Engineering and science education for nuclear power

Co-operative approaches exist to attain necessary standards of excellence

by Frances Mautner-Markhof

Experience has shown that one of the critical conditions for the successful introduction of a nuclear power programme is the availability of sufficient numbers of personnel having the required education and experience qualifications. For this reason, the introduction of nuclear power should be preceded by a thorough assessment of the relevant capabilities of the industrial and education/training infrastructures of the country involved. This requires, where necessary, upgrading or establishing national education and training capabilities in engineering and science to develop the qualified personnel needed to perform the tasks and functions for a nuclear power programme.

As educational systems vary from country to country, there is a need for flexibility in the design of educational programmes. Curricula (such as those developed for the IAEA *Guidebook on engineering and science education for nuclear power*) indicate the level and content which would provide the necessary education qualifications for engineers and scientists who are to work in a nuclear power programme, and thus could be used as a basis for building up an appropriate education programme. However, it is difficult to describe all of the measures and arrangements necessary to introduce the teaching of nuclear technology into an existing education system.

The manpower skills required are in no way relative: *There can be no compromise with the assurance or the safety and reliability of nuclear power.* Thus, although there are various ways of achieving the required level of personnel qualifications — as can be seen from the varied experiences of developed and developing countries — *a comparable level must be attained and maintained in every country which has or embarks on a nuclear power programme.*

In developing a programme on engineering and science education for nuclear power, it is necessary to keep in mind those nuclear power programme activities for which the national government or national organizations must bear the ultimate responsibility and which are thus considered essential for national participation. *(See accompanying table.)* These activities should be primarily executed by national manpower, regardless of the contractual arrangements of the nuclear power project.

A country which plans a nuclear power programme should provide most of the basic and at least some of the specialized education and training needed to produce qualified personnel for performing the essential activities of the nuclear power programme, including those required for the technology transfer and adaptation needed to enable national participation. The infrastructure for education and training for nuclear power consists primarily of universities, nuclear training centres, nuclear research centres, and industry and government organizations.

It is important to note that the costs of education and training to produce qualified personnel represents a small fraction of the cost of a nuclear power project. Experience also has shown that education costs are small compared to those incurred when a nuclear power plant must be taken out of operation for even a short time because of the lack of appropriately qualified plant personnel. A good education and training regime is not only a necessary condition for the introduction of a nuclear power programme, but also a sound investment in its future growth and in the optimum operation of nuclear power plants. For this reason, education and training should be an integral part of the long-range national planning for nuclear power.

Special needs of developing countries

In many developing countries, an insufficient number of qualified personnel is one of the principal constraints to technological development in general and to nuclear power development in particular.

The problems of some developing and industrialized countries regarding education and training requirements for nuclear power are primarily associated with limitations on the resources and capabilities of universities, training institutions, or industries in providing the required scope and quality of education and training. Particularly, secondary schools in developing countries often do not adequately prepare students by providing them with the skills and knowledge needed for undertaking university studies of the required level in engineer-

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Nuclear power programme activities

	Activity	National participation considered essential*	Technical difficulty**	Manpower effort**
1	Nuclear power programme planning and co-ordination	yes	3	1
2	Power system planning	yes	2	1
3	Development of legal and organizational framework	yes	1–2	1
4	International agreements and arrangements	yes	1–2	1
5	National participation planning and co-ordination	yes	2	1
6	Manpower development planning and implementation	yes	2–3	2–3
7	Feasibility studies	yes	3	2
8	Site evaluation	yes	2–3	1–2
9	Preparation of bid specifications	yes	2–3	1–2
10	Bid evaluation	yes	3	2
11	Contracting	yes	3	1
12	Project management (utility)	yes	3	1–2
13	Project management (main contractor)	no	3	2
14	Plant conceptual design	no	3–4	2
15	Basic design engineering	no	3–4	3
16	Detailed design engineering	no	2–3	4
17	Preparation and review of equipment and plant specifications	no	3–4	2
18	Establishment of quality assurance policy	yes	2–3	1
19	Quality control and quality assurance implementation	no	2–3	2
20	Procurement	no	1–2	1–2
21	Safety analysis reporting	no	3	2
22	Emergency planning	yes	2	1
23	Public information and public relations	yes	1–2	1
24	Safeguards and physical protection	yes	1	2
25	Equipment manufacturing	no	1–4	1–4
26	Construction management	no	2–3	2
27	Site preparation	yes	1	2–3
28	Erection of plant buildings and structures	yes	2	4
29	Plant equipment and systems installation	yes	2–3	3
30	Plant systems and component testing	no	2–3	2
31	Criticality and plant acceptance testing	no	3–4	1–2
32	Plant operation and maintenance	yes	3–4	3
33	Radiological protection and environmental surveillance	yes	1–2	1
34	Fuel procurement	yes	2	1
35	Uranium exploration, mining, and milling	no	1–2	3–4
36	Conversion	no	1–2	1–2
37	Enrichment	no	4	3
38	Fuel fabrication	no	3	2
39	Fuel management and storage at the power plant	yes	2–3	1
40	Fuel transport and off-site storage within the country	yes	1–2	1
41	Spent fuel reprocessing	no	4	3
42	Waste management	yes	2–3	2
43	Nuclear licensing and regulation	yes	3–4	2–3
44	Research and development in nuclear power	no	3–4	3

* Activities considered essential will vary somewhat depending on national participation policies and capabilities and on the contractual arrangements for the nuclear power project(s)

** Index number: 1 = low; 2 = medium; 3 = high; 4 = very high.

ing and science. Adequate attention and resources must be devoted from the outset to (1) the education and qualification of teachers, and (2) co-operation between universities and industry to ensure the provision of hands-on experience and on-the-job training in industry. This includes the organizational, contractual, and administrative aspects of managing large projects, as universities do not have sufficient capabilities for this.

A serious problem has been retaining in the home country qualified technical professionals for the nuclear power programme, especially those who have had education, training, or experience abroad. This problem is due to differentials in the conditions of employment, as well as to phase lags between the scheduling of the programmes for development of personnel and for nuclear power, resulting in people being ready when

tasks were not or vice versa. Therefore, effective and efficient personnel management is essential for the proper and timely recruitment of personnel, and for the education and training required, to achieve the qualifications needed for working in a nuclear power programme. It has generally been found necessary to recruit and train more people than are needed to fill existing vacancies, to cover the rate of training dropouts, and to meet replacement requirements due to attrition and migration of qualified personnel.

Practical training and experience

The critical need for *practical work and training* in all relevant disciplines throughout conventional and nuclear education at all levels cannot be overemphasized. It is essential for the students and teachers involved, especially in the engineering education process. While most of this practical component of education should be provided in the country itself, some may be obtained abroad in foreign industries, research centres, institutions of higher education, and government agencies through bilateral agreements or supply contracts.

Engineering and science education should, therefore, provide students with opportunities for practical work in industry or utilities before graduation from the university (or higher technological institute). Developing countries in particular should aim to increase and improve interactions between universities and industries, to prevent engineering education from becoming far removed from current practices and needs. In addition to practical engineering experience, the various tasks of a nuclear power programme will require a number of individuals with practical experience in such areas as technology assessment, economics, energy planning, administration, and public acceptance issues.

Nuclear-oriented education

Major education requirements call for nuclear-oriented graduate programmes at a university (to attain the equivalent of a bachelor of science degree) and for postgraduate programmes up to the level of a masters degree (or Diplom Ingenieur). Postgraduate academic programmes beyond the masters level are needed to ensure the availability of at least a small number of engineers and scientists highly trained academically (i.e. with a Ph.D. or equivalent degree) and with broad experience, to ensure qualified personnel for *inter alia* university-level teaching, research and development, and certain regulatory functions. Most countries do not usually have such nuclear-oriented education programmes in place when starting their nuclear power programmes.

Countries generally find it necessary to introduce postgraduate specialization courses to supplement the education and training of graduates who possess non-nuclear education qualifications, and (in some cases) professional but non-nuclear experience, who are to work in the nuclear power programme. These specialization courses are not meant to replace the longer-term need for nuclear-oriented undergraduate and postgraduate engineering and science education. Nevertheless, as a mechanism for upgrading qualifications or providing new or updated theoretical knowledge and practical skills in nuclear subjects, the specialization courses play an important role in the national education and training system. *(See accompanying figure.)*

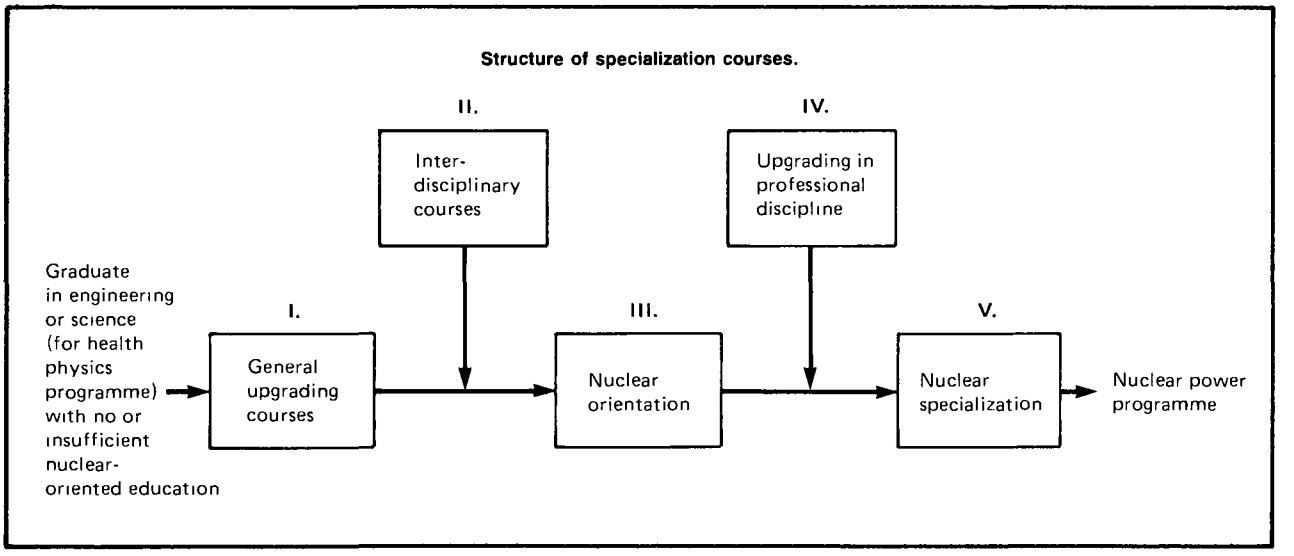
Generally, a specialization programme for engineering and science education for nuclear power would normally be introduced at the start of a nuclear power programme, to provide the required theoretical foundation and practical work in nuclear engineering for individuals from industry and government organizations with backgrounds in the classical engineering disciplines. As the nuclear power programme develops and personnel requirements increase, the education for nuclear power tends to become incorporated into the existing educational infrastructure. However, even in the case when this becomes the primary mode of education for nuclear power, specialization courses will still be required, e.g. for continuing education, to keep up with recent developments (such as new technologies, regulations), to upgrade education in specialized or nuclear areas, and to provide training for certain types of personnel such as shift supervisors, health physics officers, and other specialists.

Education/training and industrial infrastructures vary from country to country, as do the nature of the nuclear power programmes and their objectives, such as the extent of national participation. Therefore, it is difficult to recommend detailed curricula for nuclear specialization programmes, although model curricula have been proposed.* The specialization courses should thus supply overall nuclear-related knowledge and practical skills which provide the essential basis for this specialized training.

The specialization programme should be distinguished from a conventional postgraduate degree programme, as it has a stronger orientation towards the actual demands of the nuclear power programme, and it includes a high standard of traditional engineering in greater depth than in the undergraduate programmes available in the country. It also provides education and practical work in specific nuclear subjects, such as radiation effects and reactor technology. It is highly desirable to involve some universities in this programme. They would be more encouraged to upgrade their curricula, faculties, and facilities for the undergraduate and graduate programmes which are needed to meet the higher standards, required by the nuclear power programme and the national participation programme, in conventional as well as nuclear areas.

It is especially important to earmark for such training those individuals who will become the teachers of local

* *Guidebook on engineering and science education for nuclear power*, IAEA, Vienna (1986) pp. 17-40.



specialization courses. It is essential to have knowledgeable and experienced teachers for these courses, and it is recommended that special attention be paid to all aspects of their education and training, including effective pedagogical practice.

Continuing education for nuclear power

To ensure that professional technical personnel can acquire, maintain, upgrade, and update the knowledge and practical techniques needed to meet the education and training qualifications for performing the tasks or functions of a nuclear power programme, it will be necessary to have broadly-scoped and flexible possibilities for continuing education, especially in engineering. Continuing education should be provided and required for practising professionals and teachers, and included as an integral and formalized component of a countries' personnel development programme and education/training infrastructure. It should be a part of and utilize the co-operative process between universities, industry, utilities, nuclear training and research centres, and other relevant organizations. Professional societies could play a useful role in fostering certain types of continuing education. It may also require education abroad, especially in areas involving the latest technological developments and high technical complexity. International co-operation will also be valuable for providing exchanges of teachers, teaching materials, and possibly for establishing regional centres for continuing education.

The main requirement for ensuring the necessary quality of education and training is to develop, maintain, and implement sound criteria for outside review, evaluation, and accreditation of university programmes leading to nuclear-oriented engineering and science degrees, to establish and maintain minimum standards of qualifications. It is also important to provide accreditation of non-degree nuclear specialization and other continuing education programmes offered by universities and other institutions such as utilities, industries, national laboratories, and nuclear training centres.

The role of government

There are certain activities of a nuclear power programme in which full responsibility has to be borne by national organizations and should be executed primarily by national personnel, regardless of the contractual arrangements. These are considered "essential" activities for national participation. In countries now introducing or in the process of implementing a nuclear power programme, the planning, co-ordination, and control of the nuclear power programme and national participation in the programme, as well as the overall development programme for personnel, is fundamentally a governmental responsibility. The government may delegate to specific organizations under its control many of the tasks and functions involved. But it must retain the ultimate responsibility as well as the function of defining policies and strategies and making final decisions.

Governments, via the responsible organizations, generally conclude bilateral and multilateral agreements for nuclear co-operation and for nuclear supply and training. Bilateral agreements include scientific exchange arrangements between specified authorities aimed at developing infrastructures including personnel development programmes and regulatory functions. Generally, the national nuclear energy commission or authority (the nature of which depends on the national nuclear energy policy and programme) has constituted the basic governmental infrastructure and organization for meeting the responsibilities and performing the functions in the planning and implementation of the nuclear power and personnel development programmes.

Measures which could be taken by governments to enhance national engineering and science education capabilities for nuclear power include:

- Establishing the necessary standards of accreditation for academic and non-academic programmes and faculty, and adequate levels of qualification and/or licensing for engineering and other professionals;

- Improving, through the appropriate standards, support and incentives, the quality of courses, researchers, and university faculty in the relevant engineering and science programmes. This could be done through governmental (and industrial) support by providing fellowships, stipends, training facilities, and research contracts, and by appropriate funding of required improvements in curricula and laboratory/computer facilities and in research and development. Research and teaching staff may require improved conditions of employment (including higher salaries) to keep them from being drawn away into industry.

- Improving through appropriate examinations, qualification requirements, and incentives, the number and quality of students who choose to study and who complete nuclear-related engineering and science programmes at the undergraduate and graduate levels;

- Reinforcing and utilizing increasingly industry's role in providing the necessary practical work and training component of education (as well as the needed experience) by *inter alia* providing legislation, as well as financial incentives and contracts, to increase practical education, training, and experience opportunities;

- Investigating the possibilities for and advantages of providing or utilizing technical co-operation among countries.

Educational infrastructure and capabilities

The IAEA assists its Member States in a variety of ways in the development of infrastructures and capabilities for engineering and science education for nuclear power. Types of assistance provided by the IAEA to Member States include:

- Providing information in connection with the establishment or upgrading of academic and non-academic engineering and science education programmes for nuclear power (on the basis of curricula recommended in the Agency's *Guidebook on engineering and science education for nuclear power*).

- Expert assistance in setting up or upgrading laboratories and other teaching facilities; qualified teachers for setting-up and teaching nuclear-oriented engineering and science courses; expert missions to assess a country's needs in nuclear-oriented education and training; and student fellowships. Agency fellowhips could also be used to train teachers.

- Assessing the capabilities and interest of Member States and their institutions/organizations for technical co-operation among countries, especially developing ones, in engineering and science education, as well as its feasibility and usefulness. This would involve co-operation between the IAEA and the Member State to evaluate and, if needed, assist in upgrading the capabilities of selected institutions which have specific expertise in an important area of nuclear-oriented engineering and science education.

- Preparing and conducting nuclear specialization courses (e.g. on radiation protection) in various Member States.