranta University of Technology (LUT). The SAFIR programme (2003-2006) continues its work with somewhat extended research area and participation of different organisations. It develops tools and practices for safety authorities and utilities, and provides a basis for safety-related decisions.

SAFIR is an important forum for education of new nuclear experts and knowledge transfer in Finland. It provides a comprehensive national network for information exchange between researchers and organisations; some 130 persons are presently involved in the research projects of SAFIR (part time or full time). Additionally, 80 persons from the safety authority STUK, the utilities Fortum and TVO, VTT, universities and other organisations are involved in the SAFIR steering group and six reference groups, which supervise and co-ordinate the work.

The publicly financed nuclear waste management programme JYT 2001 (1997-2001) was completed concurrently with the approval of the disposal site selection. However, a decision was made to continue public research on nuclear waste management. This is accomplished by the National Research Programme on Nuclear Waste Management KYT (2002-2005), which mainly concentrates on the management and disposal of spent nuclear fuel. The objective of the programme is to support the maintenance and development of national scientific know-how essential to nuclear waste management. Besides the chosen main spent fuel management policy based on direct disposal of spent fuel in Finnish bedrock the programme covers also research on alternative solutions on spent fuel management.

The financing of the both national programmes (SAFIR and KYT) has been changed by new legislation from the beginning of 2004 so that the nuclear utilities have the biggest share in financing.

Fusion energy research in Finland is carried out in the fusion technology programme FFUSION 2 (1999-2002) and its continuation programme Fusion (2003-2006) of National Technology Agency of Finland (TEKES). These activities are fully integrated into the Euratom fusion programme.

The most important research institutes and universities taking part in nuclear research are the Technical Research Centre of Finland (VTT), the Geological Survey of Finland, the University of Helsinki, the Lappeenranta University of Technology (LUT), the Helsinki University of Technology (HUT), the Finnish Meteorological Institute and the Radiation and Nuclear Safety Authority (STUK). As the national authority of radiation issues, STUK has the laboratories for radiation physics and radiochemistry necessary for monitoring environmental radioactivity.

VTT is a multidisciplinary national research centre, which has several activities in nuclear engineering in its operating units available through the knowledge portal VTT Nuclear. VTT Processes has an excellent expertise in reactor physics and thermal-hydraulics calculations, as well as safety analysis of nuclear waste management. It also operates the Triga training and research reactor whose main research area presently is boron-neutron-capture-therapy of brain tumours. VTT Industrial Systems has hot cells for non-transuranium materials and its research field covers ageing, structural integrity and lifetime management as well as plant automation for the modernisation and planning of I&C systems.

University education in the nuclear energy field

There are three academic units in Finland that provide basic training in nuclear sciences: Lappeenranta University of Technology (LUT), Helsinki University of Technology (HUT), and the Laboratory of Radiochemistry at Helsinki University. (University units having study programmes e.g. in nuclear physics or in high-energy physics are not included here.) Master of Science degrees and postgraduate degree programmes for a licentiate or doctor degree are available in all these three universities.

The total number of MSc-degrees awarded annually in nuclear engineering has been about 10-20, which has been sufficient. The need for new graduates is, however, prominently increasing due to the new nuclear power plant project as well as retiring of the first generation of experts. Very promising is that during 2003 the amount of students taking nuclear engineering courses has doubled in the universities, the Finnish renaissance of the nuclear power construction seems clearly to have a positive effect.

Lappeenranta University of Technology (LUT), Department of Energy and Environmental Technology, Laboratory of Nuclear Engineering

LUT has recently (2001) separated Nuclear Power Engineering as a major subject from the Power Plant Technology in order to give more visibility to the nuclear field among students who select their priorities. The basic course in nuclear power engineering is compulsory for all students of energy technology. Supplementary teaching is given to all students of power plant technology. Several extra courses are available for students specialising in nuclear power engineering.

The main area of research is nuclear power plant safety, with a special focus on heat transfer and fluid dynamics modelling. The Nuclear Safety Research Unit provides experimental research and safety analyses by utilising its facilities e.g. the thermal hydraulic loop facility PACTEL, which simulates the primary circuit of the VVER-440 units on a scale of 1:305 with a maximum heating power of one MW. Passive safety systems and severe accident management studies have been carried out concerning advanced light water reactor types. The LUT Physics Laboratory has a radiation measurement laboratory. The reactor physics course visits the Triga training and research reactor in VTT.

Helsinki University of Technology (HUT), Department of Engineering Physics and Mathematics, Laboratory of Advanced Energy Systems

The nuclear engineering programme at HUT is included in the Engineering Physics study programme. The Laboratory of Advanced Energy Systems gives education both in nuclear energy (fission and fusion) and in renewable energy sources like wind and solar power, for instance. The main research topics are fusion technology and radiation physics. The synergy between fission and fusion technology have been fully exploited to train students for instance for nuclear safety analysis. The unit has a radiation measurement laboratory, and it can also utilise to the Triga training and research reactor, hot cells and radiochemical laboratory of VTT, located on the same campus area.

University of Helsinki, Department of Chemistry, Laboratory of Radiochemistry

Radiochemistry is one of the seven branches of chemistry represented at the University of Helsinki. Students attend about three years of basic courses in inorganic, organic and physical chemistry, concluding with specialised studies in radiochemistry for a minimum of two years. The Laboratory of Radiochemistry also offers courses to students from the other branches of chemistry, as well as further education for teachers. The main areas of research include the management and final disposal of radioactive wastes, environmental radiochemistry, cleaning of effluents with ion exchangers, and radiation chemistry. An important recent addition to the research and teaching facilities is a new cyclotron.

Educational co-operation

A Finnish speciality in the education of technical universities is that the Diploma work is often done in the industry, power plants, research centres or safety authority. This provides an excellent link between theory and practise; similar effect is achieved by compulsory training periods during summer time. By offering challenging and interesting positions for training and theses, nuclear organisations can have an important influence on the recruitment of new students. In addition, the quality of education can be largely improved by exploiting visiting external lectures and by performing research work in laboratories with up-to-date research equipment. Unfortunately, the required financing for this has been declining recently. Therefore, a good co-operation between the universities, authorities, utilities and research organisations is essential for the education of the new generation of experts.

The postgraduate degrees have traditionally been obtained as a part of normal work by simultaneously participating in the courses of the universities, while the subject of the thesis has usually been closely related to the daily research projects. Especially the personnel of VTT are strongly encouraged to do post-graduate studies. The part-time graduate studies lead to a rather long graduation times. A rather large number of nuclear engineers continue their post-graduate studies.

In the fall of 2002, Finnish organisations re-evaluated the man-power situation and established a working group to develop and organise basic post-graduate professional training of new recruits and staff members, especially for the acute needs of the new NPP project, but also to provide in the long-term a new generation of nuclear experts to replace the present generation which will retire within the next ten years.

The group decided to promptly organise a national training course on nuclear safety based on a similar course developed by IAEA. The Finnish application was developed so that different standpoints of all organisations were visible. Half of the 120 lecturers come from the nuclear utilities, a quarter from our safety authority STUK, rest from VTT and universities. The 51 participants of the course come from the same organisations. The course material is available also in the Internet pages of LUT to look for in advance and also for the use of nuclear post-graduate students. The location of the six-week course from September 2003 to February 2004 rotates between different organisations.

The course will be repeated in Finland during the next year and it has been proposed that our experiences of the course could be dispensed within the EC project NEPTUNO. This first Finnish course did not have any international participants or lecturers due to the large domestic need. However, the model of the course was international and there are no obstacles to arrange similar courses in future on a more international basis.

HUT and LUT joined during 2003 the ”European Nuclear Engineering Network Association” ENEN which has the goal to develop harmonised nuclear training and co-operation between the universities in Europe, and were also among the founding members of the “World Nuclear University” WNU aimed for global collaboration in mobility and education.

Training

The two Finnish nuclear power companies have recognised the personnel competence as an essential topic in the management and development of the company. Both have well-established training programmes for their personnel at a non-university level (i.e., for engineers, technicians, operators, etc.). Each plant has a training centre equipped with a full-scope simulator. Furthermore, the plants have ordinary laboratories for chemistry and radiation measurements. The university-level utility personnel occasionally participate in international courses, seminars, and conferences, as well as in workshops and technical committees organised by, for example, IAEA, OECD/NEA, and WANO. All units have been modernised during the nineties, and these modernisation programmes have had an important training aspect for the plant personnel.

In the re-organisation of the Loviisa NPP at the beginning of 2002, the transfer of knowledge and experience from the “original” staff members to the new generation have been taken as a key issue. The establishment of the Fortum Nuclear Services as a separate company inside the corporation and the partnership with the Loviisa NPP with the responsibility of preserving the needed knowledge on the specific areas ensures the necessary R&D in critical areas such as reactor physics, thermal hydraulics, material technology, nuclear fuel and waste. The R&D programmes are seen as an important element to recruit young scientists for the projects and later as permanent young experts.

The power company TVO has performed knowledge survey and updated its competence requirements for the future development of the organisation for the fifth NPP unit in Finland. TVO also currently plans knowledge transfer arrangements for replacing the retiring staff members. In the coming years TVO will recruit operating and maintenance personnel for Olkiluoto 3 NPP. An education programme will be established for this staff including training with a plant specific full scope simulator.

The regulatory body, STUK is developing its staff members through internal training programme and learning by work. New staff members have recently been recruited directly from the technical universities (HUT and LUT) to be inspectors after appropriate training arrangements. For the needs of new NPP project, also more experienced staff members are recruited and the necessary training is provided. STUK has also sent young staff members to other regulatory organisations (USNRC) for international training.

France

Overview

Status of nuclear energy in France

About 80% of the electricity produced in France is of nuclear origin, and the French policy in this domain is characterised by continuity. As shown during a recent public debate on energy, the French public opinion about nuclear energy is relatively neutral, and a large majority of policy makers agrees to keep the nuclear option open.

The main national electrical company (*Électricité de France*, EDF) is state-owned at present, but prepares itself to open its capital to private investors. This major change is not expected to affect much the nuclear policy of EDF.

Another major actor in the French nuclear landscape is the AREVA group, which gathers most French companies involved in nuclear industry. Still state-owned, AREVA has taken advantage of the mergers going on in this sector to become a major actor of nuclear industry in the world.

The industrial tool operated by the AREVA group (fuel cycle facilities by COGEMA, nuclear reactors by FRAMATOME ANP) is dimensioned beyond the national needs, and is largely export-oriented. Thanks to its reactor fleet (58 nuclear reactors), EDF is also able to export some electricity outside France.

R&D

CEA is the main actor of nuclear R&D in France, but other institutes like the French scientific research agency (CNRS) and University also have significant contributions.

According to the state of the industrial tool, which requests less development than before, the budget of nuclear R&D in France has been slightly diminishing over the last five years.

R&D related to the development of future nuclear systems is growing in the frame of the Generation IV International Forum. An important research program has also been devoted to waste management issues in the frame of the 1991 law.

Human resources

The national nuclear tool (EDF reactor fleet, AREVA factories) has requested a considerable development effort during the last decades, but is now essentially mature. A large number of qualified and trained people is needed to operate this well developed industrial tool.

Careers

All major nuclear actors in France (CEA, AREVA, EDF) propose careers in nuclear activities, characterised by a moderately attractive salary, and an excellent stability of the permanent positions.

Relatively easy personnel transfer is possible between the three main employers in the nuclear domain. Historical bonds also exist between these three, the national Nuclear Waste Management Agency (ANDRA) and the safety authority and its expert body, the Institute of Nuclear Radioprotection and Safety (IRSN). The net result is the possibility of varied careers, with a good sight on the whole nuclear system. A cycle of superior formation and training in nuclear (CFS) is open to the future top managers of all these organisms. These opportunities of thematic mobility efficiently contribute to the competence maintenance and building in the country.

Expertise

All three major French actors in the nuclear area (CEA, AREVA, EDF) have identified a population of key experts, and use these people in networks that can be solicited at will to provide scientific or technical advice in their competence domain.

The risk of loss of competence in the nuclear domain is probably less in France than in other European countries, because nuclear energy still generates an especially large volume of activity in the country. However, the length of the time constants in the nuclear area is the same everywhere, and expertise tends to disappear in some well identified technical domains, once investigated in the past and liable to reappear in the future (for example isotopic separation). In other domains like dismantling, expertise has never really emerged, in spite of their economical importance. Possible solutions lie in the international collaboration or industrial alliances at the international level.

Education and training

The educational effort of France in the nuclear domain has been globally maintained throughout the last ten years. Contrary to a general belief, the net inflow of students in Science has not decreased in France during this period. The population of students attracted by the nuclear domain is also stable, and, in addition to the traditional elite recruitment from the so-called “engineering schools”, there is a growing population of students coming from the University.

The Institute for Nuclear Sciences and Techniques (INSTN) is the French institute devoted to post-graduate education and professional training in nuclear science and technology within CEA, the French Atomic Energy Commission.

The INSTN provides unique facilities for active pedagogy and organises high level national and international academic courses, vocational training, workshops and conferences, for students, engineers, technicians and scientists in all the scientific fields related to the nuclear energy applications. It is reputed to be the CEA’s vector of knowledge to spread towards the nuclear industrial partners, the University and the medical sector.

The Institute has an in-house academic and administrative staff of around 110 people, plus the backing of some 1 000 collaborators.

The different curricula managed by INSTN are designed to put students in direct contact with specialists of each discipline immediately involved in their daily activity. The INSTN relies on the CEA's vast research potential, and particularly on Saclay, Grenoble and Cadarache centres. Intensive interaction with specialists from different professional and scientific backgrounds is essential to the INSTN's learning approach. Professors and lecturers come from the University, CNRS, CEA centres, EDF and from French nuclear companies (AREVA Group...).

Recently, a special status of teacher-researcher has been created in CEA, stimulating the enhance of the teaching activities of its agents while conferring an official recognition.

Nuclear engineering education in France falls within a specific *Génie atomique* post-graduate programme. In fact, contrary to the American system for example, no such complete academic cycle exists at the post-graduate level within French universities. Of course, there are various university programmes in nuclear physics, materials, radiochemistry and other fields, but all these theoretical and practical areas that combine to make up what can really be called "nuclear engineering" are covered only by the *Génie atomique* programme within the INSTN. Since 1956, when the programme was initiated, about 4 400 students have graduated in nuclear engineering.

INSTN also has tight bonds with the French University network: jointly with French universities and engineering schools, the INSTN participates in post-graduate programmes – "DEA" (*Diplôme d'études approfondies*, i.e. advanced studies degree) or "DESS" (*Diplôme d'études supérieures spécialisées*, i.e. specialised studies degree. They are open to students at *Maîtrise* level (close to Bachelor's degree) and last one academic year. Once they have graduated, most of the "DEA" students register for a PhD programme in advanced research fields in the CEA, the University or the CNRS.

LMD reform

A reform of the French university system is presently going on. Its main purpose is to bring it in accordance with the system in usage in the rest of Europe : License (3 years), Master (+2 years), Doctorate (+3 years). This reorganisation will be the occasion to create a small number of well targeted Master teachings with a significant nuclear content. The main ones will cover the fields of chemistry for nuclear industry; nuclear materials; simulation and modelling; and fission and fusion reactor physics.

International teaching

Another challenge is to open the French teaching system to the international network, either by enabling French students to make part of their studies abroad, or by attracting foreign students in France. The CEA participates to the European programme ENEN with this aim in mind. Participation of CEA to European Networks of Excellence (for example ACTINET, …) could also help to reach this goal.

Every year, about one hundred foreign students register for the different courses offered by the INSTN. They are admitted under the same conditions as French students, if they have received sufficient basic training (assessed by the equivalence of diplomas or by a prior examination) and if they are fluent enough in French.

CEA also organises summer schools in the topical domain of nuclear energy. For example, the "Frédéric Joliot & Otto Hahn Summer School" was created by CEA in 1995 to promote knowledge in the field of Reactor Physics, in a broad sense, and the international exchange of teachers, young scientists and researchers. The School is presently organised by the *Forschungszentrum Karlsruhe* and the Nuclear Energy Direction of CEA (CEA/DEN).

In parallel, the INSTN also organises, in French or in English, specific vocational training (lasting a few days to a few weeks) for high-level experts from developing countries, jointly with the International Atomic Energy Agency (IAEA). AIEA courses currently deal with the following topics: nuclear safety, radiation protection, radiation protection in diagnostic and interventional radiology...

The INSTN also provides assistance to foreign Atomic Energy Commissions and research institutions to advise them on how to put together their own training system in nuclear technologies. Finally, the INSTN can help specific foreign countries to set up training plans, adapted to the rate of completion of their nuclear equipment programme, taking into account their educational system.

CEA also has a policy of bilateral exchange of students (PhDs and post-docs) with some chosen foreign research institutes.

The continuity of the French effort in education and training in the nuclear domain could pay in the mid-term. Thanks to its completeness and the variety of its options, the French educational offer might become attractive for foreign students if the nuclear activity restarts in Europe. However, an adaptation effort remains necessary, as most of the teaching is done in French. Moreover, the visibility of French teaching is impaired by the small size and division of the French teaching structures. The recent creation of Federations of teaching institutes like the *Fédération Gay-Lussac* for Chemical Engineering, or the participation of French teaching institutions (Universities and Engineer schools) to networks like the Uni-Tech network should improve this situation.

Education and training by research

The CEA as a whole has a mission of education and training by research. The main vector of this mission is the thesis. The CEA welcomes about 300 new PhD students per year in its laboratories, including 45 in the specific domain of nuclear energy. Among these 45, CEA allocates a total of 30 PhD grants per year for these carefully selected students, the rest of the grants being financed or co-financed by the industry or the regions. Other institutes like CNRS, ANDRA and IRSN also welcome smaller, but significant numbers of PhD students in the nuclear domain.

A vital challenge for nuclear research is to attract high level scientists. One observes a very worrying current of emigration of young French scientists outside their country, due to the poor research conditions offered at home. However, this general tendency is not observed in the nuclear domain. The increasing involvement of France in ambitious international research programs (Gen IV, ITER, …) may contribute to maintain the attractiveness of France as a nuclear research pole.

Role of the scientific societies

Two powerful and active scientific societies play a positive role in education and training: the French Nuclear Society (SFEN) and the French Radioprotection Society (SFRP). Both propose good level courses, organise seminars and conferences, and stimulate the construction of networks. A special characteristic of these societies is the very active role played by retired professionals, who contribute efficiently to ensure the transmission of knowledge through the generations.

Training sessions (continuous professional training)

These sessions are short-term training programmes (lasting a few days to a few weeks, mainly in French language) designed for professional engineers, researchers or qualified technicians. These courses play a dual role, namely: up-dating of knowledge for those who already have a strong background in the applied field, and initiation into a discipline for those who have specialised in other fields.

In 2002, the INSTN thus hosted about 7 200 specialists in various fields: nuclear power plants, materials, nuclear fuel cycle, environment, health physics, conventional and nuclear safety, radioisotopes use in biology, molecular biology, chemistry, radiochemistry, chemical analysis, radioactivity, nuclear measurements, project management, and other topics, like a *Formation Nucléaire de Base* (FNB, 11 weeks of basic training in nuclear, intended to provide young specialists with a general view on nuclear energy). New specialized training sessions (FNS) are also foreseen.

Other aspects of competence building

Knowledge management

As anywhere else, French experts generally retire without an integral transfer of their knowledge to their successors. This problem has been identified as especially crucial for the nuclear domain, which combines highly specialized knowledge and long-time constants. No general policy has been adopted at the national level to address this problem, but capitalisation of expert knowledge is underway in AREVA, CEA, in domains where key experts are about to retire without a likely near-term replacement.

Scientific and technical information system; databases

A re-organisation of the scientific and technical information system in CEA is underway. Its main idea is the simplification of the system, by unification of the databases and adoption of a unique tool of electronic data management for the exploitation of these databases.

France also participates to the implementation of scientific international databases, under the auspices of European programs, or of OECD.

CEA still supports financially the international nuclear databases INIS and ETDE, but CEA decided in 2004 to support only the first one for the future.

On a more general level, the adoption of the quality norm ISO 9000 by most actors in nuclear will provide an incentive for coping with knowledge management and competence building in a rationalized manner.

Germany

Initiated by the worldwide concerns about nuclear education and training, the German government decided in 1999 to review the reactor safety and repository research in Germany. An Evaluation Commission was founded, with the aim to establish priorities, to plan the mid-term staffing and co-operation between institutions, and to consider the mid-term financial planning, such that the scientific skills pertaining to nuclear reactor safety and waste disposal shall be maintained. The report of the Evaluation Commission shows the decrease of government funding of nuclear research in the previous 15 years, it addresses the ageing of the present scientific and technical personnel in the field of nuclear technology, the loss of interest of the new generation of scientists and engineers to commit themselves in this field, and the danger of irrecoverable loss in scientific skills. Therefore, the Evaluation Commission adopted several recommendations, including:

- A co-operation in these areas, in terms of both personnel and contents, should be pursued vigorously in Germany aiming at improved efficiency.
- High priority tasks were specified for nuclear safety research and repository research.

- Besides the research conducted at research centres, importance is also attached to the research at other facilities in Germany. In this respect, research activities on nuclear reactor safety and waste disposal at the universities should be funded in a sustainable manner, not the least from the viewpoint of maintaining scientific competence.
- It should be ensured that Germany continues to be involved efficiently in important international activities and projects in connection with the maintenance and continuation of nuclear reactor safety and repository research. This applies to the co-operation with partners both in the Western world as well as the Central and Eastern European countries.
- Project funding and institutional funding by the government should not be further reduced in order to prevent a further drain in manpower as well as a decline in competence in this area. The financial means for nuclear reactor safety and repository research must be sufficient for the Federal government to fulfil its legal obligations.

The Evaluation Commission published its findings in [2], which contains a comprehensive survey on research facilities as well as the identification of high priority tasks.

Government initiatives

Driven by the results of the Evaluation Commission, an Alliance of Competence in Nuclear Technology (*Kompetenzverbund Kerntechnik*) has been established in March 2000 within the frame of the energy research programme of the HGF (*Hermann von Helmholtz Gemeinschaft Deutscher Forschungszentren*). This alliance includes the research centres in Jülich (FZJ), Karlsruhe (FZK) and Rossendorf (FZR), the *Gesellschaft für Anlagen- und Reaktorsicherheit* (GRS), and their neighbouring universities in Aachen, Jülich, Karlsruhe, Stuttgart, Dresden, Zittau and Munich. The aim of this alliance is expressed by the final remark of the Evaluation Commission:

"Regardless of the political decision on the phase-out of nuclear energy in Germany, maintaining Germany's competence in the field of nuclear safety is a necessary requirement for the next decades. This is an inalienable prerequisite for the government to fulfil its legal obligations with respect to protective measures and measures ensuring the safety of nuclear facilities and disposal paths in accordance with the international state-of-the-art in science and technology."

As a first action, this alliance analysed the personnel structure and future needs of nuclear technology experts at utilities, manufacturing and service industries, regulatory and licensing authorities, as well as the education capabilities at universities, including the numbers of students taking nuclear subjects. Results have been published by Fritz *et al.* (2001) in [3]. The report concludes that the education and training capabilities have still been balanced against the industry needs until 2000. However, if the current trend will be continued for another 10 to 20 years, a severe lack of nuclear competence must be expected.

University initiatives

Universities which are members of the Alliance of Competence in Nuclear Technology are directly linked to a research centre in their neighbourhood. Leading scientists from these research centres give lectures at the universities in nuclear and non-nuclear subjects to address a large number of students. Students, on the other hand, get the chance to perform internships, diploma theses or doctoral theses at fascinating laboratories and test facilities close to their home. In addition, some universities offer an impressive programme for education in nuclear technologies.

Data in the year 2000, taken from [3], show that 29 universities (including *Fachhochschulen*) were offering nuclear lectures. This number is decreasing, however, by about two each year. In 1999, about 300 to 470 students were listening to nuclear lectures. In the same year, 66 diploma theses were performed in a nuclear subject and 59 PhD theses were counted there. The special degree of a "Nuclear Engineer", however, seems not to be desired any more today. Data from 2002 were not available, but seem to be significantly less.

Industry initiatives

A first initiative to address the problem of aging personnel structures in almost all companies working in nuclear technology has been taken by the young generation of KTG (*Kerntechnische Gesellschaft*) in a workshop "Nuclear Technology has Future" in Erlangen in 2002. They invited members of the nuclear industry, as well as students to inform in an open discussion about the need of nuclear scientists and engineers in the next years

In September 2002, *Deutsches Atomforum e.V.* performed a four days-colloquium about "Perspectives in Nuclear Technology" in Karlsruhe, to motivate young students to select a subject in the nuclear area and to inform about career chances in nuclear technology. Presentations were given by the German Ministry of Economics and Labour (BMWA), by utilities and manufactures, universities and research centres. The colloquium included a visit to the NPP Phillipsburg and social events to enhance open discussions between students and industry. In parallel, some companies offered jobs and internships right at the colloquium. The resonance to this initiative was so excellent that *Deutsches Atomforum* e.*V.* decided to repeat the colloquium in 2003 again. Wasgindt [4] reports about more details.

VGB PowerTech e.V. announced a summer school "Introduction to Nuclear Power Technology", free of charge, to be performed in 2003, with the intent to fascinate students about nuclear technologies and to motivate them to start a nuclear career.

The nuclear education centre of TÜV NORD GRUPPE was established in 2002 to improve their in-house education and training capabilities. Facing the problem that more than 150 experts need to be replaced in the next years for compliance services to assure the safe operation of NPPs in the next 20 years, more than 30 teachers from TÜV NORD GRUPPE, GRS and nuclear authorities started to educate 40 students in more than 150 lectures about technology, radiation protection, law and other topics of operating NPP. Helmers *et al*. [5] report about more details.

Recruiting of young post graduates for Framatome ANP GmbH is managed in a co-ordinated action of the human resources department and the operational units: analysing and making use of contacts existing with universities and *Fachhochschulen* ensures a search adjusted to needs. These activities are supported by active participation in university job fairs and exhibitions. In addition these contacts are strengthened by funding PhD-theses coming from nearly all technical fields within the company.

Initiatives of research institutes

The research centres in Karlsruhe FZK and Jülich FZJ have recently started some innovative research projects which improved the attractiveness of nuclear research. Among these are:

- A partitioning project, including experiments in hot cells, for nuclear waste management.
- The development of a prototype vitrification plant for high level liquid waste, which is currently being commissioned.
- Analytical and experimental studies on actinide chemistry for nuclear waste management.

- A strategy fund project on PbBi technology for accelerator driven systems, including the operation of an international user laboratory.
- A strategy fund project on hydrogen phenomena and mitigation measures for nuclear reactor safety, and others.

Typically, we find a high share of young scientists in these projects. The projects are incorporated in international programmes of the European Commission.

Research centre Rossendorf (FZR) reports about challenging research projects e.g. on boron dilution transients, development of two phase flow codes for nuclear safety applications, safety aspects of molten salt reactors, or application of the master curve concept to irradiated RPV material. The radiochemical institute of FZR started a project on chemistry of actinides concerning a potential deep nuclear waste disposal.

Besides theses new and attractive research projects, FZR and other research centres aimed at an intensification of the exchange of scientists with CEE countries, participation in the STC programme between Russia and Germany in nuclear technology, intensification of collaboration within the EU, and offering permanent employments to talented young researchers in spite of general reduction of permanent positions.

The research centres are aware of their considerable responsibility for education and advanced training of young scientists and engineers. This responsibility results in a considerable amount of PhD-theses and postdoctoral lecture qualifications, in close co-operation with universities as described above.

Current R&D resources

A careful and detailed analysis of all nuclear R&D resources in public organisations in Germany has been given in [2]. Data averaged over the years 96 to 98 showed:

59.5 person-years for innovative plant design;
80.1 person-years for material development;
266.6 person-years for nuclear waste management, including decommissioning;
245.8 person-years for nuclear safety research for operating reactors.

Since then, resources in innovative plant design were reduced to zero, due to the decision by the German government to phase out of nuclear power. Resources in nuclear safety research and in material development were reduced by about 20% in research centres, whereas the resources in nuclear waste management seem to be rather constant.

A good overview of R&D resources of the nuclear industry is given in [3]: in the year 2000, the German utilities employed 400 persons with a nuclear academic career (which does not mean that they are all working for R&D projects). Manufacturers and nuclear service companies reported about 1 400 persons with a nuclear academic career, of which about 230 persons were reported to this questionnaire to work for R&D.

There is still a number of R&D facilities available in Germany, especially for material research, waste management and (out-of-pile) nuclear safety research. Research reactors and a prototype reprocessing plant, however, have been closed so that no more research and training in prototype nuclear facilities can be offered today by research centres. As a positive consequence, research centres and industry have gathered significant experience in decommissioning of nuclear facilities within recent years.

The fraction of multilateral collaborations at research centres is already quite high: at FZK and FZJ we find that about 2/3 of all third party funded research projects are multilateral collaborations. Most of them are funded by the European Commission. This fact is considered to be a consequence also of the recommendations of the Evaluation Commission [2] in 2000, which said that "it should be ensured that Germany continues to be involved efficiently in important international activities".

Trend of industry funded R&D

R&D for the future European Pressurized Water Reactor (EPR) was funded by Siemens AG until 1998. The contract with research institutes was cancelled then due to government decision. Since then, only minor activities are funded at research institutes by the industry, which are mainly short-term and related to safety of existing power plants, such as:

- support on actual problems of operating reactors;
- safety driven projects of operating reactors;
- special radiochemical analysis;
- calculations of radio-nuclide transport.

R&D for near-term future reactor systems is dominantly performed by the industry themselves.

Data in [2] indicate for 1999 a participation of the industry in the funding of research projects in the field of nuclear reactor safety, repository, and future reactor development of EUR 10.8 million.

In 2002, more than 100 persons at research centres and institutes were funded by third parties. This number includes also funding by the European Commission and other public organisations. About 1/3 of these persons are estimated to be funded by the (world wide) industry.

Trend of public funded R&D

Project funded nuclear safety and repository research of the BMWA exclusively aims at solving generic questions concerning the safety of operating reactors as well as of final repositories and other waste management strategies. The general and continuing objective of reactor safety research is to contribute to the improvement of safety technology and to continue providing improved knowledge of, and procedures for the realistic safety assessment of nuclear facilities.

The public funding of nuclear reactor safety and repository research has been decreased continuously in the past. Even world-wide leading experimental facilities under project funding had to be decommissioned and dismantled. At the same time the share of international co-operation gained even more relevance. Today, most projects are part of international programmes, such like the framework programmes of the EC. Germany is member state of the IAEA and of the OECD/NEA. German experts appointed by the Federal government are active members in their committees, commissions and working groups, and Germany participates in all OECD/NEA projects for reasons of own technical interest, financial efficiency and interest in international co-operation.

Public funding is the main source for maintaining the expertise and R&D capabilities at universities and research centres. The share of public funding of the total funding is usually about 90% or more at universities and about 70 to 85% at research centres. The research centres obtain a significant portion of their budget for investments in infrastructure to build new test facilities or maintain existing facilities. Typically, less than 50% of the institutionally funding is spent for personnel R&D costs. The situation is different at universities where usually no public funding is available for investment in infrastructure and all funding is spent for personnel.

In the industry, on the other hand, the share of public funding for R&D activities is extremely low.

As a consequence to the decision by the German government to phase-out of the nuclear option, the government does not provide public funding for long-term development programmes like Generation IV or INPRO.

Lessons learned on international collaboration

There are several positive elements of international collaboration in nuclear safety research: scientific progress will be brought forward by comparison and competition; the exchange between experts widens the knowledge base and may lead to a consensus on definition of issues, work programmes and interpretation of results; projects and experimental facilities can be realised, which would be too expensive for one single nation. On the other hand, duplicated work may be avoided.

International projects are usually well accepted today by industry and research centres in Germany, even though the bureaucratic requirement connected with EC funding are sometimes considered to be high, and the travel expenses usually exceed those of national projects.

Conclusions

The problem of ageing personnel structures in nuclear industry and research is well recognised in Germany. Several actions to communicate this problem were started, and first initiatives to attract young students have been taken to solve this problem. The resonance by the students of German universities, however, is still low, which might be caused by the negative reputation by public media in Germany, but already improving today.

The option to share nuclear facilities, to exchange know how, and to support each other with specific technologies by international collaborations will certainly enforce the national strength in nuclear education and research. Moreover, international collaboration turned out to be even an incentive to young researcher to work in the nuclear field, which is already visible by the fact that the number of young foreign nationals in nuclear technology is increasing significantly. Even without giving further incentives, most of the R&D projects performed today at German research centres are already embedded in international programmes. Also, the collaboration in the Generation IV and the INPRO programmes have highly been recommended by research councils in Germany, even though these programmes are not yet supported by public funding.

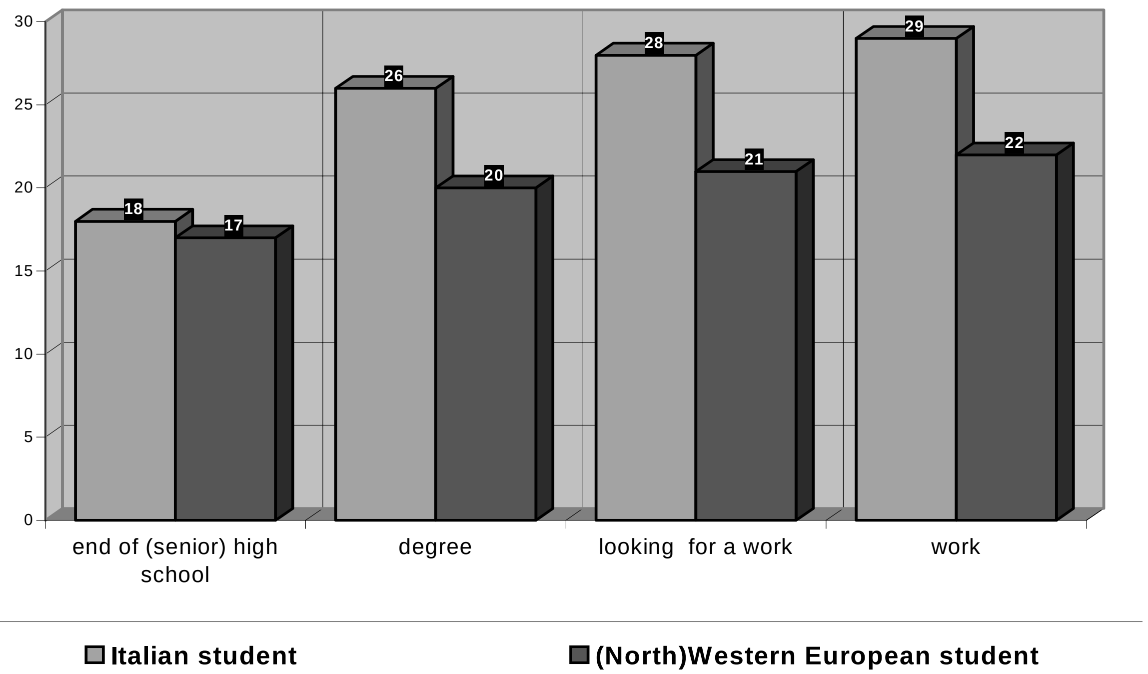
Italy

Background information on education

As already written in the report: *Nuclear Education and Training: Cause for Concern?* [1], edited by the NEA in 2000, in Italy, there are 45 state universities, three polytechnics, six private universities, three state institutes, six private institutes, two universities for foreign students and three schools for advanced studies. Till last year, the situation remained the same as that described in the above mentioned report. In synthesis, Universities and equivalent organisations, awarded three different degrees to students after successful completion of their course work. The first level degree for undergraduates was the bachelor's (*diploma*) which was awarded after successful completion of a course lasting 2-3 years. The second level degree, a graduate master's (*laurea*) was awarded to students after successful completion of a course lasting 4-6 years and followed by the preparation and discussion of a final thesis. Finally, the third level degree, a graduate doctor's (*dottorato* or *specializzazione*) was awarded to students with a second level degree after successful completion of a course lasting not less than three years which includes scientific research and discussion of a final thesis. Having a look to the following picture and keeping in mind what written above, one can see the strong difference, in years of qualification, existing between an Italian student and an equivalent European student. Failing a three-years degree, in Italy all students had to obtain a 4-6-years degree. In addition, as indicated in the graphic below, there was also the aggravating circumstance of one more year “lost” during the senior high school period.

Starting from the academic year 2002-2003, in all Italian universities a new educational reform was applied. In general, the new university is now structured with a more friendly system for the student. It can help students to manage better their time dedicated to study, allowing them to enter the labour market at 22-23, instead of 28 years old.

Thanks to the new architecture of university courses, two consecutive cycles are provided today: “normal-degree” and “specialists-degree”. Optionally, at the successful conclusion of the specialists degree, one can further increase his own education level by achieving a master degree (of first or second level).



The normal-degree is obtained achieving 180 CFUs (*Crediti Formativi Universitari*, that is University Formative Credits) and passing an examination on a European foreign language. In this manner, the normal-degree can be obtained at 22 years old, so the young can enter the labour market at the same time of his European colleague. If the young wants to continue his educational carrier, he can apply himself to a specialists-degree or to a first-level master.

The specialists-degree can be obtained achieving a total of 300 CFUs (180 from the normal-degree plus other 120). This is true in most situations but not in general. If a young with a normal-degree on Mathematics now wants to obtain a specialists-degree on Physics, only a part of his 180 CFUs could be considered valid.

The first-level master can be obtained one year after the normal-degree and represents a sort of specialisation in a more restricted field than those of specialists-degrees. One can enrol for a first-level master soon after the normal-degree, but the credits gained during the normal-degree remain valid forever, thus one can enrol for a first-level master also after a break of some years.

To slightly complicate the situation there is the so-called "One-Cycle Specialists Degree". Really, this is not a complication, because it refers only to the achievement of degrees on Pharmacy, Dentistry and Veterinary (lasting five years) and Medicine (lasting six years). For these degrees no titles are foreseen after three years but only at the finishing of a five-years cycle. For Medicine, remain the different specialisation (Paediatrics, Cardiology and so on) post-laureate.

Soon after the specialists-degree, who wants can enrol for a second-level master, which allow to improve the knowledge achieved during the previous studies. For those who want to enter the world of scientific research, a doctorate can be followed soon after the specialists-degree.

It is now worth adding some words to clarify the CFU concept. It has been calculated that a student can devote 1 500 hours of his own time in a year to study, follow the lessons, go to the laboratory and make a stage. 1 500 hours correspond to 60 CFUs therefore a unit of credit is equal to 25 hours. Almost 50% of the CFUs are reserved to the individual study and are assigned when one passes an examination. The CFUs measure the dedication needed to achieve specific goals. The exam mark is expressed in 30/30 while that of the final test before the degree in 110/110. The normal-degree foresees a final test, while the specialists one requires the discussion of a final thesis. To conclude, one can say that the CFUs measure the achievement of the educational goal while the marks indicate level of knowledge achieved.

Status of nuclear energy

Italy is still under nuclear moratorium. It is the consequence of the results of a public poll on specific subjects concerning nuclear energy held in November 1987. As a consequence, the Italian government gave the order to stop all nuclear power plants working in Italy, to stop the construction of a new one and to stop all new plant designs. Many students asked to change their course work. The six nuclear universities modified their programmes to make them less nuclear energy dependent, even if a few nuclear exams were maintained. The university of Pisa, for example, offers a course work on Industrial and Nuclear Safety Engineering. Despite the critical situation described above, Italian "nuclear" universities, research centres and some industrial sectors have made and are making relevant efforts to capture the young generation's attention. All universities now have their own Internet site. They often put details about courses using Web pages and other advertising media. They organise seminars aimed at explaining the contents of related nuclear courses. To optimise their research capability, since 1994, the six "nuclear" universities have established the Inter-university Consortium for Nuclear Technology Research (CIRTEN). CIRTEN is an independent organisation devoted to taking part, promoting and developing research activities, training courses and information in the nuclear field. It is still operating even if the situation, as years go by, becomes still more difficult.

The nuclear industry is strongly penalised by the moratorium. ANSALDO, for example, the main Italian nuclear manufacturer, works mainly abroad in joint ventures with international groups, such as AECL (Canada) and Westinghouse (USA).

New recruitment at ANSALDO NUCLEARE strongly depends on two factors: a) retirement to employment ratio; and b) availability of sufficient funds from national/international contracts in the specific field that new graduates will be working in. Recently, ANSALDO NUCLEARE has widely been involved in the construction of some parts of Cernavodã Unit 1 in Romania. ENEL, the Italian electricity board, has changed its energy policy to “stop nuclear power plants and go ahead with oil, gas and multi-fuel plants” so that Italy is now more and more oil dependent. One of the actions recently performed by ENEL, in collaboration with the university of Tuscia, was the preparation of an exhibition to show the activities realised for the environmental restoration of the site of Montalto di Castro, a former nuclear power plant. ENEA, the most important Italian research centre in the energy field, is still reducing its employees by encouraging retirements without replacing them with new appointments.

On 29 January 1999, the Italian Council of Ministers approved a decree for the restructuring of ENEA, as part of a wider reform, aimed at overhauling the country’s state-sponsored research institutions. In a bid to revitalise the organisation, the decree endows ENEA with a new, more clearly defined mission that reflects the challenges facing the Nation in today’s world and lays down a regulatory framework designed to streamline and boost the efficiency of the Organisation’s activities. Under the new regulatory framework, ENEA is defined as a public undertaking operating in the fields of research and innovation, with a view to promoting solutions aimed at enhancing development, competitiveness and employment, while at the same time protecting the environment. Unfortunately, the situation is unclear. The reserve in new recruitment, and the retirement of old people still working in the nuclear field without being replaced are signs indicating a wish to put an end to nuclear energy in Italy. But research cannot be stopped so ENEA, in the framework of the actions performed to promote the preparation of specialists and experts in the sectors of own interest, put 653 themes at disposal of students who are preparing their thesis in the Academic year 2002-2003. These themes can be completed with the help of ENEA experts. To take advantage of this proposal, the student must have not more than other four exams to get through and a mark average at least 25/30. For the academic year 2002-2003, 23 graduation theses make focus on nuclear or nuclear related matters.

Apart from ENEA, other organisations are also strongly involved in actions to disseminate scientific (and nuclear) culture. For example, the INFN (National Institute of Nuclear Physics) has invited scientists to share every possible branch of knowledge not only within the scientific community but also inside schools and universities. To this aim, INFN organises training courses for young scientists, promotes conferences and exhibitions to illustrate scientific progress and gives students the opportunity to visit its laboratories while scientists are carrying out their work.

The Main scientific organisation in Italy is the CNR (Italian National Research Council). It is a public organisation of great relevance in the field of scientific and technological research of the Country whose original institution goes back to year 1923.

The “primary function” of CNR is to carry on, through its own organs, advanced basic and applied research, both to develop and maintain its own scientific competitiveness, and to be ready to effectively and timely take part in the strategic fields defined by the national planning system. In the nuclear field, CNR focuses its attention mainly on physics, chemistry and related subjects while the nuclear energy field is specifically managed by ENEA. An average of 10-15 grants per year is awarded by CNR to the nuclear field.

And now some final words about the Italian situation following the nuclear moratorium. Many people are convinced that nuclear in Italy does not longer exist. No nuclear for ordinary people means “no nuclear at all”. It is completely wrong and also a little bit hypocritical. It is worth noting that a similar situation is now common also to other European countries. Nevertheless, no nuclear in Italy means “no nuclear for military applications”. This is true. There is no doubt that many nuclear pacific applications are largely used in Italy. Bring in mind medical applications of nuclear products and radiations, industrial applications, industrial and scientific research. In addition, there is a use of nuclear energy under a sort of masquerade form. I refer to the amount of electrical energy that Italy imports from neighbouring countries. Since 1995 a quote ranging from 14% and 18% of the Italian electrical demand has been satisfied turning to importation of nuclear electricity from foreign countries, France in particular. It means that, with the decision of stopping our nuclear power plants, we have not abandoned nuclear energy, simply we have made it a "new importation source". Meantime our energetic system is oil-dependent for over 80%. This fact implies a heavy responsibility of our government and a high risk for our country. In the past I asked: "Can a highly industrialised country be so strongly oil-dependent?" Does anyone answer this simple question? This oil-dependence from foreign countries was very expensive for our own pockets: about EUR 28 billion in year 2000. Surely, a more balanced energy supply mix would be a better strategy.

Japan

In July 2001, Advisory Committee of Natural Resources and Energy, Nuclear Energy Subcommittee published a report named *Ensuring the Infrastructure of Nuclear Energy Technology*. It shows the following idea.

"Nuclear power plants have already been well-established by the private sector. In this field, there exist plenty of technological foundations. These technological foundations are results of previous accumulation and experience of nuclear energy technologies. In the field of the on-going nuclear fuel cycle, technologies which have been developed by government need to be transferred smoothly to the private sector. In the field of nuclear fuel cycle technologies which are not yet industrialised, accumulation of scientific knowledge and R&D is important. On the other hand, diminishing R&D may have an influence on the security of long term technological foundations."

The report also indicates that in order to secure technological foundations, the following conditions need to be satisfied according to the degree of maturity of each technology in terms of construction, operation and maintenance, fuel production, reprocessing of used fuels and management of disposal.

1. R&D is promoted for the improvement of innovative technologies and for applying regulations.
2. R&D is promoted for demonstrating the feasibility of improved or innovated technologies.
3. Design and manufacturing capabilities for improved technologies exist in the industrial sector.
4. There is a steady supply of persons to take charge of these R&D, regulatory, development, production and usage issues.
5. Research facilities are well maintained and can be used at all times.
6. The situations mentioned above are attained by "organic" communication and linkages among persons and organisations.

On 17 March 2003, the Science Council of Japan published a report on the education and security of human resources related to atomic energy entitled *Reconstruction of Atomic Energy Science for Harmonization of Human Society*. In this report, the Council expressed the view that "atomic energy science is confronting a crisis in the research, education and cultivation of human resources, because of the stagnation of utilisation, research and development of atomic energy, and the decrease in the number of students who apply to join the department of atomic energy science". The Council recommended that "researchers and technicians in the field of atomic energy science should have a sense of ethics, reaffirm that this field of study plays a significant role in society, and cooperate closely with experts in various fields of study including human science and social science".

Regarding measures for ensuring excellent human resources, the report states that "education and training in atomic energy science must be reconstructed in a broad-ranging framework". The Council recommended that "to respond to requests from the industrial sector for access to the technology utilised in existing nuclear facilities, a new educational organisation, such as a nuclear technology course taught at several universities, should be founded, and it would also be beneficial to establish a centre of education and research on atomic energy science in the universities in the promising area of atomic energy utilisation". In addition, concerning the establishment of the new independent administrative corporation through the unification of the Japan Atomic Energy Research Institute (JAERI) and the Japan Nuclear Cycle Development Institute (JNC), which is now in progress, the Council stated that "the new independent administrative corporation has to cooperate more actively with universities not only in research but also in the education and training of human resources in the nuclear field".

Realistically, the nuclear power plants already providing more than one-third of electricity in Japan must continue to shoulder a large part of the electric power burden of Japan throughout the long-term. Meanwhile, the program to convert national universities into independent administrative corporations may cause a difficult situation in nuclear engineering education, decreasing the number of large-scale facilities for education. (For example, the Research Reactor of Kyoto University will close in March 2006.)

Taking into consideration such new trends, there are great expectations that the difficulties will be overcome through measures, such as establishment of BWR Operator Training Centre based on investment by companies including electric power utilities, to secure excellent human resources for the nuclear industry. At the same time, as can be seen in the movement for information disclosure through the Internet, in order to restore public confidence, the atomic energy environment of Japan should become more transparent, and more efforts should be made for the wider public acceptance of nuclear safety.

On 17 January 2003, the Japan Atomic Industrial Forum published a report on the current situation of nuclear energy entitled *Seeking Hints for Restoring Nuclear Energy in Japan*. In this report we can see the numeric trend of employees engaged in nuclear related work in the private sector. Numbers decreased by about 5% from FY 2000 to FY 2001. They decreased for three years from FY 1999 and are now at the same level as that of FY 1979. Especially in the field of plant makers, we can forecast that the total number of employees is decreasing, while some departments are increasing. This is because productivity has improved through rationalisation by applying information technology to the design and construction of sites.

After experiencing a period of new plant construction, the report says, Japan is now facing a period of operating and administering existing plants. Japan also needs persons who are engaged in next-generation technologies. Japan should examine the minimum number of technicians for maintaining technologies and should maintain technological quality through education and training.

In view of domestic and overseas circumstances, and considering the necessity for innovative nuclear systems and the social anticipation of such systems, the Atomic Energy Commission (AEC) conducted investigations and discussions by establishing the Subcommittee on the Innovative Reactor and Related Fuel Cycle Technology under the Advisory Committee on R&D. This subcommittee deliberated for 11 months in 2001, and drew up a report, *Ways to Promote the R&D of Innovative Nuclear Systems in the Future*. As a first step to tackle the R&D of innovative nuclear systems, the report describes the current status of R&D in Japan and summarises the basic concepts behind such systems and development strategies.

The Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Economy, Trade and Industry (METI), are carrying out budgetary aid programs from their respective perspective, to promote the competitive research and development of nuclear energy technology.

MEXT has implemented a new scheme that calls for research and development activities on innovative nuclear technologies by creating an environment with competitive conditions through issuing public invitations of relevant projects. With the competitive environment thus prepared, the scheme aims to strengthen co-operation among the industrial sector, the academic sector and the government sector in conducting fundamental studies on nuclear energy, develop related technologies, and examine the innovative nuclear technologies that are expected to broaden the scope of nuclear technology.

Meanwhile, METI seeks to pursue innovative and viable nuclear power technology development projects, to accelerate the industrialisation of nuclear power generation and fuel cycle technology, and thus to improve safety and cost-performance.

A Cabinet Decision on the Restructuring and Streamlining Plan for Special Public Corporations was made in December 2001. Based on this Cabinet Decision, the JAERI and the JNC will be unified, and a new independent administrative corporation in charge of the integrated research and development of atomic energy will be established. The AEC presented Basic Policies for the unification of the JAERI and the JNC in advance, for an examination by the relevant administrative organs. In MEXT, the Preparation Committee for Unification of the Two Nuclear Corporations is examining the role and functions of the new corporation, taking into consideration priorities and operational efficiency.

Republic of Korea

Background

In March 1962, a nuclear criticality was first achieved in TRIGA Mark II research reactor with the particular interest from the President. It was an adventurous investment for Korea, which had achieved her independence in 1945 and several years later had undergone the Korean War.

Ten years after the first criticality, construction work began on the first Korean commercial NPP (Nuclear Power Plant), Kori unit 1, which is rated at 600 MWe and the second era of Korean nuclear history began in 1978, when it started operation.

Since then atomic energy activity in Korea has become more vigorous and ever expanding. In spite of the financial crisis in 1997, which caused a series of big changes in the society's morale including the introduction of management fashions such as privatisation, down-sizing, re-organisation, out-sourcing etc., the vigorous growth in atomic energy activities has not slowed down. The country's rapid and sustaining growth in atomic energy activity suggests a good example for the peaceful use of atomic energy to the international societies.

Currently 18 commercial NPPs are in operation, which generate around 41.7% of the country's electricity. Of these, four are CANDUs and the rests are PWRs. Four NPPs (Ulchin units 5&6 and Shin-Kori units 1&2) are under construction and six more are planed to be constructed by 2015 according to the Basic Electricity Demand and Supply Plan of the MOCIE (Ministry of Commerce, Industry and Energy). Korea has also recorded a high availability for its nuclear units, which was 93.2% in 2001 and 92.7% in 2002.

A characteristic of Korean nuclear society is that major nuclear related organisations are in public domain. The nuclear industries such as KHNP (Korea Hydro & Nuclear Power), KNFC (KEPCO Nuclear Fuel Company), KOPEC (KOrea Power Engineering Company), KPS (Korea Plant Service), KEPRI (KEPCO Electric Power Research Institute) are under the jurisdiction of the MOCIE while research institute and regulatory expert group, KAERI (Korea Atomic Energy Research Institute) and KINS (Korea Institute for Nuclear Safety), are under the jurisdiction of the MOST (Ministry of Science and Technology).

There are six universities that provide nuclear engineering programmes and about a score of colleges that provide programmes of radiation health physics applications. About 200 nuclear engineers graduate every year. Recently the number of students, who major in science and technology, is in reducing trend and societal counter measures are being devised.

Rapid expansion of nuclear power industry in the early stage of nuclear development explains the high demands of nuclear engineers in the 1980s. However since then, in spite of the continued expansion of atomic energy uses in both power and radiation, new recruitments has been drastically slowed down. The financial crisis at the end of 1997 gave impetus to the governmental plan of Electricity Market Privatisation, which resulted in further suppression of new employments.

Government

Government policy is very important and influential to nuclear society as it lies in the public sector. The MOST formulates the "Comprehensive Nuclear Energy Promotion Plan (CNEPP)" every five years through the legal basis of the Korean AEA (Atomic Energy Act). The CNEPP includes long-term nuclear policy objectives and basic directions, sector-by-sector objectives, budget and investment plan etc, which includes the manpower issue as well. The AEA stipulates that the MOST and the heads of the concerned Ministries shall formulate sector-by-sector implementation plans for those areas under their jurisdiction in accordance with the CNEPP and shall establish and implement annual action plans.

The MOST performs routine survey on Korean status of nuclear field every year, in which the nuclear manpower status and education/training data are also included. However the purpose of the survey is to get the general outlook of Korean nuclear field rather than to assess specifically the education and training capability or to improve the attractiveness of the nuclear sector for next generation.

Recognizing the potential vulnerable nature of demand and supply system, the MOST sponsored a policy study for the investigation of nuclear manpower demand and supply, which gave clear awareness to the government of the shortage of nuclear expert in the advanced countries and the manpower status of Korean nuclear industries, research institutes and educational organisations.

Stimulated by the policy study, the MOST decided to extend the questionnaire of yearly survey to cover more detailed information on manpower. Also it expanded its nuclear manpower development programme of research and overseas training to cover undergraduate students who major in nuclear engineering. 52 undergraduate students from the six universities, received research grants of about USD 5 000 in 2002 and 76 students in 2003. And the MOST also sponsors NtUss (Nuclear Technology Undergraduate student society), which is composed of those students who received grants. The NtUss held a research institute and nuclear facility visit programme, a research camp, lecture courses and a student research conference named NtUss Forum and it becomes a leading good practice in science and technology area. A few undergraduate students received overseas training scholarships in 2002 and 2003.

The MOST set an infrastructure development programme to expand the research funding for the universities. The Ministry of Education set a BK21 (Brain Korea 21st century) programme to support university research and education. Recently the MOCIE also established manpower development programme for industries and universities relevant with electric industries. Previously the university funding is restricted to basic and applied science and engineering researches. However the recent expansion of the university support programme endows diversified researches that cover educational purposes.

Manpower status

The number of engineers working in nuclear sector in Korea in year 2001 was around 11 000. The highest peak in the age distribution appears between 35-40 and the second peak between 41-44. Thus, the ageing seems not to be very serious as a whole but the distribution contains the considerable lay-offs of senior workers due to financial crisis at the end of 1997. Generally the ageing problems in the research institutes are more serious than those in the industries.

The degrees distribution says that the B.S. (Bachelor of Science) holders are 44.8%, the M.S. (Master of Science) holders are 13.1%, the Ph.D.'s are 6.9% and the others are below B.S. 92% of below B.S workers are in either KHNP or KPS and 82.1% of Ph.D. holders are either in the KAERI or KINS.

For above B.S. workers, mechanical engineers were 25%, electrical engineers 24%, nuclear engineers 13% (total of 6 967). As some of the senior workers were already laid off in the year of 1997, when the financial crisis occurred, during next 10-15 years only small fraction of engineers will retire. Small numbers of new experts have been hired during last 5-10 years and still new recruitments are expected to be limited for a while, as the privatisation of the electricity market is in process. But the increase of operating NPPs and the expansion of the country's R&D activities raise expectations for new job positions. In 2002, the government exceptionally allowed 400 new recruitments for the nuclear utility company.

The fraction of nuclear engineers among retiring persons for the next five years is 18.2% but it decreases to about 12% for the next five years. The decreasing trends of nuclear engineers in the industry raises concerns for the weaker links among the nuclear related organisation, weaker capability, poor visions, etc.

Universities

The universities are suffering from the reducing trends of enrolments in science and technology area nationally. Nuclear engineering is along the trend. Ten years of limited opportunities of new employments and negative public perceptions on the area results in declining enrolments. Facing low enrolments, university focus shifts from education to researches. However there are even fewer enrolments in master courses.

The K-NEDHO (Korean Nuclear Engineering Department Heads' Organisation) was formed and had several meetings in 2001 to discuss the issue of decreasing enrolments. The K-NEDHO reported the problem of declining university programmes to the government in order to draw the governmental concerns and supports, which results in the expansion of the manpower development programme for undergraduate students (NtUss).

Fifteen undergraduate students from six universities had opportunity to visit Kyoto university research reactor and had two weeks overseas training in 2003 also sponsored by the MOST. The KNEF (Korea Nuclear Energy Foundation) holds nuclear facility visit programme for undergraduate students and about a hundred students visited the operating and constructing NPPs in 2002.

There has been long standing internship programme of the KAERI for graduate students. They participate in the KAERI's R&D projects and receive degrees in universities. Parts of lecture courses are provided as intensive lectures held a month period to those students. The objectives of the programme are to develop next generation researchers fit for research purposes and to enhance the coordinated researches between research institute and university. The internship often linked to employments.

The university research grants are in a trend of increasing both in quantity and quality. The public funding (Nuclear R&D Fund), which is raised at a rate of one US mill per kWh of nuclear electricity generation, is increasing due to the increase of operating NPPs. Also during the privatisation process of electricity market, the government made new fund to carry out the public roles, which previously the public electric company had done.

There are about 50 professors in nuclear field. The average age is above 50 and the youngest is 37 years old. A third of the professors are expected to retire in ten years, who naturally have more concerns on research grants rather than sustainability.

Industries

41.7% of national electricity is covered by nuclear power and NPP construction continues. The nuclear power generation is major source of funding in the country. The Korean electricity market has been in the process of privatisation since 1999. New recruitments have been artificially suppressed by the supervising government due to the uncertainties in future structure of electricity market. However as the number of NPP operation increases, the Planning and Budget Office (Korean government) exceptionally permitted 400 new recruitments to the KHNP in 2002, which was triggered by the licensing requirement of Yonggwang unit 5 by the MOST. The KHNP expanded its own manpower development programme to a mid and long-term training and education programme for its employers. The programme covers various issues of nuclear field including even the management and leadership courses and consists of internal/external training programme both from domestic and foreign training institutes.

The KHNP together with the MOCIE has established and sponsored the KNEF (Korea Nuclear Energy Foundation) of which the role is to promote proper understanding of nuclear energy and contribute to the public good by distributing objective and scientific knowledge about the peaceful use of nuclear energy. Part of its role is to carry out media promotion and advertisement, to educate nuclear energy for future generations, to offer scholarship activities and to open culture promotion projects in areas in the vicinity of nuclear power plants.

Korean industry funded nuclear R&D's has been organised by the MOCIE and the KHNP. The objectives of the R&D programmes have changed depending on the technical capability of its nuclear society. It began with the acquisition of the technology, passed the technology transfer periods and reached a stage of self-reliance of the nuclear technology. Currently the industry R&D focuses on developments of original technology and acquisition of self-reliance in NPP construction and operation.

The industry has funded both short-term projects regarding the operation and maintenance of NPPs and long-term projects such as the KSNP (Korea Standard Nuclear Plant) project and the AP1400 (Advanced PWR 1400) project. However, compared to the public funded R&D, the industry R&D have tendency to focus more on short-term projects with practically applicable outcomes, which is driven by economic improvements. Most R&D projects are dealing with the existing NPPs and radioactive waste management. After the completion of AP1400 (Advanced PWR) project, future reactor system is not considered currently.

Research institutes

In spite of the ageing of the researchers, massive retirements are not expected for a while. However recruitments are gradually increasing to replace the retired researchers and to fill the new positions by project basis.

The share of public funding to the total funding of nuclear R&D is more than 80% in 2002 contract based calculation. The public funding is composed of government budget and industry contribution. Most of the researches are domestic projects, as they are aiming the original technology development and self-reliance of the nuclear technologies. However they include international activities in themselves such as consulting, review, expert exchanges etc.

Due to the limited manpower resources, joint researches among industries, universities and/or research organisations have been done especially on the developments of the original technologies such as computer codes, experiments, safety analysis, etc.

The age distributions of research institutes are worse than those of industries. The best and brightest students tend to find their jobs outside the nuclear field.

The KAERI continues to provide a few training courses including research reactor training for undergraduate students in nuclear engineering as a curriculum of university education course. It also set up a series of Web-based education and training programmes and has plan to expand it to an ANENT (Asia Network of Higher Education on Nuclear Technology) together with the IAEA and its member states in the region.

United Kingdom

Background

In the United Kingdom, there are currently 14 nuclear power stations, which generate around 23% of the country's electricity. Of these stations, six are Magnox, which are due to close by 2010, seven are AGRs which are due to close by 2023 and there is one PWR, which is due to close by 2035.

It is the policy of the United Kingdom government to transfer the operation of nuclear power plants from the public sector to the private sector. Hence the AGR and PWR stations are operated by British Energy, a fully privatised company, and the older Magnox stations by the government owned Public Limited Company, BNFL Magnox. The government has recently outlined its energy policy in a White Paper (http://www.dti.gov.uk/energy/whitepaper/ourenergyfuture.pdf) and, at present, there are no proposals for building new nuclear power stations to replace those that close. However, the possibility of new nuclear build is not ruled out but the decision would lie with the commercial sector and would need to meet the criteria of private investors.

In the coming years it is likely that the emphasis will be on clean up rather than new generating build. The United Kingdom has an environmental restoration challenge, arising from the early weapons programme, spent fuel management and decommissioning of nuclear power stations. The government's plans for meeting this challenge are laid out in the White Paper *Managing the Nuclear Legacy* (http://www.dti.gov.uk/nuclearcleanup/). Principal among them is the establishment of a new non-Governmental Agency, the Nuclear Decommissioning Authority (NDA). The NDA, which has a target implementation date of April 2005, will have responsibility for legacy facilities in the United Kingdom and will have the dedicated skills and capability to oversee the strategic management and direction of legacy clean up.

Industry

With the uncertainty surrounding the future of nuclear power in the United Kingdom, recruitment into the nuclear industry has been become increasingly challenging. This position is exacerbated by the continuing antipathy of students towards science, engineering and technology subjects, with enrolment in these areas declining markedly in recent years. As fewer and fewer high quality technical graduates become available, the competition for them is ever greater and there are signs already that the nuclear industry is losing out. The number of those graduating with any nuclear content to their courses remains a woefully small percentage.

Succession planning is common to at least the major companies, with medium-term succession planning issues often driving recruitment. As a result, job advertisements are targeted at specific areas. As well as using conventional means, such as specialist journals, local and national media, companies are also advertising vacancies on their web sites and offering on-line recruitment. Use is also made of specialist agencies and recruitment companies, especially when seeking to attract candidates from overseas.

Companies offer career development programmes for new recruits, support for professional development and comprehensive training programmes. There is often flexibility in terms of salary and relocation expenses in order to attract staff into key critical skill areas.

Another form of recruitment is by direct contact with universities. This may arise through careers and recruitment fairs but is very often through research contracts or through support for nuclear courses.

When the energy sector was deregulated, research was also effectively deregulated and there is no longer any nuclear research institute in the United Kingdom. Deregulation also signalled the end of public funding of nuclear R&D and it is the responsibility of the individual companies to formulate and fund their own R&D programmes.

Following the completion of Sizewell B in 1995, the level of R&D in support of future reactor systems has been much reduced. For several years now, R&D funded by the United Kingdom nuclear generators has comprised mainly in-house system and operational support programmes together with a collaborative programme of nuclear safety research undertaken in response to regulatory issues raised by the Health and Safety Executive (HSE). In addition to this collaborative programme, the HSE separately commissions nuclear reactor safety research, which is funded by the generators through a levy charged by the HSE. These programmes all relate to operating reactors. Other than Sizewell B PWR, these are of one of two gas-cooled graphite moderated types unique to the United Kingdom.

BNFL continues to undertake in-house research and development associated with the fuel cycle, decommissioning and waste management, which is almost entirely focussed on the needs of existing plants.

The United Kingdom nuclear generators participate in a number of European Framework projects and in the Halden programme. The United Kingdom also participates in Generation IV with a view to sharing its expertise and informing its current and future policy considerations.

Universities

Undergraduate teaching is financed on a block-funding basis through government agencies; to get the maximum funding universities have to enrol the maximum number of students. With empty seats meaning a loss of income, universities literally cannot afford to run courses for which there are few takers. The nuclear industry has seen staff numbers decline, and hence recruitment, as it has made the transition from an expanding, emergent industry to a mature one and also as it has sought to be more competitive in a deregulated energy sector. As a result, nuclear courses became under subscribed and were replaced by those pertinent to other industries for which there is a demand.

A survey of nuclear courses at British universities in 2002 showed that although undergraduate nuclear modules are currently taught at 22 of the 130 or so universities in the United Kingdom, they constitute, typically, less than 5% of the degree. (http://www.hse.gov.uk/nsd/nuceduc.htm). There is no longer any undergraduate course with a significant nuclear content and nuclear education at this level has been reduced to taster courses within mainstream science degrees.

At several universities, raising the profile of research in the nuclear area, through the formation of industry-university research alliances, has stimulated interest among undergraduates, leading to an increase in course numbers and also to new modules. Between 2000 and 2002 the number of undergraduates experiencing nuclear modules rose from 1 300 to 1 450, primarily for this reason.

At the postgraduate level, some government funding is available through the Research Councils to support masters courses although this is limited and most courses are funded by industry. Reacting to this environment of supply and demand some universities have taken positive steps to preserve their nuclear teaching and others to present new courses. The aim in all cases has been to provide flexible, modular, courses that both appeal to students and meet the needs of employers.

A long standing masters course dealing with the physics and technology of nuclear reactors has been preserved, following the withdrawal of Research Council funding, by a partnering agreement between the Regulator, the university and 10 companies. As a result of discussions with the nuclear industry to identify needs, the same university has introduced a post-graduate certificate in radioactive waste management and decommissioning.

After lengthy discussions with several industries, another university has introduced a master’s course in safety engineering comprising a core of generic modules together with optional specialist modules. By widening the appeal, the future of the course is more assured and yet its structure guarantees a substantial nuclear content for those students taking that option.

At a third university, Medical Physics has proved to be popular and the extent of nuclear teaching is rising year by year as increasing emphasis is given to new developments in radiotherapy and nuclear medicine in response to the government’s directive to combat cancer. Apart from a cadre of scientists familiar with nuclear principles, a direct benefit to the nuclear industry is in the provision of health physicists.

A military establishment specialising in nuclear training is now accessible to civilians and at least one nuclear company has a partnership for both training and recruitment. A number of post-graduate courses are available, ratified by a local university, and others are being developed to meet demand. Below this level, there is a wide range of training courses in areas relevant to the civil industry as well as those pertinent only to the military. Such relaxation of military and civil boundaries is of benefit to the nuclear sector as a whole.

Between 2000 and 2002, the total number of students attending postgraduate courses with a nuclear content greater than 5% remained unchanged at about 165 a year. However, if only the master’s courses that are 100% nuclear are considered, then student numbers dropped from 56 to 43 a year.

All government funded academic research is managed by the Research Councils. The priority placed on nuclear research is low. In 2002, the Engineering and Physical Science Research Council had a research grant and postgraduate training portfolio of over GBP 400 million: nuclear power attracted GBP 0.8 million whilst GBP 15 million was spent on renewable energy research.

The United Kingdom nuclear companies fund R&D projects in universities. In 2000, the nuclear industry had over 250 contracts with over 50 British universities, worth around GBP 10 million a year. Hitherto, many contracts were placed on an ad hoc basis to meet specific short-term needs. Like many other companies, those in the nuclear sector are now clustering contracts in specific subject areas at specific universities as a way of not only more efficiently managing their research portfolio but also of preserving their technical competence in key areas. As already noted, the raised profile of such alliances can act to stimulate undergraduate interest in nuclear topics.

Nuclear research facilities vary considerably from university to university. There are some new and refurbished laboratories but others are in their original state and date back several decades. There is only one remaining civil research reactor, the Imperial College CONSORT reactor at Silwood Park, and the last two hot cell facilities in universities closed in 2000.

Government

Acting on the recommendation made in the OECD/NEA report *Nuclear Education and Training: Cause for Concern?* [1] that: "governments should contribute to, if not take responsibility for, integrated planning to ensure that human resources are available to meet necessary obligations and address outstanding issues" the United Kingdom government formed, in September 2001, the Nuclear Skills Group (NSG).

Sponsored by five government departments, and with a membership drawn from those departments together with industrialists, academics and a representative from the Young Generation Network (YGN), the NSG conducted a two-phase study into the provision of suitably educated and trained people to satisfy the needs of the nuclear industry over the next 10-15 years. The first phase of the study was a skills audit to establish a baseline of the industry's present needs and the skilled population currently available. In the second phase, various scenarios for nuclear power were considered and their effect on this baseline quantified.

The skill sector covered was broader than simply "power generation"; it covered all companies and organisations that apply nuclear and radiological technologies, from power generation, through defence to health and environment. The assurance of future nuclear safety competencies, vested either in organisations or the regulatory authorities, was implicit throughout this work.

The report of the study, published in December 2002, has been circulated to government ministers and is available to the public (http://www.dti.gov.uk/energy/nuclear/skills/nsg.shtml.) It concludes that, with the exception of the health sector, which is already experiencing a skill shortage, recruitment demands are being satisfied but the problem of finding suitable candidates is becoming increasingly difficult. It is conservatively estimated that, overall, the sector will require some 50 000 new entrants over the next 15 years to meet anticipated demand. Worryingly, this demand must be satisfied from the engineering and physical sciences sector, which is diminishing in size due to its unpopularity as a field of academic study and career choice.

With a significant skill shortage likely to develop over the next decade unless immediate action is taken, the report makes a number of both strategic and tactical recommendations that are aimed primarily at the industry, although they also refer to schools, universities and government. Foremost amongst the recommendations is the need to establish a permanent industry body to take ownership of the skills issue and drive it forward.

Since the report has been published, discussions have led to proposals, which have the full support of the industry, for the creation of such a body. Known as the Sector Skills Council, it will replace the NSG and be responsible, when it is formed in late 2003, for implementing the recommendations of the NSG study and for delivering the skills agenda. The Nuclear Decommissioning Authority (NDA) has a specific interest in skills, as reflected in the White Paper, and given the United Kingdom emphasis on clean up, it is likely that the requirements of the NDA will have a major influence on nuclear skills development in the United Kingdom.

United States of America

In the country report for the United States included in the 2000 document *Nuclear Education and Training: Cause for Concern?* [1] it was stated that "nuclear engineering education in the United States has shown a marked decline in the past decade." It was noted that "the number of university programmes, student enrolments, degrees granted and university research reactors have all declined sharply. There is evidence of an ageing faculty demographic and few junior faculties being hired. The ability to maintain the educational infrastructure capable of supplying well educated nuclear engineers for the existing and future nuclear industry is in peril if the current trends continue." The overall picture for nuclear energy in the United States has improved and is discussed below.

Overview – The nuclear electric power situation

As noted in the 2000 report, no new nuclear electric power plants have been ordered in the United States since 1978, but solid commercial plant performance since 1990 has accounted for an increase of 200 billion kilowatt-hours of electrical production from the 103 nuclear plants operating in the United States Since 1999, industry capacity factors have risen from 86.8% to 91.5% in 2002. For comparison purposes, in 1990 capacity factor was below 65%. From 1998 to 2001, production costs of nuclear generated electricity has decreased from 2.09 to 1.68 USD-cents/kWh.

These performance improvements have led to higher levels of public, investor and regulatory confidence in the United States nuclear power industry. Maintaining this high level of confidence is vital for the long-term operation of existing power plants, as well as for opportunities for new nuclear power generation. Since 2000, the Department of Energy (DOE) has invested in research and development for existing plant ageing and generation optimisation through the Nuclear Energy Plant Optimisation (NEPO) programme. This programme with industry has focused on activities that are more long-term. Future federal funding of R&D for the existing fleet of United States nuclear power plants will be directed toward production improvement, security and issues that must be addressed to ensure long-term operation.

With many nuclear power plants approaching the expiration of their 40-year operating licensing period, the US Nuclear Regulatory Commission (NRC), in 2001, began approving applications for 20-year license extensions on a plant-by-plant basis. Currently, the NRC has renewed the operating licenses for 14 reactors. It is reviewing applications for an additional 16 reactors and expects to receive applications for 25 more license renewals by 2006. These 55 reactors are more than half the total number operating in the United States. Most of the remaining 48 reactors are expected to apply for their licences to be renewed as well.

In 2001, the US government issued the National Energy Policy that calls for an expanded role for nuclear energy in the United States to help meet the projected increase in the need for new baseload generating capacity. In October 2002, A *Roadmap to Deploy New Nuclear Power Plants in the United States by 2010* was issued under the auspices of the Department of Energy's Nuclear Energy Research

Advisory Committee. The Roadmap recommends actions to be taken by industry and the Department to support deployment of new advanced nuclear power plants in the United States by 2010. The Department has established the Nuclear Power 2010 programme to assist the industry in overcoming barriers to deployment of new nuclear plants. This programme is a joint government/industry cost-shared effort to identify sites for new nuclear plants, develop advanced nuclear plant technologies, and demonstrate new regulatory processes leading to private sector deployment of new nuclear plants in the near-term. Under the Generation IV programme, development of the next-generation nuclear systems for deployment by 2030 is underway. These Generation IV systems will provide significant improvements in proliferation resistance, sustainability, safety and reliability and economics. These initiatives, coupled with the approval in July 2002 that Yucca Mountain be considered for development as the United States' first nuclear waste repository, signal a strong commitment to nuclear energy.

Complimentary to these efforts, the nuclear energy industry in the United States has developed its own plan to increase nuclear energy over the next 20 years to meet the projected electricity demand growth. This plan, "Vision 2020 – Powering Tomorrow with Clean Nuclear Energy", issued by the Nuclear Energy Institute, calls for the addition of 50 000 megawatts of electricity by 2020 from new nuclear plants to the United States power supply.

General manpower and education

To meet these new goals for nuclear power, the necessary manpower must be available. A survey taken of universities in the late 1990s for the Nuclear Energy Agency's (NEA) analysis of nuclear engineering education in the member countries, including the United States, found that students were reluctant to choose a nuclear curriculum because of the perception of a weak job market and because the longer-term outlook for nuclear engineers was not promising. Since 2000, students appear to be attracted to a nuclear career due to a robust nuclear job market and one of the highest starting salaries in the engineering field. At the moment, the problem appears now to be one of a shortage of educated nuclear engineers to fill the many positions being created through retirements and increased public and private investment in nuclear research and operations.

Manpower recruitment and retention is critical to the future health of the nuclear industry. Since 2000, several task forces on nuclear manpower issues have been organised. In addition to the studies conducted through the NEA and the International Atomic Energy Commission, an American Nuclear Society (ANS) and a Nuclear Energy Institute (NEI) study have concluded that, without Herculean measures, manpower shortfalls will be a threat to the continued operation and growth of the industry. The NEI study pursued human resource benchmarking and implementation activities. This work generated a set of good practices and common contributors to successful recruitment and retention programmes. The NEI report indicated that approximately 90 000 entry-level workers are estimated to be needed in the United States to fill vacancies in thirteen job classifications by 2010 simply to support existing operations. These work classifications range from nuclear engineers to health physicists to welders. So despite the recent trend of increased enrolments in nuclear engineering education at US universities, the Nation finds itself on a nuclear manpower precipice which could worsen if additional manpower needs result from new nuclear plant orders.

Since 2000, the number of research and training reactors at US universities has remained virtually constant. Twenty-seven operating university research reactors remain. The number of universities offering a degree or option in nuclear engineering at the undergraduate and graduate level has increased with two additional schools offering a nuclear engineering degree. And while undergraduate enrolments in nuclear engineering reached a nadir of about 480 students in 1998, the number of undergraduates as of 2003 exceeds 1 300.

Programme initiatives taken 2000-2003

Over the past three years, the DOE has begun a teacher's workshop for high school science teachers using the administrative and manpower resources of the ANS. This is a pre-college effort designed to educate secondary and middle school science teachers in the fundamentals of nuclear science and engineering who in turn will enlighten their colleagues and, subsequently, their students so that this career choice is known to them. To attract minorities to nuclear engineering, the University Partnership programme was commenced in 2000 seeking to develop partnerships between nuclear engineering schools and minority universities so that a degree could be earned in nuclear while still completing their other course work at their home institution. This has lead to partnerships among five nuclear engineering schools and six minority universities. Several students from minority institutions have already earned their degree in nuclear engineering and others are in the pipeline.

Other efforts include a specialised programme to promote radio-chemistry through fellowships, faculty support and curriculum support, a new fellowship programme for graduate students interested in the naval nuclear propulsion programme, and a significant new effort to support university research and training reactors and the overall infrastructure of nuclear engineering education at US universities. Approximately, USD 9.0 million (for fiscal year 2004) has been made available for this activity entitled "Innovative Nuclear Infrastructure and Education (INIE)" programme. INIE encourages universities to make new investments in both their research reactors and nuclear engineering academic programmes while establishing strategic partnerships with national laboratories and the nuclear industry. To date, six regional INIE's have been established encompassing 24 universities, numerous national laboratories and many private partners including utilities. INIE grants are for five years and began in fiscal year 2002.

DOE is not the only US government agency supporting nuclear engineering education. The Nuclear Regulatory Commission (NRC) has implemented internship programmes specifically designed to recruit students into employment with the NRC. Funds support student stipends and pay tuition and fees. The students must meet the core competencies expected by the Commission. All sponsored research is directed toward specific technical issues related to power plant performance, including re-licensing and plant life extension.

For their part, the university community over the past three years has implemented activities specifically designed to increase the quality and number of students enrolling in their nuclear engineering programmes. Universities are concerned about student recruitment and new activities have been developed and implemented to increase the attractiveness of their programmes. This includes improving the curriculum, hiring new faculty, upgrading facilities and equipment, and expanding opportunities, especially for undergraduate students. A few universities have followed the lead of other universities by hiring recruitment specialists who accepted the responsibility for increasing the number of qualified students. These specialists also seek out scholarship, fellowship, internship and research opportunities for these students, easing the financial burden on the student and the nuclear engineering department; an important factor for maintaining university support of nuclear engineering in financially challenging times. A recruitment specialist seems to be one of the keys for successfully recruiting and retaining students into the field of nuclear engineering.

The US nuclear industry has reported that the apparent shortage of nuclear workers has not had an appreciable impact on current operations. However, it was noted that future plans for the industry, to a large extent, would depend on the success of efforts to enhance the Nation's nuclear workforce. The industry has relied upon the Nuclear Energy Institute (NEI) to develop a comprehensive plan of action regarding the need to increase the number of qualified individuals for employment in the nuclear industry. NEI has studied the motivational characteristics of young engineers who are in the process of deciding on whether or not to enter a nuclear-related career. They have also pursued human resource benchmarking and implementation activities. This has lead NEI to identify four focus areas for action. These are: addressing staffing shortfalls in health physics, nuclear engineers, welders, health physics technicians, and mechanical craftsman; partnering with universities, colleges, vocational schools, unions and other educational groups to recruit degreed and non-degreed individuals; increasing the nuclear industry's visibility and image, and lobbying to increase the government's support for university reactor support and scholarship and fellowship programmes.

At US National Laboratories, new activities undertaken over the past several years have been aimed at enhancing the quality of the workforce at each individual laboratory. This is an issue of paramount concern since all labs are experiencing an ageing of their workforce and in some locations it has become an epidemic with the laboratories projecting a loss of over one-third of their scientific and technical workforce through retirement within the next ten years. Recent proactive measures taken include: implementing summer school programmes in nuclear-related areas for graduate and undergraduate students; internship programmes; offering new nuclear-related degrees for existing employees including an applied nuclear energy certificate and an accelerator physics instruction programme; entering into long-term partnerships with domestic and foreign universities; supporting selective research fellowships; creating research alliances with universities for grant applications and establishing university research award programmes which are administered by the laboratory to support ongoing mission activities.

International aspects

Much of what has been done to improve nuclear support excellence has had a domestic direction and tone. This is due, in no small part, to the less than optimal state of affairs that the nuclear infrastructure in the United States found itself in due to years of under-investment and lack of co-ordination and co-operation among the federal government, the education community, the industry/utilities and the national laboratories. The mid to late 1990s saw renewed efforts and innovative programmes to address these issues. With the US Department of Energy assuming a larger role, universities, industry, national labs and others like the ANS and NEI began work on a common goal to ensure that the nuclear infrastructure in the United States was placed on a sound footing. Some of the impacts from the years of under-investment were irreparable with the Nation having already lost some of its research reactors, university programmes and staff, industrial capabilities and its best and brightest students of the time. The effects of that period may still linger but they have ebbed. Now, that the domestic scene has stabilised and improved, attention and resources can be better directed at nuclear support issues internationally.

One of the international efforts of DOE has been the International Student Exchange Program (ISEP) where graduate students from France, Germany and Japan study at a national laboratory in the United States (usually Argonne) while US students study abroad in these three countries. This programme has operated continuously for decades but has not expanded. Other international efforts have begun and in 2001, the International Nuclear Energy Research Initiative (I-NERI) started as an activity to leverage US research funding with funding from other countries through cost-sharing arrangements. The I-NERI programme has a goal of achieving a 50:50 matching contribution with each partner country.

More recently, the Advanced Fuel Cycle Initiative (AFCI) became active internationally (fuel cycle work with France and Switzerland) with contributions to collaborative projects that involve design and construction of new testing apparatus at existing facilities. The AFCI has some restrictions based on export controls and national security that limit the total scope of international collaboration in transmutation technologies. This has not proven to be a serious obstacle in the current collaborative programmes. AFCI supports research at US universities and worldwide through the participation of over 135 students associated with the programme. More broadly, since many of the US federal nuclear research projects support overall energy development, they do make substantial contributions to the international development of nuclear technology. In the Generation IV Programme, the United States are one of ten countries that has joined together to develop future generation nuclear energy systems, maintaining a large national and international expertise base.

The Electric Power Research Institute (EPRI) is involved in a number of collaborative projects with international members that are licensees of commercial power plants. International utility members of EPRI have essentially the same rights and responsibilities as domestic members and international collaboration is effectively achieved by multilateral participation in all aspects of EPRI's nuclear R&D programme planning, product development, and technology transfer activities. Many agreements contain provisions for loaned employees, sharing data and conduct of specific research in member countries. EPRI estimates that its annual value of international funding (including assessed value of data shared) is approximately USD 40 million.

In the US, international cooperation is encouraged in areas like: Generation IV so that advanced nuclear energy systems can be developed in a collaborative environment; AFCI were there are strong incentives to expand international co-operation because of the extensive international knowledge base and because of explicit language in congressional legislation and I-NERI where international co-operation results in efficient use of funding.

Restrictions on international collaboration are few but would include the Nuclear Waste Policy Act restriction of programme funds to the Yucca Mountain project, the NERI which is restricted to use at DOE laboratories, and many fellowships and scholarships that are restricted to US citizens.

Since the events of 11 September 2001, additional restrictions have been placed on student visas and access to nuclear facilities by foreign nationals. This includes new mandates regarding export controls, and the hiring practices of national laboratories. Despite these new measures, the US government supports international collaboration in almost all nuclear-related technologies. The openness of information produced by each international project is governed by the international agreement and the export control rules of each participating country.

Conclusion

In the past four years, much progress has occurred. New programmes, along with ones in existence prior to 2000, have served to strengthen the university nuclear infrastructure by supporting more research, facility improvements and faculty and this in turn has resulted in a drastic increase in the number of students enrolled as undergraduates in nuclear engineering and science.

Clearly, the programmes begun in co-operation with industry, universities, laboratories, and the international community, such as Generation IV, NERI, I-NERI, AFCI, NEPO and recently 2010, have all served to support much needed research and focus on the future needs of nuclear development. Yet, the US nuclear infrastructure is still confronted with some lingering problems that are subtler than previous ones. The perception of nuclear energy and technology has certainly improved but more needs to be done to educate the next generation of students so that they are aware of the benefits and promise of this technology.

Despite the progress made at the university level in retaining reactors, programmes and faculty and attracting students to nuclear programmes, budget reductions at the State level threaten to undue much of the progress as administrators search for ways to shrink programmes and budgets. Nuclear programmes, typically smaller than other engineering disciplines, could be absorbed and their identity lost as consolidation becomes a mantra among university authorities. Also, security measures, being put into place to conform with new NRC regulations, can be resource intensive in terms of money and manpower. The increased costs for these measures cannot be borne by the universities, as this may give hard-pressed university administrators even more ammunition to cast nuclear programmes as adding to budget pressures at their universities. It may fall upon the Federal government to finance any increases in security stipulated by NRC. This is an area that will require increased attention.

The good news is that many of the obstacles confronting the nuclear infrastructure in the United States have been overcome through the co-operation of all sectors: government, academic, industry/utility, national laboratory and trade and interest groups, in a way that could not have been predicted or envisioned in the late 1990s; the timeframe of our former NEA study. The sobering news is that new concerns of state finances and the increased need for security have arisen. Of course, another continuing concern is the ability to educate and train the present and next generation of nuclear experts before the loss of vast amounts of institutional knowledge possessed by those now retiring from the nuclear community. These problems seem surmountable given what has been achieved to date, and knowing that the US nuclear community is better prepared and organised and certainly more focused on infrastructure issues than ever before.

Appendix 5

Questionnaire

1. Background

The objectives of this questionnaire are:

1. To identify progress against recommendations presented in an earlier study *Nuclear Education and Training: Cause for Concern?* [1]
2. To quantify human resources and identify facilities dedicated to various R&D discipline.
3. To identify mechanisms and best practices regarding international collaboration in nuclear education and nuclear R&D.

While previous OECD/NEA studies focused on nuclear infrastructure in specific activity areas, e.g. in the nuclear safety area, this study, launched by Nuclear Development Committee (NDC), addresses the issue of infrastructure as a whole, that is, over the entire cross section of activities related to nuclear power applications. This study complements an earlier study entitled *Nuclear Education and Training: Cause for Concern?* [1]

The Nuclear Science Committee, NSC, launched an activity "R&D Needs in Nuclear Science" at its meeting in December 2001. The study consists of compiling and analysing the past and the present R&D and identifying future R&D needs. Such needs were addressed in a workshop convened in Paris 7-8 November 2002. NDC and NSC has agreed that NSC would take responsibility for the objectives, covering the documentation of former, present and future R&D needs. The NSC and NDC would co-operate on questions related to R&D resources.

The NEA Committees for the Safety of Nuclear Installations (CSNI) and for the Nuclear Regulators Activities (CNRA) have for the past several years dedicated considerable attention to the issue of ensuring sufficient competence for ongoing and future activities in the nuclear safety domain. As an example, the CNRA has recently launched a follow-up of their earlier study "Assuring Future Nuclear Safety Competencies",[1] aiming to determine the progress made in the last 2-3 years on this issue. To this end, a questionnaire was sent in July 2002, which to some extent covers the same topics as the present questionnaire (mainly in relation to Section I). In order to minimise the possible duplicative work in member countries, the Secretariat will ensure that the information gathered with both questionnaires will be available for both studies. **So, if some information has already been delivered for the CNRA study there is no need to rewrite it for the current study or resubmit it.**

2. Structure of the questionnaire and the terms used in the questionnaire

The questionnaire consists of three parts:

- Section I addresses objective 1 and is a follow-up of the previous NDC study on nuclear education and training.
- Section II addresses objective 2 and gathers data on nuclear R&D resources and funding.
- Section III addresses objective 3 and collects information on international collaboration.

1. http://www.nea.fr/html/nsd/docs/2000/cnra-r2000-1.pdf.

The information gathered will provide insights on practices established in OECD member countries regarding international collaboration in the areas of both R&D and education.

The terms used in this questionnaire are defined as follows:

Period of reporting: The data shall describe the situation in 2002.

Multilateral collaboration: Activities that are performed in the framework of international organisations such as EU, IAEA, NEA or in the framework of international agreements among more than two organisations.

Bilateral collaboration: Activities that are based on an agreement between two organisations in different countries.

Researcher: Professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned. Post-graduate students at the PhD level are considered as researchers.

Important facility: A facility that is unique to nuclear industry or it is an essential part of the R&D and education infrastructure.

3. Procedure

The questionnaire should be completed electronically. Members of the working group (or members of Nuclear Development Committee of NEA, if country has no member in the group) are kindly invited to distribute the questionnaire for relevant organisations as appropriate, and to collect, review and aggregate the answers for their country. This approach should facilitate the elimination of inconsistent or duplicated answers.

4. Schedule

The deadline for returning the answers through the Working Group members to the Secretariat shall be **14 February 2003**. The Working Group will meet in **April-May 2003** to discuss the collected data and the preliminary analysis prepared by the Secretariat.

5. Contact

For further information, please contact either national Working Group member or:

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QUESTIONNAIRE
SECTION I

Education and training

The following recommendations were provided in the study *Nuclear Education and Training: Cause of Concern?* [1]:

Governments should

- engage in strategic energy planning, including consideration of education, manpower and infrastructure;
- contribute to, if not take responsibility for, integrated planning to ensure that human resources are available to meet necessary obligations and address outstanding issues;
- support, on a competitive basis, young students. They should also provide adequate resources for vibrant nuclear research and development programmes including modernisation of facilities.
- provide support by developing "educational networks or bridges" between universities, industry and research institutes.

Universities should

- provide basic and attractive educational programmes;
- interact early and often with potential students, both male and female, and provide adequate information.

Industry should

- continue to provide rigorous training programmes to meet its specific needs.

Research institutes need to develop

- exciting research projects to meet industry's needs and attract quality students and employees.

Industry, research institutes and universities need to work

- together to co-ordinate efforts better to encourage the younger generation.

Member countries should ask the NEA

- to develop and promote a programme of collaboration between member countries in nuclear education and training;
- to provide a mechanism for sharing best practices in promoting nuclear courses.

Q I-1 Government initiatives

Please describe recent (during last three years) government initiatives taken in your country to evaluate the needs for new experts, to assess the education and training capabilities or to improve the attractiveness of the nuclear sector for new students. Please describe briefly the aim and the content of these initiatives.

Q I-2 University initiatives

Please describe recent (during last three years) initiatives your university or faculty has launched to improve the attractiveness of the nuclear education sector. Please describe briefly the aim and the content of these initiatives.

Q I-3 Industry initiatives

Please describe recent (during last three years) initiatives your company has launched to facilitate recruitment in the nuclear energy sector. Please describe the extent to which considerations on succession planning or knowledge management has influenced initiatives on recruitment?

Q I-4 Initiatives of research institutes

Please describe recent (during last three years) actions taken or initiatives launched by your institute to improve the attractiveness of the nuclear research sector. Please describe briefly the aim and the content of these initiatives.

When appropriate, please indicate if and how the previous study *Nuclear Education and Training: Cause of Concern?* [1] has influenced initiatives mentioned above.

QUESTIONNAIRE
SECTION II
R&D

Q II-1 Current R&D programmes and projects

Please provide the following information on the R&D programmes and projects. Please add a note if the information from the industry is not included.

Please split the global information according to the disciplines presented below. Subtopics could be added under each main topic as necessary.

Plant designs: Includes activities such as thermal-hydraulics, reactor physics, reactor transients and integrity of equipment and structures. The activities related to development of new nuclear power and research reactors are included. Information on important research facilities have been published in OECD/NEA (1997), *Nuclear Safety Research in OECD Countries; Capabilities and Facilities,* and OECD/NEA (2001), *Nuclear Safety Research in OECD Countries; Major Facilities and Programmes at Risk.*[2]

Material development: Includes activities related to development of materials of current reactors and development of materials needed for new reactor types, for example for high temperature gas cooled reactors.

Fuel studies: Includes activities related to fuel of current reactors and development of new fuel types, for example for gas cooled fast reactor, including research reactor fuels.

Waste management: As related to nuclear power plants and other fuel cycle facilities, including research reactors. Information on research facilities is published in OECD/NEA (2001), *Going Underground for Testing, Characterisation and Demonstration (A Technical Position Paper)*.[3]

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2. Available in address: http://www.nea.fr/html/nsd/reports/nea3144-research.pdf.

3. Available in address: http://www.nea.fr/html/rwm/docs/2001/rwm2001-6-rev1.pdf.

Decommissioning: As related to nuclear fuel cycle facilities, including research reactors.

Radiation protection: As related to nuclear power, excluding for example medical use. Information on research facilities and number researchers in universities is published in OECD/NEA (2002), *CRPPH Sponsored Survey of University Level Education Programmes in Radiation Protection*.[4]

Research resources should include all the persons who are mainly or partially employed on R&D. The aim is to have an estimation of the total manpower resources available. Thus, each person should be counted only once and be located under most appropriate discipline.

Please give short description if an important facility (such as accelerator or material testing system for irradiated specimen) exist, which is not introduced in other NEA reports mentioned above. Otherwise add a note if the facility is already included in other reports.

Table II.1. **R&D resources and facilities**

Discipline	**Research resources** (persons)		**Important facilities** (yes/no, if yes, how many)
	Public org.	Industry	
Plant designs			
Material development			
Fuel studies			
Waste management			
Decommissioning			
Others			

Q II-2 Trend of industry funded R&D

Describe how the focus of industry funded R&D has evolved during last 5-10 years, such as

- long term versus short term;
- safety driven versus economics driven;
- operating reactors versus future reactor systems;
- national versus international projects.

Q II-3 Industry funding for open R&D

Does your company fund directly R&D projects in research organisations or universities and the results of which are published for example in conferences, in journals or as thesis? Give an estimation of the volume (person-years). What is purpose of this funding (for example to ensure availability of new experts)?

Q II-4 Trend of public funded R&D

Describe how the focus of public funded R&D has evolved during last 5-10 years, such as

- basic research (long term) versus applied research and development (short term);

4. Available in address: http://www.nea.fr/html/rp/docs/2001/crpph2001-8.pdf.

- safety driven versus economics driven;
- operating reactors versus future reactor systems;
- national projects versus international projects.

Q II-5 Public funding and expertise

What is the role of public funding on maintaining the expertise and R&D capabilities? Is there public funding available for investments in infrastructure, for example to construct new test facilities or to buy new testing apparatus?

Q II-6 Public versus industry funding

What is the share of public funding of the total funding of nuclear R&D?

Q II-7 R&D funding for long-term development

Does your country participate in international initiatives to develop future reactor concepts, such as Generation IV or INPRO? If yes, what is the objective?

QUESTIONNAIRE
SECTION III
International collaboration

Q III-1 Resources for international collaboration

Please fill the following table.

Table III.1. **International collaboration**

Discipline	**Researchers temporarily abroad** (% of person-years)	**Share of researchers from abroad** (% of person-years)	**Use of facilities** (as in Table II.1) **for international collaboration** (%)	**Share of contribution to international collaboration** (% of total funding)
Reactor design				
Material studies				
Fuel studies				
Waste management				
Decommissioning				
Radiation protection				
Others				

"Share of foreign researchers" and "Researchers temporary abroad" includes the researchers who are detached from their home organisation to work abroad as a part of research collaboration. Not intended to include permanent foreign employers. Give estimation for the year 2002. This is to estimate the importance of exchange of researchers as part of the international collaboration.

"Use of facilities for international collaboration" is an estimation of the share of the facility's operation time used for international collaboration projects.

"Share of contribution to international collaboration" includes all the nuclear R&D funding which is used to finance R&D activities realised in the framework of multilateral or bilateral collaboration.

Give estimation what is the ratio between funds for multilateral compared to funds for bilateral collaboration?

Q III-2 Lessons learned on international collaboration

1. Based on the general experience in your country, please provide one or more example of good practice for international R&D projects in the nuclear area.
2. What are the main positive elements in favour of international collaboration?
3. What are the main negative elements or challenges?
4. Are some criteria used to measure the value of R&D in general and of international collaboration in particular?
5. Are there restrictions to the use of the national public funding instruments for international collaboration, for example funding is limited to national organisations only?
6. Do any organisational obstacles exist, which hinder international collaboration?
7. Do the R&D funding instruments contain incentives for international collaboration or for exchange of experts and researchers? Are there difficulties (work permit, social security, etc.), which hamper the collaboration and the exchange of experts?

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