NUCLEAR ENGINEERING EDUCATION IN THE 21ST CENTURY

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Abstract
Current status of nuclear power generation in Japan is presented in comparison with the status in other countries. Energy problems in the 21st century in Japan and in the world will also be discussed. Nuclear research and development activities should continue to be important in the coming 21st century, implying the need for continuous supply of scientists and engineers trained in the nuclear field. Nuclear energy has not been fully cultivated yet, still keeping a high potential to be developed further from safety, economy and environmental points of view.

However, present situation in nuclear engineering education in Japan is facing a difficulty in various respects. Nuclear engineering departments are disappearing from universities. Also it is difficult to recruit top-class students into the nuclear fields. Job market for university graduates, particularly those from nuclear engineering departments, is very limited because of the continuing restructuring of industries after the serious economic depression.

In considering nuclear engineering education in the future, the JCO accident has exerted a big impact; enhanced public perception against nuclear energy and loss of future prospect of nuclear engineering as a career for young students.

Some important issues for the future nuclear engineering education are discussed. First, the contents of nuclear engineering have been shifted considerably in a past decade, e.g. maintenance engineering, lifetime evaluation, materials degradation and so on becoming important subjects. Once-established technology will not be maintained without adding new aspect continuously. Fundamental nuclear engineering subjects will be kept active by keeping design activities of advanced nuclear systems. Education in other energy sources and environmental engineering must accompany with traditional nuclear engineering curriculum so that the students can evaluate and better understand nuclear energy relative to other energy sources.

Conditions of selection of energy options are discussed. General trend in the 21st century is for the public to take part into various decision making processes as selection of energy options.

Introduction
Objective of nuclear engineering education is to provide qualified scientists and engineers in the field of nuclear engineering. Among various ways of education; undergraduate and graduate courses of education in universities, specialized education in
technical schools, on-job training in industries and in research organizations etc., education in universities may be the most important.

Supply and demand of qualified manpower must balance. This was accomplished when the development of nuclear energy was steadily growing. Recently, however, there is a growing concern that it might be difficult for nuclear industries to secure or to keep qualified personnel in the future. The concern has already been recognized in some countries and actions necessary to ensure the availability of qualified people in the nuclear fields have been taken or are planned [1, 2]. However, in Japan, taking counter measures to this problem has not been done or ineffective. The paper will discuss current situation in nuclear energy development, nuclear engineering education and future prospect and problems in nuclear electricity generation and problems to supply adequate number of qualified personnel in various field of nuclear energy.

**Current Activities in Various Nuclear Fields**

**Current Status of Nuclear Power Generation–Japan and in the World**

Since needs for nuclear scientists and engineers are closely related to the national nuclear power program, brief survey will be made on the current status of nuclear power generation in Japan and in the world.

Demand for energy in the world will be steadily increasing in the 21st century. Increase of about 60% from the current level is estimated in the year 2020 [3]. Fractions of energy resources in 2020 will not be much different from those at present except that slight increase in the fraction of natural gas and slight decrease in the fraction of nuclear energy are envisioned, i.e., coal: 28~29%, petroleum: 38~39%, natural gas: 22~25%. As for the nuclear energy, although its fraction will be reduced from 7.3% in 1995 to 4.4% in 2020, the absolute value of nuclear electricity generation will be increasing. In particular, in Asian countries, more rapid rate of increase is expected.

In December 1997, the third Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) was held. A goal was set for Japan to reduce the release of CO2 by 6% of the 1990 level during year 2008~2012. In order to achieve this goal, the Japanese government has been taking a policy that i) conservation of energy, ii) development of new energy sources as solar or wind energies and iii) further development of nuclear energy are important. Even if CO2 emission is limited to the same level as in 1990, Figure 1 shows an estimation of demand for electricity in 2010, indicating most of the increase in demand will have to be covered by nuclear energy. This is a very difficult goal considering current situation of public acceptance for nuclear energy. Current status of nuclear power generation in Japan is given in Table 1. Adding 6.9 GWe for five power plants under planning, which might be commissioned before 2010 in the most optimistic case, the total capacity of nuclear electricity generation is still below the necessary level to meet the demand.

However, the expected growth in demand for electricity over the next decade,
coupled with the increasing environmental pressures faced by the fossil-fuelled electricity generators and the limitation of conservation measures, the demand for secure energy supplies, the general improvement in nuclear safety and technology, and the growing scale of radioactive waste management and other operations at the back end of the nuclear fuel cycle, all of these will tend to increase the need for qualified manpower for the nuclear industry [1] and hence, education is a very important world-wide issue as a mechanism to continuously supply scientists and engineers trained in the nuclear field.

Fig. 1 Evolution and estimation of electric power generation in Japan. 2010 values are estimated assuming CO$_2$ emission is limited to the same level as in 1990 (Data from Ministry of International Trading and Industries.)

Table 1. Nuclear Power Plants in Japan (as of March 1999)

<table>
<thead>
<tr>
<th></th>
<th>Number of power reactors</th>
<th>Power generating capacity (GWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In operation</td>
<td>52</td>
<td>45.082</td>
</tr>
<tr>
<td>Under construction</td>
<td>3*</td>
<td>2.205</td>
</tr>
<tr>
<td>Preparation for construction</td>
<td>3**</td>
<td>3.563</td>
</tr>
<tr>
<td>Total</td>
<td>58</td>
<td>50.850</td>
</tr>
</tbody>
</table>

*) Tohoku-Onagawa #3, Tohoku-Higashidoori #1, JNC-Monju
**) Chubu-Hamaoka #5, Hokuriku-Shiga #2, Tohoku-Maki #1(This has been canceled.)
Development of New Power and Research Reactors

As for power reactors, there are 520 power reactors as of December 1997 (Generating capacity of more than 30MWe), among which the most abundant are PWRs (~3/4), followed by BWRs (~1/5), heavy water reactors, gas-cooled reactors and others. In Japan, one and only gas-cooled reactor was shut down in March 1999, and pressure-tube type heavy water reactor, Fugen, will be shut down in a few years. 28 BWRs (including ABWRs), 23 PWRs and one FBR (Monju) are the power reactors in operation. No plans of constructing other types of power reactors are existing. Utilization of MOX fuels in both PWRs and BWRs are being planned. Use of high burnup fuels with assembly averaged discharge burnup of 55GW•d/tM is under way.

For research and test reactors, some of university reactors (Musashi Inst Tech. and Rikkyo Univ.) are in difficult situation. Newly-built high temperature gas cooled reactor, HTTR, is under power-up operation. Fortifying JOYO reactor to 140MW (JOYO Mk-III) will soon be initiated.

These activities are somewhat contributing to create needs to recruit qualified personnel into the nuclear field.

Activities Related to Front-End and Back-End Sectors of Fuel Cycle

Japan has taken a policy to complete the uranium-plutonium cycle since 1956. In Rokkasho village in Aomori Prefecture, centrifugal fuel enrichment plant, fuel reprocessing plant and waste storage facilities are under construction and some parts are already in operation. For the front end of the fuel cycle, Japan has practically no uranium resources, the whole process starts at reconversion from imported UF₆ to UO₂.

Nuclear-Related Activities as Fusion Power Development

Nuclear fusion and accelerator development are examples of major areas demanding qualified personnel other than fission nuclear energy. Japan is keen on providing site for ITER (International Thermonuclear Experimental Reactor: original version; 1.5GWth) construction. Large Helical Device (LHD) in National Institute for Fusion Science has been in operation since March 1999.

Advanced neutron source project is on-going. This is a spallation neutron source using intense proton beam accelerator. Another intense neutron source for fusion materials irradiation testing (IFMIF) is being planned.

Present Situation in Nuclear Engineering Education in Japan

Nuclear Engineering in Universities - updated.

Current status of nuclear engineering education in Japanese universities has been discussed in Proceedings of the previous meeting [4,5]. A few additional remarks are made here.

During the period from 1993 to 1998, reform was made in all national universities having nuclear engineering department. Major changes are to emphasize education
in a graduate school level. The name of the department for undergraduate education has been changed in most of the universities. Nuclear engineering departments have disappeared from national universities except Hokkaido University. Instead, the key words for the new department names are energy, quantum, system and science [6]. The key words, nuclear or nuclear energy are retained in the names of the graduate courses. Engineering fundamentals are emphasized in undergraduate education.

Although above changes have been made, present situation in nuclear engineering education in Japan is facing a difficulty in various respects. For example, it has been increasingly difficult to recruit top-class students into the nuclear fields. Job market for university graduates, particularly those from nuclear engineering departments, is very limited because of the continuing restructuring of industries as a whole after the serious economic depression. Not only in nuclear industries but in many other industries, over-investment in equipment as well as in manpower is prevailing and personnel in nuclear related sectors are often transferred to other sectors as semiconductors, electronics and information engineering. Retiring personnel in nuclear sectors are not replaced by younger personnel. An impression often prevails among the young generation that there is lack of future prospects for satisfying careers in nuclear industries [1].

Owing to the reform described above, it has become very difficult to teach comprehensive nuclear engineering subjects for undergraduate students. The same is true for graduate courses because time allotted for schooling is limited compared with that for thesis work.

Social Environment

One of the greatest problems facing the nuclear community is public perception of nuclear accident risks, in particular after Chernobyl accident. Specifically in Japan, series of accidents have been reported in mass media; sodium leak in Monju in December 1995, fire in asphalt solidification plant in March 1996, invention of inspection data of spent fuel transportation casks in October 1997, criticality accident in JCO in Tokaimura in September 1999. The latest one; the JCO accident is extremely serious because it seems to suggest the present deteriorating situation of Japanese technologies. In considering nuclear engineering education for the future, it is impossible to consider it without referring the lessons derived from the JCO accident, which clearly demonstrates that nuclear safety is a far-reaching goal.

One of the factors of the accident is a complete lack of proper on-job training for personnel. However, more serious is a trend that people in general would not like to accept complicated scientific and technical training.

People do not like complicated technologies. They would not even try to comprehend them. Highly technical and elaborate achievements are not appreciated by the majority. Younger generations loose their incentive to take part into the highly complex technologies as their career. The number of applicants to engineering faculties, in particular to nuclear engineering departments is decreasing because they see no successful career in engineering fields as influenced by extremely blaming argument in
Most people think that engineering achievement will last forever. This is not true. Engineering achievement needs continuous effort to maintain it. Otherwise it will be degraded easily. This implies that continuous supply of qualified manpower is required to maintain technical achievement or to make further technical progress. Therefore, the current situation of reducing number and degraded quality of manpower in nuclear engineering fields is of a serious concern for safe maintenance of nuclear installations. In this context, it is important to identify what should be taught at nuclear engineering department in universities. This will be argued in the following section.

**Related Demand in Industries - Job Market for University Graduates**

To keep the quantity and quality of university graduates in a high level, it is essential to have an adequate national nuclear power program. In fact, the manpower situation in each country depends on its nuclear power program[1]. See Table 2. In ref.[1], detailed analyses of manpower allocation in each sector of nuclear field have been made, though the database is fairly old. In some countries, a large proportion of the work force is nearing retirement. This distortion in the age structure from that prevalent in other industries will probably lead to marked losses of qualified manpower in the very near future [1]. In Japan, birth rate is very low and the distortion in age structure is becoming a serious social problem.

**Table 2. Number of Qualified Manpower in Several Countries [1]**

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of qualified manpower</th>
<th>Nuclear capacity(GWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>860</td>
<td>5.5(5.5)</td>
</tr>
<tr>
<td>Finland</td>
<td>394</td>
<td>2.3(2.3)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>413</td>
<td>0.5(0.5)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>708</td>
<td>3.0(3.0)</td>
</tr>
<tr>
<td>Sweden</td>
<td>1621</td>
<td>10.0(10.7)</td>
</tr>
<tr>
<td>Canada</td>
<td>3232</td>
<td>11.9(15.4)</td>
</tr>
<tr>
<td>Japan</td>
<td>9843</td>
<td>27.6(49.7)*</td>
</tr>
<tr>
<td>U.K.</td>
<td>14013</td>
<td>11.2(9.9)</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>74511</td>
<td>98.0(104.0)</td>
</tr>
</tbody>
</table>

a) Figures are for 1989 data (OECD/NEA, Nuclear Energy Data, 1990)
b) Figures in parenthesis are forecast values in Ref. [1].
* Actual nuclear capacity in 2000 is 45.082GWe.

**Nuclear Engineering Education and Nuclear-Related Activities in the 21st Century**

**Near Term Actions and Counter Measures to Overcome Difficult Situation in Nuclear Engineering Education**

As mentioned in the previous section, personnel with technical developmental
ability must be maintained to keep or to further develop an established technology in nuclear energy area. Otherwise, the once-established technology will by dying sooner or later. Current status of nuclear engineering education is in a critical state from the view point of supplying qualified personnel to nuclear related field. In view of these current situation, some important issues for the future nuclear engineering education will be discussed.

First, the contents of nuclear engineering to be emphasized have been shifted considerably in a past decade. In addition to fundamental nuclear engineering, maintenance engineering, lifetime evaluation, materials degradation and so on are becoming important subjects. As discussed above, once-established technology will not be maintained without adding new aspect of aging of nuclear installations. The subjects listed above are the contents of new engineering to be pursued and established. Education in universities must accompany research activities. Fundamental nuclear engineering as reactor physics, reactor design, thermal-hydraulics etc. will be kept active by keeping design activities of new advanced nuclear energy systems such as inherently safe reactors, reactors using inert matrix fuels, or even fusion reactors for hydrogen production. Education of other natural energy sources and environmental engineering must accompany with traditional nuclear engineering curriculum so that the students can evaluate and understand pros and cons of nuclear energy relative to other energy sources. This point is important also in social education in nuclear engineering.

Secondly, counter measures to maintain balance between supply and demand of manpower and to keep technological ability to develop further advanced nuclear energy systems will be discussed.

Several countries have already initiated actions to support nuclear research and development and education in order to ensure an adequate supply of qualified manpower. These actions include [1]:
1) government funding of research and development programs, possibly including equipment, at universities, institutes of technical education, research establishments and industries.
2) government and industry funding of students and lecturers in universities and specialized summer courses;
3) close co-operation between nuclear utilities, research centers and universities in carrying out research and development projects, student and personnel training and exchange, etc.;
4) support of relevant educational activities of public research institutions

As an example in U. S. A., presidential committee on science and technology (PCAST) presented a report in 1997, in which recommendations are made to maintain technological power and to this end, it was proposed to increase federal expenditure on nuclear energy R&D to a level equivalent to early 1990s. The program is called NERI (Nuclear Energy Research Initiative) and its target is focused on promoting fundamental research in universities [7].

Imbalance between supply and demand has been discussed among universities in
Decline of student numbers is remarkable as shown in Table 3. In some universities, similar actions as listed above have been conducted actually [2].

In Japan, "Nuclear engineering education and research special committee" under Atomic Energy Society of Japan has been organized for many years, exchanging opinions. But no strong actions have not been made.

Table 3. Number of Students in Nuclear Engineering Department in U. S. A.

<table>
<thead>
<tr>
<th>Year</th>
<th>Undergraduate</th>
<th>Masters degree</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Enrollment</td>
<td>Awarded</td>
</tr>
<tr>
<td>1979</td>
<td>1800</td>
<td>800</td>
</tr>
<tr>
<td>1999</td>
<td>600</td>
<td>300</td>
</tr>
</tbody>
</table>

Nuclear Energy Education in the 21st Century

Graduates from nuclear engineering department will find the needs in the following categories:
• Front and back end of the fuel cycle,
• Nuclear power plant construction, manufacturing and operation,
• Regulatory,
• Education and research and development [1].

It is evident that nuclear energy cannot cover all the energy needs. Nuclear energy is an option to be selected from technical, safety, economic, environmental, social, political --- reasons. In concert with this situation, other energy options are required to be compared with nuclear energy. In that sense, new type of "learning of energy" which has integral, transdisciplinary nature may have to be established.

Public Education - from a Spectator to Decision Maker

In relation to social or public education, it is often discussed that people should take part in the selection of energy options. To realize this, information disclosure and transparency and accountability of decision making must be maintained. At the same time, public must have minimal background knowledge to understand scientific and technical problems. In that sense, not only nuclear engineering education but also general science and engineering education is equally important. So far, general public have been spectators, kept out from any major decisions, just watching and criticizing the events of the outside world and blaming the faults. General trend in the 21st century is for the public to take part into various decision-making processes, so that they will share the responsibility to the decisions.

Conclusions

In conclusion, the present situation of nuclear engineering education in universities in Japan is not sound for the nuclear energy utilization and development in the 21st century. Some measures should be taken to maintain basic research and development activities and to keep a capacity of supplying well educated university graduates to nu-
clear engineering area. Importance of general science and engineering education and of public education and so on has also been pointed out.

References