NUCLEAR EDUCATION AND TRAINING

Cause for Concern?

A Summary Report

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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

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

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

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 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 program services for participating countries.

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

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faut-il s'inquiéter ?

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EXECUTIVE SUMMARY

This report is a summary of the study "Nuclear Education and Training: *Cause for Concern?*", which was undertaken to consider the concerns raised by the OECD/NEA Member countries that nuclear education and training is decreasing, perhaps to problematic levels.

Mankind now enjoys many benefits from nuclear-related technology in areas as diverse as medicine and advanced materials, as well as electricity production. Today, nuclear technology is widespread and multidisciplinary. Yet the advancement of this technology, with all its associated benefits, will be threatened, even curtailed, unless the declining number of university courses associated with it, and the declining interest among students in it, is arrested.

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 to those programmes, meet future staffing requirements of the nuclear industry, and conduct leading-edge research in nuclear topics is becoming seriously compromised. A number of concerns exist:

- The decreasing number and the dilution of nuclear programmes.
- The decreasing number of students taking nuclear subjects.
- The lack of young faculty members to replace ageing and retiring faculty members.
- Ageing research facilities, which are being closed and not replaced.
- The significant fraction of nuclear graduates not entering the nuclear industry.

There currently appears to be enough trainers and quality staff in industry and at research institutes. However, the provision of suitable trainers in the near future is becoming a concern because of the university situation.

Student perception, an important factor contributing to low enrolment, is affected by the educational circumstances, negative public perception, the downsizing of the industry, and reductions in government-funded nuclear programmes, where little strategic planning is occurring. 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.

A wide range of initiatives to encourage the younger generation to enrol in the nuclear field have had great success. However, these are often taken by individuals rather than by organisations; there are few national initiatives.

Governments are responsible for doing what is clearly in their countries' long-term national interest, especially in areas where necessary actions will not otherwise be taken without government. They have an important multifaceted role in the nuclear field: managing the existing nuclear enterprise, preserving nuclear power as a long-term option, sustaining international influence of nuclear safety and security, and enhancing technology competitiveness.

Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. We must act now on the following recommendations.

Strategic role of governments

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

The challenges of revitalising nuclear education by university

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

Vigorous research and maintaining high-quality training

- Provide rigorous training programs to meet specific needs.
- Develop exciting research projects to meet industry's needs and attract quality students and employees (research institutes).

Benefits of collaboration and sharing best practices

- Industry, research institutes and universities need to work together to co-ordinate efforts better to encourage the younger generation.
- Develop and promote a programme of collaboration in nuclear education and training, and provide a mechanism for sharing best practices in promoting nuclear courses between Member countries.

I. INTRODUCTION

This report is a summary of the study "Nuclear Education and Training: *Cause for Concern?*", which was undertaken to consider the concerns raised by Member countries of the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA) 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: nuclear and reactor physics; thermal hydraulics and mechanics; material science; chemistry; health science; information technology; and a variety of other areas.

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 electricity produced in the OECD/NEA Member countries. Some countries, such as Japan and Korea, have electric energy plans that include new nuclear power plants. 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 master properly 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.

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.

The emerging shortfall of nuclear expertise has been recognised by OECD/NEA Member countries. 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-supply the pipeline of students, faculty, researchers, operators, regulators and the companion infrastructure. This study:

- Shows the current situation of nuclear-related education and training.
- Identifies the issues associated with nuclear-related education and training.
- Suggests possible ways of encouraging students and young research fellows to enrol in nuclear courses.
- Sends clear messages on human development and staffing issues to senior officials and decision-makers in government, industry and academia so that they can take necessary action.

To quantify the trends in nuclear education and training from 1990 to 1998, the OECD/NEA sent a questionnaire in 1998 to Member countries. Responses were received from almost 200 organisations (including 119 universities, research institutions, power companies, manufacturers, engineering offices and regulatory bodies) in 16 Member countries (Belgium, Canada, Finland, France, Hungary, Italy, Japan, Korea, Mexico, the Netherlands, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States).

II. THE DETERIORATION OF NUCLEAR EDUCATION

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 needed leading-edge research is becoming seriously compromised.

Concern 1: The decreasing number and the dilution of nuclear programmes

The number of universities that offer nuclear programmes, i.e. curricula that consist of a set of courses on nuclear subjects, is declining. Faced with declining enrolment, some 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. 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.

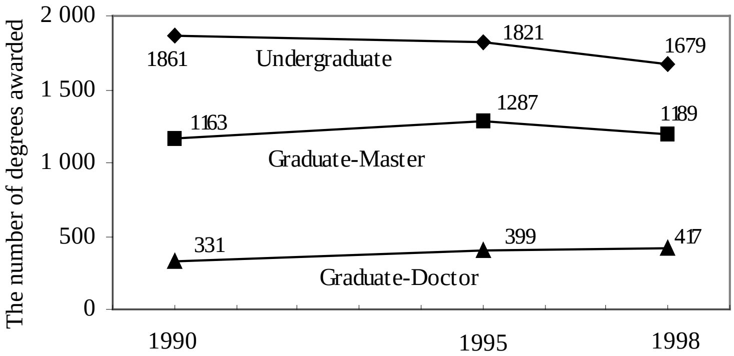
Some departments have sought to widen the appeal of their courses either by broadening the content or by changing the name. However, while advanced energy systems or nuclear and radiological engineering may be more successful in attracting students, they are much less specific, in both name and content 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.

During the period of the survey, some new courses have been started. France started 6 programmes, Japan started 3 programmes, and Mexico started new Master and Doctoral programmes. Some of the new courses are directly related to nuclear power and deal with 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.

Concern 2: The decreasing number of students taking nuclear subjects

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 Masters level remained fairly constant, and the number at the Doctoral level increased by 26% (Figure 1). Of significance are the decreases observed between 1995 and 1998 at the undergraduate and Masters levels. In this period, trends in the number of degrees awarded differ significantly from country to country, but sharp declines are observed in several countries.

Figure 1. **Number of 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.

Although the overall picture for the number of graduates during this period may seem reassuring, there are underlying causes for concern. The nuclear content of many undergraduate courses has declined with time. The pool of knowledge at the undergraduate level is therefore decreasing year by year. This will eventually have serious repercussions on the Masters and Doctoral levels, where the situation is currently far more encouraging in terms of both quantity and quality of graduates. With fewer nuclear courses available there will be fewer students wanting to study nuclear topics for higher degrees, and with a broadening and hence dilution of courses, there will be fewer students 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 and 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 demand of the industry, let alone to staff an expanding industry.

Concern 3: The lack of young faculty members to replace ageing and retiring faculty members

The number of full-time faculty members in nuclear fields has decreased in the United Kingdom and the United States but has increased in France and Japan. In other countries, the numbers have remained fairly constant over the period in question. The numbers of part-time faculty members in the field are generally rising, especially in countries where the number of full-time faculty members is falling.

The generally observed average age of faculty members is construed as a risk to sustaining high-quality expertise. The age distribution of faculty members peaks at 41-50 and 51-60 in most countries (Table 1). The average age of faculty members is almost 50 years. Most universities have a retirement age around 65.

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 faculty members. 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 faculty members, and unless something is done to arrest it, the downward spiral will continue.

Table 1. **Age distribution 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**

Concern 4: Ageing research facilities, which are being closed and not replaced

Most of the universities are equipped with experimental facilities capable of supporting a diverse curriculum. Many universities not equipped with experimental facilities on their campus have access to such facilities at nearby large research laboratories.

Most university equipment and facilities are over 25 years old (Table 2). Many research reactors and hot cells have been decommissioned, and no replacements are 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 members from working in the nuclear area.

Table 2. **The number, average age and age range of nuclear facilities at universities in 1998**

Facility	Number		Average age (years)	Range (years)
	1990	1998		
Research reactors	46	39	32	13–47
Hot cells	31	28	28	10–44
Radiochemistry facilities	66	67	24	1–45
Radiation measurement facilities*	92	92	25	1–44

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

Concern 5: The significant fraction of nuclear graduates not entering the nuclear industry. The current supply of entry-level workers in nuclear areas may not meet demand in some countries

By and large, at both the undergraduate and Masters levels, only 20% to 40% of students choose to continue to study; at the Doctoral level, between 30% to 70% of graduates, depending on the country, choose a career at an academic institution or nuclear research institute. It is also evident that a significant fraction (20-40%) of graduates in nuclear fields at all levels do not enter the nuclear industry. 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.

Table 3. **Occupational distribution by qualification in 1994-1998 (as a percentage of total)**

Country	Graduate school			Utilities			Nuclear manufactures			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 programme. NA: Data are not available.

Levels of degrees: B = Undergraduate; M = Graduate-Master; D = Graduate-Doctor

The figures may not sum to 100, because some of the sectors more rarely cited are not reported in the table (e.g. government, regulatory, military).

III. THE STATUS OF IN-HOUSE TRAINING

There currently appear to be enough trainers and quality staff in industry and at research institutes. However, the provision of suitable trainers in the near future is becoming a concern because of the more serious university situation.

The value of training is highly regarded

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. Because of the small size of some organisations, or the small size of 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.

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.

The subjects cover broad areas in both theoretical knowledge and practical skills. Theoretical courses cover subjects such as: reactor physics; radio-chemistry; radiation protection and health physics; operation, procedure, and accident analysis; mechanical and electrical equipment, instrumentation, and control; regulation, codes, and safeguards. Courses in practical skills include: training using simulators; practice in control room procedures; non-destructive testing, welding, and maintenance.

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

OECD/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 years for most countries. It is logical that experienced staff be used as trainers. Belgium, France, and Spain, which show an age peak at 31-40 years 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.

Table 4. **The number, average age and age range of nuclear facilities for training in 1998**

Facility	Number		Average age (years)	Range (years)
	1990	1998		
Research reactors*	16	13	27	2–38
Hot cells	9	8	30	10–39
Radiochemistry facilities	19	20	23	4–39
Radiation measurement facilities	25	27	21	4–39

* One reactor was constructed.

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.

Concern 6: Repercussions of the deteriorating university situation on in-house training

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.

However, 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 large 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.

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.

IV. CAUSES FOR CONCERN

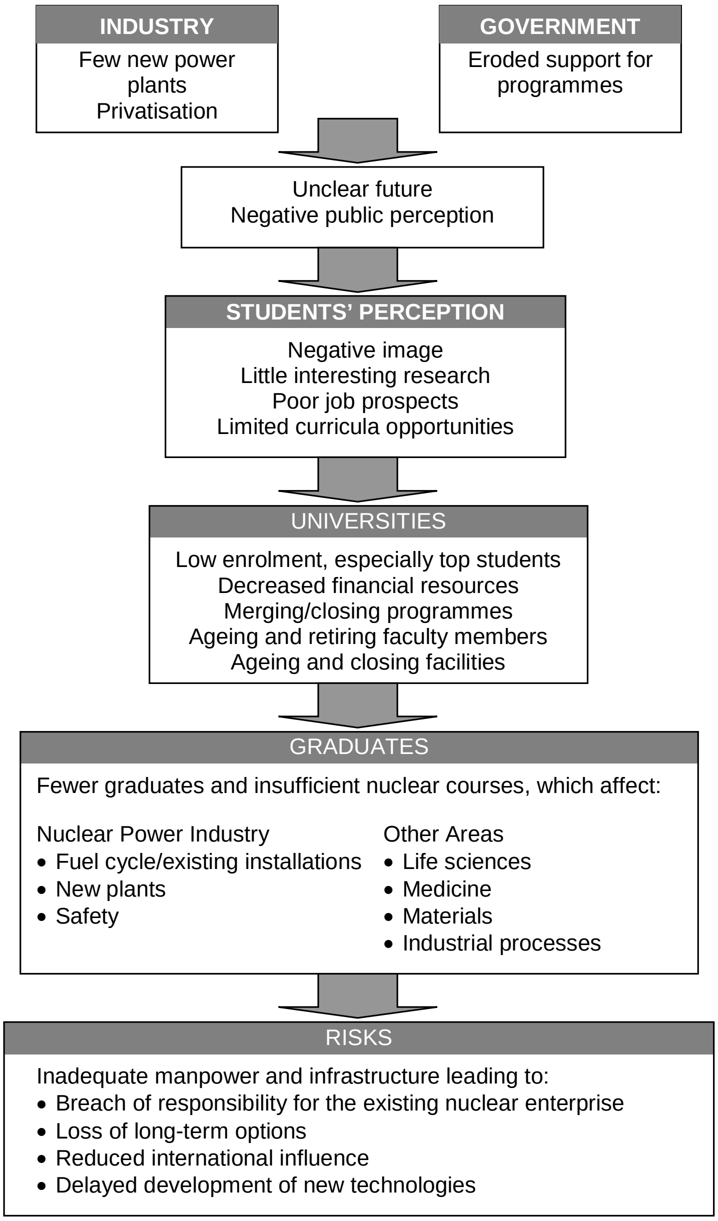
Student perception, an important factor contributing to low enrolment, is affected by the educational circumstances, public perception, industry's activities, and government-funded nuclear programmes, where little strategic planning is occurring. Low enrolment directly affects budgets, and budgetary cuts then limit the facilities available for nuclear programmes.

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 trend is observed in most OECD/NEA Member countries. The principal reasons for the deterioration of nuclear education and its anticipated eventual impact on the nuclear industry are illustrated in Figure 2.

Cause 1: Little strategic planning

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, privatisation, and downsizing, there are increasing pressures for decisions to be made based upon economic short-term considerations. As a result, the nuclear industry in many OECD countries is consolidating and contracting. Now there are few new nuclear power plants in OECD countries. Governments are the appropriate institutions for assuring longer term well-being when it appears that market forces alone will not be sufficient. But government support for nuclear programme has been being eroded.

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



Cause 2: Students' negative perception

The number of degrees with a nuclear content awarded to students has generally decreased. 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.

Cause 3: The downward spiral of low enrolment and budgetary cut

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 re-supply the pipeline of students, faculty, researchers, operators, regulators, and the companion infrastructure.

Risks: The impact of the deterioration of nuclear education

With insufficient nuclear courses there will be a shortfall of quality graduates to cope with the existing concerns of nuclear power industry and other areas. Inadequate manpower and infrastructure then lead to risks: breach of responsibility for existing nuclear enterprise, loss of nuclear power as a long-term option, reduced international influence, and delayed development of new technology (see Chapter on "Role of Government").

V. EFFORTS TO ENCOURAGE THE YOUNGER GENERATION

A wide range of initiatives to encourage the younger generation to enrol in nuclear subjects have had great success and are shown as "Examples of best practices" in Box 1. However, these are often made by individuals rather than by organisations; there are few coherent national initiatives.

Effort 1: Curriculum change, pro-active marketing and external contact by universities

In some cases, the numerous changes in nuclear-related academic courses cited in Chapter II 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.

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.

Effort 2: Advertising, good working conditions and career development by 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 1- or 2-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.

Effort 3: Collaboration among universities, industry and government

Collaboration between industry and academia is widespread for many, but not all, Member countries. There are some common themes. 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, scholarships from industry, and internships to students.

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 United States has established the Glenn T. Seaborg Institute for Transactinium Sciences to further the fundamental and applied science and technology of the transactinide elements.

Concern 7: The lack of communication and co-ordination

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.

Government participation in collaborative programmes has generally declined. It most often appears limited to the financial support to 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.

Effort 4: International collaboration

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 OECD/NEA, promotes international discussion and collaboration through its various committees and expert groups.

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 Euros over 4-year periods.

Box 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, specialists' 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.

VI. THE IMPORTANT ROLE OF GOVERNMENTS IN NUCLEAR EDUCATION

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, influencing international actions on nuclear matters that affect safety and security, and enhancing technology competitiveness.

Role 1: 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 cleanup; waste management; maintaining the safety of nuclear deterrent forces in the absence of nuclear testing; and advancing health physics. These needs call for a guaranteed supply of not only new students, but also high-quality students and vigorous research.

Role 2: 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.

Role 3: 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, the OECD/NEA Member countries, among the developed nations, must have the access and the necessary influence to assure that it is done in the appropriate manner with regard to such issues as safety, environment, waste management, and non-proliferation.

Role 4: 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.

VII. RECOMMENDATIONS

The large experience and continuing development of nuclear technology within the OECD/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.

We must act now

> ***Recommendation 1:*** *We must act now. The actions, described in subsequent recommendations, should be taken up urgently by government, industry, universities, research institutes and the OECD/NEA.*

Nuclear education and training are not yet at a crisis point, but they are certainly under stress in many of the OECD/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 OECD/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 4 to 5 years 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.

Strategic role of governments

> ***Recommendation 2:*** *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.

> ***Recommendation 3:*** *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.

> ***Recommendation 4:*** *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.

> ***Recommendation 5:*** *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 as well as nuclear fuel and storage facilities for spent fuel.
- Matching investments from industry for university research and development projects.

The challenges of revitalising nuclear education

> ***Recommendation 6:*** *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.

> ***Recommendation 7:*** *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".

Vigorous research and maintaining high-quality training

> ***Recommendation 8:*** *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.

> ***Recommendation 9:*** *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.

Benefits of collaboration and sharing best practices

> ***Recommendation 10:*** *Industry, research institutes and universities need to work together to co-ordinate efforts better to encourage the younger generation.*

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.

> ***Recommendation 11:*** *The Member countries should ask the OECD/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 OECD/NEA Member countries, they are certainly under stress. Although individual countries may face shortfalls, the combined expertise and resources of the OECD/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.

> ***Recommendation 12:*** *The Member countries should ask the OECD/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 offered courses 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, from open days to scholarships (see Box 1). Initiatives, however, have been taken largely in isolation. Benefits would multiply if universities and other organisations shared techniques and efforts.

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