Nuclear Development

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# Nuclear Education and Training: Cause for Concern?

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

## ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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– 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.

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## 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 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, 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 programme 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.

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# FOREWORD

This study was undertaken to examine the concern raised by OECD/NEA Member countries that nuclear education and training is decreasing, perhaps to problematic levels. The data gathered from the study and the follow-up analysis provide credence to the initial view.

Mankind now enjoys many benefits from nuclear-related technologies. For example, advances in health care and medicine are increasingly dependent upon expertise in nuclear physics and engineering. The fabrication of advanced materials from components the size of computer chips to the largest construction equipment is dependent on knowledge that stems from the nuclear industry. Nuclear technology is widespread and multidisciplinary.

Although the number of nuclear scientists and technologists may appear to be sufficient today in some countries, there are indicators (e.g. declining university enrolment, changing industry personnel profiles, dilution of university course content, and high retirement expectations) that future expertise is at risk. In most countries there are now fewer comprehensive, high-quality nuclear technology programmes at universities than before. The ability of universities to attract top-quality students, meet future staffing requirements of the nuclear industry, and conduct leading-edge research is becoming seriously compromised.

Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. Governments, academia and industry must assure that crucial present requirements are met and future options are not precluded.

## Acknowledgement

The NEA would like to acknowledge the co-operation of those organisations which replied to the questionnaire submitted to them through their country's representative to the Expert Group.

## TABLE OF CONTENTS

## EXECUTIVE SUMMARY

### Background issues

This study was undertaken to examine the concern raised by NEA Member countries that nuclear education and training is decreasing, perhaps to problematic levels. The data gathered from the study and the follow-up analysis provide credence to the initial view, as the following paragraphs will show.

Many diverse technologies, currently serving nations worldwide, would be affected by an inadequate number of future nuclear scientists and engineers. Mankind now enjoys many benefits from nuclear-related technologies. For example, advances in health care and medicine are increasingly dependent upon expertise in nuclear physics and engineering. The fabrication of advanced materials from components the size of computer chips to the largest construction equipment is dependent on knowledge that stems from the nuclear industry. Nuclear technology is widespread and multidisciplinary: nuclear and reactor physics, thermal hydraulics and mechanics, materials science, chemistry, health science, information technology and a variety of other areas. Yet the advancement of this technology, with all its associated benefits, will be threatened if not curtailed unless the declining number of courses associated with it, and the declining interest among students, is arrested.

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

A broad and deeply rooted nuclear education competence is essential to properly master the wide area of science and technologies extensively used in the nuclear domain. The universities and advanced technical schools are the only institutions capable of providing this education. In-house training, as a complementary form of education, is important for the proper and wise operation of nuclear facilities. This type of education is mostly, although not exclusively, provided by industry.

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

Experts worldwide continually forecast future energy and technology needs and estimate the resources required to fulfil them. Although the number of nuclear scientists and technologists may appear to be sufficient today in some countries, there are indicators (e.g. declining university enrolment, changing industry personnel profiles, dilution of university course content, and high retirement expectations) that future expertise is at risk. A key concern is that future nuclear options will be precluded if governments, industry, and academia fail to act in response to these indicators.

> ***"Although the number of nuclear scientists and technologists may appear to be sufficient today in some countries, there are indicators (e.g. declining university enrolment, changing industry personnel profiles, dilution of university course content, and high retirement expectations) that future expertise is at risk."***

The emerging shortfall of nuclear expertise has been recognised by the NEA. There is concern about an imbalance between the public perception of the extent of nuclear energy use and the continuing need for nuclear expertise worldwide, particularly with respect to investing in education and training now to meet future operational and regulatory requirements. If budgets and human resources suffer dramatic reductions, the lack of new talent coupled with the needs of the nuclear power and non-power community could reach crisis proportions. And there will be no quick fix to re-supplying the pipeline of students, faculty, researchers, operators, regulators, and the companion infrastructure.

### Emerging shortfall of nuclear expertise

To bring attention to this international problem of declining nuclear expertise and to quantify the trends in nuclear education and training from 1990-1998, the NEA submitted a questionnaire in 1998 through 16 Member countries to almost 200 organisations (including 119 universities, research institutions, power companies, manufacturers, engineering offices, and regulatory bodies). Some responses provided collective answers representing a group of organisations.

Several concerns are reflected in the quantitative data and qualitative information:

- Trends in the quantitative data differ significantly from country to country, but sharp declines are observed in several countries that are dependent on large nuclear infrastructures.[*]
- Qualitative information illustrates significant changes in student perception and attitudes: a decline in spirit and enthusiasm and decreasing interest in science and technology in general.
- The generally observed average age of faculty members is construed as a risk to sustaining high-quality expertise.
- Research facilities are ageing with almost no replacements planned.
- A significant fraction of nuclear graduates are not entering the nuclear industry.
- The current supply of entry-level workers in nuclear areas may not meet demand in some countries.

Although the overall picture for the number of graduates during this period may seem reassuring, there are underlying causes for concern. Although it is difficult to quantify from the questionnaire,

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* Care must be taken in analysing the data across countries as respondents interpreted questions consistent with national norms, which vary from country to country regarding issues such as what constitutes a "nuclear degree" or programme.

because there is no unique definition of what constitutes nuclear education, it is the collective judgement of the Expert Group that the nuclear content of many undergraduate courses has declined with time. The pool of knowledge at the undergraduate level is therefore decreasing year by year. This will eventually have serious repercussions on the master and doctoral levels, where the situation is currently far more encouraging than for undergraduates, in terms of both quantity and quality of students. With fewer nuclear courses available there will be fewer students wanting to study nuclear topics for higher degrees, and with a broadening and hence dilution of courses at the undergraduate level, there will be fewer students capable of studying for them. In terms of numbers, it is true that the present needs of the industry are being met. However, doubts as to the quality of graduates are already being expressed by industry in a period of consolidation with a decreasing demand. Unless the situation is at least stabilised, in the next few years there will be a shortfall of quality graduates to cope with the existing concerns of the industry, let alone to staff an expanding industry.

Because lead times in the nuclear field can exceed a decade or more, unmitigated trends could cause countries to lose control of their energy options due to a lack of technical expertise. Concerns here are:

- Little strategic planning – involving government and industry – is occurring in which nuclear technology is recognised as potentially important in helping to solve important future problems such as increasing greenhouse gas emissions in the face of strongly growing global energy demands and limited energy choices. In an era of deregulation, downsizing, and business cycles, there are increasing pressures for decisions to be made based upon short-term considerations. Governments are the appropriate institutions for assuring longer-term well-being when it appears that market forces alone will not be sufficient. Governments have an important multifaceted role in dealing with nuclear issues.
- The nuclear content of courses at universities is diminishing.
- The fundamental science and advanced classes – necessary for in-depth critical thinking about this complex subject area – have fewer students, even though a broader fraction of students may receive overviews of science and nuclear subjects.
- Research funding is more difficult to obtain than previously.

**Conclusions and recommendations**

> ***"Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. Governments and industry must assure that crucial present requirements are met and future options are not precluded."***

The large experience and continuing development of nuclear technology within NEA Member countries represent an enormous asset for society as a whole. This is more true than ever in the current global situation of rapidly growing energy demands and corresponding environmental concerns, as well as to assure the adequate handling of current nuclear activities that will exist for decades. The present trends observed in nuclear education are thus particularly worrisome and call for urgent action. It is in this light that this study's conclusions and recommendations have been formulated. Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. Governments and industry must assure that crucial present requirements are met and future options are not precluded.

***Nuclear education appears to be deteriorating***

In most countries there are now fewer comprehensive, high-quality nuclear technology programmes at universities than before. The ability of universities to attract top-quality students, meet future staffing requirements of the nuclear industry, and conduct leading-edge research is becoming seriously compromised. Facilities and faculties for nuclear education are ageing, and the number of nuclear programmes is declining. The number of degrees with a nuclear content has generally decreased. As Figure S.1 shows, student perception is affected by the educational circumstances: public perception, the industry's activities, and reductions in government-funded nuclear programmes. This negative perception may be shared by many others, including a student's parents, teachers, and friends. With an unclear image of the future, many young students now believe that job prospects are poor and that there is little interesting research. Low enrolment directly affects budgets, and budgetary cuts then limit the facilities available for nuclear programmes. Unless something is done to arrest it, this downward spiral of declining student interest and academic opportunities will continue.

***Recommendation:*** We must act now. The actions, discussed in subsequent recommendations, should be taken up urgently by government, industry, universities, research institutes and the NEA.

> ***"In most countries there are now fewer comprehensive, high-quality nuclear technology programmes at universities than before. The ability of universities to attract top-quality students, meet future staffing requirements of the nuclear industry, and conduct leading-edge research is becoming seriously compromised. Unless something is done to arrest it, this downward spiral of declining student interest and academic opportunities will continue."***

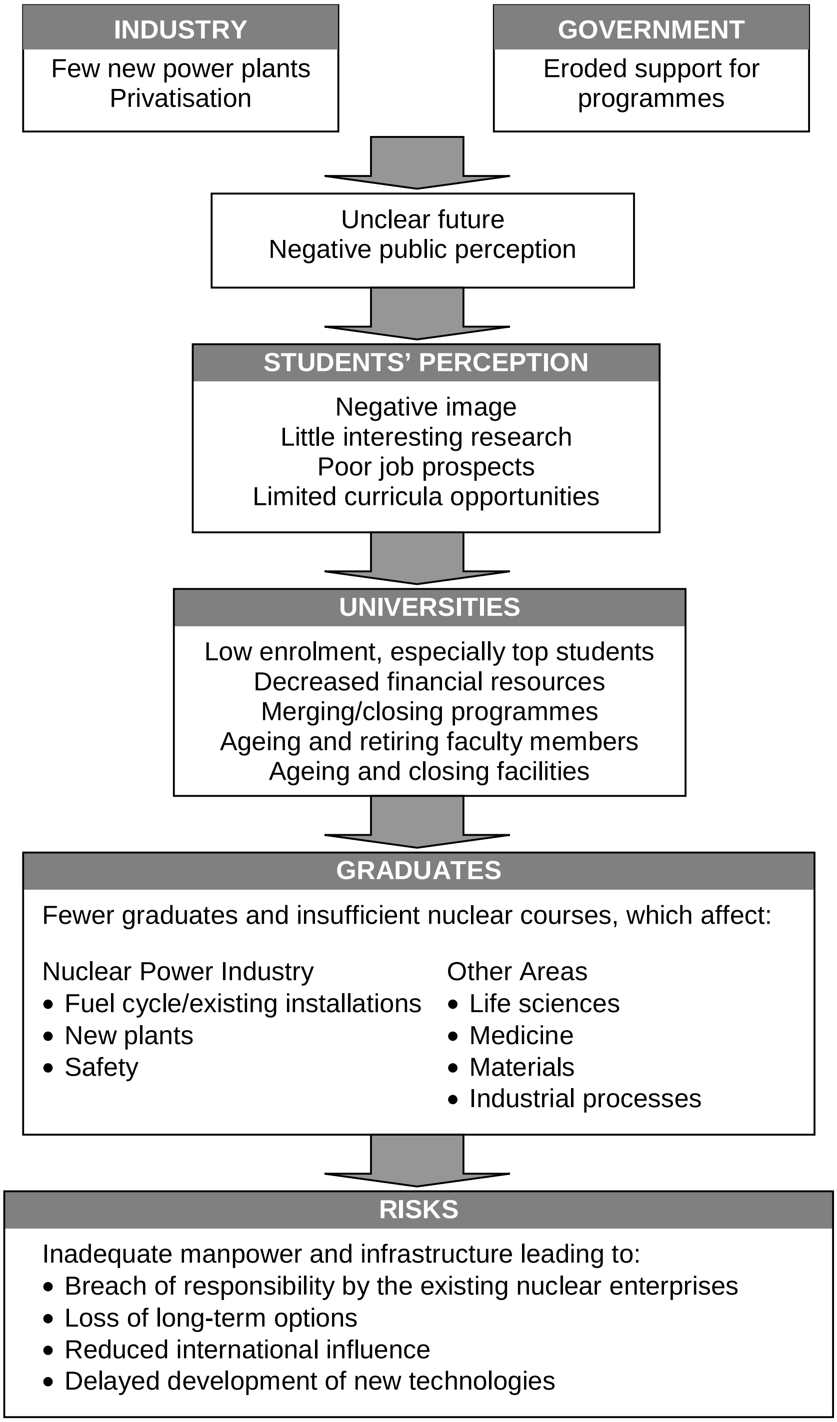
***Governments are responsible for doing what is clearly in their countries' national interest, especially in areas where necessary actions will not be taken without government***

Governments have an important multifaceted role in dealing with nuclear issues:

*Managing the existing nuclear enterprise.* Whether one supports, opposes, or is neutral about nuclear energy, it is evident that there are important current and long-term future nuclear issues that require significant expertise. This is largely independent of the future of nuclear electric power. These issues include: continued safe and economic operation of existing nuclear power and research facilities, some of which will significantly extend their planned lifetimes; decommissioning and environmental protection; waste management; and advancing health physics. These needs call for a guaranteed supply of not only new students, but also high-quality students and vigorous research.

*Preserving medium and long-term options.* While few new nuclear power plants are currently on order, governments must consider and protect their countries' medium and long-term energy options. Expertise must be retained so that future generations can consider the role of nuclear power as part of a balanced energy mix that will reduce $CO_2$ levels, preserve fossil fuel resources, contribute towards sustainable development, and respond to geopolitical and other surprises that are sure to occur.

Figure S.1. **The current situation of nuclear education**



Box S.1. **Examples of best practices**

- **Create a pre-interest in the nuclear domain.**
  Include steps such as advertisements aimed at undergraduate candidates, high school "open days" at campuses or research facilities; regular reactor visits and campus tours for students; newsletters, posters, and web pages; summer programmes; preparation of a resource manual on nuclear energy for teachers; sponsorship of an advanced laboratory for high school students; recruiting trips and nuclear introduction courses for freshmen; and conferences given by industry and research institutes.

- **Add content to courses and activities in general engineering studies.**
  Increase emphasis on nuclear in physics and applied physics courses; organise seminars on nuclear in parallel or in liaison with the existing curriculum using speakers external to the university; set up informational meetings on the nuclear sector, existing graduate programmes, research and thesis topics; discuss employment potential and professional activities; and call attention to the environmental benefits of nuclear (energy from fission, fusion, and renewables in comparison to fossil resources).

- **Change programme content in nuclear science and technology education.**
  Include advanced courses (such as reliability and risk assessment); broaden the programme to include topics such as nuclear medicine and plasma physics; assure that the education covers the full scope of nuclear activities (fuel cycle, waste conditioning, materials behaviour); provide early real contact with hardware, experimental facilities, and industry problems; and provide interesting internships in industry and research centres.

- **Increase pre-professional contacts.**
  Encourage the participation of students in activities of the local nuclear society and its "young generation" network.

- **Provide scholarships, fellowships, and traineeships.**
  In addition to promoting several support activities (mostly technical), industry participates financially by providing scholarships and, in several instances, has initiated new educational and training schemes. The size of the awards varies widely from one country to another. Academic societies, national research institutes, and governments also provide financial help. The number of these grants has remained relatively stable.

- **Strengthen nuclear educational networks.**
  Establish and promote national and international collaborations in educational and/or training programmes, e.g. summer school, specialist courses.

- **Provide industry employees activities that are professionally more interesting and challenging and that pay more than those in the non-nuclear sectors.**
  It is an exception, rather than the usual case, that a higher salary is used as a means to attract younger graduates.

- **Provide early opportunities for students and prospective students to "touch hardware", interact with faculty and researchers, and participate in research projects.**

- **Provide opportunities for high school and early undergraduates to work with faculty and other senior individuals in research situations.**
  Use the Web and other information techniques to proactively develop more personal communication with prospective students.

*Sustaining international influence.* The safe operation of nuclear installations is of paramount importance, and countries will only seek advice and be influenced by those who are at the cutting edge of nuclear technology. When the developing world moves to further exploit nuclear technology, it would be helpful that NEA Member countries have the necessary infrastructure and know-how to assist them upon request on issues such as safety, environmental protection and waste management.

*Pushing the frontiers in the new technologies.* Investment in nuclear research and development has created new technologies and brings benefits to a wide area, as nuclear technology has widespread multidisciplinary character and requires the enhancement of many cutting-edge technologies with varied non-nuclear applications. Government should consider nuclear research and development as a part of their technology policy to enhance technology competitiveness.

***Recommendations:*** Governments should :

- engage in medium and long-term strategic energy planning and international collaborations necessary to sustain a healthy nuclear enterprise;
- 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;
- provide adequate resources for vibrant nuclear research and development programmes including modernisation of facilities; and
- provide support by developing "educational networks" among universities, industry, and research institutes.

### *The challenge of revitalising nuclear education is great*

The ability to offer nuclear programmes is deteriorating, and the number and quality of students are declining.

***Recommendations:*** Universities should provide basic and attractive educational programmes; interact early and often with potential students, both male and female; provide early research opportunities; and provide adequate information. Illustrations of successful best practices are shown in the context of educational programmes. (See Box S.1. Examples of best practices.)

As an introduction to undergraduate nuclear engineering, universities should provide basic and broad courses including general energy, environment, and economic issues arising in the $21^{st}$ century. Efforts should continue to adjust the curriculum, develop new disciplines, and implement measures to keep pace with the evolution of nuclear technologies so as to develop research areas that are attractive and exciting to students and meet the needs of industry.

Potential students such as freshmen and high school students do not have appropriate and sufficient information on nuclear education in universities. Information should be provided to arouse their interest in nuclear technology. Faculty members should visit high schools, hold "open days", and work with them. Potential students can be reached by allowing them to "touch hardware" and learn more about challenges and opportunities through a highly "interactive web."

***Industry must recognise its role and interests in assuring an adequate supply of capable students and vigorous research, as well as maintaining the high-quality training that is needed for staff in industry and research institutes***

There currently appear to be enough trainers and quality staff in industry and research institutes; however, data do not show the whole picture.

***Recommendations:***

- Industry should continue to provide rigorous training programmes to meet specific needs.
- Research institutes need to develop exciting research projects to meet industry's needs and attract quality students and employees.
- Industry, research institutes, and universities need to work together to better co-ordinate efforts to encourage the younger generation through mechanisms such as grants, research funding, partnerships, and international collaborations.

***More collaboration and sharing best practices would be greatly beneficial***

Renewed investment in nuclear education by NEA Member countries would help sustain their balance of energy usage, human resources, technology and economics. Collaboration between industry and academia varies widely. "Where collaboration exists and runs effectively, it is highly valuable, particularly when a university is involved in nuclear professional activities with industry." Collaborations keep the academic subjects relevant to the actual problems encountered in industry – a key element for attracting students to the field.

***Recommendations:*** Member countries should ask the NEA to develop and promote a programme of collaboration between Member countries in nuclear education and training, and provide a mechanism for sharing best practices in promoting nuclear courses (see Box S.1. Examples of best practices).

# 1. INTRODUCTION

## Background

This study was undertaken to examine the concern raised by the OECD/NEA Member countries that nuclear education and training is decreasing, perhaps to problematic levels. This concern could take many years to resolve.

Many diversified nuclear technologies – from nuclear medicine tracers to non-destructive materials testing to electric power generation – currently serving nations worldwide would be affected by a decrease in the number of future qualified nuclear scientists and engineers. Decreasing educational offerings and student participation in nuclear technologies may limit future contributions.

Nuclear technology has been applied and is still progressing in a wide area: generation of electric and thermal power, medical diagnosis and therapy, agriculture, non-destructive testing, among other things. In 1998, 345 nuclear power plants with a total net capacity of 292 GWe supplied 23.8% of all electric power produced in NEA Member countries [1]. Radioactive tracers are used for diagnosis. Neutron and charged heavy particle beams have been used for cancer treatment. Breed improvement for agriculture has been achieved through irradiation. Neutron radiography makes it possible to inspect materials, such as aircraft components, that gamma-ray radiography can not.

Nuclear energy has an important role in energy policy as a valuable option in helping to achieve sustainable development and alleviating the risk of climate change; therefore, research and development on safe, environmentally acceptable, and economical nuclear energy continues to be needed. Even if some countries are not now developing additional nuclear power, they still need to operate the existing plants and fuel-cycle facilities (many of which will operate for decades), respond to technical challenges as facilities age, and manage the radioactive waste. Also, existing plants must be decommissioned at some time in the future, and the requirements to do so must be anticipated.

Nuclear education competence is important, not only from the viewpoint of ensuring the availability of qualified human resources for the industry and regulatory bodies, but also for sensitising a wider audience to nuclear-energy-related issues.

A positive feature of nuclear education, which should serve as an important incentive for young scientists and engineers entering the field, is its widespread interdisciplinary character. The systems approach, as well as the specific technical knowledge acquired, can often be applied to broad classes of problems, so that nuclear engineers sometimes find employment in areas quite different from that of their specialisation.

The education of young people, however, which is a key element of the nuclear infrastructure needed for the safe and economic operation of existing nuclear power plants and future nuclear energy deployment, is facing considerable difficulties. Both university education and in-house training provided by nuclear research institutes and companies have played significant roles in the history of nuclear development. However, some universities' nuclear programmes and courses are being merged with other subjects or, in the worst cases, simply closed down. Some universities cannot maintain nuclear-related courses – mainly because of the decreasing number and quality of students. Although a decrease in enrolment is observed in practically all fields of science and engineering, the trend is particularly prominent in the nuclear sector. Budget cuts result from this situation. Research institutes as well as private companies are facing similar budgetary constraints and they too are diversifying into non-nuclear fields.

## Objective and scope of the study

The decrease in educational offerings and student participation must be analysed so that governments, industry, and other institutions can take a considered view as to the importance of remedying the situation. Sharing information about actions already undertaken can help these entities to deal with issues. Therefore, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) decided to undertake a study aimed at analysing the situation of educational programmes in the nuclear field in Member countries and drawing the attention of governments to the need to take corrective initiatives. This study aims to:

- Show the current situation of nuclear-related education and training, based on quantitative data and qualitative information analysis;

- Identify the issues and current and future needs of government and industry relative to nuclear-related education and training;

- Suggest possible ways of encouraging students and young research fellows to enrol in nuclear courses; and,

- Send clear messages on human development and staffing issues to senior officials and decision-makers in governments so that they can take necessary action.

## Methodology

This study has been undertaken by the Expert Group for the Survey and Analysis of Education in the Nuclear Field, which was established to conduct this study under the auspices of the NDC. It was carried out in association with the European Commission (EC). The Expert Group consists of experts from 17 Member countries: Belgium, Canada, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Mexico, the Netherlands, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The members of the Expert Group are listed in Annex 1. Respondents to the questionnaire represented many facets of the nuclear community (Table 1).

This study has taken advantage of the collective wisdom of experts drawn from 17 Member countries as well as the NEA and the EC to analyse the data, to ensure that the proper implications are drawn, and to provide expert opinion where it adds value.

The questionnaire was prepared and sent out in mid-1998 to gather information on education in Member countries from 1990 to 1998 for analysis by the Expert Group. The questionnaire consists of three parts. The first section asks for data on nuclear-oriented curricula offered within universities and equivalent organisations. The second part surveys in-house training carried out by research organisations, public institutes, and companies. The third section solicits case studies of experiences obtained in the country. The first and second sections were designed to collect the information on individual universities and organisations, while the third section provides a wider view of the country as a whole.

Responses were received from almost 200 organisations, including some 119 universities, research institutes, power companies, manufacturers, engineering offices, and regulatory bodies. The nuclear power plants of the countries covered by this study supplied 91% of all nuclear electricity generated in Member countries. In addition to information from these participating organisations, other existing data were added. More details are found in Annex 2.

Due to the wide variety of situations in the various countries and the specific situation in many of them, the members of the Expert Group provided Country Reports that provide a review of how nuclear education is embedded in the local educational structure and practices. Country Reports are in Annex 3.

Table 1. **Participants in the study by country and organisation**

| Country | University | Research Institute | Power Company | Manufacturer | Engineering Office | Regulatory Body | Total |
|---|---|---|---|---|---|---|---|
| Belgium | 7 | 1 | 1 | | 1 | 1 | 11 |
| Canada | 5 | | | | | | 5 |
| Finland | 3 | 2 | 2 | | 1 | 1 | 9 |
| France | 4 (a) | 1 | | 2 | 1 | | 8 |
| Hungary | 4 | 3 | 1 | 1 | | | 9 |
| Italy | 6 | 1 | | 1 | | | 8 |
| Japan | 21 | | 8 | 8 | | | 37 |
| Korea | 6 | 1 | 1 | | | | 8 |
| Mexico | 4 | 2 | 1 | | | 1 | 8 |
| Netherlands | 1 | 1 | 1 | | 2 | | 5 |
| Spain | 6 | | 1 | | 1 | | 8 |
| Sweden | 7 | | 4 | | | 1 | 12 |
| Switzerland | 9 | 1 | 4 | | | 1 | 15 |
| Turkey | 5 | 1 | | | | 1 | 7 |
| United Kingdom | 9 | 1 | 1 | 1 | | 1 | 13 |
| United States | 22 (b) | 2 | 5 (c) | 2 | 1 | 1 | 33 |
| **TOTAL** | **119** | **17** | **30** | **15** | **7** | **8** | **196** |

Note: (a) INSTN provided the collective answer of 10 courses.
(b) In addition to the participants, the survey by USDOE covering all US universities was also used for the analysis [2].
(c) INPO provided the collective answer of US utilities. Four also provided individual responses.

## Limitations of the study

This study covers almost all types of organisations related to nuclear education. However, as it was difficult to cover all organisations related to nuclear education in some countries, it is the trends rather than the absolute numbers that are important.

The Expert Group concentrated on collecting and analysing data only on the supply side of qualified personnel. It collected only qualitative information on the demand side. Demand was the subject of a previous NEA study, which is mentioned in the following section, and has often been difficult to project accurately.

Generally, nuclear education is defined in a broad sense. It can include one or more of several disciplines such as nuclear power engineering, radiochemistry, radiation physics, nuclear medicine, and basic nuclear physics. Furthermore, the definition is often country-specific. The Country Reports in Annex 3 are, therefore, important inputs to properly understand both quantitatively and qualitatively the position of nuclear education in each country. While the data are consistent within each country, one must take great care in analysing the data across countries. Answers to questions such as the number of undergraduate degrees awarded for nuclear education programmes are interpreted quite differently from country to country.

**Other relevant studies**

The NEA has published a report on the demand for and supply of qualified manpower for nuclear-related fields such as nuclear industries, regulation sectors, and education sectors in Member countries [3]. This report shows that several countries have already initiated actions to support nuclear research and development and education and to ensure an adequate manpower supply through government funding of research and development programmes, government and industry funding of students and lecturers in universities, and closer co-operation between nuclear utilities, research centres, and universities. In addition, the report recognises the importance of measures to make potential students more aware of the social, environmental, and intellectual role of the nuclear sector.

The European Commission is currently assessing the status, recent evolution, and future trends of nuclear expertise in Europe and other leading countries, with the aim of building a solid knowledge base, among other purposes, for specifying future Commission research activities and for helping national policy makers in their decision processes.

## 2. CURRENT STATUS AND TRENDS IN NUCLEAR EDUCATION

### Introduction

The data from 1990 to 1998 presented in this chapter arise not only directly from the questionnaire but also from the country reports (Annex 3) and an existing study [2]. The country reports provide important information and are an integral part of this report.

As mentioned in the Introduction, nuclear education is broadly defined by the scientific content of the course or programme and the level of qualification of the student. Formal (university) education extends from the first Bachelor degree to the doctoral degree.

In-house education and training is even more broadly defined, addressing a wide range of participants from holders of a Doctorate degree to technicians specialised in, for example, welding, electronics, or chemical processing. Together, these levels provide much of the highly competent manpower required for the efficient and safe operation of the nuclear industry.

### The status of nuclear education in universities

The survey covered 119 educational institutions in 16 countries. With such diversity it must be recognised that it is impossible to formulate a unique definition of what constitutes a nuclear curriculum. Harmonisation within the Expert Group was achieved by comparing and contrasting the data from one country to another, and then by each country representative considering and verifying the data from each of that country's universities in light of the group discussion and the definition given by the university itself. Educational curricula varied from a specifically designed nuclear degree provided to students already holding a Bachelor or a master degree in engineering to a largely classical engineering or science curriculum, but broadened so as to encompass the nuclear field as defined by their university. Usually the curriculum broadening was in the form of optional courses or project work. In light of the above, caution must be exercised in comparing data from country to country because it often reflects very different situations.

Within this context, the number of institutions offering nuclear programmes remained stable over the period considered (1990 to 1998), except in Belgium and the United States, where it decreased, and in France, where it increased.

In addition to quantitative data, the questionnaires also yielded qualitative information in the form of comments to questions. Further information and commentary were obtained through the country reports (Annex 3).

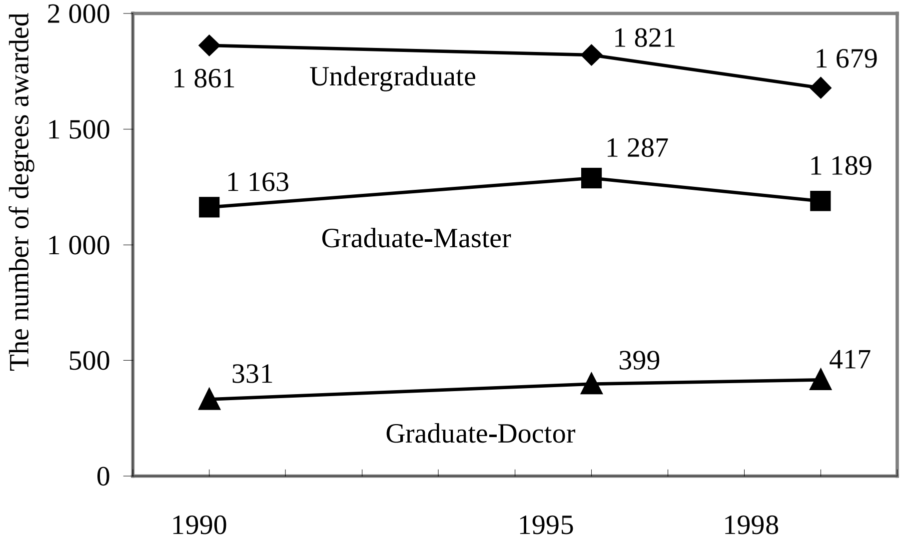
Although the data show few changes occurring in the period 1990 to 1995, significant trends are apparent between 1995 and 1998 and are substantiated by the comments from Member countries.

*Students*

The number of degrees awarded, rather than the number of students enrolled, is a better indicator of both the health of nuclear education and of the number of young, qualified people available to the industry.

Figure 1, below, shows the total number of degrees awarded in nuclear subjects in 1990, 1995, and 1998 for the institutions covered by this survey. Details of both the number of students enrolled and the number of degrees awarded is given for each country in Table A2.3 of Annex 2.

Figure 1. **Number of degrees awarded in 1990, 1995 and 1998**




Note: The data cover 154 institutes: 119 institutes that responded to the questionnaire plus additional data provided by the USDOE [2].

While there was a 10% decrease in the number of degrees awarded at the undergraduate level between 1990 and 1998, the number awarded at the master level remained fairly constant, and the number at the doctoral level increased by 26%.

Of significance are the decreases observed between 1995 and 1998 at the undergraduate and master levels. In this period, a country-by-country analysis of these data (Table A2.3 of Annex 2) reveals a diverse picture. In the United States, a sharp decrease is observed at all levels; in the other 15 OECD/NEA Member countries, the status quo is roughly maintained at all levels.

With the exception of the United States, a country-by-country analysis of the number of degrees awarded at all three educational levels shows:

- A slight increase in France, Japan, Korea, Mexico, Sweden, and the United Kingdom.
- Virtually no change in Finland, Hungary, Italy, the Netherlands, and Switzerland.
- A decrease in Belgium, Canada, Spain, and Turkey.

While it is difficult to quantify from the questionnaire, primarily because there is no unique definition of what constitutes a nuclear curriculum, it is the collective judgement of the Expert Group that the nuclear content of many undergraduate courses has declined with time. The pool of knowledge at the undergraduate level is therefore decreasing year by year. This will eventually have serious repercussions on the master and doctoral levels, where the situation is currently far more stable.

***Faculty members***

The number of full-time faculty members has decreased in the United Kingdom and the United States but has increased in France and Japan. In other countries, the numbers have remained fairly constant over the period of the survey. There is no full-time faculty member in Belgium and the Netherlands. The number or man-hours of part-time faculty members are generally rising but decreasing in Belgium and Hungary. The data are given in Table A2.3 of Annex 2.

The age distribution of faculty members is another important indicator of the health of nuclear education. Table 2 shows the distribution by age in 1998 for each country. The full details are given in Tables A2.4 and A2.5 of Annex 2.

Belgium, Canada, Japan, Switzerland, the United Kingdom, and the United States all have their largest fraction of faculties in the 51 to 60-year-old range. Hungary, Italy, Korea, Mexico, Spain, and Sweden have their largest fraction in the 41 to 50-year-old range. France is alone in having its largest fraction in the 21 to 30-year-old range. Turkey has its largest fraction in the 31 to 40-year-old range. Finland shows an even distribution across the age ranges, and the Netherlands lists only 5 part-time faculty members. The average age of faculty members is almost 50 years. Most universities have a retirement age around 65.

Table 2. **The age distribution (as a percentage) and average age of faculty members in 1998**

| Country | Age distribution (% of total) | | | | | | Average age |
|---|---|---|---|---|---|---|---|
| | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ | |
| Belgium | 6 | 1 | 31 | 47 | 14 | 0 | 52 |
| Canada | 13 | 19 | 31 | 34 | 3 | 0 | 45 |
| Finland | 13 | 25 | 25 | 25 | 13 | 0 | 46 |
| France | 49 | 33 | 5 | 8 | 5 | 0 | 34 |
| Hungary | 7 | 16 | 33 | 30 | 14 | 0 | 48 |
| Italy | 0 | 10 | 31 | 29 | 28 | 2 | 54 |
| Japan | 3 | 18 | 23 | 43 | 13 | 0 | 50 |
| Korea | 0 | 5 | 57 | 36 | 2 | 0 | 49 |
| Mexico | 0 | 20 | 52 | 18 | 9 | 0 | 47 |
| Netherlands | 0 | 60 | 0 | 40 | 0 | 0 | 44 |
| Spain | 4 | 32 | 46 | 4 | 14 | 0 | 45 |
| Sweden | 19 | 19 | 22 | 15 | 22 | 4 | 47 |
| Switzerland | 0 | 0 | 27 | 73 | 0 | 0 | 53 |
| Turkey | 15 | 37 | 30 | 15 | 3 | 0 | 41 |
| United Kingdom | 9 | 21 | 24 | 34 | 9 | 2 | 47 |
| United States | 1 | 15 | 35 | 35 | 13 | 1 | 50 |
| **TOTAL** | **7** | **18** | **29** | **33** | **13** | **1** | **48** |

For the countries with a nuclear installed capacity above 10 gigawatts, the largest fraction of faculties is between 40 and 60 years old. For the countries below 10 gigawatts, the age distribution is spread more evenly.

***Facilities***

Most of the 119 educational institutions are equipped with experimental facilities capable of supporting a diverse curriculum (Table 3). The number and average age of facilities for each country are given in Table A2.6 of Annex 2.

Table 3. **Type and number of facilities in educational institutions in 1998**

| Facility | Number | |
|---|---|---|
| Research reactors | 39 | (46 in 1990) |
| Subcritical facilities | 6 | |
| Hot cells | 28 | (31 in 1990) |
| Radiochemistry laboratories | 67 | (66 in 1990) |
| Radiation measurement laboratories | 92 | (92 in 1990) |
| Laboratories for radioecology/geology protection | 6 | |
| Neutron sources | 7 | |
| Accelerators | 21 | |
| Irradiation sources | 11 | |
| Irradiators | 2 | |
| X-ray generators | 1 | |
| Patient irradiation rooms | 3 | |
| Isotope separation laboratories | 1 | |
| Simulators | 3 | |
| Corrosion, material testing laboratories | 3 | |
| Thermal hydraulics laboratories | 13 | |

Many universities not equipped with experimental facilities on their campus have access to such facilities at nearby large research laboratories.

Many facilities entered service some time ago (Table 4). The present age and the expected lifetime of the different types of experimental facilities vary from university to university. In some cases, the incremental replacement of equipment on a continuing basis keeps the facility not only operational but also up to date. Nonetheless, the average age of many facilities is in excess of 25 years.

Table 4. **The average age, age range and expected lifetimes of nuclear facilities at universities in 1998**

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

* Seven reactors were decommissioned between 1990 and 1998.

** The continuous upgrading of radiation-measurement equipment keeps those laboratories operational and up to date.

*Occupational distribution of graduates*

For this survey, occupation was defined as the sector in which the graduates were engaged for a 5-year period after obtaining their final degrees. The data reflect the first choice that the new graduates made for their future career.

Table 5 shows the occupational distribution by qualification in 1994-1998, expressed as a percentage, for all countries. The last heading includes non-nuclear research institutes, non-nuclear manufacturers, and others. Because some of the sectors more rarely cited are not reported in the table (e.g. government, regulatory, military), the figures may not sum to 100. Full details of sector and academic level are given for each country in Table A2.7 of Annex 2.

Table 5. **Occupational distribution by qualification in 1994-1998 (as a percentage)**

| Country | Graduate school | | | Utilities | | | Nuclear manufacturers | | | Research/ education | | | Non-nuclear field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | M | D | B | M | D | B | M | D | B | M | D | B | M | D |
| Belgium | – | 0 | NA | – | 50 | NA | – | 8 | NA | – | 8 | NA | – | 20 | NA |
| Canada | 39 | 37 | 0 | 16 | 6 | 15 | 8 | 6 | 0 | 3 | 11 | 77 | 29 | 17 | 0 |
| Finland | – | 9 | 7 | – | 16 | 2 | – | 6 | 0 | – | 21 | 61 | – | 31 | 20 |
| France | 10 | 0 | 0 | 10 | 2 | 0 | 20 | 27 | 0 | 5 | 4 | 40 | 40 | 50 | 54 |
| Hungary | 27 | 11 | 0 | 8 | 15 | 0 | 1 | 3 | 0 | 21 | 41 | 68 | 32 | 23 | 18 |
| Italy | – | 1 | 0 | – | 5 | 0 | – | 5 | 0 | – | 4 | 33 | – | 61 | 33 |
| Japan | 48 | 19 | 0 | 3 | 10 | 1 | 5 | 13 | 11 | 1 | 5 | 50 | 32 | 46 | 30 |
| Korea | 33 | 48 | 0 | 10 | 17 | 17 | 2 | 2 | 11 | 4 | 10 | 59 | 40 | 7 | 0 |
| Mexico | 20 | 2 | 93 | 19 | 18 | 0 | 0 | 0 | 0 | 2 | 52 | 7 | 1 | 6 | 0 |
| Netherlands | – | 0 | 0 | – | 0 | 0 | – | 0 | 0 | – | 0 | 50 | – | 50 | 50 |
| Spain | 2 | 0 | 0 | 63 | 7 | 18 | 0 | 6 | 16 | 10 | 36 | 26 | 2 | 33 | 10 |
| Sweden | 9 | 0 | 0 | 27 | 39 | 8 | 55 | 11 | 8 | 0 | 17 | 38 | 0 | 17 | 13 |
| Switzerland | 10 | – | 5 | 17 | – | 12 | 1 | – | 0 | 6 | – | 28 | 53 | – | 33 |
| Turkey | 26 | 15 | 0 | 5 | 2 | 0 | 1 | 0 | 4 | 14 | 21 | 81 | 31 | 39 | 7 |
| United Kingdom | 26 | 28 | 0 | 4 | 2 | 0 | 1 | 10 | 6 | 1 | 5 | 32 | 55 | 47 | 43 |
| United States | 22 | 34 | 12 | 26 | 10 | 5 | 14 | 21 | 20 | 1 | 3 | 12 | 22 | 18 | 27 |

–: No nuclear education programme. NA: Data are not available.
Levels of degrees: B = Undergraduate; M = Graduate-Master; D = Graduate-Doctor.

By and large, the data show that at both the undergraduate and master levels, a significant proportion of students chose to continue to study; at the doctoral level, a large proportion of graduates chose a career at an academic institution or nuclear research institute. It is also evident that some number of graduates at all levels did not enter the nuclear industry.

A country-by-country analysis shows that the country-specific definitions of nuclear education, combined with the local practices of employers, strongly influence the young graduates' first choice. In particular, where the curriculum consists of a set of eclectic courses on nuclear subjects within a programme mainly centred on classical engineering specialities, the fraction of students entering non-nuclear fields is, as one would expect, higher.

### *Recent changes in nuclear-related courses*

Universities and higher technical institutes have responded to the consolidation of the nuclear industry in a variety of ways. These include:

- A decrease in the number of undergraduate programmes centred on nuclear subjects and a move to broaden the programmes to related fields that emphasise medical applications, radiation health engineering, and computer sciences.

- The merger of some programmes with mechanical, energy-related, or environmental programmes, or the offer of a nuclear-engineering specialisation within other major options.

- An increase in the number of courses related to the fuel cycle, waste management, and radiochemistry.

- The emergence of new courses in reliability, safety systems, and thermal hydraulics that, although not specifically nuclear, find many applications in the nuclear field. Such courses are also offered within general engineering curricula.

In a number of cases, such changes in the content of the programme are reflected in changes to the name of the curriculum, or the transfer of courses from the faculty of science to that of applied sciences.

At the graduate level, some universities merged other specialisations with the nuclear-specific curriculum that they offer students already holding a master's degree in engineering.

## The status of in-house training

In-house training is defined as a systematically structured set of courses given to the scientific and technical staff who have already graduated from educational organisations and are hired by research institutes, government services, utilities, and industrial companies. These programmes provide the staff with a nuclear competence within their domain of professional activity. In-house training is intended mainly for employees and is paid for by the company. In cases where external applicants attend, there is usually a fee.

Courses are often provided to new employees as an introduction to their function within their organisation. Training is also provided to experienced staff when a change in their work or a strengthening of their competence is needed.

In-house training often addresses the needs of employees who must acquire skills and knowledge that is not addressed through the curriculum of universities and higher technical institutes. It often prepares technicians and skilled workers for specialist duties.

The data for this report are provided by 77 institutions: 17 research institutes, 30 power companies, 15 manufacturers, 7 engineering offices, and 8 regulatory bodies.

The subjects cover broad areas in both theoretical knowledge and practical skills.

Theoretical courses cover subjects such as: reactor physics; radiochemistry; radiation protection and health physics; operation, procedure, and accident analysis; mechanical and electrical equipment, instrumentation, and control; and regulation, codes, and safeguards.

Courses in practical skills include: training using simulators, practice in control room procedures, non-destructive testing, and welding and maintenance.

***Number of trainees and instructors and man-hours of training provided***

Table 6 shows the situation in each country for 1990 and as a ratio thereof for 1995 and 1998. Full details are given in Table A2.8 of Annex 2.

Although the number of trainees varies considerably from country to country, probably because of the definition of a trainee, overall the numbers have increased from 1990 to 1998, but there has been a decline from 1995 to 1998.

In contrast, the number of instructors has shown a marked decrease between 1990 and 1998, although there was a slight rise between 1990 and 1995.

In all countries except France, Turkey, and Hungary, in-house training (as quantified by the number of man-hours of training provided annually) increased over the period 1990-1998, showing the importance that employers place on the competence of their personnel.

Table 6. **Comparison of annual averages of the number of trainees, instructors, and hours for training**

| Country | Trainees | | | Instructors | | | Hours of training | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Ratio from 1990 | | Number | Ratio from 1990 | | Number | Ratio from 1990 | |
| | 1990 | to 1995 | to 1998 | 1990 | to 1995 | to 1998 | 1990 | to 1995 | to 1998 |
| Belgium | 9 120 | 0.96 | 0.83 | 40 | 3.43 | 2.68 | 3 200 | 1.40 | 3.99 |
| Finland | 592 | 1.25 | 1.42 | 20 | 1.00 | 1.25 | 1 720 | 0.88 | 1.02 |
| France | 1 134 | 1.54 | 1.61 | 642 | 1.10 | 0.15 | 56 738 | 0.93 | 0.70 |
| Hungary | 1 780 | 1.23 | 0.49 | 162 | 1.11 | 0.83 | 3 562 | 1.22 | 0.66 |
| Italy | (a) 120 | NA | NA | (a) 12 | NA | NA | (a) 100 | NA | NA |
| Japan | 4 317 | 1.85 | 1.94 | 154 | 1.14 | 1.49 | 15 592 | 1.09 | 1.04 |
| Korea | 4 495 | 1.33 | 1.29 | 136 | 1.12 | 1.14 | 3 580 | 1.36 | 1.04 |
| Mexico | 4 734 | 1.19 | 1.37 | 149 | 0.38 | 0.54 | 10 156 | 1.20 | 1.29 |
| Netherlands | 466 | 1.11 | 1.05 | 29 | 1.14 | 0.86 | 10 060 | 1.05 | 1.11 |
| Turkey | 118 | 0.51 | 0.63 | 36 | 0.56 | 0.56 | 544 | 0.65 | 0.59 |
| Spain | 789 | 2.07 | 0.58 | 50 | 1.04 | 0.76 | 54 692 | 1.16 | 1.12 |
| Sweden | 130 | 1.56 | 1.23 | NA | NA | NA | (b) 72 | 1.78 | 1.72 |
| Switzerland | 1 065 | 1.17 | 1.13 | 35 | 1.00 | 1.00 | 8 350 | 1.14 | 1.33 |
| United Kingdom | 1 500 | 3.95 | 1.00 | 21 | 1.19 | 1.14 | 9 800 | 2.29 | 2.31 |
| United States | 3 830 | 1.75 | 1.40 | 141 | 1.31 | 1.15 | 140 300 | 2.39 | 2.32 |
| **TOTAL** | **34 070** | **1.45** | **1.21** | **1 615** | **1.10** | **0.71** | **318 366** | **1.70** | **1.64** |

Note: (a) number in 1998. (b) man-weeks.

*Age distribution of trainers*

The age distribution of trainers and instructors in industry and research institutes is given for each country in Table 7. Details are given in Tables A2.9 and A2.10 of Annex 2. As for their counterparts in academia, the age profile is indicative of the health of nuclear training. For most countries, the largest number of trainers occur in the 41 to 50-year-old group. For Belgium, France, and Spain, the largest number is in the 31 to 40-year-old group. Only Switzerland shows a higher value at 51-60.

Table 7. **The age distribution (as a percentage) and average age of trainers and instructors in 1998**

| Country | Age distribution (% of total) | | | | | | Average age |
|---|---|---|---|---|---|---|---|
| | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ | |
| Belgium | 16 | 33 | 30 | 16 | 4 | 1 | 41 |
| Finland | 9 | 12 | 64 | 16 | 0 | 0 | 44 |
| France | 5 | 58 | 25 | 12 | 0 | 0 | 40 |
| Hungary | 0 | 24 | 58 | 16 | 2 | 0 | 45 |
| Italy | 0 | 25 | 42 | 25 | 8 | 0 | 47 |
| Japan | 9 | 24 | 42 | 22 | 3 | 0 | 44 |
| Korea | 0 | 20 | 48 | 32 | 0 | 0 | 47 |
| Mexico | 0 | 39 | 60 | 1 | 0 | 0 | 42 |
| Netherlands | 0 | 35 | 50 | 15 | 0 | 0 | 44 |
| Spain | 10 | 56 | 30 | 4 | 0 | 0 | 38 |
| Switzerland | 11 | 17 | 31 | 34 | 6 | 0 | 46 |
| Turkey | 0 | 25 | 75 | 0 | 0 | 0 | 43 |
| United Kingdom | 0 | 35 | 48 | 17 | 0 | 0 | 44 |
| United States | 4 | 29 | 45 | 22 | 0 | 0 | 44 |
| **TOTAL** | **6** | **29** | **45** | **18** | **1** | **0** | **44** |

*Facilities*

Forty-six organisations described the facilities they have available for training purposes (see Table 8 below). The respondents consider that these facilities contribute highly to training quality and trainee competence.

Table 8. **Research facilities and average ages by group in 1998**

| Facility | Number | Average age (in years) | Changes in status from 1990 to 1998 |
|---|---|---|---|
| Research and training reactors | 13 | 27 | 1 reactor constructed,<br>4 reactors decommissioned |
| Hot cells | 8 | 30 | 1 hot cell decommissioned |
| Laboratories for radiochemistry | 20 | 23 | 1 laboratory constructed |
| Laboratories for radiation measurement | 27 | 21 | |
| Others (largely simulators) | 36 | 11 | |

***Qualification and certification***

Institutions providing in-house training often award trainees with a certificate indicating compliance with the requirements set for the course.

The formal value accorded to the training, however, varies widely with the nature of the course, the recognition afforded to the institution organising the training, and legal or regulatory requirements. In some cases, the training organisation must be officially qualified to grant a legally recognised certification of competence to trainees that have satisfactorily fulfilled the requirements of the course.

In some cases, the validity of the certificate or license is limited in time.

In other cases, no certificate is given to the trainee, but access to the records is open to the trainee and his or her supervisor, or the records are inserted in the trainee's file held by the personnel administration of the institution.

The value of training is highly regarded by almost all organisations. Training is often considered to be essential to the organisation's mission and in many cases is reinforced by an operative legal framework.

Because of the small size of some organisations or small groups for specific training, some organisations find it difficult to organise in-house training courses. In those cases, either training is bought from other organisations, companies, and consultants, or inter-organisational training units are set up.

## Collaboration among universities, industry and governments

The wide range of subjects cited in the responses reflects the differing situations at the 119 universities spread over the 16 countries that responded to the questionnaire.

To attract candidates to university programmes, collaboration with other, often foreign universities, was considered to be highly beneficial. However, several universities deplored the lack of communication and co-ordination among universities within their own country. This deficiency has led to a lack of coherence and completeness of programmes – for example, some topics are not covered or, conversely, lecture content overlaps between programmes.

Collaboration between industry and academia varies widely. Where collaboration exists and runs effectively, it is highly valuable, particularly when a university is involved in nuclear professional activities with industry. Collaborations keep the academic subjects relevant to the actual problems encountered in industry – a key element for attracting students to the field. Traditionally, a main area of collaboration has been between the research or development branch of industry and a university. This aspect of collaboration is not as great now as it was in the past.

Typical examples of collaborative activities include industry providing: supervision or other support for thesis work, staff with industrial experience to teach university courses, sponsorship of professorships and co-operative research, help in organising technical sessions, a yearly prize for the best thesis in nuclear engineering, and internships to students.

Government participation in collaborative programmes has generally declined. It most often appears limited to the financial support of large-scale expensive facilities such as university research reactors and a few research programmes.

By and large, the collaborations among industry, research centres, and governments frequently rely more upon personal initiatives than upon an institutional policy. However, institutions that do have active collaborative programmes tend to find their situations more satisfactory, particularly in the area of recruitment.

The European Community Action Scheme for the Mobility of University Students (ERASMUS), established in 1987, promotes students to carry out a period of study (between 3 months and a full academic year) in another of the 24 participating countries and provides Mobility Grants for Students. The Marie Curie Fellowships give young researchers better research training circumstance. For example, the Marie Curie Industry Host Fellowships are aimed particularly at young researchers without previous industrial or commercial research experience, give the opportunity to receive transnational industrial research training in companies, and encourage co-operation and the transfer of knowledge and technology between industry and academia. The EURATOM Framework Programme consists of co-funding and co-ordinating “research and training” activities in the form of multipartner contracts involving industry, utilities, regulatory authorities, research organisations, and universities across the 15 Member States of the European Union (EU) for a total budget of approximately 200 million Euro over 4-year periods (see Annex 3).

**Efforts to encourage the younger generation**

Activities and initiatives are being taken by universities, industry, and to a lesser extent, research institutions to tackle the problem of low enrolment for science and engineering in general and nuclear subjects in particular in institutions of higher learning. This problem is attributable to numerous interlinked factors, including a negative public image, few new power plant construction projects, the general lack of sufficient government programmes and research projects, and the perception of a job sector with poor opportunities because of an unclear future.

Data from the questionnaire show that a wide range of initiatives has been undertaken by universities, industry, and research institutions. However, the objectives of the initiatives appear diverse, in that they were not aimed exclusively at encouraging the younger generation to enter the nuclear field. Some initiatives aim to increase the confidence of the public; some reflect the evolution of institutions to a scientifically and technically changing field.

The data do not indicate that there are any efforts made at the national level to encourage the younger generation to enrol in nuclear subjects. Such efforts are often made by individuals active within organisations.

In some cases, the numerous changes in nuclear-related academic courses cited in the present chapter appear to correspond more to the normal evolution of science and technology than to the decreasing number of students and the ageing of the teaching staff.

Many respondents are fully aware that information dissemination effort takes a lot of time over long periods before it becomes effective and results are identified. This is particularly true when the target is a fairly general public (for example, high school teachers and students).

## 3. DISCUSSION

### Causes for concern

#### *Public perception*

In recent years, the public perception of the nuclear industry has generally been poor, very often as a result of adverse media coverage. The low opinion that the public has held of the industry (an opinion that is generally ill-informed) has resulted in a lack of political support. However, the political stance is beginning to change as governments re-examine their approach to nuclear energy in the light of the role that it could play as concerns grow regarding climate change and global warming.

#### *Students' perception*

Given the low opinion by the public of the nuclear industry, it is hardly surprising to find students are less than enthusiastic about it. Anti-nuclear sentiment among young people plays its part, but the perceived lack of career prospects is the most widely reported reason for low enrolment. Students will not choose nuclear academic programmes unless nuclear-related jobs and good salaries are offered them after graduation. With the industry going through a phase of consolidation, such guarantees cannot be made in many countries. Ironically, perception differs from reality in a few countries, especially the United States, and the job market is actually quite healthy. Whether the perception is real or apparent, the effect is the same; some countries are already reporting that the number of students choosing a nuclear orientation is too low to respond to industry needs. It appears that this mismatch may grow.

#### *University programmes*

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

At the undergraduate level, although the number of places has remained fairly constant, the number of degrees awarded has decreased in all countries except the United Kingdom and Japan. At the master level, there is an almost even split between countries reporting an increase in the number of graduates and those reporting a decrease. At the doctoral level, the number of graduates is stable or increasing; only Hungary and the United States report a decrease. The data show that, overall, a high percentage of graduates, at all levels, having a nuclear content to their education enter the nuclear industry.

Box 1. **The health of nuclear engineering at universities**

*Select questionnaire responses:*

"Given low enrolment, long-term survival of the programme is questionable." (Belgium)

"The threat scenario is that the increasing retirement happens together with a decreasing interest of the younger generation in the nuclear field." (Finland)

"Perhaps in the next few years, the educational programmes may not be able to survive." (Sweden)

"Universities are suffering from the general public mentality against basic research in general and against nuclear research in particular". (Switzerland)

"The condition of 'traditional' nuclear engineering training is very poor with only one MS course and some undergraduate taster modules". (United Kingdom)

Although the overall picture for the number of graduates during this period may seem reassuring, there are underlying causes for concern. Although it is difficult to quantify from the questionnaire, because there is no unique definition of what constitutes nuclear education, it is the collective judgement of the Expert Group that the nuclear content of many undergraduate courses has declined with time. The pool of knowledge at the undergraduate level is therefore decreasing year by year. This will eventually have serious repercussions on the master and doctoral levels, where the situation is currently far more encouraging than for undergraduate, in terms of both quantity and quality of students. With fewer nuclear courses available there will be fewer students wanting to study nuclear topics for higher degrees, and with a broadening and hence dilution of courses at the undergraduate level, there will be fewer students capable of studying for them. In terms of numbers, it is true that the present needs of the industry are being met. However, doubts as to the quality of graduates are already being expressed by industry in a period of consolidation with a decreasing demand. Unless the situation is at least stabilised, in the next few years there will be a shortfall of quality graduates to cope with the existing concerns of the industry, let alone to staff an expanding industry.

The number of full-time faculty members has decreased in the United Kingdom and the United States but has increased in France and Japan. In other countries, the numbers have remained fairly constant over the period in question. The data for part-time faculty members are somewhat confused, but the numbers are generally rising, especially in countries where the number of full-time faculty members is falling. The age distribution of faculties shows a peak at 41-50 for most countries, with Belgium, Japan, Switzerland, and the United Kingdom showing a higher age peak at 51-60, Turkey showing a lower age peak at 31-40, and France showing a lowest age peak at 21-30.

The main concern is that there are few young faculty members coming through. This is particularly worrying in countries where the age peak is 51-60, and it is a serious concern where the age peak is 41-50. When faculty in these age brackets and above have retired, there will be a significant drop in the number of faculties. The inevitable outcome will be a reduction in the number and choice of courses, which in turn, will dramatically affect the quantity and quality of graduates. From these graduates will come the next generation of faculties, and unless something is done to arrest it, the downward spiral will continue.

Most university equipment and facilities are over 25 years old. Research reactors and hot cells have been decommissioned, with no replacements planned. However, although three radiochemistry laboratories were closed, four new ones were opened, and laboratories for radiation measurement are regularly modernised.

Generally, there is a decline in facilities, which will increasingly affect the capability of universities to do leading-edge research for industry. Because the industry is currently concentrating on operating existing plants more efficiently, it could be argued that this is not important at present. However, such a decline erodes future capability and deters both students and faculty from working in the nuclear area.

***Industry programmes***

Companies offer training programmes to support both broad-based knowledge and specific skill development. Training is designed for both new graduates and experienced staff with the aim of increasing the competence of the trainees in their specific function within the organisation. In-house training is intended mainly for employees and is paid for by the company. When external applicants attend, they must pay for the training.

In-house training is generally increasing, with a wide range of courses being offered. Only Belgium, Hungary, Turkey, and Spain show a decrease in the number of trainees between 1990 and 1998. Likewise, the amount of time devoted to training has increased over this period for all countries except France, Hungary, and Turkey. With the nuclear industry consolidating in NEA Member countries, a decrease in training might be anticipated. In reality the opposite is true; increasing regulatory requirements and the need for more flexible workforces have led to increasing training requirements.

The age profile of trainers shows a peak at 41-50 for most countries. While it is logical that experienced staff be used as trainers, it must not be forgotten that, with early retirement schemes operating in many organisations, a considerable number of those trainers are likely to retire over the next few years. While young trainers are coming through, the numbers are not as great as those that will be leaving. Given the deteriorating university situation, the provision of suitable trainers in the near future is a matter of concern. Belgium, France, and Spain, which show an age peak at 31-40 for trainers are much better positioned.

Most of the facilities are old, usually in excess of 20 years. More research reactors were decommissioned than built, and one hot cell was decommissioned during the period. On a positive note, one laboratory for radiochemistry was constructed.

Generally, in terms of facilities and trainers, the needs of the industry are being met. As the industry evolves, it would be expected that in-house training competence evolves so that demand is always satisfied. Certainly, with the decline in university facilities and faculties, there will be little opportunity to outsource training there. Also, because the situation regarding nuclear education is roughly the same from one country to another, there can be no guarantee that what is no longer available at home can be obtained abroad. There is already evidence that companies, if not actively collaborating, are at least making available places in courses to other organisations, and it may be expected that this trend will continue.

**Positive developments**

Many specific activities, submitted by respondents, have had great success and are shown as "Examples of best practices" in Box 3 in the Conclusions and Recommendations.

***Universities***

In spite of the overall contraction in nuclear education in universities during the period of the survey, some new courses have been started. France started six programmes, Japan started three programmes, and Mexico started new master's and doctoral programmes. Some of the new courses are directly related to nuclear power and deal with the fuel cycle and waste management; others are more biased towards engineering and deal with reliability, safety systems, and thermal hydraulics; and some lie outside nuclear power but have a nuclear content, for example, radiation science and nuclear medicine.

Some departments have sought to widen the appeal of their courses either by broadening the content or by changing the name. However, while advanced energy systems or nuclear and radiological engineering may be more successful in attracting students, they are much less specific, in both name and content to, for example, nuclear engineering. In some universities, nuclear programmes have been merged with mechanical, other energy-related, or environmental programmes. While this approach keeps nuclear education alive in the short term, there is the danger that the nuclear content will diminish with time and may eventually disappear altogether in select countries. Faced with declining enrolment, other universities have combined forces and reduced the number of courses to match the number of students. For example, in Belgium, six university nuclear programmes have been coalesced into two.

In addition to these pragmatic and responsive measures, many universities are pro-actively marketing their nuclear courses. High school students are offered open days and summer "taster" programmes. Newsletters and web pages offer additional information and help sustain any initial interest. Freshmen are encouraged to take at least an introductory nuclear course as part of their degree. Most universities are able to offer several scholarships a year worth from USD 500 to over USD 10 000. These are funded by nuclear industry societies, national research institutes, regulatory bodies, utilities, and/or governments. It is encouraging to note that, overall, the number of grants and fellowships remain relatively stable.

Industry and research institutes provide lecturers so that students can better relate theory to practice. Students are motivated by links with external laboratories and institutes, and many universities encourage internship, the length of which typically varies from 3 months to as long as 16 months. Because the delivery of material is also important, universities are moving away from dwelling on pure science to emphasising its application in developing new technologies. Use of multi-media resources (for example, CD-ROM) also helps to stimulate interest.

***Industry***

The nuclear industry is in a period of consolidation, which makes it difficult to attract the comparatively small number of high-quality new recruits that are needed each year. Companies are tackling the problem in a number of ways. Advertising (either as corporate publicity or specifically targeted recruiting efforts), encouraging student visits, holding open days, and organising short courses are common in many countries. Links with universities are particularly effective. Companies provide lecturers and input to courses, sponsor professorial chairs, and help universities organise technical sessions. Direct contact with students is made by providing summer and part-time jobs. Students thus become informed about the industry and obtain a realistic view of career prospects without any obligation while the company receives what is effectively an extended interview. A one or two-month-long summer project, including lectures and field trips, is an effective way of engaging those already disposed to join the industry. A few countries offer enhanced salaries, but most follow what could be called traditional patterns of recruitment, i.e., good salaries and working conditions, continuous professional development, and the prospect of secure employment.

Although a wide range of courses is offered with a strong focus on individual company needs, much training is in response to regulatory requirements. In such cases, certification from the regulatory body or an external organisation is the norm. For other types of training, some companies award a certificate as an incentive for the individual. Most companies keep training records, which form a skill record for the individual that can be included in a career summary, another incentive for training. Some companies stipulate that without fulfilling specific coursework the individual will not be qualified to rise to a higher grade in the company.

Because of the increasing technical and regulatory challenges, the quality and success of in-house training must be high. In broad terms, a site licence as well as a competitive edge in a deregulated energy market require the continuing provision of a satisfactory level of training for all staff.

Box 2. **Employment opportunities**

*NOTE: Examples of individual responses to the questionnaire.*

"... despite its low value, the number of graduates seemingly still largely exceeds the needs of the nuclear energy industry." (Belgium)

"All our graduates easily find positions in the nuclear fields." (France)

"Now it is more than needed, in the near-term programmes it will not be sufficient." (Spain)

"The current level of nuclear education is sufficient for the supply of manpower caused by retirement…" (Sweden)

"Current level of nuclear education seems – at the moment – to be sufficient." (Switzerland)

"... there has been a very good uptake rate of graduates by the industry coming from specialised master's level courses." (United Kingdom)

" ... a prevailing perception that the job market is poor for nuclear engineers, while the reality is that the market is currently very good." (United States)

***Collaborations***

Collaboration between industry and academia is widespread for many, but not all Member countries, and as already noted, there are some common themes. Internship programmes, lectures from industry experts, scholarships from industry, and sponsored professorial chairs are common to many countries.

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

Sweden has established a Nuclear Technology Centre, which is a collaborative effort by industry and universities to improve educational and research activities in nuclear technology. In the United Kingdom, a centre of excellence in nuclear chemistry is being established with industry support to ensure that this core competence is preserved in at least some UK universities. Collaboration among utilities, the national research centre, and universities has been effective in supporting doctoral students and young researchers in Switzerland. Industrial research chairs at universities, combining funding from industry research institutes and government, have been particularly successful in Canada in stimulating nuclear research and training highly qualified personnel. The Lawrence Livermore National Laboratory in the U.S. has established the Glenn T. Seaborg Institute for Transactinium Sciences to further the fundamental and applied science and technology of the transactinide elements.

International collaboration is somewhat limited. The Frederic Joliot-Otto Hahn Summer School in Reactor Physics at Cadarache and Karlsruhe is valued by a number of countries. At the other end of the spectrum, the American Nuclear Society operates an international student exchange programme. The International Youth Forum in Obninsk, Russia, allows young scientists from different countries to meet. Countries in the European Union are involved in various programmes supported by the Union, such as 5th Framework, 1998-2002. The NEA, based in Paris, promotes international discussion and collaboration through its various committees and expert groups.

# 4. CONCLUSIONS AND RECOMMENDATIONS

The large experience and continuing development of nuclear technology within NEA Member countries represent an enormous asset for society as a whole. This is truer than ever in the current global situation of rapidly growing energy demands and corresponding environmental concerns. The present trends observed in nuclear education are thus particularly worrying and call for urgent action. It is in this light that this study's conclusions and recommendations have been formulated. Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. Fulfilling crucial present requirements and maintaining important future options will thus be precluded, constituting a breach of responsibility on the part of governments and industry for longer-term strategic planning.

## The deterioration of nuclear education

### *Conclusion*

> ***There are now fewer comprehensive, high-quality nuclear technology programmes at universities than before.***

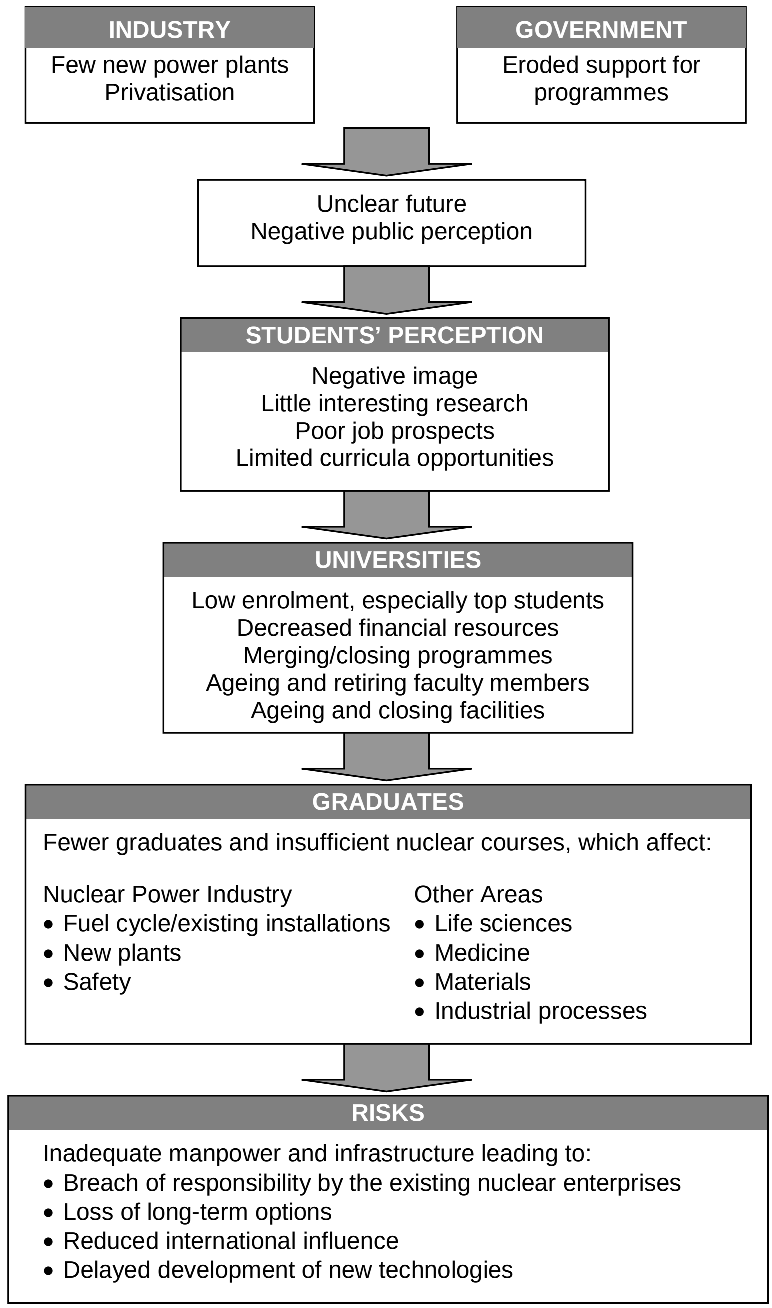
The ability of universities to attract top-quality students, meet future staffing requirements of the nuclear industry, and conduct needed leading-edge research is becoming seriously compromised. Facilities and faculties for nuclear education are ageing, and the number of nuclear programmes is declining. The trend is observed in most NEA Member countries. Principal reasons for the deterioration of nuclear education and its anticipated eventual impact on the nuclear industry are illustrated in Figure 2.

The number of degrees with a nuclear content awarded to students has generally decreased. Although this trend is not directly visible in the data, members of the Expert Group have expressed concern about the depth and extent of the nuclear content of undergraduate degrees currently being awarded. There is a serious concern that the knowledge acquired by students at the undergraduate level is decreasing year by year. Major repercussions on the master and doctoral levels could occur soon, although the situation has been stable over the period covered by the report.

As depicted in Figure 2, student perception, an important factor contributing to low enrolment, is affected by the educational circumstances, public perception, industry's activities, and government-funded nuclear programmes. The negative perception may be shared by many in the public, including a student's parents, teachers and friends. The lack of new nuclear power plant construction (a symbolic issue in nuclear activities), the privatisation of nuclear plants, and weak government support to nuclear programmes create an unclear image of the future. The combination leads young students to believe that job prospects are poor and that there is little interesting research. Nuclear is broader than "nuclear power", but it is hardly ever perceived as such. Consequently, students hesitate to enter the nuclear field.

Because of these limiting conditions, nuclear programmes have failed to attract young students, who are sensitive to educational circumstances and career opportunities. Low enrolment directly affects budgets, and budgetary cuts then limit the facilities available for nuclear programmes. Unless something is done to arrest it, the downward spiral will continue. And there will be no quick fix to resupplying the pipeline of students, faculty, researchers, operators, regulators, and the companion infrastructure.

Figure 2. **The current situation of nuclear education**



***Recommendation***

| |
|---|
| ***We must act now. The actions, described in subsequent recommendations, should be taken up urgently by government, industry, universities, research institutes and the NEA.*** |

Nuclear education and training are not yet at a crisis point, but they are certainly under stress in many NEA Member countries, the notable exceptions being France and Japan. The needs of the industry, in both recruitment and research, have declined as it has reached maturity and seeks to be more competitive in a deregulated energy sector. However, a sufficiently robust and flexible nuclear education is crucial to support the industry as it evolves. Research institutes and the NEA also share the benefits and responsibilities of maintaining vigorous education programmes. They can provide creative means and help to co-ordinate activities in order to interest candidates in becoming the future experts of the university and industrial community. In addition, governments have important responsibilities for keeping nuclear programmes in universities healthy and able to attract top-quality students.

Human resources do not materialise instantly, a minimum of four to five of higher education is needed to train someone in nuclear technology. If the present trends and their consequences are to be averted, an investment in nuclear education must be made today.

## The important role of governments in nuclear education

***Conclusion***

| |
|---|
| ***Governments are responsible for doing what is clearly in their countries' national interest, especially in areas where necessary actions will not be taken without government. They have an important multifaceted role in dealing with nuclear issues: managing the existing nuclear enterprise, insuring that the country's energy needs will be met without significant environment impact, and influencing international actions on nuclear matters that affect safety and security.*** |

*Managing the existing nuclear enterprise.* Whether one supports, opposes, or is neutral about nuclear energy, it is evident that there are important current and long-term future nuclear issues that require significant expertise. This is largely independent of the future of nuclear electric power. These issues include: continued safe and economic operation of existing nuclear power and research facilities, some of which will significantly extend their planned lifetimes; decommissioning and environmental protection; waste management; and advancing health physics. These needs call for a guaranteed supply of not only new students, but also high-quality students and vigorous research.

*Preserving medium and long-term options.* While few new nuclear power plants are currently on order, governments must consider and protect their countries' medium and long-term energy options. Expertise must be retained so that future generations can consider the role of nuclear power as part of a balanced energy mix that will reduce $CO_2$ levels, preserve fossil fuel resources, contribute towards sustainable development, and respond to geopolitical and other surprises that are sure to occur.

*Sustaining international influence.* The safe operation of nuclear installations is of paramount importance, and countries will only seek advice and be influenced by those who are at the cutting edge of nuclear technology. When the developing world moves to further exploit nuclear technology, it would be helpful that NEA Member countries have the necessary infrastructure and know-how to assist them upon request on issues such as safety, environmental protection and waste management.

*Pushing the frontiers in the new technologies.* Investment in nuclear research and development has created new technologies and brings benefits to a wide area, as nuclear technology has widespread multidisciplinary character and requires the enhancement of many cutting-edge technologies with varied non-nuclear applications. Government should consider nuclear research and development as a part of their technology policy to enhance technology competitiveness.

***Recommendations***

***Governments should engage in strategic energy planning, including consideration of education, manpower and infrastructure.***

In the absence of widely acceptable, technically sound, and affordable alternatives for providing an environmentally sustainable energy supply, nuclear power will be needed. It is part of the prudent mix of energy efficiency, renewable energy resources, nuclear, and fossil fuels that analysts believe will be required to meet energy demand and quality-of-life issues in the future. However, as with energy efficiency, renewable energy and others, market forces without government involvement may not preserve nuclear power as an option.

By nature, nuclear power stations have a long lead time to operate and are capital intensive, and a significant return on investment is realised only towards the end of the station's lifetime. These characteristics contrast with the short-term economic considerations that are currently beginning to dominate the energy sector as it becomes deregulated and is led more by market forces than by government strategy. The nuclear industry has risen to the challenge by increasing the efficiency of operating existing plants and power stations. The result is consolidation with little investment in new power stations. There is an air of uncertainty over the medium and long-term future of the nuclear industry in spite of the potential benefits offered by nuclear power. Strategic energy planning by governments would help define and make more secure the role of nuclear energy.

***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.***

As a consequence of current economic strategies, the nuclear industry is going through a period of consolidation. Universities have reacted to the decreasing requirements of the industry by reducing their commitment to research and teaching in nuclear areas. This has led to a worrying erosion of the knowledge base that is clearly identified in this report. Yet, there is a responsibility to ensure that, at the very least, resources and expertise are adequate to address properly the nuclear activities that are necessary today – operating plants and facilities and addressing decommissioning issues. There is also an obligation to the next generation to maintain and advance nuclear expertise so that the role of nuclear power can be adequately assessed, and future options can be informatively considered, even by countries that currently have a nuclear moratorium. Governments need to step up and meet these responsibilities and obligations.

***Governments should support, on a competitive basis, young students. They should also provide adequate resources for vibrant nuclear research and development programmes including modernisation of facilities.***

The facilities available for nuclear education are ageing, and the number of students is declining. These situations aggravate each other. To break the downward spiral, governments should fund modernisation by supporting outstanding nuclear research and development on a competitive basis and provide scholarships for the best and brightest graduate and undergraduate students.

***Governments should provide support by developing "educational networks or bridges" between universities, industry and research institutes.***

Collaboration can help universities and research institutes to provide high-quality education, attract positive attention to the nuclear industry, provide unique opportunities for students and, hence, foster innovation and create momentum. Governments should provide support by developing educational networks between universities, industry and research institutes by providing:

- An institutional framework for students to study in joint programmes among universities, industry and research institutes.
- Large experimental facilities such as research reactors that universities and institutes share for research or education.
- Matching investments from industry for university research and development projects.

## The challenges of revitalising nuclear education

### *Conclusion*

***The ability of universities to offer nuclear programmes is deteriorating, and the number and quality of students that participate are declining.***

Conditions for offering comprehensive, high-quality nuclear technology programmes at universities are less favourable than earlier. The ability of universities to conduct leading-edge research for the nuclear industry is becoming seriously compromised because the facilities and faculties for nuclear education are ageing and the number of nuclear programmes is declining.

For nuclear programmes that remain, new courses have been added in some cases, but generally the picture is one of courses being eliminated or merged. Some universities have managed to preserve their programmes by broadening their content to appeal to a wider audience, but the danger is that the nuclear content is becoming diluted.

The number of available facilities has declined, and the average age of those remaining in service exceeds 25 years. Whereas small and medium-sized facilities are well-maintained and constantly upgraded, large facilities must manage increasing maintenance costs and increasingly strict regulations while facing budgetary cuts. In particular, several of the research and training reactors that provide various experimental tools have been decommissioned during the last eight years. The average age of the remaining research and training reactors is 32 years.

The age distribution of faculty members shows a peak in the 41-50 age range and the 51-60 age range for most countries. When the senior staff members retire, there will be a significant drop in numbers. Their replacement by faculty members of equivalent knowledge and experience is somewhat in doubt. The inevitable outcome will be a reduction in the number and choice of courses, which will affect the quantity and quality of graduates who, in turn, will be the determining factors for the next generation of faculty members.

As the number of faculty members decreases, fewer independent expert witnesses will be available for the industry and regulatory bodies to call upon. This will have an inevitable negative effect on the decision-making processes in the nuclear industry, to the detriment of both the industry and society at large.

***Recommendations***

***Universities should provide basic and attractive educational programmes.***

As an introduction to undergraduate nuclear engineering, universities should provide basic and broad courses including general energy, environment, and economic issues arising in the 21st century. Efforts should continue to adjust the curriculum, develop new disciplines, and implement measures to keep pace with the evolution of nuclear technologies so as to develop research areas that are attractive and exciting to students and meet the needs of industry.

***Universities should interact early and often with potential students, both male and female, and provide adequate information.***

Potential students such as university freshmen and high school students do not have appropriate and sufficient information on nuclear education in universities. Information should be provided to arouse their interest in nuclear technology. Faculty members should visit high schools, hold “open days”, and work with them. Potential students can be reached by allowing them to “touch hardware” and learn more about challenges and opportunities through a highly “interactive web.”

**High-quality training needed for staff in industry and research institutes**

Industry must recognise its role and interests in assuring an adequate supply of capable students and vigorous research, as well as maintaining the high-quality training needed for staff in industry and research institutes.

***Conclusion***

***There currently appear to be enough trainers and quality staff in industry and at research institutes; however, data do not show the whole picture.***

The age range for trainers in industry shows a peak at 41-50 years in most countries. Although young trainers are being trained, their numbers are not as great as those who will be leaving. Because of the more serious university situation, the provision of suitable trainers in the near future is becoming a concern.

Although there are few specific supporting data, members of the Expert Group report that there is already concern about the quantity and quality of graduates entering the industry. A shortage will affect the industry directly and will also affect the regulatory bodies because they traditionally recruit from industry.

### *Recommendations*

***Industry should continue to provide rigorous training programmes to meet its specific needs.***

Questionnaire data indicate that industry perceives its training as high-quality; companies sometimes make places in courses available to other organisations, and they expect the trend to continue.

***Research institutes need to develop exciting research projects to meet industry's needs and attract quality students and employees.***

The industry gains appeal from the public in general and students in particular when collaborations are publicised. An example of efforts to heighten appeal is a publicised opportunity for a student to spend a semester or summer at a foreign institute working with faculty, students and industry representatives.

***Industry, research institutes and universities need to work together to co-ordinate efforts better to encourage the younger generation.***

Both industry and university comments indicate that success occurs when individuals in their organisations assume leadership and market an exciting programme. With more pro-active leadership in nuclear education, there would be more professors and industry staff encouraging the younger generation to enter the nuclear field. Examples of successful efforts include: changing curricula, proactive marketing, financial support, and collaboration between industry and academia.

## Benefits of collaboration and sharing best practices

### *Conclusion*

***Renewed aggressive investments in nuclear education by NEA Member countries would help sustaining their balance of energy usage, human resources, technology, and economics.***

Many contributors to the country reports in this document voice fears of the consequences should investments decrease in nuclear education and the number of future nuclear experts decline.

Box 3. **Examples of best practices**

- **Create a pre-interest in the nuclear domain.**
  Include steps such as advertisements aimed at undergraduate candidates, high school "open days" at campuses or research facilities; regular reactor visits and campus tours for students; newsletters, posters, and web pages; summer programmes; preparation of a resource manual on nuclear energy for teachers; sponsorship of an advanced laboratory for high school students; recruiting trips and nuclear introduction courses for freshmen; and conferences given by industry and research institutes.

- **Add content to courses and activities in general engineering studies.**
  Increase emphasis on nuclear in physics and applied physics courses; organise seminars on nuclear in parallel or in liaison with the existing curriculum using speakers external to the university; set up informational meetings on the nuclear sector, existing graduate programmes, research and thesis topics; discuss employment potential and professional activities; and call attention to the environmental benefits of nuclear (energy from fission, fusion, and renewables in comparison to fossil resources).

- **Change programme content in nuclear science and technology education.**
  Include advanced courses (such as reliability and risk assessment); broaden the programme to include topics such as nuclear medicine and plasma physics; assure that the education covers the full scope of nuclear activities (fuel cycle, waste conditioning, materials behaviour); provide early real contact with hardware, experimental facilities, and industry problems; and provide interesting internships in industry and research centres.

- **Increase pre-professional contacts.**
  Encourage the participation of students in activities of the local nuclear society and its "young generation" network.

- **Provide scholarships, fellowships, and traineeships.**
  In addition to promoting several support activities (mostly technical), industry participates financially by providing scholarships and, in several instances, has initiated new educational and training schemes. The size of the awards varies widely from one country to another. Academic societies, national research institutes, and governments also provide financial help. The number of these grants has remained relatively stable.

- **Strengthen nuclear educational networks.**
  Establish and promote national and international collaborations in educational and/or training programmes, e.g. summer school, specialist courses.

- **Provide industry employees activities that are professionally more interesting and challenging and that pay more than those in the non-nuclear sectors.**
  It is an exception, rather than the usual case, that a higher salary is used as a means to attract younger graduates.

- **Provide early opportunities for students and prospective students to "touch hardware", interact with faculty and researchers, and participate in research projects.**

- **Provide opportunities for high school and early undergraduates to work with faculty and other senior individuals in research situations.**
  Use the Web and other information techniques to proactively develop more personal communication with prospective students.

***Recommendations***

***Member countries should ask the NEA to develop and promote a programme of collaboration between Member countries in nuclear education and training.***

If nuclear education and training are not yet at a crisis point in many NEA Member countries, they are certainly under stress. Although individual countries may face shortfalls, the combined expertise and resources of NEA Member countries in nuclear education are still sufficient to support the needs of the industry. Some individual countries believe that the decline in nuclear education may be averted by increased international collaboration.

***Member countries should ask the NEA to provide a mechanism for sharing best practices in promoting nuclear courses.***

Faced with declining enrolment, a few universities have reduced the number of courses offered to match student numbers. Some have sought to widen the appeal of their courses by broadening content or changing the name. Others have merged nuclear programmes with mechanical, energy or environmental programmes. In addition, most universities are trying to market their nuclear courses through a wide range of activities (see Box 3), from open days to scholarships. Initiatives, however, have been taken largely in isolation. Benefits would multiply if universities and other organisations shared techniques and efforts.

## REFERENCES

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*Annex 1*

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*Annex 2*

## NUMERICAL DATA

Table A2.1 **The number of participants in the study by country and organisation**

| Country | University | Research Institute | Power Company | Manufacturer | Engineering Office | Regulatory Body | Total |
|---|---|---|---|---|---|---|---|
| Belgium | 7 | 1 | 1 | | 1 | 1 | 11 |
| Canada | 5 | | | | | | 5 |
| Finland | 3 | 2 | 2 | | 1 | 1 | 9 |
| France | 4 (a) | 1 | | 2 | 1 | | 8 |
| Hungary | 4 | 3 | 1 | 1 | | | 9 |
| Italy | 6 | 1 | | 1 | | | 8 |
| Japan | 21 | | 8 | 8 | | | 37 |
| Korea | 6 | 1 | 1 | | | | 8 |
| Mexico | 4 | 2 | 1 | | | 1 | 8 |
| Netherlands | 1 | 1 | 1 | | 2 | | 5 |
| Spain | 6 | | 1 | | 1 | | 8 |
| Sweden | 7 | | 4 | | | 1 | 12 |
| Switzerland | 9 | 1 | 4 | | | 1 | 15 |
| Turkey | 5 | 1 | | | | 1 | 7 |
| United Kingdom | 9 | 1 | 1 | 1 | | 1 | 13 |
| United States | 22 (57) | 2 | 5 (b) | 2 | 1 | 1 | 33 (68) |
| **TOTAL** | **119 (154)** | **17** | **30** | **15** | **7** | **8** | **196 (231)** |

The numbers in parentheses include the number of universities whose data refer to another survey by USDOE.
(a) INSTN provided the collective answer of 10 courses.
(b) INPO provided the collective answer of US utilities. Four also provided individual responses.

Table A2.2 **The number of nuclear universities and programmes reported in the survey**

| Country | Universities (a) | | | Undergraduate | | | Graduate-Master | | | Graduate-Doctor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 1998 | 1990 | 1995 | 1998 | 1990 | 1995 | 1998 | 1990 | 1995 | 1998 |
| Belgium | 7 | 6 | 4 | 1 | 1 | 1 | 6 | 5 | 3 | 1 | 1 | 1 |
| Canada | 5 | 5 | 5 | 3 | 3 | 2 | 6 | 6 | 6 | 6 | 6 | 6 |
| Finland | 3 | 3 | 3 | – | – | – | 3 | 3 | 3 | 3 | 3 | 3 |
| France | 8 | 9 | 12 | 2 | 2 | 2 | 9 | 11 | 12 | 9 | 11 | 12 |
| Hungary | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 5 | 5 | 4 | 5 | 5 |
| Italy | 6 | 6 | 6 | – | – | – | 6 | 6 | 6 | 6 | 6 | 6 |
| Japan | 13 | 13 | 13 | 12 | 12 | 13 | 14 | 15 | 15 | 13 | 13 | 14 |
| Korea | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 |
| Mexico | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 3 | 3 | – | – | 1 |
| Netherlands | 1 | 1 | 1 | – | – | – | 1 | 1 | 1 | 1 | 1 | 1 |
| Spain | 6 | 6 | 6 | 5 | 5 | 5 | 3 | 3 | 3 | 6 | 6 | 6 |
| Sweden | 3 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 7 | 7 |
| Switzerland | 8 | 8 | 9 | 8 | 8 | 9 | – | – | – | 4 | 4 | 4 |
| Turkey | 5 | 5 | 5 | 2 | 2 | 2 | 5 | 5 | 5 | 4 | 4 | 4 |
| United Kingdom | 9 | 9 | 9 | 6 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 |
| United States | (b) 57 | (b) 51 | (b) 45 | 19 | 19 | 19 | 22 | 22 | 22 | 19 | 20 | 22 |
| **TOTAL** | **144** | **138** | **134** | **74** | **73** | **74** | **97** | **102** | **101** | **92** | **97** | **102** |

(a) The number of universities with nuclear programmes.

(b) Data from another survey by USDOE.

## Table A2.3 **Number of students and faculty members in universities**

| Country | | Belgium | Canada | Finland | France | Hungary | Italy | Japan | Korea | Mexico | Nether-lands | Spain | Sweden | Switzer-land | Turkey | United Kingdom | United States | **TOTAL** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Undergraduate** | | | | | | | | | | | | | | | | | | |
| Number of students | 1990 | 15 | 29 | – | 55 | 120 | – | 503 | 544 | 22 | – | (d) 100 | 97 | 94 | 146 | 364 | 1 398 | 3 487 |
| | 1995 | 15 | 31 | – | 63 | 150 | – | 504 | 583 | 20 | – | (d) 134 | 132 | 86 | 189 | 376 | 1 017 | 3 300 |
| | 1998 | 8 | 28 | – | 56 | 170 | – | 540 | 527 | 21 | – | 207 | 121 | 85 | 150 | 427 | 570 | 2 910 |
| Number of degrees awarded | 1990 | 12 | 25 | – | 35 | 101 | – | 481 | 214 | 15 | – | 74 | 0 | 93 | 58 | 320 | 433 | 1 861 |
| | 1995 | 12 | 26 | – | 43 | 86 | – | 476 | 211 | 14 | – | 80 | 0 | 86 | 52 | 319 | 416 | 1 821 |
| | 1998 | 6 | 24 | – | 31 | 94 | – | 503 | (d) 174 | 13 | – | 59 | 0 | 85 | 44 | 356 | 290 | 1 679 |
| **Graduate-Master** | | | | | | | | | | | | | | | | | | |
| Number of students | 1990 | 27 | 52 | 22 | 257 | 24 | 393 | 267 | 65 | 12 | 6 | 74 | 25 | – | 147 | 73 | 722 | 2 166 |
| | 1995 | 22 | 44 | 29 | 329 | 52 | 317 | 323 | 76 | 19 | 4 | 74 | 32 | – | 199 | 77 | 602 | 2 199 |
| | 1998 | 15 | 40 | 27 | 304 | 73 | 242 | 382 | 93 | 18 | 4 | 61 | 28 | – | 209 | 78 | 460 | 2 034 |
| Number of degrees awarded | 1990 | 18 | 27 | 13 | 230 | 22 | 109 | 257 | 67 | 4 | 1 | 74 | 4 | – | 40 | 77 | 220 | 1 163 |
| | 1995 | 26 | 17 | 15 | 295 | 21 | 82 | 281 | 71 | 5 | 3 | 73 | 8 | – | 26 | 84 | 280 | 1 287 |
| | 1998 | 12 | 16 | 13 | 274 | 28 | 106 | 339 | 74 | 8 | 1 | 63 | 5 | – | 16 | 82 | 152 | 1 189 |
| **Graduate-Doctor** | | | | | | | | | | | | | | | | | | |
| Number of students | 1990 | 1 | 31 | 58 | 60 | 12 | 17 | 46 | 26 | – | 8 | 76 | 18 | 10 | 30 | 23 | 701 | 1 117 |
| | 1995 | 1 | 36 | 62 | 112 | 18 | 18 | 67 | 29 | – | 8 | 79 | 32 | 10 | 49 | 26 | 585 | 1 132 |
| | 1998 | 1 | 23 | 60 | 75 | 13 | 20 | 114 | 26 | 1 | 6 | 79 | 34 | 11 | 52 | 28 | 490 | 1 033 |
| Number of degrees awarded | 1990 | 1 | 5 | 2 | 55 | 7 | 16 | 23 | 11 | – | 0 | 51 | 1 | 8 | 3 | 15 | 133 | 331 |
| | 1995 | 1 | 10 | 8 | 99 | 7 | 15 | 42 | 17 | – | 1 | 50 | 5 | 8 | 5 | 15 | 116 | 399 |
| | 1998 | 1 | 6 | 9 | 98 | 4 | 16 | 60 | 14 | 0 | 3 | 50 | 9 | 8 | 6 | 15 | 118 | 417 |
| **Number of Faculty Members** | | | | | | | | | | | | | | | | | | |
| Full-time (number) | 1990 | 0 | 21 | 7 | 40 | 33 | 155 | 261 | 37 | 12 | 0 | (d) 20 | 6 | 13 | 13 | 80 | 164 | 862 |
| | 1995 | 0 | 21 | 7 | 50 | 33 | 153 | 281 | 40 | 14 | 0 | (d) 21 | 7 | 11 | 13 | 72 | 153 | 876 |
| | 1998 | 0 | 18 | 6 | 53 | 27 | 151 | 303 | 42 | 15 | 0 | 210 | 7 | 11 | 11 | 61 | 150 | 1 065 |
| Part-time (man-hours) | 1990 | 3 115 | 4 540 | 700 | (a) 596 | 1 805 | 548 | 1 469 | 480 | 245 | 2 000 | (d) 315 | 1 130 | 1 720 | (e) 2 | (e) 13 | (e) 53 | (f) 18 731 |
| | 1995 | 2 620 | 4 540 | 700 | (b) 645 | 1 485 | 668 | 1 472 | 1 164 | 245 | 2 000 | (d) 380 | 1 330 | 1 720 | (e) 2 | (e) 26 | (e) 55 | (g) 19 052 |
| | 1998 | 1 880 | 6 530 | 700 | (c) 758 | 1 505 | 668 | 2 292 | 1 434 | 255 | 2 000 | 440 | 1 400 | 1 740 | (e) 1 | (e) 31 | (e) 62 | (h) 21 696 |
| Total yearly man-hours of the faculty spent on the programme | 1990 | 3 115 | 33 000 | 7 200 | 7 187 | (d) 2 108 | 20 238 | 139 897 | 8 284 | 28 722 | 2 000 | (d) 4 924 | 9 000 | 18 220 | 966 | 5 920 | 217 435 | 508 216 |
| | 1995 | 2 620 | 33 250 | 7 700 | 7 664 | 5 790 | 20 238 | 146 478 | 9 696 | 34 422 | 2 000 | (d) 5 464 | 11 300 | 15 220 | 742 | 4 535 | 201 335 | 508 454 |
| | 1998 | 1 880 | 28 600 | 7 800 | 8 239 | 5 814 | 20 238 | 180 990 | 10 372 | 37 322 | 2 000 | 12 901 | 9 500 | 15 240 | 182 | (d) 2 935 | 201 920 | 545 933 |

(a) 320 man-hours + 276 staff. (b) 320 man-hours + 325 staff. (c) 320 man-hours + 438 staff. (d) A university did not provide the number.
(e) The number of part-time faculties. (f) 18 387 man-hours + 344 staff. (g) 18 644 man-hours + 408 staff. (h) 21 164 man-hours + 532 staff.

Table A2.4 **Age distribution of faculties in universities in 1998 (numbers)**

| Country | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ |
|---|---|---|---|---|---|---|
| Belgium | 4 | 1 | 22 | 33 | 10 | 0 |
| Canada | 4 | 6 | 10 | 11 | 1 | 0 |
| Finland | 2 | 4 | 4 | 4 | 2 | 0 |
| France | 31 | 21 | 3 | 5 | 3 | 0 |
| Hungary | 3 | 7 | 14 | 13 | 6 | 0 |
| Italy | 0 | 16 | 47 | 44 | 43 | 3 |
| Japan | 10 | 69 | 88 | 162 | 47 | 0 |
| Korea | 0 | 2 | 24 | 15 | 1 | 0 |
| Mexico | 0 | 9 | 23 | 8 | 4 | 0 |
| Netherlands | 0 | 3 | 0 | 2 | 0 | 0 |
| Spain | 1 | 9 | 13 | 1 | 4 | 0 |
| Sweden | 5 | 5 | 6 | 4 | 6 | 1 |
| Switzerland | 0 | 0 | 3 | 8 | 0 | 0 |
| Turkey | 12 | 29 | 24 | 12 | 2 | 0 |
| United Kingdom | 11 | 24 | 28 | 40 | 11 | 2 |
| United States | 2 | 25 | 59 | 59 | 23 | 2 |
| **TOTAL** | **85** | **230** | **368** | **421** | **163** | **8** |

Table A2.5 **Age distribution of faculties in universities in 1998 (ratio of total)**

| Country | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ |
|---|---|---|---|---|---|---|
| Belgium | 0.06 | 0.01 | 0.31 | 0.47 | 0.14 | 0.00 |
| Canada | 0.13 | 0.19 | 0.31 | 0.34 | 0.03 | 0.00 |
| Finland | 0.13 | 0.25 | 0.25 | 0.25 | 0.13 | 0.00 |
| France | 0.49 | 0.33 | 0.05 | 0.08 | 0.05 | 0.00 |
| Hungary | 0.07 | 0.16 | 0.33 | 0.30 | 0.14 | 0.00 |
| Italy | 0.00 | 0.10 | 0.31 | 0.29 | 0.28 | 0.02 |
| Japan | 0.03 | 0.18 | 0.23 | 0.43 | 0.13 | 0.00 |
| Korea | 0.00 | 0.05 | 0.57 | 0.36 | 0.02 | 0.00 |
| Mexico | 0.00 | 0.20 | 0.52 | 0.18 | 0.09 | 0.00 |
| Netherlands | 0.00 | 0.60 | 0.00 | 0.40 | 0.00 | 0.00 |
| Spain | 0.04 | 0.32 | 0.46 | 0.04 | 0.14 | 0.00 |
| Sweden | 0.19 | 0.19 | 0.22 | 0.15 | 0.22 | 0.04 |
| Switzerland | 0.00 | 0.00 | 0.27 | 0.73 | 0.00 | 0.00 |
| Turkey | 0.15 | 0.37 | 0.30 | 0.15 | 0.03 | 0.00 |
| United Kingdom | 0.09 | 0.21 | 0.24 | 0.34 | 0.09 | 0.02 |
| United States | 0.01 | 0.15 | 0.35 | 0.35 | 0.13 | 0.01 |
| **TOTAL** | **0.07** | **0.18** | **0.29** | **0.33** | **0.13** | **0.01** |

Table A2.6 **The number and average age of facilities in universities**

| Country | Research & training reactor | | | | Hot cell | | | | Laboratory for radiochemistry | | | | Laboratory for radiation measurement | | | | Others | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age |
| Belgium | 1 | 1 | 1 | 30 | NA | NA | NA | NA | 3 | 3 | 3 | 33 | 3 | 3 | 3 | 33 | 7 | 7 | 7 | 24 |
| Canada | 4 | 4 | 3 | 25 | 1 | 1 | 1 | 39 | 3 | 4 | 4 | 25 | 6 | 6 | 6 | 23 | 3 | 4 | 4 | 18 |
| Finland | NA | NA | NA | NA | NA | NA | NA | NA | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 17 | 1 | 1 | 2 | 5 |
| France | 3 | 3 | 3 | 35 | 2 | 2 | 2 | NA | 2 | 2 | 2 | NA | 3 | 3 | 4 | 22 | 4 | 4 | 4 | 30 |
| Hungary | 1 | 1 | 1 | 27 | 2 | 2 | 2 | 24 | 3 | 2 | 2 | 25 | 3 | 2 | 2 | 21 | 3 | 3 | 3 | 14 |
| Italy | 2 | 2 | 2 | 37 | 2 | 2 | 2 | 27 | 2 | 2 | 2 | 33 | 5 | 5 | 5 | 23 | 6 | 6 | 6 | 24 |
| Japan | 6 | 6 | 6 | 35 | 9 | 9 | 9 | 32 | 14 | 14 | 14 | 28 | 13 | 13 | 13 | 28 | 22 | 22 | 22 | 21 |
| Korea | 1 | 1 | 1 | 15 | NA | NA | NA | NA | 3 | 3 | 3 | 12 | 4 | 5 | 5 | 17 | NA | NA | NA | NA |
| Mexico | NA | NA | NA | NA | 1 | 1 | 1 | 10 | 3 | 3 | 3 | 21 | 4 | 4 | 4 | 21 | 3 | 3 | 3 | 23 |
| Netherlands | 1 | 1 | 1 | 35 | NA | NA | NA | NA | 1 | 1 | 1 | 35 | 1 | 1 | 1 | 35 | 1 | 1 | 1 | NA |
| Spain | 2 | 1 | 0 | – | NA | NA | NA | NA | 3 | 3 | 3 | 27 | 4 | 4 | 4 | 24 | 2 | 2 | 3 | 6 |
| Sweden | 1 | 1 | 1 | 30 | 1 | 1 | 1 | 20 | 2 | 2 | 2 | 7 | 4 | 4 | 4 | 17 | 5 | 7 | 7 | 18 |
| Switzerland | 2 | 2 | 2 | 27 | NA | NA | NA | NA | 4 | 4 | 4 | 16 | 6 | 6 | 6 | 16 | 4 | 3 | 3 | 16 |
| Turkey | 1 | 1 | 1 | 19 | NA | NA | NA | NA | 2 | 3 | 3 | 17 | 4 | 4 | 4 | 26 | 5 | 5 | 5 | 15 |
| United Kingdom | 2 | 1 | 1 | 38 | 3 | 2 | 2 | 28 | 5 | 5 | 6 | 23 | 8 | 8 | 8 | 26 | 6 | 6 | 6 | 28 |
| United States | 19 | 18 | 16 | 33 | 10 | 9 | 8 | 33 | 15 | 15 | 14 | 29 | 21 | 20 | 20 | 31 | 21 | 22 | 22 | 21 |
| **TOTAL** | **46** | **43** | **39** | **32** | **31** | **29** | **28** | **28** | **66** | **67** | **67** | **24** | **92** | **91** | **92** | **25** | **93** | **96** | **98** | **20** |

Table A2.7 **Occupational distribution of graduates of nuclear programmes**

| Country | Belgium | Canada | Finland | France | Hungary | Italy | Japan | Korea |
|---|---|---|---|---|---|---|---|---|
| **Graduate school** | | | | | | | | |
| Undergraduate | – | 0.39 | – | 0.10 | 0.27 | – | 0.48 | 0.33 |
| Master | 0.00 | 0.37 | 0.09 | 0.00 | 0.11 | 0.01 | 0.19 | 0.48 |
| Doctor | NA | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Electricity utility** | | | | | | | | |
| Undergraduate | – | 0.16 | – | 0.10 | 0.08 | – | 0.03 | 0.10 |
| Master | 0.50 | 0.06 | 0.16 | 0.02 | 0.15 | 0.05 | 0.10 | 0.17 |
| Doctor | NA | 0.15 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.17 |
| **Nuclear manufacturer** | | | | | | | | |
| Undergraduate | – | 0.08 | – | 0.20 | 0.01 | – | 0.05 | 0.02 |
| Master | 0.08 | 0.06 | 0.06 | 0.27 | 0.03 | 0.05 | 0.13 | 0.02 |
| Doctor | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.11 |
| **Academic career (universities)** | | | | | | | | |
| Undergraduate | – | 0.00 | – | 0.00 | 0.20 | – | 0.00 | 0.03 |
| Master | 0.01 | 0.00 | 0.11 | 0.00 | 0.25 | 0.01 | 0.01 | 0.02 |
| Doctor | NA | 0.08 | 0.29 | 0.12 | 0.45 | 0.33 | 0.27 | 0.14 |
| **Nuclear Research Institute** | | | | | | | | |
| Undergraduate | – | 0.03 | – | 0.05 | 0.01 | – | 0.01 | 0.02 |
| Master | 0.07 | 0.11 | 0.10 | 0.04 | 0.15 | 0.03 | 0.04 | 0.08 |
| Doctor | NA | 0.69 | 0.32 | 0.27 | 0.23 | 0.00 | 0.24 | 0.45 |
| **Government (administrative work)** | | | | | | | | |
| Undergraduate | – | 0.00 | – | 0.00 | 0.03 | – | 0.01 | 0.02 |
| Master | 0.03 | 0.00 | 0.05 | 0.01 | 0.00 | 0.06 | 0.03 | 0.02 |
| Doctor | NA | 0.00 | 0.05 | 0.01 | 0.00 | 0.00 | 0.03 | 0.08 |
| **Regulatory body (other than the above category)** | | | | | | | | |
| Undergraduate | – | 0.02 | – | 0.00 | 0.03 | – | 0.01 | 0.01 |
| Master | 0.03 | 0.03 | 0.10 | 0.00 | 0.03 | 0.01 | 0.01 | 0.03 |
| Doctor | NA | 0.08 | 0.05 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| **Military** | | | | | | | | |
| Undergraduate | – | 0.02 | – | 0.00 | 0.03 | – | 0.00 | 0.05 |
| Master | 0.00 | 0.09 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.06 |
| Doctor | NA | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 |
| **Engineering office (not manufacturer)** | | | | | | | | |
| Undergraduate | – | 0.02 | – | 0.15 | 0.03 | – | 0.09 | 0.02 |
| Master | 0.08 | 0.11 | 0.03 | 0.04 | 0.04 | 0.18 | 0.04 | 0.05 |
| Doctor | NA | 0.00 | 0.00 | 0.02 | 0.14 | 0.33 | 0.01 | 0.02 |
| **Non-nuclear manufacturer** | | | | | | | | |
| Undergraduate | – | 0.10 | – | 0.15 | 0.21 | – | 0.10 | 0.09 |
| Master | 0.08 | 0.00 | 0.08 | 0.05 | 0.11 | 0.29 | 0.27 | 0.03 |
| Doctor | NA | 0.00 | 0.15 | 0.10 | 0.05 | 0.22 | 0.10 | 0.00 |
| **Non-nuclear research institute** | | | | | | | | |
| Undergraduate | – | 0.02 | – | 0.05 | 0.03 | – | 0.00 | 0.02 |
| Master | 0.02 | 0.09 | 0.15 | 0.00 | 0.11 | 0.20 | 0.00 | 0.00 |
| Doctor | NA | 0.00 | 0.05 | 0.02 | 0.00 | 0.11 | 0.07 | 0.00 |
| **Others** | | | | | | | | |
| Undergraduate | – | 0.18 | – | 0.20 | 0.08 | – | 0.22 | 0.28 |
| Master | 0.10 | 0.09 | 0.08 | 0.45 | 0.00 | 0.12 | 0.18 | 0.03 |
| Doctor | NA | 0.00 | 0.00 | 0.42 | 0.14 | 0.00 | 0.13 | 0.00 |

Table A2.7 **Occupational distribution of graduates of nuclear programmes (*continued*)**

| Country | Mexico | Nether-lands | Spain | Sweden | Switzer-land | Turkey | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|
| **Graduate school** | | | | | | | | |
| Undergraduate | 0.20 | – | 0.02 | 0.09 | 0.10 | 0.26 | 0.26 | 0.22 |
| Master | 0.02 | 0.00 | 0.00 | 0.00 | – | 0.15 | 0.28 | 0.34 |
| Doctor | 0.93 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.12 |
| **Electricity utility** | | | | | | | | |
| Undergraduate | 0.19 | – | 0.63 | 0.27 | 0.17 | 0.05 | 0.04 | 0.26 |
| Master | 0.18 | 0.00 | 0.07 | 0.39 | – | 0.02 | 0.02 | 0.10 |
| Doctor | 0.00 | 0.00 | 0.18 | 0.08 | 0.12 | 0.00 | 0.00 | 0.05 |
| **Nuclear manufacturer** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.00 | 0.55 | 0.01 | 0.01 | 0.01 | 0.14 |
| Master | 0.00 | 0.00 | 0.06 | 0.11 | – | 0.00 | 0.10 | 0.21 |
| Doctor | 0.00 | 0.00 | 0.16 | 0.08 | 0.00 | 0.04 | 0.06 | 0.20 |
| **Academic career (universities)** | | | | | | | | |
| Undergraduate | 0.02 | – | 0.10 | 0.00 | 0.03 | 0.10 | 0.00 | 0.01 |
| Master | 0.17 | 0.00 | 0.09 | 0.11 | – | 0.15 | 0.01 | 0.03 |
| Doctor | 0.07 | 0.00 | 0.07 | 0.29 | 0.07 | 0.67 | 0.19 | 0.12 |
| **Nuclear Research institute** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.00 | 0.00 | 0.04 | 0.04 | 0.01 | (a) |
| Master | 0.35 | 0.00 | 0.27 | 0.06 | – | 0.06 | 0.04 | (a) |
| Doctor | 0.00 | 0.50 | 0.20 | 0.08 | 0.22 | 0.15 | 0.13 | (a) |
| **Government (administrative work)** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.23 | 0.00 | 0.00 | 0.02 | 0.06 | 0.02 |
| Master | 0.18 | 0.00 | 0.00 | 0.06 | – | 0.02 | 0.05 | 0.07 |
| Doctor | 0.00 | 0.00 | 0.02 | 0.00 | 0.04 | 0.04 | 0.08 | 0.09 |
| **Regulatory body (other than the above category)** | | | | | | | | |
| Undergraduate | 0.58 | – | 0.00 | 0.09 | 0.01 | 0.17 | 0.02 | (b) |
| Master | 0.02 | 0.00 | 0.07 | 0.11 | – | 0.10 | 0.02 | (b) |
| Doctor | 0.00 | 0.00 | 0.08 | 0.08 | 0.01 | 0.04 | 0.06 | (b) |
| **Military** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.12 |
| Master | 0.00 | 0.00 | 0.00 | 0.00 | – | 0.02 | 0.01 | 0.05 |
| Doctor | 0.00 | 0.00 | 0.03 | 0.25 | 0.01 | 0.00 | 0.00 | 0.03 |
| **Engineering office (not manufacturer)** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.00 | 0.00 | 0.11 | 0.03 | 0.03 | 0.01 |
| Master | 0.00 | 0.50 | 0.11 | 0.00 | – | 0.09 | 0.00 | 0.02 |
| Doctor | 0.00 | 0.00 | 0.16 | 0.00 | 0.14 | 0.00 | 0.04 | 0.12 |
| **Non-nuclear manufacturer** | | | | | | | | |
| Undergraduate | 0.01 | – | 0.00 | 0.00 | 0.31 | 0.02 | 0.37 | (c) |
| Master | 0.00 | 0.00 | 0.13 | 0.06 | – | 0.04 | 0.13 | (c) |
| Doctor | 0.00 | 0.00 | 0.03 | 0.13 | 0.10 | 0.04 | 0.24 | (c) |
| **Non-nuclear research institute** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.00 | 0.00 | 0.01 | 0.01 | 0.17 | (a) |
| Master | 0.06 | 0.50 | 0.09 | 0.00 | – | 0.00 | 0.07 | (a) |
| Doctor | 0.00 | 0.50 | 0.03 | 0.00 | 0.18 | 0.04 | 0.17 | (a) |
| **Others** | | | | | | | | |
| Undergraduate | 0.00 | – | 0.02 | 0.00 | 0.21 | 0.27 | 0.02 | 0.22 |
| Master | 0.00 | 0.00 | 0.11 | 0.11 | – | 0.35 | 0.27 | 0.18 |
| Doctor | 0.00 | 0.00 | 0.03 | 0.00 | 0.05 | 0.00 | 0.03 | 0.27 |

(a) Graduates into nuclear and non-nuclear research institutes were included in "others". (b) Graduates into regulatory body were included in "government". (c) Graduates into non-nuclear manufacturer were included in nuclear manufacturer.

Table A2.8 **The number of trainees and trainers in industry and research institutes**

| Country | Number of trainees | | | Number of trainers/instructors | | | Annual man-hours provided by the trainers/instructors | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 1998 | 1990 | 1995 | 1998 | 1990 | 1995 | 1998 |
| Belgium | 9 120 | 8 740 | 7 577 | 40 | 137 | 107 | 3 200 | 4 470 | 12 760 |
| Finland | 592 | 738 | 841 | 20 | 20 | 25 | 1 720 | 1 520 | 1 750 |
| France | 1 134 | 1 744 | 1 831 | 642 | 703 | 99 | 56 738 | 53 049 | 39 781 |
| Hungary | 1 780 | 2 191 | 872 | 162 | 180 | 134 | 3 562 | 4 337 | 2 345 |
| Italy | NA | NA | 120 | NA | NA | 12 | NA | NA | 100 |
| Japan | 4 317 | 8 005 | 8 368 | 154 | 176 | 229 | 15 592 | 17 016 | 16 253 |
| Korea | 4 495 | 5 989 | 5 811 | 136 | 152 | 155 | 3 580 | 4 885 | 3 727 |
| Mexico | 4 734 | 5 627 | 6 489 | 149 | 57 | 80 | 10 156 | 12 176 | 13 102 |
| Netherlands | 466 | 515 | 489 | 29 | 33 | 25 | 10 060 | 10 570 | 11 144 |
| Turkey | 118 | 60 | 74 | 36 | 20 | 20 | 544 | 352 | 320 |
| Spain | 789 | 1 637 | 461 | 50 | 52 | 38 | 54 692 | 63 350 | 61 468 |
| Sweden | 130 | 203 | 160 | NA | NA | NA | (a) 72 | (a) 128 | (a) 124 |
| Switzerland | 1 065 | 1 244 | 1 208 | 35 | 35 | 35 | 8 350 | 9 560 | 11 120 |
| United Kingdom | 1 500 | 5 926 | 1 500 | 21 | 25 | 24 | 9 800 | 22 400 | 22 600 |
| United States | 3 830 | 6 704 | 5 370 | 141 | 185 | 162 | 140 300 | 336 000 | 325 750 |
| **TOTAL** | **34 070** | **49 323** | **41 171** | **1 615** | **1 775** | **1 145** | **318 294** | **539 685** | **522 220** |

(a) Man-weeks.

Table A2.9 **Age distribution of trainers and instructors in industry and research institutes (in numbers)**

| Country | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ |
|---|---|---|---|---|---|---|
| Belgium | 21 | 43 | 39 | 20 | 5 | 1 |
| Finland | 7 | 9 | 49 | 12 | 0 | 0 |
| France | 6 | 64 | 27 | 13 | 0 | 0 |
| Hungary | 1 | 53 | 128 | 36 | 4 | 0 |
| Italy | 0 | 3 | 5 | 3 | 1 | 0 |
| Japan | 24 | 61 | 108 | 56 | 7 | 1 |
| Korea | 0 | 31 | 74 | 50 | 0 | 0 |
| Mexico | 0 | 33 | 50 | 1 | 0 | 0 |
| Netherlands | 0 | 9 | 13 | 4 | 0 | 0 |
| Spain | 5 | 28 | 15 | 2 | 0 | 0 |
| Switzerland | 4 | 6 | 11 | 12 | 2 | 0 |
| Turkey | 0 | 5 | 15 | 0 | 0 | 0 |
| United Kingdom | 0 | 8 | 11 | 4 | 0 | 0 |
| United States | 7 | 46 | 72 | 35 | 0 | 0 |
| **TOTAL** | **75** | **399** | **617** | **248** | **19** | **2** |

Table A2.10 **Age distribution of trainers and instructors in industry and research institutes (ratio of total)**

| Country | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71+ |
|---|---|---|---|---|---|---|
| Belgium | 0.16 | 0.33 | 0.30 | 0.16 | 0.04 | 0.01 |
| Finland | 0.09 | 0.12 | 0.64 | 0.16 | 0.00 | 0.00 |
| France | 0.05 | 0.58 | 0.25 | 0.12 | 0.00 | 0.00 |
| Hungary | 0.00 | 0.24 | 0.58 | 0.16 | 0.02 | 0.00 |
| Italy | 0.00 | 0.25 | 0.42 | 0.25 | 0.08 | 0.00 |
| Japan | 0.09 | 0.24 | 0.42 | 0.22 | 0.03 | 0.00 |
| Korea | 0.00 | 0.20 | 0.48 | 0.32 | 0.00 | 0.00 |
| Mexico | 0.00 | 0.39 | 0.60 | 0.01 | 0.00 | 0.00 |
| Netherlands | 0.00 | 0.35 | 0.50 | 0.15 | 0.00 | 0.00 |
| Spain | 0.10 | 0.56 | 0.30 | 0.04 | 0.00 | 0.00 |
| Switzerland | 0.11 | 0.17 | 0.31 | 0.34 | 0.06 | 0.00 |
| Turkey | 0.00 | 0.25 | 0.75 | 0.00 | 0.00 | 0.00 |
| United Kingdom | 0.00 | 0.35 | 0.48 | 0.17 | 0.00 | 0.00 |
| United States | 0.04 | 0.29 | 0.45 | 0.22 | 0.00 | 0.00 |
| **TOTAL** | **0.06** | **0.29** | **0.45** | **0.18** | **0.01** | **0.00** |

Table A2.11 **The number and average age of facilities in industry and research institutes**

| Country | Research & training reactor | | | | Hot cell | | | | Laboratory for radiochemistry | | | | Laboratory for radiation measurement | | | | Others | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age | 1990 | 1995 | 1998 | Av. age |
| Belgium | 2 | 2 | 2 | 35 | 1 | 1 | 1 | 35 | 2 | 2 | 3 | 30 | 2 | 2 | 3 | 30 | 1 | 1 | 2 | 10 |
| Canada | 1 | 1 | 1 | 13 | NA | NA | NA | NA | NA | NA | NA | NA | 1 | 1 | 1 | 28 | 1 | 1 | 1 | NA |
| Finland | 1 | 1 | 1 | 36 | 1 | 1 | 1 | 20 | 4 | 4 | 4 | 24 | 4 | 4 | 4 | 27 | 1 | 1 | 1 | 8 |
| France | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Hungary | 1 | 1 | 1 | 17 | 1 | 1 | 1 | 39 | 1 | 1 | 1 | 39 | 2 | 2 | 2 | 30 | 3 | 4 | 4 | 13 |
| Italy | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Japan | 3 | 3 | 3 | 32 | 2 | 2 | 2 | 35 | 2 | 2 | 2 | 31 | 2 | 2 | 2 | 14 | 3 | 3 | 3 | 24 |
| Korea | 1 | 1 | 1 | 2 | NA | NA | NA | NA | NA | NA | NA | NA | 1 | 2 | 2 | 10 | 1 | 2 | 2 | 10 |
| Mexico | 1 | 1 | 1 | 30 | 1 | 1 | 1 | 30 | 2 | 2 | 2 | 10 | 2 | 2 | 2 | 10 | 0 | 1 | 1 | 7 |
| Netherlands | 1 | 1 | 1 | 38 | NA | NA | NA | NA | NA | NA | NA | NA | 3 | 3 | 3 | 18 | 1 | 1 | 2 | 6 |
| Spain | 1 | 1 | 0 | – | NA | NA | NA | NA | 1 | 1 | 1 | NA | 1 | 1 | 1 | NA | 4 | 4 | 6 | 10 |
| Sweden | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Switzerland | 2 | 1 | 1 | 31 | 1 | 1 | 1 | 35 | 2 | 2 | 2 | 25 | 1 | 1 | 1 | 35 | 3 | 4 | 5 | 11 |
| Turkey | 1 | 0 | 1 | 17 | NA | NA | NA | NA | 1 | 1 | 1 | 34 | 1 | 1 | 1 | 34 | 1 | 1 | 1 | NA |
| United Kingdom | 1 | 0 | 0 | – | 2 | 2 | 1 | 10 | 2 | 2 | 2 | 23 | 2 | 2 | 2 | 35 | 2 | 2 | 2 | 15 |
| United States | NA | NA | NA | NA | NA | NA | NA | NA | 2 | 2 | 2 | 10 | 3 | 3 | 3 | 10 | 6 | 6 | 6 | 10 |
| **TOTAL** | **16** | **13** | **13** | **27** | **9** | **9** | **8** | **30** | **19** | **19** | **20** | **23** | **25** | **26** | **27** | **21** | **27** | **31** | **36** | **11** |

*Annex 3*

## COUNTRY REPORTS ON EDUCATION IN THE NUCLEAR FIELD

## BELGIUM

### Historical overview

Belgium, with its 10 million inhabitants, is an example of a small, densely populated (330 inhabitants/km$^2$), highly industrialised country with a large energy consumption per capita, but almost no indigenous energy resources. In the overall energy consumption, electricity amounts to 30% of the total of which and 60% is nuclear, generated by seven NPPs, and totalling 5.7 GWe.

Partly as a result of its industrial past, the nuclear activities started early after the war. The national nuclear research centre was founded in 1952. It could rely upon a strong university centred research basis (mainly in physics) and an industrial experience in nuclear metallurgy. Both the manufacturing industry and the electric utilities founded nuclear engineering offices before the mid fifties. The first (research) reactor reached criticality in 1956 and, the first nuclear electricity was produced in 1962 by an 11.5 MWe PWR. The first large scale power reactor (300 MWe, built jointly with France) started operation in 1967. Seven PWRs, totalling 5.7 GWe, were sequentially connected to the grid between 1974 and 1985. In recent years their load factor amounted to 85-90% and their production corresponds to 55-60% of the electric production and about 18% of the total primary energy consumption. Uranium and plutonium fuel fabrication started in the late 1950s and their present yearly output amounts respectively to 400 tU/year and 35 t Pu/year. Research on waste treatment and disposal, and radio-isotope production also belong since an early date to the country's nuclear background.

At State level, the legal and regulatory rules were fixed in laws voted in 1955 and 1963. The universities and higher technical schools have organised nuclear curricula since the mid-1950s.

### Nuclear education

Historically, engineering education is provided at two levels leading to a degree in "industrial engineering" granted by higher technical institutes after four years of schooling and a degree in "civil engineering" granted by the faculties of applied sciences of the country's seven universities after successful completion of an entrance examination, followed by five years of schooling (the term "civil" is historic to distinguish it from "military" engineers).

Due to the small size of the country and the large diversity of its industrial activities, emphasis was and still is centred on a strong and broad background of basic science and technology followed by the necessary specialisation in the classical engineering disciplines (electrical, mechanical, civil, chemical, etc.). Any further specialisation is taught after graduation in the frame of a one year curricula leading to an additional degree in the relevant field of engineering.

In the nuclear field, the same line of thought was kept and, except for a few higher technical institutes, the nuclear specialisation was hence provided only to students already holding an engineering degree. Starting in the mid-fifties, all universities progressively offered specialised one year curricula in nuclear engineering, however not as a new department, but within existing departments (electrical, mechanical, chemical, etc.). The teaching staff was found within the university with, in most cases, the help of part-time external instructors coming from industry or research centres. Staff active exclusively in the nuclear field has never existed in this academic structure.

Hence, for the young graduate nuclear is almost always a specific choice: he steps into an additional field and an additional year of study rather than directly into a career in line with his newly acquired degree.

For a long period, the high demand for nuclear engineers combined with the attractive power of this new sector allowed all universities and higher technical institutes to offer their nuclear curricula to a sufficiently large number of students. When the nuclear expansion ceased and the public image of the nuclear sector declined, the number of students progressively decreased. Furthermore, in times of high demand for engineers by industry, devoting one full year to an additional specialisation is a difficult choice for the young graduate. This difficulty is further enhanced in times of declining enrolment in science and technology. The declining number of students and of degrees granted in the report period had to be seen in this context. Other causes for the decline exist, however, as one also observes a decreased enrolment in the higher technical schools leading, after four years, directly to a nuclear degree without any additional year devoted to the nuclear specialisation.

During the reporting period, the declining number of students and prevailing administrative constraints have progressively led the universities to merge their nuclear programmes rather than cancel them. The number was hence reduced from six to two. As a result the number of man-hours of staff devoted to nuclear teaching has decreased.

The age of the teaching staff peaks in the 50-60 bracket, but no problem in staff replacement is presently seen. However, difficulties are experienced within the existing curricula in organising highly specialised courses with an almost exclusively nuclear orientation (i.e. of only minor interest to non-nuclear students) due to the limited number of students. Inter-university and international collaborative schemes may offer solutions. Such schemes, but with a broader aim, are also being looked into.

There has been no systematic effort at the national level to stimulate nuclear enrolment, but initiatives in this direction have come mostly from individuals (e.g. organisation of information meetings for potential candidates) or from some institutions (study grants by the Belgian Nuclear Society, thesis work within industry, prices for a best thesis). One must mention the successful collaborative schemes set up since 1994 by the national nuclear research centre with universities and providing financial and scientific aid to 12-15 doctoral candidates or post-doctoral researchers with the aim of improving and increasing the nuclear scientific staff of the country.

Beside the academic institutions industry, engineering and regulatory offices contribute to the qualification of their personnel by offering a great variety of in-house training programmes.

# CANADA

## Introduction

As a result of political decisions and international agreements in the 1940s, nuclear research in Canada became centred on heavy-water-based technologies. Subsequently, the heavy-water-moderated and -cooled reactor CANDU® (CANada Deuterium Uranium) was developed and became the only commercial power reactor deployed in the country. Today, the utilities of the provinces Ontario, Quebec and New Brunswick base about 50%, 2% and 35% respectively of their generating capacity on CANDU reactors.

Canada is also an exporter of nuclear technology and has produced commercial CANDU units that are operating in Argentina, Korea and Romania and has construction under way for new units in China. In addition, versions of a CANDU prototype were exported to Pakistan and one to India in the 1960s; the latter subsequently became the model for the Indian fleet of PHWRs.

Even before nuclear technology was being researched in Canada, uranium ore from the Northwest Territories was used to produce radium (mainly for medical purposes) and uranium. By the time the CANDU concept was under development, the country's potential as a supplier of uranium and nuclear fuel was recognised. Large mining and refining operations grew in Ontario, and lately the rich deposits of uranium ore in northern Saskatchewan make Canada a major uranium exporter as well as a producer for domestic use.

The tradition of radioisotope production for medical use continued and grew along with nuclear power development. The availability of research reactors, chiefly the NRX and NRU reactors at the Chalk River Laboratories of Atomic Energy of Canada Limited, has ensured a steady supply over the years of isotopes such as $^{99}Mo$ and $^{60}Co$, which have satisfied much of the world demand.

These developments of nuclear technology in Canada necessitated the establishment of extensive R&D, design and engineering infrastructures. Throughout the process, government agencies and private industry have been involved. Those infrastructures have influenced the way in which nuclear education and training have developed.

## Nuclear industry infrastructure

The consolidation of nuclear R&D began in the mid-1940s at the new Chalk River Laboratories in Ontario as the work was transferred from the government laboratories of the National Research Council (NRC) in Montreal. The establishment of the government-owned crown corporation Atomic Energy of Canada Limited (AECL) in place of NRC as the nuclear agency in the early 1950s marked the recognition that the nuclear programme had a significant industrial component.

The development of the first CANDU demonstration reactor, NPD, was a collaborative effort of industry, utility and AECL engineers and scientists that began in 1954. This was very much a response to the burgeoning demand for energy in the post-war economic boom and the realisation that hydroelectric sites in Ontario were mostly used up.

In 1958, the design and engineering function of AECL was moved to a division newly set up for that purpose in Sheridan Park, near Toronto. The 20 MWe NPD reactor was commissioned in 1962; its location, 25 km upstream of the Chalk River Laboratories on the Ottawa river in Ontario, was an important factor in the decision to build the Nuclear Training Centre (NTC) for Ontario Hydro on the same site. New employees in the nuclear division could then take advantage of the proximity of the AECL laboratories and NPD to obtain training in any aspect of nuclear technology.

The nuclear capacity of Ontario Hydro expanded rapidly in the 1960s and 1970s, with the prototype 200 MWe Douglas Point reactor coming on stream in 1966 and the four Pickering A (500 MWe each) and four Bruce A (800 MWe each) reactors being in service in 1973 and 1979, respectively; the activity at NTC increased accordingly. Since there was, at that time, a shortage of trainees from Canadian sources, many people were recruited from abroad. This situation was not new in Canada, where the nuclear industry was founded as a result of international agreements and the original research performed by an international community at Chalk River.

The 1960s and 1970s saw nuclear technology expanding elsewhere in Canada, too. A new AECL research site was opened at Whiteshell in Manitoba in 1963, and the organic-cooled research reactor WR-1 achieved criticality there in 1965. In response to an expression of interest in nuclear power by Hydro-Québec, a boiling-light-water-cooled version of CANDU was built at Gentilly on the St. Lawrence river and achieved its design output of 250 MWe in 1972. This reactor concept was later abandoned by AECL, who also decided against developing the organic-cooled CANDU and concentrated their design and development effort on the 600 MWe version of CANDU, which became their “flagship” reactor CANDU 6. Hydro-Quebec and New Brunswick Power both ordered CANDU 6s (Gentilly 2 and Point Lepreau, respectively) which came on stream in 1982 and 1983, about the same time as Wolsung 1 in Korea and Embalse in Argentina. Many staff members from those reactors received at least part of their training at NTC and Chalk River via agreements with Ontario Hydro and AECL.

By the early 1980s Ontario Hydro had itself built up a substantial nuclear design and engineering capability. The doubling of the size of the Pickering plant by 1985 and the Bruce plant by 1987 by the addition of the B units was therefore accomplished with little input from AECL. Subsequently, the Darlington plant of Ontario Hydro (four 850 MWe units) was brought into service, again with minimal AECL contribution.

In the mid-1980s, the NPD reactor was shut down and NTC was closed. The nuclear training facilities of Ontario Hydro became centred on their larger facilities near Toronto. The nuclear infrastructures at New Brunswick Power and Hydro-Quebec were by that time able to sustain substantial training schemes of their own for staff of the Point Lepreau and Gentilly reactors, though some portions were contracted out to engineering specialists and universities. At the present time, all the Canadian nuclear utilities have contributed to the training of overseas personnel associated with CANDU sales, either by receiving reactor staff for in-house training or by sending experts to CANDU sites abroad.

## University connections

While Canadian universities in the past have enthusiastically promoted courses with nuclear content – particularly during the rapid growth phase of the industry – no department offering first degrees in Nuclear Engineering has ever been set up. Instead, conventional engineering schools offering degrees in chemical, mechanical, etc., engineering have provided option programmes based on nuclear subjects. At the same time, specialised departments have offered degrees in nuclear subjects at the master's and doctorate level.

The fundamental research activities of AECL traditionally maintained strong links with universities. In nuclear physics, for example, university staff and students would spend time at Chalk River working on facilities such as the tandem accelerator superconducting cyclotron (TASCC) while in materials science they would study the properties of matter via neutron beam facilities at the NRU reactor. Many engineers and scientists at the AECL laboratories have held adjunct professorship at universities and it is not uncommon for AECL employees to obtain a research degree whilst doing their experimental work at the laboratories.

Several universities have co-operated with the nuclear industry in Canada in setting up research chairs. Such chairs are tenure-track appointments held in departments of particular interest to the industry or industries that are involved in the funding. Typically, the industry funds are used to attract matching grants from government so that an infrastructure can be built and a research programme put in place. The industry connections ensure some relevance to a particular nuclear subject while the government and university connections maintain academic depth and a commitment to training highly qualified personnel. Since the early 1980s, AECL has been involved – often in conjunction with a utility or industry partner – with about a dozen such chairs.

The universities and colleges may also contract services for training nuclear personnel and for preparing training material. The authority regulating nuclear matters in Canada – the Atomic Energy Control Board (AECB – soon to be called the Nuclear Safety Commission or NSC) – imposes strict training requirements on personnel running nuclear facilities. To fulfil these requirements, the utilities Hydro-Quebec and New Brunswick Power with perhaps limited nuclear training facilities of their own may then use appropriate university services to fill in the gaps, which are often in the underlying science and engineering areas. Moreover, the AECB itself may use universities or colleges, which are independent of direct industry influence, to fulfil some of its own training needs.

## The current state of affairs

The nuclear industry in Ontario in 1999 is changing rapidly as the provincial government moves towards privatisation of Ontario Hydro (which has already been split into sectors dealing with generation, transmission, etc. – similar to the model of the UK industry) and prepares for deregulation of electricity markets across North America. Since Ontario Hydro has dominated the nuclear industry from the utility standpoint in Canada for so long, the impact on the other nuclear utilities and AECL is considerable. The structure for funding nuclear R&D at AECL by the utilities via the CANDU Owners Group (COG) is being changed; AECL has already experienced a severe drop in funding as a result. This has come on top of cuts in federal government allocations that have taken place in the last few years with the intention of making AECL a self-sufficient supplier of CANDU reactors. The fundamental scientific activities, such as nuclear physics at Chalk River have already been curtailed to accommodate this philosophy and all the AECL projects at the Whiteshell Laboratory are coming to a close. While AECL revenues from service contracts to utilities and from other commercial work have increased, the amounts are insufficient to offset the cuts already suffered. A rationalisation of resources and infrastructure will inevitably result.

The consequences of these changes for the universities and colleges are likely to be significant. Already, the perceived malaise in the industry is reducing the popularity of nuclear-related courses with administrators, so that nuclear engineering subjects, for example, tend to be offered under the aegis of courses with titles like “advanced energy topics”. Furthermore, the cutbacks to AECL have taken their toll on the employment of students at the laboratories for summer projects or for co-operative programmes; this can only have a negative influence in the long run on attracting young people into the industry. Similarly, the cutbacks in funding generally of nuclear R&D will ultimately affect the universities adversely.

Curiously, though, the survey results for Canada in this report paint a less pessimistic picture – at least for the period from 1990 up to 1998. Thus, at the five universities that gave data on programmes, the numbers of undergraduates and the awarded bachelor degrees with nuclear content remained about the same. Offsetting this in the future, however, will be the demise of the undergraduate option programme at the University of Toronto. Master’s and doctoral students and the numbers of degrees awarded at those levels have declined somewhat over the period, but probably not outside the expected statistical variations for such small numbers. The numbers of teaching staff have remained fairly constant, too. Clearly, though, the future heralds an overall decline in enrolments and in course offerings, trends that are already occurring in the traditional basic nuclear engineering subjects such as reactor design and thermalhydraulics.

In terms of research facilities at the universities, the recent shutdown of the Slowpoke reactor at the University of Toronto will have a major impact on programmes – in particular in Ontario. The event no doubt reflects the curtailment of undergraduate option programmes at that university. Elsewhere, however, the remaining five university reactors remain viable. The Slowpoke reactor at the École Polytechnique in Montreal has just received a new core, and that at Dalhousie University in Halifax is in the process of being refurbished. The Slowpokes at the Royal Military College in Ontario and the University of Alberta also operate steadily as required, and the larger 5 MW pool-type reactor at McMaster University in Ontario is now operating successfully with a new management scheme. Although not all of these reactors are involved in nuclear-engineering programmes *per se* (neutron activation analysis being the major role of the Dalhousie Slowpoke, for example), they all involve important aspects of nuclear technology in their operation and their research and teaching functions.

In conclusion, while the survey shows no drastic change in the nuclear education and training statistics at the universities in Canada in the period from 1990 up to 1998, the future situation is likely to be far from stable. Current events in Ontario – in particular the cuts in funding for R&D from Ontario Hydro and, indeed, the reorganisation of Ontario Hydro itself – will have repercussions that will be felt in those universities with nuclear-related programmes. The image of the industry, already at a low point, has not been improved by these events and this will undoubtedly be reflected in the numbers of students expressing interest in nuclear subjects. Although the current job market for new graduates with a nuclear engineering background is quite good because of utility efforts in refurbishing operating reactors etc., the availability of such graduates is likely to decline until a more positive atmosphere reigns in the industry. This could be brought about when governments pay serious heed to the Kyoto accord on reducing greenhouse gas emissions and take notice of statements such as that recently issued by the Royal Academy of Engineering and the Royal Society of London [1], which urges the reduction of fossil fuel burning and the increased use of renewables and nuclear power.

## REFERENCE

[1] The Royal Academy of Engineering and the Royal Society of London, *Nuclear Energy – The Future Climate*, United Kingdom, 1999.

# FINLAND

## Overview

### *Nuclear Power Plants (NPPs)*

There are two operating NPPs in Finland with a total of four units, which were built in the late seventies and early eighties, as indicated in the table below. The nuclear share in electricity production is nearly 30%.

Table A3.1 **Finnish nuclear power plants**

| Plant unit | Type | Net capacity (MWe) | Commercial operation |
|---|---|---|---|
| Loviisa 1 | VVER-440 | 445/500 | 1977 |
| Loviisa 2 | VVER-440 | 445/500 | 1981 |
| Olkiluoto 1 | BWR | 660/710/840 | 1979 |
| Olkiluoto 2 | BWR | 660/710/840 | 1982 |

Both PPS, Loviisa and Olkiluoto, have recently been modernised, and the resulting upgraded capacities are also given in the above table. It should be underlined here that these modernisation programmes have had an important training aspect – they have created interesting new tasks for the plant personnel.

As the consumption of electricity has increased by about 30% during the last ten years, there have been plans to build a fifth NPP unit in Finland. However, in autumn 1993, parliament rejected the government’s proposal to grant the decision in principle for the construction of a new plant unit. This was a negative signal to the nuclear engineering field in Finland, as well as to the younger generation. In 1997, however, the government, in its national energy strategy, decided to keep the nuclear option open and to maintain the high level of nuclear expertise in the country. Also, the new government programme (1999) keeps the nuclear option open. Site selection for the final disposal of spent nuclear fuel will be the next big decision to be taken by the government in the year 2000.

The Finnish nuclear power plants 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, most importantly, a full-scope simulator. Furthermore, the plants have ordinary laboratories for chemistry and radiation measurements. The university-level 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.

***University education in the nuclear energy field****

No university unit in Finland has a study programme in nuclear energy subjects at the Bachelor degree level. On the next level, the total number of Master of Science degrees awarded annually in the nuclear energy field is about 10-20, as indicated in the tables of Annex 2. This amount has been sufficient for current needs.

Above the master level, the Finnish universities have two different higher degrees: the so-called degree of Licentiate and the degree of Doctor. (These two degrees are merged into the category of Graduate-Doctor in Annex 2 for Finland.) The higher 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 may have been closely related to the daily work. Because there is no time limit for the degrees, the duration of these higher studies may be quite long, which explains the relatively large total numbers of Graduate-Doctor students in Annex 2.

Three university units in Finland currently have study programmes in nuclear energy subjects, (university units having study programmes e.g. in nuclear physics or in high-energy physics are not included):

*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 activities are focused on radiation and reactor physics, and on fusion technology. The unit has a laboratory for radiation measurements, and access to the Triga training and research reactor, hot cells and laboratory of radiochemistry at the Technical Research Centre of Finland (VTT, see below), which is located on the same campus in Espoo near Helsinki.

*Lappeenranta University of Technology (LUT), Department of Energy Technology, Laboratory of Nuclear Engineering.*

The nuclear engineering programme at LUT is taught as an optional specialisation within the Power Plant Engineering Section. A basic course in nuclear engineering is compulsory for all the students in the department, and a more advanced course is then taught to all the students of power plant engineering. Finally, several additional courses are provided for those students who wish to specialise in nuclear power plants. The Laboratory of Nuclear Engineering along with the Physics Laboratory of LUT has laboratories for conducting radiation measurements. In association with VTT, the Laboratory of Nuclear Engineering has a thermal-hydraulics laboratory equipped with a facility (PACTEL) for simulating the primary circuit of the Loviisa NPP units on a scale of 1:305 with a maximum heating power of 1 MW. The main research activities are concerned with the safety of nuclear power plants, with a special focus on thermal-hydraulics. The VTT Triga training and research reactor in Espoo is used in the reactor physics course.

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* A more extensive presentation on the Finnish situation in nuclear engineering education can be found in: Vanilla, T., Mattila, L., and Reiman, L., Ways to Maintain Nuclear Safety Competence in Finland, OECD Workshop on Assuring Nuclear Safety Competence into the 21$^{st}$ Century, Budapest, Hungary, October 12-14, 1999.

*University of Helsinki, Department of Chemistry, Laboratory of Radiochemistry.*

Radiochemistry is one of the seven branches of chemistry represented at the University of Helsinki. Only *laudatur* level courses are offered in radiochemistry as part of the studies for the Master of Science degree. Students attend about three years of basic courses in inorganic, organic and physical chemistry and then do specialisation courses 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 research activities focus on the management and final disposal of radioactive wastes, on environmental radiochemistry, on ion exchange purification of effluents, and on radiation chemistry. An important addition to the research and teaching facilities is a new cyclotron.

### ***Technical Research Centre of Finland (VTT)***

Finland has no nuclear research centre. Instead, various units inside the multidisciplinary national research centre, VTT, have activities in nuclear engineering. The most important unit in this respect is VTT Energy, which has an excellent expertise in reactor physics and thermal-hydraulics calculations. VTT Energy and LUT have built the thermal-hydraulic facility PACTEL, as mentioned above. VTT Chemical Technology runs the Triga training and research reactor, as also mentioned above. The main research area of Triga is focused on the boron neutron capture therapy of brain tumours. VTT Manufacturing Technology has hot cells for non-transuranium materials. Located mainly on the same campus in Espoo as HUT, VTT has good links with the universities. The personnel of VTT are strongly encouraged to do post-graduate studies.

### ***Radiation and Nuclear Safety Authority (STUK)***

Similarly to the nuclear power plants, the Finnish nuclear regulatory body STUK has well-established training programmes for its personnel. As the national authority of radiation issues, STUK has the laboratories for radiation physics and radiochemistry necessary for monitoring environmental radioactivity.

## Initiatives taken in nuclear education

At the moment, the current level and volume of education seems to be sufficient in Finland. However, this situation may change in the future. As the NPPs were constructed in the end of the seventies and early eighties, the age distribution of the present workforce has a peak around the age of 50 years. Therefore, retirements will start to increase considerably during the coming ten years. This scenario of increasing retirement is threatening to happen at a time that coincides with decreasing levels of interest by the younger generation.

The students at the Finnish Universities of Technology have compulsory training periods in industry, power plants, research centres, and/or safety authority. In addition, most of the theses for the master’s and doctor’s degrees are done in these organisations. By offering challenging and interesting positions for training and theses, the organisations in the nuclear energy field can have an important influence on the recruitment of new students. Therefore, a good co-operation between the universities, authorities, utilities and research organisations is essential for the education of the new expert generation.

Referring to the government's decision to keep the nuclear option open and to maintain the high level of expertise in the country, the Finnish National Research Programme on Nuclear Safety (FINNUS) for 1999-2002 has defined among its aims, the education of nuclear experts. Every project in FINNUS will offer both master's and doctor's level thesis positions.

The system of scholarships is well developed in Finland. However, there are no scholarships especially for the nuclear engineering students. In any case, the probability of obtaining a scholarship from various foundations is rather high for the Doctor's level students.

The Finnish Nuclear Society has started its Young Generation (YG) activities. It is too early to evaluate the results, but certain organisations, especially VTT, support the YG activities as a potential channel of recruiting new staff.

## FRANCE

In 1999, in addition to the present NEA survey, another survey was launched by the European Union on the “Evolution of nuclear expertise in Europe” and, in France, the High Commissioner of the *Commissariat à l'énergie atomique* (CEA) decided to evaluate the main nuclear engineering course entitled “Génie Atomique”, organised by the *Institut national des sciences et techniques nucléaires* (INSTN), the CEA’s education department.

All these surveys address the status of nuclear education in France, which is far from hopeless. This view is supported by objective reasons. There are 58 NPPs in operation today, generating 78% of the nation’s electricity.

Electricité de France (EDF) has around 50 000 employees in the engineering and maintenance sectors. Framatome, Cogema, SGN, Technicatome and other nuclear companies employ another 60 000 workers.

In R&D, the CEA employs 3 000 to 4 000 researchers, increased by another 1 000 from the research departments of EDF, Framatome and Cogema. The National Centre for Scientific Research (CNRS), universities and engineering schools also have about 1 000 researchers in the basic nuclear sciences.

The inventory would be complete by adding military nuclear activity with around 35 000 employees, and the medical field, which uses nuclear techniques to diagnose diseases and treat patients.

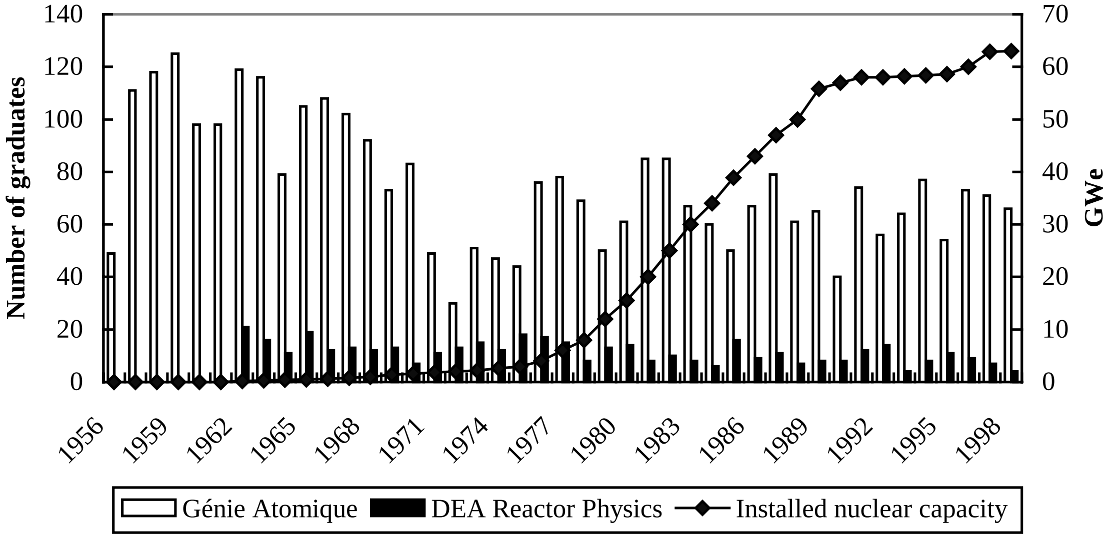
All in all, the French nuclear sector employs around 200 000 people. And what is the country's educational system for them? For most, the general part of the national educational system. There is no nuclear education at the undergraduate level except for radiological protection.

The backbone of nuclear engineering education consists of specialised courses organised at the INSTN, of which two are long-standing: “Génie atomique” (Atomic Engineering) and “Diplôme d'études approfondies” (DEA) in reactor physics (Ph.D level).

Figure 1 shows the number of graduates for these two courses from the outset, alongside the growing French nuclear power plant capacity over the same period. It is striking to remark the apparent unconnectedness of the two sets of data.

The French government decided to launch a huge nuclear programme in 1973. Of the total number of “Génie atomique” graduates from inception in 1956, to 1973, nearly half were EDF engineers. They subsequently formed the nucleus of the EDF staff involved in NPP construction and operation.

Figure A3.1 **Atomic Engineering graduates, DEA Reactor Physics graduates, installed nuclear capacity from 1956 to 1998**




Since the mid-1970s, the student body in "Génie atomique" is composed of young graduates from universities or engineering schools without any previous professional activity. It is worth noting that since 1984, about 30 students graduate annually from the "Génie énergétique et nucléaire" course in Grenoble. This course is organised as a 2nd and 3rd year option at the *École Nationale Supérieure de Physique de Grenoble* (ENSPG), and includes specific nuclear modules added to a general energy curriculum.

Figure A3.1 also shows the number of graduates in the DEA Reactor Physics course. These graduates generally go on to a Ph.D and are finally recruited by the research departments of CEA, EDF, Framatome, etc.

The number of graduates in DEA Reactor Physics corresponds to the average input needed to keep the number of researchers at a reasonable level. Fluctuations in this figure reflect the number of graduates, and reveal the difficulties in keeping this historic course active.

A more precise description of the specialisation courses in nuclear engineering must mention the recent creation of nuclear options in several engineering schools: "Nuclear Energy and Associated Technologies" option at *École des Mines de Nantes*; "Nuclear Energy and Safety" option at *École nationale supérieure d'ingénieurs de Bourges*; and one module (120 hours) on "Cycle Back-End Chemistry" at the *École nationale supérieure de chimie de Paris*.

Many engineering schools also have multi-annual agreements with INSTN to enable their students to attend the "Génie atomique" course instead of the last two years.

A wide variety of DEAs are also organised in scientific fields closely related to nuclear engineering, such as nuclear materials, structural mechanics, analytical chemistry, etc, which contribute to the education of a broad range of specialists for the nuclear industry.

The Frédéric Joliot summer school offers to ~50 young post doctorates from ~20 different countries the opportunity of upgrading their knowledge in modern reactor physics in yearly sessions organised in Cadarache since 1995. It will now be organised as "Frédéric Joliot-Otto Hahn" summer school alternatively in Cadarache and Karlsruhe.

To maintain a high level of general expertise, considerable importance is also attached to in-house training at EDF, Framatome, Cogema, and adult education organised at INSTN. For example, every year, the INSTN trains 7 000 persons in 600 sessions on about 120 different topics, mainly in radiological protection, but also in materials, fuel cycle, safety, radiobiology, radioactivity measurements, etc.

The *Conservatoire National des Arts et Métiers* (CNAM) allows workers to attend evening lectures on nuclear technologies and to obtain an engineering degree after several years. CNAM also dispenses adult education.

In conclusion, a recent SOFRES survey of 121 last year students from four engineering schools provided valuable information on their state of mind, as revealed in the following selection of questions/answers:

Q1: Does the nuclear field offer job opportunities?

- many 5%
- a few 83%
- none 12%

Q2: Do you think jobs in the nuclear field will last?

- yes 84%
- no 14%
- don't know 2%

Q3: What are the characteristics of the nuclear field?

- very dynamic 6%
- dynamic 59%
- not very dynamic 34%
- not at all dynamic 2%
- don't know 1%

Q4: Is it possible for a nuclear engineering graduate to find a job in other fields?

- yes, easily 50%
- yes, with difficulty 44%
- no 4%

and, finally:

Q5: Will you try to land your first job in the nuclear field?

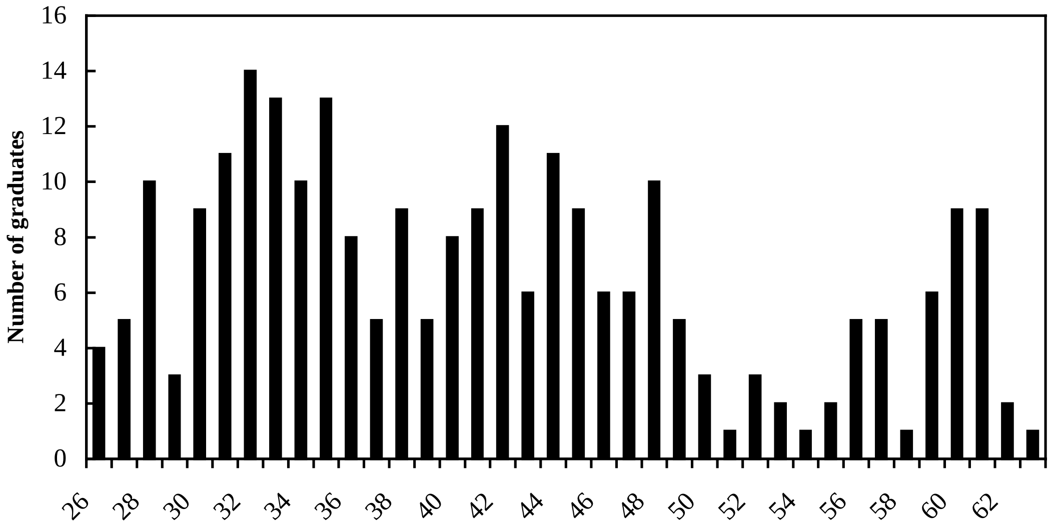
- certainly 6%
- probably 12%
- probably not 48%
- certainly not 26%
- don't know 7%

Thus, despite the positive assessments of the main characteristics of the nuclear professions, the reservations of the most concerned students can probably be explained by the general context of society. Nuclear energy no longer enjoys the same prestige as in its beginning, and other sectors are more attractive for the best students: communications, automotive, etc. The information effort aimed at these students must therefore be intensified if we want to be able to supply the industry and the research organisations with the scientific staff they need in the coming years. This is the chief concern today.

On the other hand, France faces no imminent risk of the disappearance of the teachings because of an ageing teaching body or because their survival is contingent on mergers with increasingly distant disciplines. In fact, the health of nuclear education depends exclusively on that of the research organisation (CEA, EDF, Framatome and Technicatome research departments, etc.) from which it draws its teachers, and there is no basic cause for concern on this point.

As an example, the age breakdown of Atomic Engineering graduates recruited by the CEA (Figure A3.2) reveals a relatively young population capable of keeping its expertise alive for years to come.

Figure A3.2 **Distribution of Atomic Engineering graduates within the CEA by age**




**Remarks concerning the French data in the survey**

The survey incorporates data from the following institutions:

***"Universities and similar"***

- ***École nationale supérieure de physique de Grenoble*** for the "Génie énergétique et nucléaire" course (GEN) and the "Génie atomique" (GA) (data included in Figure 1 of the present summary)
- ***Fondation EPF Sceaux***
- ***Consevatoire National des Arts et Métiers***

- ***Institut national des sciences et techniques nucléaires*** for 10 courses:

  a) Nuclear Engineering Course: “Génie atomique”;
  b) Qualification in radiological and medical physics;
  c) DEA “Solids, Structures and Mechanical Systems, option Dynamic of Structures”;
  d) DEA “Metallurgy and Materials”;
  e) DEA “Analytical Chemistry”;
  f) DEA “Radio-isotopes, Radionuclides, Radiochemistry”;
  g) DEA “Radiobiology”;
  h) DEA “Physics and Modelisation of Complex Systems, option Reactor Physics”;
  i) DESS “Radioprotection”;
  j) DESS “Science of Aerosols, Aerocontamination Engineering”.

The first two courses mentioned above are fully organised by the INSTN. The DEA and DESS are always organised with one or several universities, one of them being the leader (registration of the students, delivering the degrees, co-ordination with the Ministry of Education, financing the scholarships, etc.); the INSTN brings its specific competencies in fields where the CEA has developed research generally not performed in the Universities.

***“Companies”***

FRAMATOME
TECHNICATOME
CEA
INTERCONTRÔLE

## HUNGARY

### Overview

#### *Nuclear facilities in Hungary*

Hungary has nuclear facilities at three different locations. Two low power reactors operate as research and training institutions, one at the Atomic Energy Research Institute, and the other at the Budapest Technical University. The reactors with an output of 10 MW and 100 kW have been providing support to Hungarian research work, education, medical sciences and agriculture since 1959 and 1971, respectively.

The only industrial nuclear facility of the country is the Paks nuclear power plant which, with its Russian-designed 4 x VVER440/V213 reactors, producing a total of 1 840 MWe, covers around 40% of the domestic electricity needs. The units were brought into commercial operation in 1983, 84, 86 and 87. The operational performance and the safety upgrading activity of the plant are internationally acknowledged.

In the first years of its operation, until 1989, the Paks N-plant, as a domestic industrial facility of major importance, enjoyed wide public and governmental acceptance and support. The high standards and volume of technology applied there had positive effects on both the Hungarian industry in general and on the scientific background. Aimed at contributing to solve quality problems arising from the Russian design and manufacturing as well as to train plant, support company and institute staff, nuclear training began to boom. The Atomic Energy Research Institute played a considerable role in casual training events during regular academic education at the Budapest Technical University. The Hungarian researchers and scientists were given considerable space to do their job around the nuclear plant.

In this framework, and in order to cover long-term needs for qualified staff, a secondary vocational school was established in 1986, at the plant’s initiative and with its support. A year later, the Mechanical Engineering Faculty of the Budapest Technical University created an affiliated local faculty in Paks providing high-level education. In the general energetic training programme a major emphasis was placed on the nuclear field.

### The status of nuclear training in the period studied

Education specifically targeting the nuclear field has never existed, but it was included as part of general energetic studies.

At the Mechanical Engineering Faculty of the Budapest Technical University, subjects preparatory to nuclear energetics already appeared in the 1960s (commercial operation of unit one was then planned for 1975). Between 1968 and 1996, the university hosted a postgraduate programme for the training of engineers in the specialisation of reactor techniques: 175 persons were awarded diplomas here and they now hold middle and high-level managerial positions in different fields of nuclear energetics, mainly at Paks nuclear power plant and the Hungarian Atomic Energy Authority.

The Natural Sciences Faculty of the Budapest Technical University, and the Institute for Nuclear Techniques, launched a physicist engineering training course in 1992, specialising in nuclear techniques. After taking a three-year physicist training course, participants studied nuclear physics, reactor physics, reactor technology, nuclear energetics, thermal-hydraulics, radiochemistry, nuclear measurement techniques as well as radiation and environmental protection. The majority of the engineers who graduated from this programme have found jobs in scientific work.

We expect to launch in the autumn of 2000, a 5-year post-graduate training course in energetics. Hopefully, it will provide a better opportunity for a potential nuclear specialisation to be created later. In case of a need (e.g. construction of a new plant) this specialisation can quickly be initiated.

## Factors influencing the future of nuclear training

Attempts made to keep nuclear training alive have been closely related to the future of the Paks plant. But even in the case of the potential hold-off of the plant extension project, there are many factors in favour of keeping nuclear training and retaining the qualified staff trained in the 1980s as well as ensuring the education of future recruitment. Some important features of these factors are:

- By the turn of the millenium, the plant will have passed half of its life span so it there will be a need to change the ageing staff recruited in the 1970s.

- The decommissioning, life extension or construction of new plants necessitate well-trained nuclear specialists.

- As a result of the redefinition of the legal background of nuclear regulatory activities and the increasing expectations against these activities, the Hungarian Atomic Energy Authority managed to introduce visible human resources and a technical development programme in the 1990s. Consequently, the regulator imposes higher requirements on both its own staff and those working in the nuclear industry. This is beneficial to the enhancement of the nuclear training system.

- The plant makes significant attempts to meet international expectations for nuclear safety and technical conditions. These efforts engage intellectual capacities and a considerable number of experts and high levels of expertise are needed.

- In order to maintain the competence of the staff, in 1994 the plant management launched, jointly with the IAEA, a project to completely refurbish the in-plant professional training system and the conditions thereof. Within the frame of the four-year project, the job-specific training programmes based on a state-of-the-art methodology were redefined, a worldwide unique maintenance training centre was built and a new generation of full-time instructors were developed to take over in-site training.

## Conclusions

The future of nuclear training in Hungary is closely related to the changes in the nuclear energy industry. The Paks NPP performs all the necessary measures to fully comply with the worldwide-accepted nuclear safety and technical standards. Another major objective is to remain competitive under the conditions of a liberalised electricity market. Achieving these objectives imposes strict requirements on the plant staff and also on the supporting institutes. To perform the related tasks successfully we should maintain a high level of competency for professionals, and attract new specialists into the nuclear field.

The nuclear training activities should be renewed and reinforced with elements such as environmental protection, quality standards, marketing and public relations skills.

# ITALY

In Italy, there are 45 state universities, 3 polytechnics, 6 private universities, 3 state institutes, 6 private institutes, 2 universities for foreign students and 3 schools for advanced studies. This composite configuration can be considered sufficient to satisfy and cover almost homogeneously all national territory.

Universities and equivalent organisations, according to Italian Law No. 341/90, award three different degrees to students after successful completion of their course work. The first level degree for undergraduates is the bachelor's (*diploma*) which is awarded after successful completion of a course lasting 2-3 years. The course work is aimed at providing students with technical knowledge and procedures to meet the formative level required by specific professional sectors. Today, Italian universities no longer award undergraduate degrees in the nuclear energy field. The probability of maintaining such a decision into the coming future is high, mainly because the law of supply and demand indicates a slight excess of young nuclear engineers in comparison with the demand by industry and research centres. Many universities award undergraduate degrees in energetic and mechanical engineering. The Polytechnics of Milan and Turin and the University of Pavia have regular courses on energetic engineering while 30 other universities propose regular courses on mechanical engineering for undergraduates.

The second level degree, a graduate master's (*laurea*) is awarded to students after successful completion of a course lasting 4-6 years and followed by the preparation and discussion of a final thesis. The course work is aimed at providing students with technical knowledge and scientific procedures of a high professional level. Finally, the third level degree, a graduate doctor's (*dottorato* or *specializzazione*) is awarded to students with a second level degree after successful completion of a course lasting not less than 3 years which includes scientific research and discussion of a final thesis. The course work is aimed at increasing the existing knowledge on investigation techniques and research methods focusing the attention on specific scientific, economic, literary, and financial aspects. Almost equivalent to the *dottorato* is the *specializzazione* degree, which takes 2-4 years and is awarded by schools where many branches characterise different subjects, such as the various medical departments, for example. Unlike the *specializzazione*, the *dottorato* degree is legally recognised only for an academic career. Industry does not require it. Generally, a graduate doctor is well accepted in high-tech sectors while a normal graduate has more chances in all other industrial branches.

The basis of the Italian nuclear education programme was instituted at the beginning of the 1960s in the Polytechnics of Milan and Turin and in the Universities of Bologna, Palermo, Pisa and Rome "La Sapienza". Education programmes in energetics (Universities of Bari, Genoa, Padua) and physics (almost all Italian universities) include a number of nuclear related courses but a comprehensive nuclear programme is developed specifically in the above mentioned six nuclear engineering schools. In general, a complete nuclear education programme is composed of 27-29 courses including physics, mathematics, specific professional subjects, a foreign language and a final thesis. Globally, 32-33 exams are requested to complete an entire programme in nuclear engineering. The legal duration of the education programme is 5 years but the effective difficulty and the great number of exams normally leads to 7 years. In Italy, the law that is referred to for nuclear education programmes today is DPR 20 May 1989. Recently, the Ministry for University and Scientific Research (MURST) planned a new structure for Italian universities in order to facilitate student mobility within European Member countries.

Italy is subjected to nuclear moratorium. In November 1987, a public poll based on specific subjects concerning nuclear energy was held in Italy. The outcomes were not successful for nuclear energy. As a consequence, the Italian government gave the order to stop Trino and Caorso nuclear power plants, to start decommissioning procedures for Latina nuclear plant, to stop the construction of Alto Lazio nuclear plant and to stop all new plant designs. The Italian Nuclear Standard Project (PUN), prepared for the construction of new NPPs in Italy, was cancelled. Following consultation with the public, the image of nuclear energy in Italy suffered a strong blow. 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.

Taking a step backward, one can note an increase of Italian students in the nuclear field between the 1960s and the 1980s. Soon after the first international oil crisis (1974/75), the number of degrees granted was about 300 per year. After the Italian poll on nuclear energy use (1987), it dropped to 100 degrees per year.

Nuclear energy is now leading a “latent existence” in Italy. People know that Italian scientists are still involved in nuclear research programmes both in Italy and in other countries but no one wants to speak of nuclear energy and many are not in favour of new nuclear power plants. The nuclear industry is paying heavily for the nuclear 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). 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. Another indicator of Enel’s new trend is that the figure of nuclear engineers has disappeared from any call for enrolment of new graduates. They were looking for new mechanical, chemical, and electrical engineers but nuclear engineers were no longer wanted. ENEA, the most important Italian research centre in the energy field, reduced its employees by encouraging retirements without replacing them with new appointments. Over the last 10 years, ENEA has hired no new graduates in the nuclear field trained to work in the nuclear fission division.

Despite the critical situation described above, Italian “nuclear” universities, in particular, but also 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 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.

An interesting initiative was achieved by “La Sapienza” University of Rome thanks to CATTID (Centre for Application of Television and Distance Education Techniques). CATTID is a structure within “La Sapienza” University of Rome. It was created to allow teachers and students to use modern technologies for their didactic activities, to promote and develop multimedia research programmes, to organise training courses on the use of the most advanced research and teaching technologies.

CATTID prepared for the Division of Engineering and Technology of UNESCO[1], a postgraduate course in Energy Engineering, composed of 26 modules focusing on specific subjects relevant for a postgraduate level of education in the field. These modules are devoted to nuclear power plants and foresee 17 lectures prepared by leading teachers.

A traditionally good agreement exists between ENEA and Italian universities and acts as a driving force to develop common research and educational programmes. ENEA can be seen as the converging point of university and industry. The organisational effort made by ENEA in the field of specialist undergraduate and graduate training from 1995 to 1997, can be summarised as follows:

a) capacity for up to 1 500 students in the various ENEA research centres[2] to prepare their graduation thesis with the help of ENEA experts;
b) grants[3] given to graduate masters to develop scientific topics for their *dottorato* degree;
c) 179 grants for masters to go ahead with their scientific work at ENEA centres;
d) 53 grants directly managed by organisations linked to ENEA in joint research projects; and
e) funds to activate specialist post-graduate schools.

About 10% of places for graduate thesis, 2-3% of places for masters and 1% of total grants were designed for students in nuclear engineering.

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 (National Council for Scientific Research). CNR periodically offers a number of grants to graduates in scientific subjects. 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.

DNU, the nuclear division of ANSALDO, prepared a number of Web pages on Internet that included a number of details, initiatives and peculiarities of the Division. A limited number of grants and subjects for graduate thesis are provided yearly by ANSALDO. The main purpose of this initiative is to attract bright young graduates into the nuclear field and to hire them if funds are available.

Concerning university, the current number of full time faculty students in the nuclear field is 120. Age is not a problem for professors as, on average, they are only slightly above 50. The age of structures is a more relevant problem in some universities: laboratories, tools and infrastructures are

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1. UNESCO is a widely recognised cultural organisation of the United Nations, in Paris, founded on 4th November 1945 to increase reciprocal knowledge between peoples and for the diffusion of culture and preservation of cultural heritage in the whole world.

2. Northern Italy: Bologna, Brasimone, Saluggia, Ispra, Santa Teresa and Faenza. Central Italy: Rome Casaccia, and Frascati. Southern Italy: Trisaia, Portici and Manfredonia.

3. In addition to grants made available by the Ministry of University and Scientific Research (40 for the 11th cycle, 44 for the 12th and 36 for the 13th).

30 years old in many cases. On the contrary, the current level of nuclear education is sufficient for the supply of manpower replacement caused by retirement in the industry and in other institutions. University education is still providing well-qualified manpower for several fields of industrial applications as well as for administrative and academic occupations. At university level, there are a few inter-organisational and international collaborations to encourage students to study nuclear subjects. Owing to the current situation in Italy, one can notice a strong one-way flux of students from Italy to foreign countries in which nuclear energy has not been inhibited. Students from abroad rarely come to Italy to follow nuclear courses. The reason is clear: although nuclear knowledge and teaching standards are high, Italy does not guarantee any concrete possibility of work in that field. Thanks to bilateral agreements on mutual collaboration between Italy and the Central-Eastern European countries, officialised by Italian Law No. 212, many nuclear scientists and professors can easily access Italy from central and Eastern Europe. In the past, some Western European national organisations including Italy, tried to organise a network aimed at exchanging human resources in the context of international agreements in common nuclear programmes. Unfortunately, this action did not produce the expected results.

Italian laws do not require new graduates to attend preparatory training for recruitment in the nuclear field. Consequently, specific professional courses dealing with nuclear issues are not common practice in Italy. They are prepared as in-house courses by industry and research centres specifically for their own new graduates, using their own teachers and tutors. On the contrary, many courses on energy related subjects are organised for trainees coming from industry, public administration, health, and research centres. Since 1996, the Energy Department of ENEA promotes and organises, at national level, professional in-house courses on Energy Management, as indicated by Italian Law No. 10/91 – article 19. FIRE, the Italian Federation for the Rational Use of Energy, collaborates with ENEA to perform this task. Industrial firms, the tertiary sector, state companies, public health services, universities and any other organisation in which large amounts of energy are consumed can need energy managers. Trainees may be both internal and external applicants. In 1998, such courses were attended by 120 trainees and taught by 12 trainers/instructors. The teaching staff is almost equally distributed in the age intervals: 31-40, 41-50 and 51-60. Professional courses provide participants with suitable organisational, legislative, normative and technical bases to carry out the energy management role at best.

As stated, the main nuclear industry in Italy is ANSALDO. Two types of in-house industrial training courses are planned there: professional training (organised and paid directly by ANSALDO) and formal training imposed by Finmeccanica National Industry (ANSALDO belongs to Finmeccanica Company). The professional training course is specifically aimed at the new labour force and is managed directly by the person responsible for the sector in which new graduates will be working. Each new graduate is placed into the care of a tutor who technically supports him for an initial period, known as the "supporting period". Supporting periods must be as short as possible. Formal training, instead, lasts only one week and represents, for the new graduate, a moment of institutional formation. Nuclear training is aimed at preparing young graduates to replace those retired to maintain a good balance between employment and retirement, in order to assure an unchanged number of people in nuclear staff. Since 1990, the number of nuclear staff at ANSALDO has been maintained and almost unchanged at 200 people. For experienced staff, periodical seminars and refresher courses are organised. To summarise, new recruitment at ANSALDO DNU depends mainly 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.

ANSALDO DNU has been widely involved in the construction of some parts of Cernavodã Unit 1 in Romania. Now a consortium headed by the Atomic Energy of Canada Limited (AECL) has been awarded a contract worth USD 200 million to continue work on a second reactor at that site. ANSALDO is a partner of AECL in the project. Other funds arrive from collaboration with Westinghouse. A hope now arises from Superphenix's decommissioning and from a preliminary interest expressed by some Far-Eastern countries such as Korea or China in cogeneration using nuclear power plants.

In the past, when the nuclear moratorium was not imposed in Italy, interactions between the nuclear industry and university were rather frequent. Today, industry's new recruitment in the nuclear field is very low and does not require any co-ordination with university. A natural conclusion is that, unless the Italian moratorium ceases, any residual collaboration between industry and university, including consulting and co-operative research is doomed to fail.

Unfortunately, the situation is unclear. The stop imposed on nuclear power plants, 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.

Nowadays, the nuclear moratorium is mainly a political problem but politicians do not want to face it because the nuclear debate is not well accepted by people. Obviously, the problem must be solved by looking at the public's acceptance of nuclear power plants. On the other hand, to be honest, nuclear energy for the production of electricity is not as competitive as oil or gas. For many years, the price of the oil barrel was not as low as it is today.

"Gas and oil are cheaper than nuclear" people say.

In reality, the use of nuclear energy today implies political, social, economic and strategic decisions, but:

- "Can a highly industrialised country be so strongly oil-dependent?"
- "Is it a good solution to change from oil-dependency to gas-dependency?"

Surely, a good strategy would require an appropriate differentiation of energy sources.

## JAPAN

### Transition from advanced technology to key technology

The traditional agenda in which science and technology are defined as the exploration of a new world is to be changed to a new one in which people will open a new world through critical selection of available science and technology.

In the history of nuclear applications, active scientists have opened the door for nuclear power plants and beam applications, which were followed up by industries to establish them as key technologies for the current industrial society. This transition corresponds to economic growth and also the increase of students in engineering courses both at universities and colleges in Japan. With a positive flavour for exploration into a new engineering field and a new energy resource for the growing economy, the departments of nuclear engineering in Japan succeeded in attracting excellent students, who constituted a hot group of science and technology in the 1960s and 70s.

By taking advantage of such human resources, the nuclear industry in Japan has managed to solve different engineering problems in the first phase and it has been establishing the technology. The intensive works carried out by the hot group have created a feeling of togetherness within the group and increases a sense of incongruity with other groups. The targets of the nuclear industry are now focused on opening its contents more, improving its economy and ensuring that it is correctly understood by the public, including the people living in the vicinity of power plant sites; by doing so, it will share the public common evaluation criteria for nuclear applications which is also important for everyone in the nuclear science and technology field.

Students interests are spreading more and more from manufacturing to services because of the restructuring of manufacturing industries, from venture businesses to established and traditional industries, as a balance of more interests for open possibilities and a stability for the future. Those diversities, as discussed in many places, might be due to the fruitful results of science and technology on the one hand, and the resulting overproduction on the other. This situation results in decreasing returns of advanced science and technology facing market competition and environmental limits.

Wide varieties of job markets have been opened by economic growth on the basis of such industrial infrastructures as energy, transportation and information, while such negative facts as TMI and the Chernobyl accidents and the so-called Dohnen problems happened in the nuclear field. There are only small changes with respect to the total numbers of students in the nuclear departments owing to a relatively stable university system, so that as synergistic effects, there are big changes in the minds of students and the resulting contents and qualities. This fact is not described explicitly in the answers to the questionnaire.

As a background to students' attitudes, the public has forgotten the effects of the energy crisis on the industrial society and/or it has not seriously learned the importance of energy security for Japan. It takes a long time to learn how to find a suitable use for nuclear energy by solving different issues and conflicts while going through the transient period from closed, special and centralised/top-down nuclear applications to open and common key technologies committed by the public.

Educational contents are to be expanded from developing technologies simply for hardware to utilising available technologies perfectly for hardware, software and experts, and finally to creating a way of co-existence between nuclear technologies and the public. Associated issues are becoming more and more complex, which requires new types of people with a challenging mind to solve the sophisticated issues of the key technology.

Relatively bigger budgets are required to maintain the infrastructure for nuclear technology but this is not easily understood. If peer reviews on the nuclear field are carried out in a similar way to other fields, nuclear will be at a disadvantage because of its intrinsic features, namely, heavy infrastructures and the difficulty of handling radioactive materials which used to require a long time to get research results and of fissile materials for safety aspects. The big problems now are the ageing of facilities for nuclear education, and some of them have been unfit for use after small maintenance problems due to the shortage of budgets for repair and/or understanding/preference of citizens living in the vicinity of such facilities. To strengthen the potentiality of nuclear technology, it is very important to make efforts not only for the understanding by experts in other fields of the above special features but also to overcome the disadvantages.

**Vision into the future**

In universities new relevant research fields have been tried out to keep and stimulate the challenging minds of the younger generations in nuclear science and technology. These fields involve the exploration of something new such as the spin-offs of nuclear fields: the application of particle beams for minor chemical analysis and tailoring of materials, human factors and knowledge engineering, computer simulations of multiscale and multidisciplinary aspects and "meta-technica" of social, environmental and ethical considerations.

Actions concerning these aspects are the renaming of nuclear departments, the restructuring of nuclear courses with other relevant fields by applying MOE (Ministry of Education, Science, Sports and Culture) university reform movements. The result has been an increase in graduate students in different specialities as a result of broadening research fields. In parallel, graduate students from different Asian and Eastern-European countries are increasing, reflecting the recent increases in MOE scholarships. This implies an increasing diversity of students and the importance of the transfer of technology between different disciplines, and countries with different technological infrastructures, cultures and generations.

On the contrary, nuclear specific projects such as spin-ons of relevant technologies have been decreasing in governmental organisations (national research and developing centres, university research centres), which seem to require a change in research attitudes from naive leading edge development attitudes to holistic attitudes of *noblesse oblige, and* keeping challenging minds to explore new fields. In the nuclear engineering industry, business is decreasing; chances of on-the-job-training have been decreasing for designing and manufacturing of new plants and increasing for licensing and maintenance. Reflecting these statuses, responses to the questionnaire have a relatively negative flavour. Answers from power utility companies are perfect and show that they are carrying out sufficient and substantial in-house training to respond to the public needs including sufficient consideration for different groups of people.

The future role of industry, power utility companies, national laboratories, government and universities differ and consequently, the focal points of educational activities are not the same. Power utility companies prepare a perfect training curriculum for their operators to ensure safe operation and a stable power supply. In order to share the necessary information for engineering of power plants, industries have made an effort to provide documentation on important experiences acquired through R&D and the solving of technical problems. The effective transfer of technology among experts from different disciplines and to the next generation is very important for collaborative engineering and to keep and improve technical potential. Government commits such neutral and overall businesses as long-term planning of energy policy, licensing, inspection and so on for the public, which concerns the uncertainty and complexity of society and technology.

National laboratories cover the necessary R&D projects to realise government plans and businesses. Universities supply students for the various groups mentioned above, for example, operation and maintenance of power plants, development of new instruments, performance analysis of key components, manufacturing of materials, components and plants, life cycle design, energy security, and public acceptance. This implies that the role of university concerns basic and universal parts derived from *ad hoc* issues.

It takes time for specialised experts to learn how to survive during this transitional period from a closed and specifically nuclear option to open and shared nuclear. In Japan, education in the nuclear industry has been done in a collaborative way through different approaches in universities, national research and developing organisations, industries, power utility companies and governments. However there is a sign of global necessity for educational collaboration, beyond the frame of OECD, in addition to the care taken for domestic needs.

**Actions in education for the future**

Job markets are changing and the population spectrum is shifting to older generations, gradually caused by a low birth rate and longer lives. The industrial needs 5 years ago for human resources were expected to increase up to 1.5 times more than the actual size before 2010, but now, with the restructuring process of the nuclear industry, decreasing interests in human resources are being observed. In addition, the decreasing interest of younger generations in science and technology is generally regarded as having a serious effect on the future, and many actions against this trend have now started.

It takes time for everyone to understand why there is a serious need for nuclear energy, and to get rid of set ideas such as the self-appraisal of nuclear technology and “not-in-my-backyard” attitudes. Adequate ways of explaining the various issues to people with different opinions and levels of knowledge should be acquired rather than use the typical simplified dichotomic ways.

Challenging minds to solve very sophisticated issues in society are required, and one of the roles of education is to tailor an environment of different incentives to solve such issues individually, independently and collaboratively, namely:

- Curiosity-driven incentives as was the case in the first phase of nuclear applications; for example, new targets should be defined to improve knowledge on the status of water chemistry in the reactor core, and an exchange of information environment set up for collaborative purposes, and so forth.

- Business-driven incentives such as improving operation and maintenance procedures to optimise labour cost while maintaining the total quality of services, developing a new type of reactor like the ABWR, establishing a new maintenance technology such as the exchange of shroud in the reactor, and innovations like spin-offs of established technologies, and so on.

- Knowledge-intensive thinking incentives with future perspectives, not only as an observer of current and past science and technology but as one who explores into the future with skills and knowledge. These could be the linking of relevant projects, establishing academic cores for nuclear engineering, long-term planning of collaborations including waste management and build-up of local economies, and improving the learning procedures by the public.

As a conclusion to this short report, the author would like to say that the direction of education in universities is now oriented towards basics and fundamentals for critical thinking on all important issues relating to nuclear energy, both in depth and liberally, especially after the hard lesson from the JCO critical accident.

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## MEXICO

### Overview

By law, the use of nuclear energy for power and heat generation is limited to the Mexican State. The Secretariat of Energy (SE) is in charge of regulating its use in the country through a specialised technical body, the *Comisión Nacional de Seguridad Nuclear y Salvaguardias* (CNSNS), which is responsible for the regulation of nuclear and radiological safety, physical security and safeguards for all nuclear and radioactive facilities.

The current National Energy Plan which was issued in 1990 calls for a production dependent on oil. In the case of nuclear energy, it calls for the production of 3% to 6.9% of electrical energy of nuclear origin by the year 2010. However, several factors, including changes in the national economic situation and shifts in public opinion regarding nuclear power, have led to an impasse regarding new nuclear power plants.

Mexico has only one nuclear power plant in operation with two BWR reactors of 654 MWe net each. For the time being there are no plans for new units or plants.

### *Nuclear activities*

The Laguna Verde Nuclear Power Plant is located in the Gulf of Mexico about 300 km from Mexico City. Unit 1 of Laguna Verde started commercial operation in 1990 and the second one, in 1995. The Federal Electricity Commission [*Comisión Federal de Electricidad* (CFE)] is the state-owned national utility and is the only entity in the country that can utilise nuclear materials to generate nuclear power. The policies for its use are defined by the Secretariat of Energy.

The performance of Laguna Verde Unit 1 has been quite good so far and during 1994, it generated 4 239 GWh which represented 3.08% of the total generation in the country. With two units in operation, Laguna Verde generated 9 561.5 GWh corresponding to 5% of the total electricity production in 1999.

Due to the low cost of uranium currently available on the world market, all exploration and mining activities have been suspended, although Mexico has uranium resources of about 10 000 t. Uranium is bought either as hexafluoride or as concentrates that are converted to hexafluoride by Comurhex in France; the enrichment services are provided by the U.S. Department of Energy, and fuel fabrication is currently undertaken by General Electric.

The high-level wastes of Laguna Verde are being stored on site. Detailed site studies are now under way at the plant site for the low and intermediate level wastes produced by the plant, so that the engineering design basis of a “triple-barrier” repository using a French approach can be determined.

The repository is planned to have capacity for wastes generated during the operating life of at least four nuclear reactor units, and could also include the waste generated by medical and industrial radioisotope applications in the country.

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

There is an interim repository in Mexico for all the low and intermediate level wastes produced by medical and industrial radioisotope applications. This repository will have to be replaced by a permanent one in the future.

The nuclear R&D is carried out by the National Institute for Nuclear Research (ININ) and the Electric Research Institute (IIE). Three main fields have received attention: nuclear thermalhydraulics of boiling-water reactors (BWR), core neutronics and probabilistic safety analysis. A particular task was successfully completed by the IIE regarding the design and construction of a full-scope operational plant simulator to the Laguna Verde Nuclear Power Plant. Some preliminary consideration is also being given to projects on artificial intelligence and fracture mechanics, as applied to BWR nuclear power plants.

The main research facilities are located at the nuclear centre (ININ) which has been in operation since 1968 and has among its facilities a 1 MW research reactor, a 12 MeV Tandem Van de Graaf accelerator, a 500 000 curie gamma irradiator, a metrology centre for ionising radiation.

The Mexican regulatory body (CNSNS) has taken steps to train its staff in the nuclear field (on topics like radiation protection, nuclear reactor safety, thermalhydraulics, health physics, etc.) by providing local courses to enable its staff to keep up their basic skills in the kind of job they will be responsible for. Occasionally, it makes use of international agreements (IAEA, NRC) to send them abroad on specialised courses and they also attend short courses at universities. The lack of applicants with a formal knowledge in nuclear engineering has resulted in the need for the nuclear industry to provide training for its new applicants (mechanical engineers, chemical engineers, electrical engineers, and physicists) in the nuclear technology basics.

At the National Institute for Nuclear Research (ININ) things have been very similar but its framework is different because the main objective is to develop science and technology, provide services to the nuclear industry and also short training courses, mainly in the area of radiation protection. No training courses in nuclear engineering, nuclear reactor physics nor any other fields directly related to nuclear are offered. With respect to in-house training, the increase in annual man-hours provided by the trainers or instructors responds more to the need to satisfy an increasing market in the use and application of radio-isotopes (hospitals and industry) than to the nuclear field itself. On the other hand, this institute allows BSc, MSc and also Ph.D students of some universities to be involved in research projects that will enable them to get their corresponding degrees. This practice has given good results and quite recently a postgraduate programme leading to MSc and Ph.D degrees in several fields, including nuclear, was opened. Unfortunately, the nuclear field is almost empty and most of the applicants go into material sciences research.

In addition, the Electrical Research Institute (IIE) has run a similar fellowship programme to ININ, allowing students to do their thesis at bachelor, master or doctorate level. It has also given economical support to its staff undertaking postgraduate studies in and out of the country but this is coming to an end.

Finally, the utility (CFE) also offers its personnel continuing education through local courses given by its own staff and whenever necessary by private companies. It also has a simulator to provide training to its reactor operators and staff. It is important to have in mind that the first nuclear unit started to be commercially operated in 1990 and the second one in 1995. There is a strong probability that the increase in the number of trainees and trainers between 1995 and 1998 is closely related to this fact.

The numbers appearing in the table that provides a comparison of annual averages of the number of trainees, instructors, and hours for training are dominated by those coming from operation, radiation protection and quality control areas of the utility (CFE) including several kind of courses, some of them lasting for only 1 day and required to be attended by both old and new personnel.

The above organisations have certainly taken care of training their own personnel properly. However, things are completely different with respect to nuclear educational programmes at universities.

### *Educational system*

In Mexico the teaching of topics related to the nuclear field has practically been reduced to just a few institutions, namely:

- Instituto Politécnico Nacional (IPN)
- Universidad Nacional Autónoma de México (UNAM)
- Universidad Autónoma Metropolitana-Iztapalapa (UAM-I)
- Universidad Autónoma de Zacatecas – Centro Regional de Estudios Nucleares (UAZ-CREN)

### *Trend in nuclear education*

The oldest programme in nuclear engineering at the master level in our country is offered by IPN. The programme was created in 1961. In the first half of its life, the Nuclear Engineering Department (DIN), a department of the School of Physics and Mathematics (ESFM), had a numerous collegiate body with a top level and quality required for these kind of studies. It was undoubtedly one of the best postgraduate departments in the nuclear engineering field in Latin America during the 1965-1975 period. After 37 years, this programme no longer has the quantity or the quality of professors it had for almost twenty years. Today, it only has three full-time professors and two part-time. The research side has practically vanished and most of it is limited to BSc and MSc theses. In 1979, the DIN started to offer courses in the nuclear engineering field at BSc level. The idea behind it was twofold: first, to prepare students with a wider knowledge than the one offered to students involved only in physics and second, to have better prepared applicants for the postgraduate studies of the master programme. This proved to be successful for almost 15 years but at present, students had rather be more involved in the traditional studies of physics and mathematics than in nuclear engineering. On the other hand, the governmental institute that supports the development of science and technology, CONACyT, initiated the rating of postgraduate studies in the country as those of excellence and those that did not have the merits of a postgraduate programme. The programme offered by DIN at ESFM-IPN was included in that list and appeared on it for six years, but today, it is no longer included. In the near and medium-term future, nuclear education in Mexico is not promising and there is a strong possibility that in the next years, the nuclear engineering programme offered at IPN will come to an end like some of the others in the country.

The original programme offered by UNAM, a master in nuclear sciences with three options (nuclear engineering, nuclear fuel, and nuclear chemistry) was cancelled in 1997 and a master and a Ph.D programme in chemical sciences with an option in nuclear chemistry appeared in its place. The main contribution of the old programme was in nuclear chemistry and not in nuclear engineering or nuclear reactor physics.

The programme offered by UAM-I deals with the energy sector, and not only the nuclear field, and covers subjects related to the study of conventional energy sources (oil, natural gas, hydraulic, mineral coal, etc.) and unconventional ones (sun, eolic, nuclear, geothermic, etc.). In fact only a low percentage of the students enrolled in this programme (bachelor level) are involved in fields such as nuclear engineering, nuclear reactor physics, radiation safety and protection. Even in this case, the students are not compelled to take the whole body of courses in this area.

The programme that UAZ-CREN offers in the nuclear field started in 1995. It follows 4 main lines of specialisation: nuclear medicine, nuclear measurements, nuclear electronics, and nuclear engineering. Although several students were enrolled at the beginning of this programme, only two managed to see it through. Since then, the programme has had two students per year involved mainly in nuclear electronics and nuclear engineering.

***What the study does not include***

The study does not show what happened at universities before 1990. In short, there was a master degree in nuclear medicine at IPN’s School of Medicine (ESM) that started in 1980 and was finally cancelled around 1988. Some of the DIN faculties taught part of this programme’s courses. The reasons for its closure are not clear but were probably due to the lack of specialists in the area and to the low number of students who succeeded in finishing a master thesis.

On the other hand, there was presumably a master in radiation metrology at UANL (Universidad Autónoma de Nuevo León) in the northern part of the country.

Very recently there has been an increasing concern to offer programmes at the bachelor and master level in medical physics at UNAM’s Faculty of Sciences (FC) and also at ININ.

For years, most of the students who completed their graduate courses but did not graduate, were nonetheless hired by private and governmental institutions. Today those institutions are promoting their graduation. Paradoxically, one of those institutions approached DIN at IPN to make a proposal to promote joint doctoral studies in nuclear engineering. Unfortunately, there is a lack of faculties offering this Ph.D degree course, and therefore the proposal was left aside.

Based on what has been mentioned so far, the future of nuclear education in Mexico in the coming years is somewhat uncertain.

Low rate student enrolment, faculties close to retirement age, nuclear programmes vanishing fast from university offers, these are but a few of the afflictions that the national educational system is having to face to provide human resources in the nuclear field.

## Initiatives

### *Government initiatives*

At present, there is no specific initiative from the government to promote or motivate nuclear education in Mexico. However, CONACyT, a governmental agency offering scholarships to outstanding students willing to perform postgraduate studies at local and foreign universities, is still providing support to those applicants interested in nuclear postgraduate studies. Also, CONACyT has several programmes to fund well-defined research projects in science and technology. Besides the main merits of a proposed project, another mandatory requirement to obtain funds is that the project leader be a renowned specialist in the area. Recently, CONACyT launched a new programme aimed at improving the faculty staff of universities and research institutes by increasing the exchange of professors and researchers from abroad. Then one would expect a realistic plan to follow for the universities in the coming years which would consider scholarships for outstanding students, funds to develop good quality research, high level full-time professors related to the nuclear field, and at least one Ph.D programme in nuclear engineering to motivate students to continue their studies.

It is important to have in mind that the preparation of a new young generation of human resources in the nuclear field, if needed, demands an investment of at least 4 to 5 years. On the other hand, if nuclear energy resurges once again, some countries, including Mexico, will probably not have enough human resources to face up to it.

### *University initiatives*

Some years ago there was an agreement between the American Nuclear Society (ANS) and the Sociedad Nuclear Mexicana (SNM) for the international exchange of students. Unfortunately, this effort was cancelled as a result of the economical crisis in Mexico. It is important to point out that this agreement was an initiative of both nuclear societies with the support of research institutes (IIE, ININ) and the regulatory body (CNSNS). Some students from our universities certainly benefited from that action.

### *Industry initiatives*

At present there are no efforts by the industry as a whole to promote nuclear engineering studies.

### *Collaborative initiatives*

Very recently, the utilty (CFE) has been offering a programme for bachelor and master students to be part, *in situ*, of the activities of several tasks during fuel reload. Up to now, around 15 students have benefited from this initiative where CNSNS and also SNM have provided partial support to these students for their stay at the nuclear power plant.

**Interesting activities run by individual universities, professors, or organisations**

It is possible to say that the time students spend (6 months, 4 hours daily) with some of the organisations previously mentioned makes it the most interesting activity they can be involved in for learning purposes because it enables them to put into practice what they have learned at school while, at the same time, providing the opportunity for hands-on training in a real life situation. Moreover, the role played by the SNM has been decisive in maintaining student interest in the nuclear field. For instance, every year, during its national meeting, the SNM organises sessions for the students to enable them to present their papers. The SNM, local and foreign companies provide almost all the support they need to participate in the meeting. Finally, an initiative is addressed by some professors and organisations, the utility (CFE), the regulatory body (CNSNS) and the research institutes (IIE, ININ) to encourage their own engineers to give lectures or talks related to their work. These lectures have been presented at some of the universities.

## THE NETHERLANDS

There have never been nuclear specific undergraduate courses in the Netherlands like the nuclear engineering courses in a number of other countries. Education in the nuclear energy field at the academic level exists only in the form of optional lectures. Delft University of Technology is the only university to offer such lectures, including others on reactor physics, radiation shielding, reactor engineering, radiochemistry and chemistry of the nuclear fuel cycle. The lectures are given by four part-time professors.

Part of Delft University of Technology is the Interfaculty Reactor Institute (IRI) that operates a 2 MW swimming-pool type research reactor; this institute has departments in reactor physics, radiation physics, radiation technology, radiochemistry and radiation chemistry. It is the national centre for training and research in the fields of material research with neutrons, electrons and positrons including other nuclear techniques, physical aspects of nuclear reactors, research in radiation physics (in particular neutron scattering studies), radiation technology, radiochemistry, radiation chemistry (with a 3 MV pulsed electron accelerator as main facility) and environmental research. Teaching activities include courses for MSc and Ph.D students (the lectures mentioned before are given by academic staff members of the institute), as well as courses in health physics. The institute has somewhat more than 200 employees of which 140 are directly involved in research and education; 35 of the latter are academic staff members, about 40 are Ph.D students. It should be stressed, however, that only a minor part of the activities (about 10%) is in the nuclear energy field (mainly reactor physics), the emphasis being on the use of radiation as a research tool in the sciences.

The research reactor of IRI is the only university reactor in the country and is presently 36 years old. Its technical life expectancy is at least another 10 to 15 years. Because of the lack of sufficient space for experimental set ups around the reactor, a new experiment hall was recently built to accommodate neutron and positron beam experiments in the near future.

Nuclear energy activities are declining. Since the closure of the Dodewaard nuclear power plant in 1997, the only NPP in the Netherlands is the 450 MWe PWR plant at Borssele. In order to meet up-to-date safety requirements for modern NPPs, a large project costing 500 million Dutch guilders was undertaken and resulted in the complete upgrade of the plant in 1997. Nevertheless, the government has decided to close the plant at the end of 2003. This decision illustrates the *de facto* moratorium on nuclear energy in the Netherlands. Another indication is the discontinuation of the so-called PINK programme last year. The Dutch government, with the aim of intensifying nuclear competence, sponsored this programme; part of the financial support was for Ph.D studies at the IRI of Delft University of Technology.

The general trend is a decline of interest among young people in technical studies; technical universities suffer from decreasing enrolment rates. For the nuclear field an additional handicap is the negative image; keywords are moratorium and decommissioning, and at best, lifetime extension, none of which are appealing. So, young people are not motivated to look for a future in the nuclear field. The number of undergraduate students majoring in the nuclear field at Delft University of Technology can be counted on the fingers of one hand. The number of Ph.D students has decreased to 2 at present.

It is difficult to find good candidates for a Ph.D student position, particularly inside the country. This is a threat to university research, which is based to a high extent on Ph.D research programmes. Most of the young Ph.Ds of the last decade have taken positions outside the nuclear field because no (permanent) positions are available in the field.

During the aforementioned PINK programme, the Energy Research Foundation at Petten and the IRI of Delft University of Technology co-operated in postgraduate courses in specialised nuclear subjects but these activities came to an end, coinciding with the discontinuation of PINK.

IRI contributes to the Frederic Joliot-Otto Hahn summer school with teaching activities and is involved in its management's executive board.

Over the last years, no opinion polls have been held in the Netherlands, but the general attitude seems to be rather negative.

## SPAIN

### Nuclear industry

The initial Spanish nuclear programme was provided in the late 1950s by the Public Administration Department, through the *Junta de Energía Nuclear* which was involved in basic control activities. The generation facilities were owned by utilities from the electricity industry.

The first Spanish nuclear power plants were projects with foreign reactors and primary system suppliers, in which national industry participated as a subcontractor. The José Cabrera plant in Zorita (Guadalajara) was the first one to be contracted (1963); it has a 160-MW pressurised light water reactor (PWR) based on Westinghouse technology and began operating in 1968. The Santa María de Garoña plant, with a 450-MW General Electric-design boiling water reactor (BWR), and the Vandellós I plant, with a 500 MW French technology graphite-gas reactor, started operating in 1970 and 1972, respectively.

That same year, a second group of plants was contracted. These projects were organised "by components", a formula that favoured national industry participation and technology transfer. The national share in the seven units included in this group, with powers approaching 1 000 MW, increased to 70-75%, over the 40-45% of the previous stage.

Projects for another seven 1 000 MW reactors were undertaken in 1975. The rate of participation of the Spanish nuclear industry, by then consolidated, in these projects was of the order of 85% in investment. At present the NPPs in operation in Spain are the following:

| Name | Type | Power in MWe |
|---|---|---|
| Jose Cabrera | PWR | 160 |
| Sta. Mª de Garoña | BWR | 466 |
| Almaraz I | PWR | 973 |
| Almaraz II | PWR | 982 |
| Asco I | PWR | 973 |
| Asco II | PWR | 980 |
| Cofrentes | BWR | 1 025 |
| Trillo | PWR | 1 066 |
| Vandellos II | PWR | 1 009 |

Numerous Spanish firms joined the nuclear industry, and this required an extraordinary effort of adaptation to meet the demanding quality standards required by the industry. For this purpose, it was absolutely essential to adapt structures and assimilate leading-edge technologies. As a result of the successful adaptation of these companies to industry requirements, Spain today has engineering firms, service companies and heavy equipment manufacturers that have achieved a high level of development.

Equipos Nucleares S.A. (ENSA), a company that was created especially to work in the nuclear sector, has developed capabilities ranging from detail design to manufacturing of large equipment such as reactors and steam generators.

It is worth mentioning the work undertaken by Empresarios Agrupados and INITEC. These companies have implemented the most modern techniques in their procedures and installed powerful computer networks and programmes to execute their projects in the technical, scientific and management fields.

Special mention should also be made of the training, inspection, quality control and radiological protection services that led other firms to take part in the nuclear programme. In this way, TECNATOM S.A. was created by the electric utilities, and carries out in-service inspection, technical operating assistance, personnel training activities, as well as full-scope simulators of PWR and BWR plants and interactive graphic simulators.

Also worth mentioning are ENWESA, with broad service offerings for plant maintenance, LAINSA, which is specialised in decontamination and radiological protection services, and other companies specialising in inspection and quality assurance-related services such as SGS TECNOS.

Likewise, in the areas of construction and assembly, Spanish firms have had a definitive participation in the nuclear programme from the start, developing new technical, quality and management capabilities in the areas of civil work, assembly and testing.

As regards the fuel cycle, there are two large firms that work in this field: Empresa Nacional del Uranio (ENUSA) and the firm in charge of radiaoactive waste management, ENRESA. The former deals with uranium mining, fuel assembly manufacture and refuelling engineering, and the latter with the back end of the fuel cycle and low and medium-level radwaste.

Immediate interest in nuclear power or, in other cases, a desire to prepare for a future revival has led to the decision in various countries to promote development of a new generation of nuclear power plants. The aim is to achieve safer advanced plants in order to respond to social concerns, and more reliable and economic plants in order to compete with other energy alternatives.

In December 1988 the Spanish electrical industry set up its “Research Project on Advanced Reactors” through UNESA, to maintain the technology and prepare the Spanish industry for the future.

The Spanish Advanced Reactor Project established the following areas of action:

- European Advanced Plant Programme.
- EPRI Passive Nuclear power Plant Programme.
- EPRI Evolutionary Nuclear Power Plant Programme.

In order to control these projects, transfer the acquired technology and commercialise it, the nuclear electricity sector has created a specific organisation, the *Agrupación Eléctrica para el Desarrollo Tecnológico Nuclear*” (DTN), which is responsible for co-ordinating all activities.

The Spanish Nuclear Society (SNE) is a scientific and technical association whose members are dedicated to nuclear science and technology. The objective of the SNE is to contribute to the enhancement and development of these fields throughout Spain. In keeping with its objectives, the SNE provides support for investigation in the nuclear field, prepares and distributes scientific and technical information, collaborates with public organisations and companies in nuclear-related subject areas, organises national and international conferences dealing with scientific and technical issues in the nuclear field, advises on regulation and standardisation in this field, awards professional prizes and scholarships, and co-ordinates the scientific and technical activities of its members.

Since 1962, the Spanish Nuclear Industry Forum has brought together Spanish companies whose business is related to the peaceful uses of nuclear power ensuring that their interests are integrated and co-ordinated with the highest standards of safety and reliability in the operation of nuclear power plants. In its objectives, it has also included the promotion of education and training in nuclear power-related issues in collaboration with other institutions.

CIEMAT is a Public Research Institution attached to the Ministry of Industry and Energy through the State Secretariat of Energy and Mineral Resources. As a technological research centre, there has to be a link between basic research, mainly performed in the academic world, and the national industry. CIEMAT's projects in the nuclear field are directed at making progress in the safety of nuclear fission energy and demonstrating the role of nuclear fusion as an alternative energy with a future.

The Spanish Nuclear Council is the official institution in charge of the Nuclear Safety and Radiation protection regulations. It was created in 1980 and is directly attached to Parliament.

**University education system**

There are 7 polytechnic universities that offer nuclear education as a specialisation in the energy courses, because graduation in nuclear engineering does not exist. These polytechnic universities are located in Madrid, Barcelona,Valencia, Bilbao, and Oviedo.

In 1976, a six-year plan was implemented with the study of technical subjects in the nuclear field during the last two years of the course. After the sixth year, graduation in industrial engineering, mining engineering or naval engineering could be reached. At present, this old plan is only applied to the Polytechnic University of Madrid. The remainder of the technical schools have a five-year plan, in which nuclear subjects are of an optional nature.

Doctoral courses with nuclear subjects have been opened and each university offers different courses. After 32 credits, students can present their theses (*viva voces*), after which they receive their Doctor's title.

Funding for university research comes from several sources: the Ministry of Industry and Energy, the Spanish Nuclear Regulatory Council, the Spanish Nuclear Waste Management Company (ENRESA), utilities, and the European Union Programmes.

## SWEDEN

### Overview

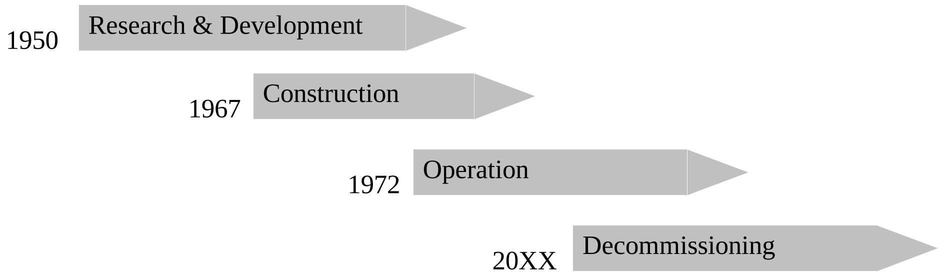
In 1980, a referendum in Sweden concerning the future use of nuclear energy and the resulting political decisions stated that all nuclear power plants should be shut down by 2010. Furthermore, a new law was legislated that prohibited Swedish companies from developing and constructing new facilities for nuclear power generation in the country.

Recent statements indicate that the present government may alter the decision regarding shutdown. The political majority is now trying to bring about a premature shutdown of the two plants at Barsebäck in southern Sweden.

The political turmoil in the field of nuclear energy that has been prevailing for almost two decades has had a restraining influence on R&D activities. The general uncertainty about the future development of the nuclear industry has also made education in the nuclear field less attractive to students possessing the right educational background and calibre.

### Development of nuclear power

The development of nuclear power in Sweden started in the early fifties. The focus has changed from initial research and development (R&D) to construction and, at present, operations, safety improvements and major back-fittings. In the future, an orientation towards disposal of high-level radioactive waste and finally decommissioning can be foreseen.




### University education system

In recent years a new education programme has been set up. It is a 2-3 year university course that includes mechanics, electricity, construction, chemistry and computer science. There is, however, no specific nuclear engineering course. The programme is based on a 3-year senior high school science/ technical course. Engineers who graduate from this programme fit very well the basic educational requirements for many positions in nuclear power operation, maintenance and manufacturing.

The original university courses for graduate engineers are 4-5 years, based on a three-year senior high school science/technical course. The courses are offered at technical universities and institutes. There is no specific, complete course in nuclear engineering, but in some courses, students can specialise in reactor technology, nuclear power safety, reactor physics, nuclear chemistry and health physics towards the end of the course.

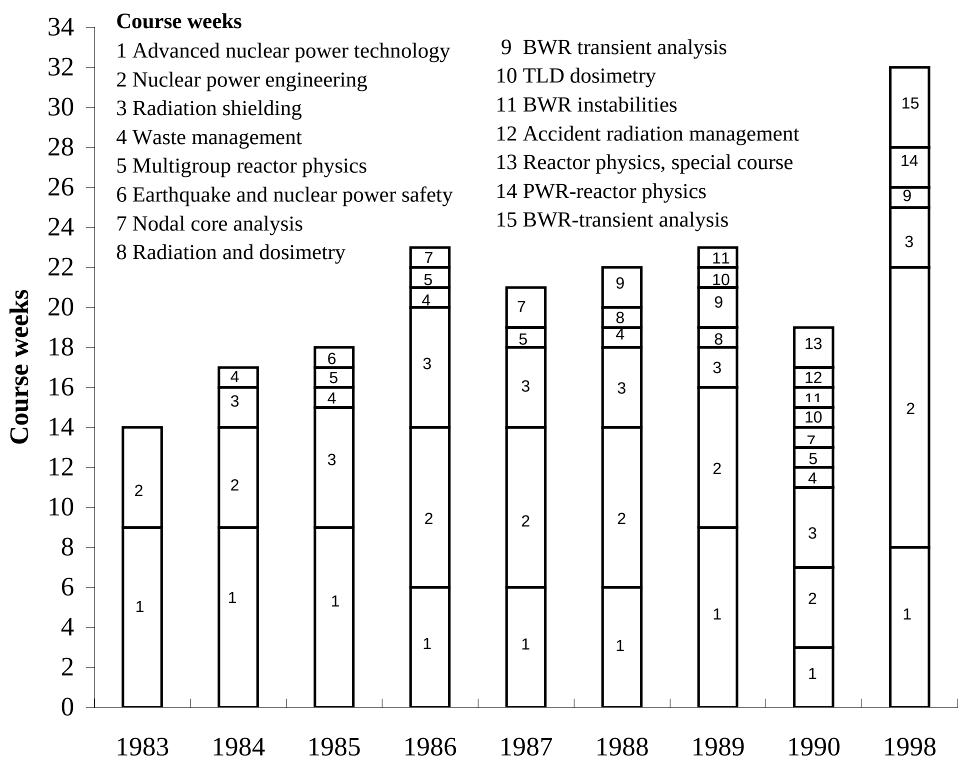
A new international M.Sc course in Sustainable Energy Engineering and including nuclear energy has recently been introduced at the Royal Institute of Technology.

The number of students in traditional nuclear science at Master and Ph.D. level is rather constant. A trend that can be observed is that the number of Swedish students slightly decreases whilst the number of foreign students increases.

## Training systems of the nuclear industry

Students specialising in nuclear science are a small but important part of the number of engineers recruited by the nuclear industry. Most engineers and scientists recruited are mechanical and electrical chemistry graduate engineers. To meet the specific theoretical training needs of engineers with a more general background, the nuclear industry has developed applied nuclear training courses, provided to the industry as "in-house training" by a jointly owned company. The average number of students is about 150 per year. The spectrum of courses is shown in Figure A3.3.

Figure A3.3 **Courses of in-house training**



This type of in-house training is judged to be sufficient for well-educated and trained personnel to meet the needs of the nuclear industry in the operating phase. The education system involves the following positive features:

- High quality and flexibility: specialists in different subjects can be called upon; demand and supply can be balanced.
- Relevant information: information directly related to the training needs of the nuclear power plant can be presented.
- Modern education methods: use of computer-based training material.

**Demand for and supply of qualified manpower**

The demand for and supply of qualified engineers and scientists is at present well balanced and suited to maintain safe operation of the nuclear plants. However, the time scale for turning the focus to new areas to satisfy future needs of the nuclear industry is very long. This is of special importance in the areas of research and development. Nuclear safety and transmutation are examples of research topics which could also attract students to “conventional” nuclear technology and revive the spirit of meaningful and important research.

**Trends and initiatives**

Notwithstanding the fact that a majority of the public in Sweden generally has a positive attitude towards nuclear power, the negative political position has affected education in the nuclear field at the universities. The faculties have experienced budget cuts. There is, however, a common understanding within the nuclear community that, in order to maintain sufficient and effective education, there must be a limit to cutbacks. In order to reinforce “a critical mass”, some actions and initiatives have been taken:

- Government funding of nuclear safety research and development activities by means of specific research budgets from the Swedish Nuclear Agencies.
- Sponsoring of professorships at the Royal Institute of Technology.
- A Swedish Centre of Nuclear Technology has been established with members from the Royal Institute of Technology and other universities together with the nuclear power industry. The centre shall support nuclear research in order to safeguard national nuclear competence.

## SWITZERLAND

### Introduction

Nuclear power plants (NPPs) currently account for 40% of the electricity generation in Switzerland. There are, however, no fully-fledged university-level nuclear engineering programmes in the country so that, for the purpose of this survey, education in the nuclear field has been considered in a broader sense. Thus, the questionnaire was distributed to 9 different educational institutions which, at university and technical college levels, offer optional courses related to nuclear engineering, reactor physics, radiochemistry and radiation physics (nuclear medicine and radiopharmacy, as also basic nuclear physics, were not included). In addition, individual organisations with nuclear energy related in-house training programmes were addressed, as were also certain inter-organisational units with corresponding educational and training activities.

### Trends and analysis

The number of undergraduate students choosing nuclear related optional courses (usually in their final year) has remained fairly steady during the 1990-98 period covered by the survey. This is so in spite of the fact that a countrywide moratorium with respect to new NPP projects has been in force during this time. A factor which has contributed to the relative constancy of student interest is that course titles and contents have commonly been modified to broaden the scope of the topics covered. Thus, for example, nuclear engineering optional courses offered at one of the universities currently include related or overlapping power engineering aspects (energy production and use, safety, heat transfer, simulation, etc.). This makes the subject matter more attractive to students who are motivated to enter the energy field with a general, rather than specifically nuclear, orientation. In any case, it is only a fraction (typically ~ 20%) of the students taking nuclear course options at the various educational institutions, who also carry out a nuclear-related research project ("Diplomarbeit") as part of their degree work.

The overall situation with respect to doctoral research is qualitatively similar in that the total number of Ph.D. students in the nuclear field has remained relatively constant as well. This is, however, to be viewed in the context of a significant general increase in the number of doctoral degrees awarded in scientific and engineering disciplines across the country. The fact that nuclear-related doctoral research has been held fairly steady in absolute terms is at least partly attributable to the increase in collaborative efforts between educational institutions, the Paul Scherrer Institute (PSI) as national research centre and the Swiss Nuclear Utilities (see following section ). Thus, for example, although the infrastructure for doctoral research in reactor physics at one of the universities is no longer available, a 1994 collaboration agreement ensures that the concerned institution's doctoral students in this area can be integrated into corresponding R&D projects at PSI.

That the faculty members teaching nuclear subjects are largely in the upper age groups (see Figure 2) is indicative of the fact that the major surge of young scientists and engineers into the field occurred during the sixties and seventies. Concerning the facilities, the current situation in Switzerland can still be regarded as satisfactory. Although the 10 MW research reactor SAPHIR at PSI, which was widely used for reactor practicals earlier, was decommissioned in 1994, two low-power teaching reactors (at Basel and Lausanne) continue to operate, as does also the critical research facility PROTEUS at PSI. Several institutions maintain laboratories for radiochemistry and/or radiation measurements, while a major hot-cell facility and associated infrastructure are available for both educational and industrial research at PSI. Despite the earlier-mentioned national moratorium on new nuclear installations, the latter institute was nevertheless able to build certain facilities relevant to nuclear research, e.g. PANDA for passive-cooling thermalhydraulics studies. In addition, the operation on the site of new large facilities for fundamental research, such as the spallation neutron source SINQ and the synchrotron light source SLS (under construction) should offer further opportunities for nuclear-related R&D, particularly in the materials area.

The percentage of graduates who have done some nuclear specialisation and/or completed a doctoral thesis in the field, but who then choose to enter non-nuclear professions, is rather high, i.e. over 40% on average. This is related partly to the current job market situation and partly to the inter-disciplinary character of nuclear education. The latter feature is often perceived by young scientists and engineers as an important incentive to study nuclear subjects, the systems approach as well as the specific technical knowledge acquired being found to be applicable in a generic sense to quite different areas.

In-house training has been addressed in the current survey mainly in the context of NPP personnel. Although staff fluctuations are low, regular retraining of operators, technicians and engineers is required practice, and each Swiss NPP has a corresponding in-house training programme. Simulator training is the most important single aspect of the in-house activities, the basic nuclear education for the operating personnel being provided by the Reactor School at Villigen. The latter is, in fact, an inter-organisational unit which is run/financed jointly by PSI and the Swiss Nuclear Utilities and offers formally recognised educational courses for NPP staff. A second inter-organisational unit is the School for Radiation Protection, also at Villigen, offering a wide range of shorter training courses, some of which directly address NPP personnel. It should also be mentioned that the Swiss Association for Atomic Energy, which has a special commission on educational matters, usually organises topical courses twice a year for nuclear specialists, mainly from the NPPs. The general situation with respect to the education and training of NPP personnel in Switzerland is thus quite satisfactory, and there are generally increasing trends in the number of both trainees and trainer/instructor man-hours invested. This is qualitatively in line with the conclusions drawn in a recent survey made by the Swiss Federal Nuclear Safety Inspectorate.

## Promotional efforts

Efforts to promote nuclear education have been made in collaboration, as well as individually, by some of the universities and engineering colleges, by PSI as national research centre and by the Swiss Nuclear Utilities, as well as by the Swiss Association for Atomic Energy and the Swiss Nuclear Society.

As mentioned earlier, nuclear subjects have been combined with more general topics at several educational institutions. Clearly, the major goal thereby is helping to maintain an adequate number of young scientists and engineers with the interest and potential for entering the nuclear field as qualified specialists. A second, equally important, perceived aim is to try to inculcate a greater awareness for nuclear power among a larger fraction of the students at large. This is not easy to do in view of the current political climate in the country, as also the difficulties encountered in trying to modify basic university curricula. An interesting example of corresponding "awareness enhancement" efforts is the recent introduction at one of the universities of a half-day reactor experiment as part of the general physics practicals offered to engineering undergraduates. Each year, as a consequence, a considerable number of students from various disciplines receive some "hands on" experience with a reactor and have certain elementary nuclear engineering notions explained to them.

The Swiss Nuclear Utilities actively support nuclear energy and safety related research, which is largely conducted at PSI. A significant number of R&D posts are funded with the explicit aim of encouraging young researchers, including doctoral students and post-doctoral fellows. This has contributed in an important way to the significant increase in the number of doctoral students working on theses in the nuclear field at PSI. There is also some industrial collaboration on activities based at the engineering colleges ("Fachhochschulen", in the new Swiss system), but it is felt that this needs to be stronger in the future. Schemes for student internees are available at the NPPs, as well as in the Nuclear Energy and Safety Department at PSI. These are often also availed of by students from foreign universities. The Swiss Nuclear Society, which recently implemented a "Young Generation" network, has also established a new scheme for supporting students/young researchers for practical training in foreign nuclear industry.

Switzerland also contributes actively to the organisation of the Frederic Joliot-Otto Hahn summer school in Reactor Physics, which represents a noteworthy international co-operative effort in nuclear education. On a more general plane, it should be mentioned that international research collaboration in the nuclear field, e.g. PSI's bi- and multilateral links with R&D groups in other NEA Member states, constitute an important motivating factor for young researchers including doctoral students.

**General remarks and conclusions**

All in all, the present level of nuclear education in Switzerland is considered sufficient to cover manpower replacement needs in the short-term. This is to be viewed in the context that the country does not have a nuclear manufacturing industry and that current utility and regulatory body requirements for new personnel are rather limited. The needs of the national research centre fluctuate more strongly, and seeking specialists abroad to complement candidacies from within the country is common practice in this context.

The real challenge appears to be the ability to maintain, in the medium and long term, both the number and the high quality of professionals as has been traditional for the nuclear field in the past. The present decline in interest among young scientists and engineers in Switzerland is viewed as a threat to keeping the nuclear option open. There are several explanatory factors, such as the generally, often exaggerated negative image of nuclear energy projected by the media (safety, wastes, radiation exposure),; and the lack of political will to actively promote nuclear as a necessary $CO_2$ reducing element of national energy policy.

There is a significantly high probability that, at the turn of the century, the country's current moratorium with respect to new NPP projects might be extended by popular vote for another 10 years. Clearly, more needs to be done (and achieved) in terms of improving the general situation with respect to public perception and political support of nuclear energy. It is only then that most of the country's younger generation will be able to view nuclear fission as an essential component of a "sustainable" energy mix.

## UNITED KINGDOM

There are no longer any nuclear specific undergraduate courses in the United Kingdom. Yet, over the period surveyed, 1990-1998, the number of undergraduates reported as having a nuclear content in their university education has remained at least constant and has possibly slightly increased. The paradox is explained by the extent of the nuclear content of the courses. Whilst the survey does not adequately reveal this, it seems that this has declined with time and it is unlikely that any undergraduate programme in the United Kingdom could now claim any appreciable nuclear content. Thus despite apparently healthy numbers, it seems that the knowledge pool in nuclear sciences is decreasing at the undergraduate level. Further, because the student population has increased over this period, the percentage of students studying nuclear sciences, to any extent, may well have fallen.

Both at the master’s and doctorate levels, the number of students pursuing nuclear courses has slightly increased over the period. Master’s programmes are where the main specialisation into disciplines of relevance to the nuclear industry is focused. What the survey does not show is that research council funding for post-graduate work in the nuclear area is steadily becoming more difficult to obtain. If the viability of some postgraduate activity became critical, it could disappear very quickly. There would then be a knock-on effect in that associated elements of some undergraduate courses would also cease.

Whilst one university introduced a new master’s programme in Radiometrics, together with a new Radio-chemistry training laboratory, and another introduced an undergraduate module on Nuclear Radiation Chemistry, other universities witnessed cutbacks. A graduate nuclear engineering course closed, reductions in practical teaching because of staff reductions and financial restraint were reported and some universities have had to internally restructure to bring a number of nuclear subjects into a single school. The overall trend is for universities to reduce or even cease their support for nuclear related courses. This is linked to the consolidation of the industry as it focuses on operating existing plants and power stations more efficiently rather than on building new plants and stations. However, through their promotional efforts, by maintaining close links with the industry and by broadening the content of their courses to appeal to a wider audience, several universities have managed to maintain their position against the trend.

The survey did not cover non-nuclear programmes that provide good quality, although non-specialised, graduates and postgraduates for the industry. A number of research areas provide Ph.Ds or post-doctoral fellows for the more challenging aspects of nuclear R&D such as Materials Science, Metallurgy, Ceramics etc. The numbers graduating in engineering subjects (Civil, Mechanical, etc.) have remained relatively constant whilst the number of postgraduates in these subjects has sizeably increased. Taken overall, there is a substantial number of well-qualified engineers emanating from British universities and available, therefore, to the nuclear industry.

The number of university staff involved in teaching nuclear subjects is hard to define precisely because of the way the data were provided by the various respondents but it does appear to be generally declining. There is a significant peak in the 51-60 age bracket with nearly as many in this bracket and above as there are below age 50.

Whilst many of the facilities in universities are over 30 years old, most will be available for the foreseeable future. These include radio-chemistry laboratories, radiation measuring laboratories, a cyclotron, a dynamitron and radioecology facilities. However, hot cell facilities are only available in two universities and both facilities are likely to close around 2000. The survey records only one research reactor as having closed but in reality many were closed in the 1980s and early 1990s. Britain now has only one research reactor, which is expected to be available until at least 2010.

Details of the employment destinations of students who had taken a course with a nuclear content are less than complete. Nevertheless, there are sufficient data to show that a high percentage of the students from the master's programmes entered the industry, as did at least half of those who pursued doctoral programmes. This contrasts with data for graduates from nuclear related courses which shows little more than one tenth entering the industry. However, the graduate population is an order of magnitude higher than the post-graduate population. In any event, supply will be regulated by demand from the industry. With no design development and the industry contracting and becoming ever cost conscious, recruitment is currently at a low level.

Historically the nuclear industry commanded the best brains because it offered the best resources and facilities and enjoyed the privilege of being at the cutting edge of technical development. Now the perception of many potential graduates to the industry is negative. They do not see the industry as being in the forefront of technical innovation but more as a dinosaur. Although not evident in the survey, concerns are beginning to be voiced by the industry about the availability of appropriately qualified people.

With respect to recruitment, the efforts made by UK industry have followed what might be called traditional patterns i.e. the principal mechanisms for attracting young people have been good salaries and working conditions and the prospects for secure employment. In addition, companies also offer comprehensive training programmes and continuous professional development. The public relations activities companies use to raise their profile are not specifically geared to recruitment but certainly help it. Examples are educational initiatives, from primary school through to university, newspaper and television advertising and exhibitions.

Once employed, companies offer training schemes to support both broad-based knowledge and specific skills development. Training is designed for both new graduates and experienced staff with the aim of increasing the competence of the trainees in their specific function within the organisation. Although a wide range of courses is being operated with a strong focus on individual company needs, much training is in response to regulatory requirements. Companies fund their own in-house training.

The age peak of trainers is between 40 and 50, which is consistent with companies using experienced staff for training purposes. Overall, the number of trainers seems to have remained fairly constant.

As with the universities, most of the facilities are quite old but have a good projected life span. Facilities are maintained according to specific need and include hot cells, radiochemistry laboratories and radiation measuring laboratories. The industry also has access to the sole remaining research reactor.

Industry-academic collaborations are mainly in support of doctoral and post-doctoral research of direct interest to the sponsoring company. There is also some support for master's programmes and contributions to undergraduate programmes. International collaboration is limited to some EU activities and a small programme through the European Nuclear Society. Two universities cite the Frederic Joliot summer school, and its fellowships, as a source of inter-organisational collaboration and both are involved in its management through the Executive Board.

Successive privatisation programmes have removed the provision of energy from government control and strategic planning is now led by market forces. There is not seen to be any national need to make direct provision for the future availability of nuclear energy, nor of the requirement for a technological infrastructure for it. With both the industry and government unable or unwilling to offer support, resources and particularly human resources, are not being replaced. In several universities facilities and courses have been closed or severely restricted due to retired staff not being replaced.

The necessary specialist skills in areas such as radiation protection and radiochemistry are currently being maintained at adequate levels, primarily by diversifying the customer base for such activities in the universities. Where diversification is not possible, courses and research have ceased as the industry has become more cost conscious. The notable exception is safety research, considered essential by the industry and the regulator.

Nuclear education is not yet at crisis point in the United Kingdom but it is certainly under stress. The needs of the industry, both in terms of recruitment and research, have declined as it has reached maturity and as it seeks to be more competitive in a deregulated energy sector. No new power stations are being built and none are planned for the foreseeable future. In this context it is natural that nuclear education should have declined. However, it is crucial that the area of nuclear education is sufficiently robust and flexible to support the industry as it evolves. The concern is that the decline in nuclear education is such that it may not be able to do this.

Because of that concern, one company, BNFL, is working with universities to establish a centre of excellence in nuclear chemistry so that it will be able to preserve its core competence in this area. Support will be given for doctoral and post-doctoral programmes with research and training being carried out both at the universities and at the company's new facilities. Graduate and master's programmes will be encouraged to use the facilities so that there will be a pool of appropriately qualified people available to the industry.

The inescapable conclusion is that the future prospects for nuclear education in the United Kingdom are not good. In line with the market-led approach to the energy sector, there is no central planning. Accordingly, there is no one with an overall view capable of making provision for the availability of innovative nuclear technologies, and the people to develop them, should they be needed to help meet energy demand and quality of life issues in the future.

## UNITED STATES

Nuclear engineering education in the United States has shown a marked decline in the past decade. The number of university programmes, student enrolments, degrees granted and university research rectors have all decreased sharply. There is evidence of an ageing faculty demographic and few junior faculty students 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 nuclear electric power situation

There have been no new nuclear electric power plants ordered in the United States since 1978 and the last reactor ordered that eventually was put into operation was in 1974. However, since 1980, 40 U.S. nuclear power plants have entered into service. At its peak, 110 plants were operating, the number now standing at 103. Industry capacity factors have increased from about 55% to about 75% in the past 20 years; however, electricity restructuring adds a degree of uncertainty about future operations, decommissioning and license renewal of existing plants and the building of new plants.

The accident at Three Mile Island and the devastating accident at Chernobyl stimulated negative opinions toward nuclear energy. However, recent public opinion polls show a clear majority favouring the continued use of nuclear power, the extension of licenses for operating plants, and keeping the option available for new plants in the future. This occurs despite the U.S. programme for permanent disposal being well behind schedule, resulting in a continuing build-up of spent fuel at commercial reactors throughout the United States.

Thus the near-term outlook for nuclear power is often characterised as stagnant at best and in serious decline by others. Such perceptions have clearly played a role in the dramatic reductions in enrolment captured in the survey. Many respondents commented that students were reluctant to choose a nuclear curriculum because of the perception that the job market and longer term outlook for nuclear engineers were poor or because they saw an “occupational stigma”. Ironically, at the same time, many nuclear department heads responded to the survey by indicating that the job market was strong and that they now did not have enough graduates to meet demand.

This continuing mismatch occurs at a time when the horizon begins to show a broad range of new nuclear challenges, independent of when and whether there is a short-term return to new nuclear power plant growth. Understanding the ageing of existing plants, moving to relicense them for extended operation, the shutdown and decommissioning of some older plants, the clean-up, decontamination, and management of wastes are just some of the important emerging issues which will require an expert workforce for decades. This arises at a time when the workforce is ageing and many nuclear departments have either closed, merged with other departments, or broadened their curricula to appeal to a wider student and industrial community.

**The survey**

During the period surveyed, 1990-1998, the trend in nuclear education and training in the United States was generally one of decline and consolidation. Undergraduate enrolment declined from 1 400 to fewer than 600, with master's and doctorate enrolments falling by about one-third. An understanding of events that transpired before and during the survey periods is helpful in properly understanding the data and in reaching conclusions about appropriate future actions.

Since the 1960s the number of university nuclear engineering programmes has dropped from 59 to 33, with one university closing its programme this past year. From a high of 64 university research reactors, the United States now counts only 29 reactors on 27 campuses. In the last two years, four university research reactors have been abandoned by universities who do not see the financial payback of operating these reactors nor the scientific necessity due to the lack of students and users. One has been added. Almost all the remaining facilities are more than 20 years old.

With the number of undergraduate nuclear engineering students declining precipitously over the survey period and the advanced nuclear engineering numbers dropping more slowly, the universities have responded in an attempt to make nuclear engineering a more appealing field of study. Some have broadened their nuclear engineering curricula beyond the electric power aspects to include topics such as radiation health physics, radiation science, waste management, environmental effects, space applications, medical science, plutonium disposition and probabilistic risk assessment. One university merged its Nuclear Engineering and Engineering Physics programme with the Environmental engineering programme and now offers degrees in nuclear engineering, engineering physics, and environmental engineering. Another university moved the Radiation Health Physics from the College of Science to the department of Nuclear Engineering. Others have had their nuclear engineering departments merged with other engineering departments, some creating nuclear engineering options rather than entire curricula.

This array of scientific fields is intended to appeal to a larger campus-wide audience and is designed to attract students from a variety of undergraduate degree programmes. Survey results were mixed as to the effectiveness of this approach, although many believed that the decline in enrolment had been stopped or even reversed.

The number of faculty among the remaining departments declined modestly over the survey period. There were instances reported of new faculty hiring. In areas where programmes were merged and broadened, the number of faculty available to educate those pursuing a profession may have increased. The age profile of faculty were evenly split with 35% each in the 41-50 and 51-60 age ranges, older than those reported by most other countries, and only 16% of faculty under 40.

The number of non-university respondents to the survey was comparatively small and as such the number of responses to the level of training offered by companies was meager. Most considered training to be well structured and important to the state of the art. Training occurred through on the job experience or instruction and job rotation assignments. Compared to 1995, the training activities available in the United States were, like most countries of the survey, decreasing. The peak age of the instructors was in the 41-50 category, but with a large percentage in the 31-40 category, an encouraging sign in an industry not known for youthful demographics.

**Actions taken**

There has been a degree of innovation shown that is most evident in the area of recruitment. Schools have advertised their programmes through the distribution of literature on career opportunities, newsletter publications, outreach to high schools, open houses for freshmen, summer programmes and tours of the campus, mailings to potential students, and recruiting posters. In addition, schools have held seminars on opportunities in the nuclear industry at community colleges, emphasising the environmental aspects of nuclear, and teacher workshops. Other steps identified in the survey have included the hiring of a full-time recruiter, advertising to local private and government organisations, visits by undergraduates and graduate students to regional high schools, advertising on the internet, and the initiation of programmes where freshmen work on research directly with a faculty member. The results of these actions have been mixed as reported by survey respondents.

Industry has been even more active in taking steps to attract students into the nuclear field although survey results indicate that these efforts are not very widespread. Activities range from participating in engineering week activities and advertising industry's work to college-bound students to sponsoring regional education programmes that are focused on grades K-12. These efforts include teacher training and hands-on learning experiences with a focus on building a math and science foundation. With the 7-12 grade students, technology laboratories, science seminars and mentoring are used to attract students into technical careers. At least one industry employer believes that utilising students from middle school through post-doctorates for research is a lever for recruiting individuals into the nuclear education path. The middle school students attend summer camps and are taught by professional scientists and taken on extended field trips to power plants, future nuclear waste repositories, etc. Younger students have the opportunity to participate, outside of their normal classrooms on a Saturday morning, in science activities. Other private companies partner with local universities to teach a nuclear seminar for teachers, while still others lecture at universities which leads to the hiring of students from the university and the sustaining of the companies manpower infrastructure. The American Nuclear Society provides over USD 110 000 in fellowships and scholarships to graduates and undergraduates studying nuclear engineering. In addition, industry through the Institute for Nuclear Power Operations' National Academy for Nuclear Training provides about one million dollars annually in graduate fellowships and undergraduate scholarships. Together, these programmes support over 185 undergraduates and 55 graduate students who are pursuing courses of study to prepare them for work in the nuclear industry.

One of the keys for faculty retention, particularly in a climate of declining enrolments, is ensuring that the faculty is self-supporting; that is, attracting research funding to the university. Obviously, universities will support faculty that can sustain themselves thus preserving the university's financial resources. A relatively new programme entitled Nuclear Engineering Education Research grants was instituted by the U.S. Department of Energy to address this need of faculty research in the area of nuclear engineering. The programme awards grants, on a peer reviewed competitive basis, to faculty members undertaking innovative nuclear engineering research in one of eight technical areas. In the first two years of the programme there were 39 grants awarded to 39 different professors totalling USD 6.5 million for (primarily) three year research efforts. No one faculty member can be the principle investigator on more than one award and some preference is given to young investigators (those with less than 10 years of university experience) as a way to encourage the retention of these faculty members by the universities.

Efforts to increase funding for nuclear energy research and education have met with success. In a 1997 study by the President's Committee of Advisors on Science and Technology (PCAST), nuclear energy was identified as one of the technologies that could alleviate global climate change and address other energy challenges, including reducing dependence on foreign oil, diversifying the U.S. domestic supply system, expanding exports of U.S. energy technologies and reducing air and water pollution. As a result, beginning in fiscal year 1999, nuclear energy research and development funding (USD 19 million) was provided to the Nuclear Energy Research Initiative programme, which is designed for universities, national laboratories and industry to research, develop and demonstrate advanced technologies that address nuclear energy's key issues. Also, there has been a dramatic increase in the level of federal government funding for university nuclear engineering activities. These activities include support for students in the form of fellowships, scholarships and research funding, research funding for the faculty, fuel assistance for university reactors, and cost sharing with industry to support the nuclear engineering infrastructure at universities. In a typical year, approximately one and one-half million dollars is provided to graduate and undergraduate students by the federal government for fellowships and scholarships in nuclear engineering. These funds provide for over 20 fellowships and more than 50 scholarships. In addition, there is a programme that provides funding to the universities to encourage reactor sharing with other educational institutions and an outreach programme is beginning to familiarise entering college freshman/high school seniors with nuclear engineering by providing instruction for high school science teachers at locations throughout the U.S. Funding for these university programmes has grown from USD 3 million to USD 12 million in just three years.

**Outlook**

Nuclear engineering education in the United States is reflective of the perceived health of the nuclear electric power industry within the country. Just as new commercial reactor orders have vanished and some power plants have shut down, so too have university enrolments shrunk and research reactors closed. This decline in nuclear trained specialists and the disappearance of the nuclear infrastructure is a trend that must be arrested and reversed if the United States is to have a workforce capable of caring for a nuclear power industry to not only meet future electric demand but to ensure that the over 100 existing plants, their supporting facilities and their legacy in the form of high level waste and facility clean-up are addressed. Additionally, the United States has an obligation to support and maintain its nuclear navy and other defence needs. And, lastly, if the United States is to have a meaningful role in the international use of nuclear power with regard to safety, non-proliferation and the environment, then it is imperative that the country continues to produce world-class nuclear engineers and scientists by supporting nuclear engineering education at its universities.

The continued support of the federal government and industry for university nuclear engineering and nuclear energy research and development is essential to sustain the nuclear infrastructure in the United States. Even with this support, and the continued excellent operation of the existing fleet of nuclear electric power plants, it is conceivable that nuclear engineering as an academic discipline may fall victim to poor communications and a tarnished public image. What is needed is a combination of federal and industrial support along with the creativity of the universities to expand their offerings to include more than power production. The objective is a positive message on careers in nuclear related fields, and recognition of the important role of nuclear energy in meeting the country and the world's energy needs, while helping to curb global warming. The redevelopment of a positive outlook for nuclear energy in the United States will encourage the recruitment and education of a new generation of students to meet the nuclear manpower needs of the next several decades.

## EUROPEAN UNION

This little note deals with the strategy of the European Union (EU) research and training activities conducted through multi-partner scientific co-operation projects in the area of nuclear fission safety under the EURATOM Framework Programmes, with emphasis on reactor safety. The objective of EU research in reactor safety is twofold: to contribute to the development of risk minimisation techniques in nuclear installations while improving operational performances, and to maintain a high level of nuclear expertise in the EU (thereby keeping the nuclear option open).

Besides the main immediate concerns of the public at large, which are connected with human health and safety, and hence usually related to the minimisation of technological risks, namely: the fear of severe accidents (a matter of reactor safety), the safe management of radioactive waste and the application of safeguards, there are two socio-economic factors which have more to do with the minimisation of socio-economic risks:

- the question of the social acceptance (raised by the general request for sustainability): the nuclear option is often faced with mistrust by the public at large, even though this option, in synergy with other sustainable energy sources, can be seen as a viable solution to the concerns about the environmental impact of the world-wide growing energy consumption (minimisation of social risks);

- the question of the economic attractiveness of the nuclear option (raised by the general request for competitiveness): the newly introduced deregulation and globalisation of the electricity market is concentrating the attention of the independent power producers on the quick recovery of capital investments and cost reductions wherever possible (minimisation of financial risks).

Ensuring an appropriately qualified scientific community, able to deal with the above challenges, and improving human potential to prepare for the unexpected is a priority in the Euratom Framework Programmes. In the last years, particular attention has been devoted to training and education of the young generation, especially through the funding of grants under the Marie Curie fellowship programme, aimed at increasing the transnational mobility of young researchers within the European Union and Associated States (i.e. Switzerland as well as candidate Central and Eastern European Countries).

In the particular area of reactor safety, worth mentioning also are the EUROCOURSEs, which are complementary to the Community research activities. The topic “Analysis of Severe Accidents in LWRs” was chosen for EUROCOURSE-97 (Polytechnic University of Madrid, 13-17 October 1997): the emphasis was put on mitigation strategies for the 3 main risk issues of severe accidents (i.e. molten corium behaviour, critical hydrogen explosions and source term). The EUROCOURSE-99 “Advanced Nuclear Reactor Design and Safety” (GRS Garching/Munich, 17-21 May 1999) was devoted to advanced reactors and safety management schemes operating with the most advanced technologies.

Safety has always been the primary objective of Euratom research in nuclear fission – and it is also directly linked to public confidence – but economy also is important. Good safety and operating performance are a prerequisite for good economy. Performance improvement means, among other things, increasing plant availability, controlling operation and maintenance costs, and improving the fuel cycle. Of particular interest is the possibility to extend the service life of the existing reactors. For advanced reactor designs, in particular, simplifying plant operation and inspection, extending service life of systems and components, and reducing capital cost in general are prime objectives. How to optimise plant safety and economics is the new challenge of the current Euratom research.

As far as safety strategy is concerned, it is reasonable to anticipate that ensuring the safety of nuclear installations will become particularly demanding in countries where large-scale evacuation and land contamination will be “practically” prohibited for accidents because of high public pressure. In these countries, ideally, severe accidents should be ultimately designed out, as an additional layer to the traditional defence-in-depth strategy (in line with the trends of the regulatory authorities in some EU countries). To meet this goal, there is a need for specific safety upgrading programmes for the existing plants and/or for a new generation of advanced (evolutionary or innovative) reactors, as revisited HTRs.

Maintaining the fission product boundaries intact under all conceivable reactor conditions is the main purpose of the preventive measures, but this might no longer be possible in the highly unlikely case of severe accidents involving core meltdown. Therefore, a great deal of RTD in reactor safety has been devoted until now to accident management strategies, including both prevention and mitigation. The co-ordination of this research effort within the EU Member states (15 in total) – together with the injection of EU funds (approximately EURO 50 million over 4 years only for reactor safety) – was the main task of the 4$^{th}$ framework programme 1994-1998 (FP-4), including all key players, with the aim of making the nuclear option both more competitive and sustainable.

A total of 67 European multi-partner projects were devoted during the 4$^{th}$ framework programme to the study of severe accidents with emphasis either on accident phenomenology or on mitigation measures. Approximately 50 contracting organisations were involved (including the key actors, i.e. industry, utilities, regulatory authorities, universities and research organisations – in particular the Joint Research Centre of the EC), from 12 EU Member states, Switzerland and some Central and eastern European Countries. Technical conclusions were drawn in terms of industrial and regulatory applications at a recent international symposium (FISA-99, EC Luxembourg, 29 November-1 December 1999/83 papers, 300 participants, proceedings in April 2000).

Whatever the future decision for the nuclear option is, research on advanced safety features and new reactor designs, be they of the evolutionary or innovative type, is a necessity because of the natural trend of every mature industry towards modernisation. Another reason for more research – of a slightly innovative type, however – in the area of reactor safety is the need to meet certain requirements of the “changing world”, such as:

- compliance with increasingly stringent national reactor safety requirements and with new international agreements;

- compliance with new economic constraints like further improvements in plant performance and maintenance operations while further decreasing overall investment and operational costs;

- implementation of new technological developments (in both software and hardware), including innovations in materials, equipments, instrumentation and control, as well as in man-machine interfaces.

Whereas FP-4 was devoted to the reduction of technological risks, the 5$^{th}$ Euratom framework programme 1998-2002 (FP-5) is tackling the additional challenge of reducing the socio-economic risks. In the area of reactor safety, this means that FP-4 was examining essentially reactor accident issues with the aim of reducing both their frequency and their magnitude, and to reduce the uncertainties relevant to these 2 factors. Under FP-5, efforts will be devoted also to economic attractiveness and risk perception issues, with the ultimate aim of restoring the confidence of both the decision-takers and the public at large. Access to information on the Community research activities can easily be done through the following EC World Wide Web servers: (http://www.cordis.lu/fp5-euratom) for the Community R&D policies, (http://www.cordis.lu/improving) for training activities and (http://europa.eu.int/ comm/dg12) for specific DG Research implementation activities.

The Euratom Framework Programmes are implemented either via direct actions under the responsibility of the Joint Research Centre (JRC), or via indirect actions co-ordinated by DG Research of the EC. The latter are carried out mainly via projects involving experimental and analytical activities and through training schemes. The aim of the Community research activities is to optimise the synergy between the available resources in an efficient way, by stimulating co-operation among public and private organisations of different Member states, thereby avoiding unnecessary duplication efforts**.** Usually a Community research project is conducted by a group of organisations (research centres, universities, industries, utilities and/or safety authorities) within the EU and/or the Associated States, as a multi-partner project co-ordinated by one of the organisations and supervised by EC staff, often in the framework of clusters of projects sharing the same objective. Most of the Community research projects are of the cost-sharing type, i.e. up to 50% funding from the EU and the rest from the project's partners. European Universities however have privileged access conditions and receive 100% funding from the EU.

## Conclusion

Whatever the future trend will be, the safety of nuclear installations and of the fuel cycle will remain a priority of the public at large and its international aspects will continue to be prominent. Therefore, the EU research programmes in the area of nuclear installations safety will continue to play an important role in the technological solution of risk-relevant issues, especially in connection with reactor and fuel cycle safety. Besides research on technological solutions, the 5$^{th}$ EURATOM framework programme is also emphasising the socio-economic aspects of nuclear energy, in line with the overall objectives of competitiveness and sustainability. The Community research programmes in nuclear reactor safety will continue to run in close co-operation with all key actors in the EU (namely: the regulatory authorities, the industrial sector and the research community, as well as governments, financial institutions, interest groups and the public at large), and in synergy with similar programmes organised at the international level outside the EU.

***Need to keep the nuclear option open.*** It is expected that the world demand for energy will experience unprecedented growth in the coming decades. At the same time, the global ecological consequences of emissions from energy production and use will cause increasing concern and attention from governments and policy makers internationally. Central among these issues is that of the effect of $CO_2$ emissions on the global climate. The choice of energy options and strategies remains open in the long-term: however, nuclear power should play a significant role for satisfying the world's growing energy requirements in an ecologically friendly way.

***Role of Community research in general.*** To prevail in a competitive environment, the Commission, just like any national organisation or private company, must be the driver of change, not be driven by it. Therefore, it is essential, in particular, to transform scientific findings of Community co-funded projects into practical, applicable technologies. Nevertheless, the road from R&D to industrial implementation is long and difficult. In this respect, the nuclear industry's problems are international, and extensive and fruitful co-operation is becoming mandatory. Research and development will therefore continue to play a crucial role, especially when customer needs, markets and technologies are constantly changing.

***Role of Community research in reactor safety.*** Community research in reactor safety, in particular, will still be important for meeting the needs and expectations of the electricity market. As we look to the immediate future of reactor needs, 2 research areas should be looked at carefully, namely: (1) further improvement in the management of existing nuclear facilities, and (2) advances in technology for the whole fuel cycle, for both the present and the next generation of reactors. In all cases, generic issues like human reliability and organisational factors will continue to play an important role in improving the traditional defence-in-depth approach.

Looking beyond our frontiers, a special challenge lies in the enlargement of the EU and the involvement of the researchers, utilities and regulatory authorities in the Community research programmes to guarantee the safe operation of all reactors in an enlarged Union.

Looking beyond 2010, when most European plants will come to their end-of-life, we need to address in the EU research programmes the factors which are seen as weaknesses of nuclear power in terms of competition and sustainability, and enhance the strengths. Besides safety, we need to address, in particular, licensing aspects and construction times, as well as capital costs and public acceptance. We may also need to consider novel fuel cycles and enhanced safeguards as well as new decommissioning and waste management techniques to further reduce the back-end costs. Although the application may appear far in time, such development is urgent, as many of the decisions will need to be made much sooner.

***Need to convince the main actors.*** "Helping exploit the full potential of nuclear energy in a sustainable manner", which is the main aim of FP-5, is quite a challenge: we have to convince the public, interest groups, utilities, governments and financial institutions. At the same time, we have to set up national and international programmes for the exchange of operational experience and scientific findings in co-operation with industry, utilities, safety authorities and research organisations – including, in particular, the universities.

*Annex 4*

## DEFINITIONS OF TERMS USED IN THE REPORT

**Education:** systematic process of instruction for educating students at higher educational organisations, such as universities and polytechnics.

**In-house training:** systematically structured set of courses given to the scientific and technical staff who have already graduated from educational organisations and been hired by research institutes, government services and industrial companies. The aim of this set of courses is to provide the staff with a nuclear competence within their field of professional activity. Training courses are usually given by employers, but are not necessarily restricted to their employees.

**Degrees:**

*Undergraduate (Bachelor)*: the first degree awarded to students after successful completion of course work of typically three to four years (or maybe longer for part-time courses). Such degrees are granted by a university or an equivalent educational organisation, such as a polytechnic.

*Graduate (Master)*: the first or second degree awarded to students or to bachelors after successful completion of course work and/or research work of typically a few years and the completion of a thesis or dissertation, at a university or an equivalent educational organisation.

*Graduate (Doctor)*: the second or third degrees awarded to graduates after successful completion of a doctoral thesis, the same as a "Ph.D."

**Education programmes**

The main scope of section I of the questionnaire is nuclear oriented programmes such as nuclear engineering, nuclear physics, health physics. In addition to these, it is also desirable to collect the data from other programmes ("nuclear-related" programmes), since nuclear industries are recruiting students not only from nuclear programmes but also from non-nuclear but "nuclear-related" programmes, such as mechanical engineering, electrical engineering, chemical engineering, etc.

*Nuclear education programme*: curricula which consist of a set of courses (see below) on nuclear subjects. A department of the university often provides one or several nuclear education programmes. A degree is in many cases granted by each programme.

*Nuclear Course*: a course on a specific nuclear subject such as reactor physics, nuclear fuel engineering, hydro-dynamics, radiation shielding. For example, a course may have lecture classes of 2 hours twice per week for one semester.

**Faculty:** professors, associate professors, lecturers who spend more than 25% of their time for that course. Question 1 asks for the numbers of full time faculty and part-time faculty. Emeritus professors shall be excluded in most cases.

**Data series:** in order to determine the trends of educational programmes, the date of reference has been chosen for the years 1990, 1995 and 1998. The data shall be as of January 1998.

*Annex 5*

## SUMMARY OF THE QUESTIONNAIRE FOR THE STUDY ON THE SURVEY AND ANALYSIS OF EDUCATION IN THE NUCLEAR FIELD

The questionnaire consists of three parts. The first section aims at obtaining data on nuclear oriented curricula offered within universities and equivalent organisations. The second part is for in-house training, carried out by research organisations, public institutes, and companies. The third section is for case studies of experiences obtained in the country. The first and second sections are to collect the information on individual universities and organisations, while the third section is to have a wider view on the whole country. In this regard, there are a few duplicated questions in these sections.

Members of the Expert Group distributed the questionnaire in June 1998, and collected and reviewed the answers for their country in September 1998.

### SECTION I: information on educational organisations

#### *Q I-1. Number of students and faculties*

Please provide information with the number of places available, the number of students, and the number of degrees awarded per anum for undergraduates, graduate-master's, and graduate-doctor's, the number of faculties and man-hours spent for each nuclear education programme at each university in 1990, 1995, and 1998.

#### *Q I-2. Age structure*

Please describe the age structure of the faculty of your university or equivalent organisation. (The data shall be as of January 1998)

*Q I-2-1. If there is an official retirement age at the faculty, what is it?*

#### *Q I-3. Facilities*

Please give information on facilities of research and training reactors, hot cells, laboratory for radiochemistry, laboratory for radiation measurement, etc., available for education in your university or equivalent organisation in 1990, 1995, and 1998.

*Q I-3-1 Decommissioning*

If any of the above facilities has been decommissioned, please give the date of decommissioning.

*Q I-3-2 Vintage of the facilities*

Please give the average age and the expected life of the facilities.

***Q I-4. Occupational distribution***

Which sector did the graduates from your universities go to after finishing university in the past five years? Please give average numbers of students per annum.

***Q I-5. Recent changes in the nuclear-related courses***

Please describe recent changes, elimination, addition or mergers of the courses or changes in the course names (e.g. from "nuclear engineering" to "energy system engineering"), if any.

***Q I-6. How do you characterise the situation of nuclear education in your university?***

***Q I-7. What type of efforts has your university made in order to encourage and attract younger generations into nuclear fields? (other than scholarships)***

**SECTION II: information on in-house training**

***Q II-1 Please give information on in-house training given by companies, research institutes, etc., in your country.***

*Q II-1-1 Who organises and pays for the in-house training?*

*Q II-1-2 Are the trainees only the employees, or do they include both internal and external applicants?*

*Q II-1-3 Is the training designed for new graduates or experienced staff?*

*Q II-1-4 What is the aim of the training? Is it aimed at providing a broad in-depth coverage of the specified subjects (a full complete set of the courses) OR at increasing the competence of the trainees in their specific function within their organisation (more specifically tailored courses)?*

*Q II-1-5 What subjects are taught at theoretical courses and practical skill courses in the training?*

***Q II-2. Numbers of trainees and trainers and the budget for in-house training***

Please provide the number of trainees per annum, the number of trainers/instructors, and annual man-hours provided by the trainers/instructors in 1990, 1995, and 1998.

***Q II-3. Age structure***

Please describe the age structure of the trainers who are engaged in the above training programme (the data shall be as of January 1998).

***Q II-4. Facilities***

Please give information on facilities of research and training reactors, hot cells, laboratory for radiochemistry, laboratory for radiation measurement, etc., available for the training in 1990, 1995, and 1998.

*Q II-4-1 Decommissioning*

If any of the above facilities has been decommissioned, please give the date of decommissioning.

*Q II-4-2 Vintage of the facilities*

Please give the average age and expected life of the facilities.

***Q II-5. Qualification/certification***

Is there any certificate that is given to those trainees who finish the training? Or, alternatively, is there any certificate delivered by another organisation for the professionals? Please describe the system below, in particular, in terms of encouraging staff to participate in the in-house training offered.

***Q II-6. How do you characterise the situation of nuclear training in your organisation?***

***Q II-7. What type of efforts has your organisation made in order to encourage and attract younger generations into the nuclear field? (other than scholarships)***

Please give similar information to SECTION II if **inter institutional, inter-organisational** (including international) training programmes are given to the graduates.

**SECTION III: information on experiences in the country**

***Q III-1. How do you characterise the situation of nuclear education, particularly at university level, in your country?***

***Q III-2. What type of efforts has your country made in order to encourage and attract younger generations into the nuclear field? (other than scholarships)***

*Q-III-2-1 Efforts by universities*

*Q-III-2-2 Efforts by industries*

*Q-III-2-3 Efforts by collaboration*

*Q-III-2-3-1 Internship*

Does the programme include training periods in industry or at laboratories where students can put some of their academic knowledge into practice during the studies (e.g. internship)?

***Q III-3. Scholarships/fellowships/grants***

Are there any scholarships/fellowships/grants specifically for nuclear programme students, in order to attract them into nuclear subjects? If more than two schemes are offered, please mention it and give answers for each of them.

A. How many students/researchers can receive them?
B. When did the scheme begin?
C. Who provides (pays for) the scheme?
D. How much are the scholarships/fellowships/grants per person per annum? Please give annual tuition fees for comparison purposes.
E. Has the number of students increased since the beginning of the scheme? Or what kind of improvements have been noticed?

***Q III-4. Evaluation***

How do you evaluate the result of the efforts described in questions Q III-2&3? Please also explain the reasons for their success or failure.

***Q III-5. Inter-organisational and/or international collaboration***

Are there any inter-organisational and/or international collaborative projects to encourage young students to study nuclear subjects? Please describe.

***Q III-6. Other information***

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