Chapter 20
Nuclear Engineers for Society: What Education can do

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Abstract Engineering education is a key factor in determining the range of engineers' expertise, the attitude and the behavior of engineers, and the culture of the engineering professional community. This chapter is devoted to nuclear engineering education post-Fukushima Daiichi nuclear accident. Prior to education itself, knowledge and attitudes required of nuclear engineers are firstly discussed, focusing on social aspects of nuclear technology. I emphasize the importance of mutual communication with society, not only with the general public but also with experts in other fields, by referring to 3 points which are essential for appropriate advancement of nuclear engineering and can be reinforced with mutual communication: social legitimacy of nuclear technology, introspection within the nuclear professional community, and public trust in nuclear technology and the professional community. These points are not only needed for smooth utilization of nuclear technology, but also, and more importantly, needed for enhancing the safety of nuclear technology utilization and advancing nuclear technology to provide more benefits and welfare to society. Finally, I propose 4 items for education reform, which are mainly designed to make mutual communication with society more effective while maintaining a high level of technical expertise: standardization and internationalization, transparency and sharing, social-scientific literacy education, and development and evaluation of faculty.

Keywords Nuclear engineering education · Social aspects of nuclear technology · Social legitimacy · Introspection · Trust

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20.1 Introduction

When an accident or a scandal related to science and technology occurs, education—especially higher education such as undergraduate-school and graduate-school education—often draws social attention. This social reaction is natural because higher education is the first opportunity for to-be-experts to gain expertise in a comprehensive manner for several years and is thus influential. Indeed, engineers continuously update and reinforce their expertise even after the completion of higher education, mostly through on-the-job experiences. However, what they learned at the beginning of their professional career inevitably affects how they improve their expertise and what they learn from the experiences. Therefore, higher education is a key factor in determining the range of expertise as well as the attitude and the behavior of engineers. It also affects the culture of professional community because the culture is constructed by collective behaviors and attitudes of community members.

Considering its extensive influence, this chapter presents a discussion on nuclear engineering education. However, since the goal of education largely depends on human resources required in society, a major part of this chapter is devoted to clarifying the knowledge and attitudes required of nuclear engineers, especially focusing on social aspects of nuclear technology, as follows.

In Sect. 20.2, first of all, I look back on some actions on educational reform which were carried out in Japan before the Fukushima Daiichi accident. We see that Japanese nuclear professionals were aware of the importance of social aspects of nuclear technology and then tried to incorporate some relevant contents into nuclear engineering education.

Indeed, the importance of social aspects, which often includes communication with society on science and technology, was recognized not only in nuclear engineering but also in other engineering and science fields in those decades. In Sect. 20.3, I briefly review why the social aspects were increasingly thought to be important with focus on communication with society.

In Sect. 20.4, some key efforts made in relation to social aspects and the communication with society on nuclear technology are introduced. However, I must say that these activities hardly brought fruitful results in the reality.

In Sect. 20.5, the causes of the unfruitful results in communication are discussed. There was/is often a big gap in the purposes of mutual communication for the general public (or society) and for nuclear engineers (or nuclear professional community): the former expects changes in nuclear engineering and its professional community, while the latter expects changes in the general public and society.

In Sect. 20.6, I reconsider the significance of mutual communication in advancing nuclear engineering. I bring three viewpoints for this: legitimacy, introspection, and trust. I try to explain that they are requisite to the safe utilization of nuclear technology and to the appropriate advancement of nuclear engineering, and that they are underpinned by mutual communication with society. Here, communication with society is extended: not only with the general public but also with experts in other science and engineering fields.

In Sect. 20.7, I discuss what kinds of communication are doable and effective in practice.

In Sect. 20.8, I propose 4 ideas on higher education reform based on the discussion given in the previous sections.

Section 20.9 ends this chapter with some concluding remarks.

Finally, before entering the main contents, I would like to briefly introduce my educational and professional background. I am a researcher in nuclear materials science and engineering. I am interested in both nuclear fission and fusion reactors technology. I received my primary, secondary, and higher education in Japan. After them, I worked in a Japanese university for about 6 years at its nuclear engineering department, worked in a U.S. university for 1 year at the materials science and engineering department, and now work as an assistant professor at a Korean university since 2013 in the nuclear engineering department. Due to this background, the description in this chapter is centered on Japan's situation and history. Non-Japanese readers may feel some strangeness in the contents. However, based on my experience and observation in Japan, U.S., and Korea, I believe that there are large similarities in the characters of nuclear expert communities in Asian countries and some similarities even between Asian countries and Western countries, more than expected, because the culture of a nuclear engineering community is strongly influenced by the nature of nuclear technology itself.

20.2 Nuclear Education Reform Before the Fukushima Daiichi Accident

Before the Fukushima Daiichi accident, there were several initiatives in Japan to reform higher education in nuclear engineering. The classical engineering higher education predominantly aims to make students acquire natural-scientific and technological knowledge and skills relevant to nuclear engineering. Here I want to introduce an education-reform project undertaken by the Department of Nuclear Engineering and Management, the University of Tokyo. The project was named "Nuclear Education and Research Initiative" (GoNERI). GoNERI was financially supported under the Global Center of Excellence (GCOE) program led by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT). The general objectives of the GCOE program were to "establish education and research centers that perform at the apex of global excellence to elevate the international competitiveness of the Japanese universities" and to "strengthen and enhance the education and research functions of graduate schools, to foster highly creative young researchers who will go on to become world leaders in their respective fields through experiencing and practicing research of the highest world standard" [1].

GoNERI was selected as one of the GCOE subjects and the program ran during FY2007-FY2011. GoNERI aimed to "develop a well-rounded research and education program in response to a variety of world-wide nuclear utilization subjects such as protection of the global environment, supply of safe and stable nuclear energy, radiation application for healthy, productive and prosperous lives" and to "perform the first systematic education on nuclear energy in the world, incorporating the social, liberal arts and technical subjects as they relate to nuclear utilization [2]." GoNERI specified three realms for education and research, which were nuclear sociology, nuclear energy, and radiation application, and intended to implement them into the curriculum in an integrated manner [2]. Among them, "nuclear sociology" is of particular interest. It involves nuclear energy law, nuclear non-proliferation, and harmonization of technology and society, and puts a special focus on "public understanding for harmonization between society and technology" [2].

There was another similar education reform program led by Tokyo Institute of Technology in FY2003-FY2007. In its purpose statement [3], "the relationship between nuclear energy and society" was frequently mentioned. Considering these two reform programs in different universities, it would be reasonable to assume that the awareness of the importance of social aspects of nuclear technology, especially harmonization with society, was widely shared in the nuclear professional community. It was recognized that some social-scientific disciplines related to the social aspects of nuclear technology should be taught in nuclear engineering education. This awareness and recognition must have been brought about by long-lasting frictions in society over the utilization of nuclear technology, such as the delay in selecting a high-level radioactive waste disposal site.

20.3 Communication on Science and Technology

The importance of social aspects in the development and utilization of science and technology has been increasingly recognized not only in the nuclear engineering field but also in other science and engineering fields. The cause for this realization is the increase of social conflicts related to science and technology, such as environmental problems, ethical concerns in frontier engineering (e.g. genetics), etc. [4].

In this context, two cases immediately draw our attention [4]: the study by Wynne [5] on how the general public understands and deals with scientific knowledge about environmental contamination in the vicinity of the Sellafield-Windscale site in U.K., and the circumstances of U.K.'s government response to the Bovine spongiform encephalopathy (BSE) issue [6]. It is explained, for example, that the "deficiency model," which considers that miscommunication and misunderstanding on science and technology mainly rest on the deficiency of the citizen's knowledge, is not plausible in many cases [5]. Then, not only the importance of the trust in information of science and technology but also the importance of the trustworthiness of an organization which deals with the information are claimed [4]. One of the effective ways to foster the trust and the trustworthiness is mutual communication between citizens and experts, not one-way communication from experts to citizens, such as teaching and enlightening. The mutual communication may include the reflection of public opinion in the development and the utilization of science and technology, public involvement in the decision making process for science and technology issues, etc.

In Japan, the importance of communication on science and technology has been clearly recognized since around the year 2000, and methods to collect public opinions via *public comment* or *consensus meeting* have been widely implemented [4]. In higher education, three universities (The University of Tokyo, Hokkaido University, and Waseda University) embarked on education of science and technology communication in 2005 under the support of MEXT. For example, The University of Tokyo launched a *Science Interpreter Training Program* [7]. All three universities had a similar motivation, which was that “even though the importance of science and technology in our daily lives has increased, the distance between society and science-and-technology has been stretched and people’s distrust of science and technology is emerging. So we need human resources who can bridge society and science-and-technology” [4].

20.4 Attempts in Nuclear Engineering Community

Regarding public involvement and technology communications in the nuclear engineering field, the *Round-Table Conference on Nuclear Power Policy* was launched by the Atomic Energy Commission (AEC) in 1996, which aimed to “seek the views of all levels and sectors of society in Japan, and to incorporate their diverse opinions as part of future nuclear energy policy” [8]. Public comment and consensus meetings were also widely held ancillary to meetings or conferences organized by national/local governments or governmental agencies. It can be said that activities to increase transparency in the decision-making process and to foster public involvement in the decision-making process have been formally built up year by year. However, when a nuclear-related topic is the agenda, it seemed that both pros and cons become extreme, and they do not reach any agreement. For example, at the round-table conferences, it was frequently observed that the participants for nuclear technology tried to persuade the citizens. In addition, it is often criticized that such an activity is utilized as mere “evidence” of public involvement [9].

In the Atomic Energy Society of Japan (AESJ), which most Japanese nuclear professionals belong to, social aspects of nuclear technology were also recognized as a key issue. Such recognition was materialized as the foundation of the Social and Environmental Subcommittee (SES) in AESJ in 1999. The prospectus of the subcommittee was set as follows [10]:

> … A significant relationship with society is a notable characteristic of atomic energy technology, and the Society and Environment Subcommittee was established to engage in academic research of social aspects, as well as to exchange and disseminate the resulting information.
>
> We analyze the features and the characteristics of nuclear technology from the viewpoint of technological theory and cultural theory. We study various aspects of nuclear energy which appears in realms of politics, economics, laws, society, international relations, environmental harmonization, etc. Then, we search for nuclear technology which is adjusted so as to go well with the age of competition, global environmental concerns, post-cold war and global economics. Namely, we search for an appropriate form of nuclear technology under strong correlations between human beings, societies, environment and technologies….

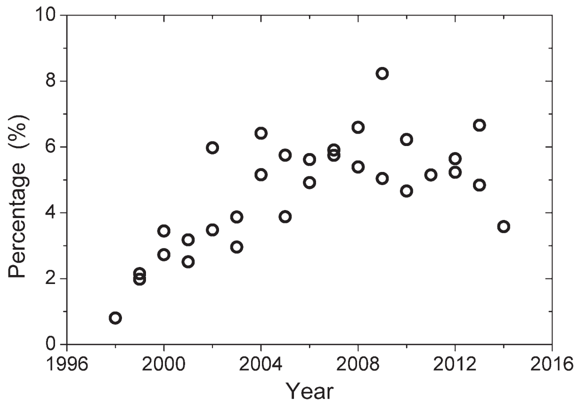
This prospectus says that its main objective is to reconsider the roles and meanings of nuclear technology in society and to find how nuclear engineering should be, not to inform society about nuclear policy nor to promote public acceptance of nuclear technology utilization. Communication on nuclear technology is often attempted to change the perception of the general public on nuclear technology by modifying the way of showing and explaining the technology. In this case, reformation of nuclear engineering itself is not taken into account. What the prospectus explains seems contrastive to it. To achieve the aims written in the prospectus, releasing information to enlighten the general public is clearly insufficient. Instead, nuclear professionals are required to listen to and to understand society so that they can reflect the opinions of society in the development and the utilization of nuclear technology.

20.5 Unfruitful Results from the Attempts

I became interested in the social aspects of nuclear technology around 2008. At least since that time, I saw many research presentations by social-aspects experts at biannual meetings of AESJ (Fig. 20.1). This indicates that social-aspects experts had secured a certain position in the nuclear professional community. It must have made them feel at ease and made technological experts feel free from struggles to communicate with society, as the communication was often time-consuming and tough for engineers. This new situation, where technological experts can focus on their conventional engineering work and social-aspects experts face society, seemed to be reinforced in the last decade. The reinforcement is reasonable because it was beneficial for both experts. However, I think fruitful results were hardly achieved in line with the prospectus of SES.

One of the reasons of the unfruitful outcome is that social-aspects experts were prone to turn their faces more toward citizens and less toward nuclear technology experts. Most of communication practitioners and social-aspects experts do not have enough knowledge and skills about nuclear technology to advance the technology by

Fig. 20.1 The number of papers on the social aspects (categorized in general issues session), which were presented in the biannual AESJ meetings since 1998. We see a clear increasing trend



themselves. Hence, in order to reflect what they gathered from society on nuclear technology development and utilization, social-aspects experts should have transferred opinions from society to engineers so that engineers could consider and reflect it in their work; however, this was not done sufficiently. Even when mutual communication is carried out between citizens and social-aspects experts or communicators, if the accumulated information is not appropriately transferred to engineers, the communication is virtually no different from enlightenment-type one-way communication.

In addition, it should be recognized that the opinion of society hardly appears on opinion polls or answers to questionnaires, such as agreement rates on "Do you agree with nuclear power utilization?" Many data from opinion polls and questionnaires have been accumulated over these decades. These data are resourceful, but the data in raw formats are not significant enough to stimulate engineers so as to bring some changes in the technology. Furthermore, such raw data sometimes gave engineers misleading perceptions on the opinion of citizens.

For example, after the occurrence of an incident, we nuclear experts are often anxious about opinion polls and regard their results as the opinion of citizens. Then, when the polls start to become more positive, we engineers often simply assume that the public sentiment has recovered and society has forgiven the incident. However, in most cases, this is not due to forgiveness, but mainly due to oblivion because nuclear energy is not the sole agenda for society. Even after the opinion polls recover to around the level before the incident, some bad memories are deeply and subconsciously inscribed in public minds. Then, when another incident occurs in the future, society reacts excessively due to the accumulated bad records in the past. Such an excess reaction puzzles nuclear engineers and makes engineers think that citizens are irrational.[1] To avoid such misunderstanding on the behavior and the intention of citizens, we engineers should seek out the true opinion and intention of citizens rather than apparent ones.

To extract more true opinion and intention of society, those raw data should be carefully and thoroughly studied considering historical, cultural, and political contexts, as described in the prospectus of SES. For this, some disciplines in social sciences, and even sometimes humanities and literature, should be useful. However, as far as I know, most social-aspects experts in the nuclear professional community did not have enough educational background in social sciences.[2] Probably partly

[1] We engineers usually believe that we can improve technology so as to prevent future occurrence of mistakes that have happened in the past. Due to this belief, we tend to evaluate the status of the engineering as separate from the fact that the mistake happened in the past. On the other hand, citizens usually do not separate the current status of engineering from the previous mistakes, because the current status is regarded as a point on the line continued from the past and continues into the future. In this sense, public reaction is reasonable and rational. The difference from that of engineers is mostly how they construct the framework to look at technology advancement.

[2] Although the statistics need to be carefully checked, many social-aspects experts chose their focus of expertise in graduate courses and did not receive comprehensive social-scientific education in undergraduate courses in Japan.

due to this, most information shown to nuclear engineers from social-aspects experts was not deep enough to motivate nuclear engineers to think about it.

Of course, the problems did not exist only among social-aspects experts but also among nuclear engineers. They did not have an attitude of sincerely listening to and collaborating with social-aspects experts. As seen in the previous sections, nuclear engineers became aware of the importance of social aspects. However, it was mostly done in a passive and reluctant manner, and they did not really understand how social aspects are related to nuclear technology. Then, engineers left most things about society up to social-aspects experts so that they can be free from mutual communication with society.

In summary, I observe two types of miscommunication between nuclear-technology experts and social-aspects experts, rather than between social-aspects experts and citizens: (1) a quantitative one, which is due to insufficient communication between nuclear-technology experts and social-aspects experts, and (2) a qualitative one, which is due to the fact that most information provided from social-aspects experts to nuclear engineers was not deep enough to stimulate nuclear engineers. Consequently, it may even be said that the mutual communication between citizens and nuclear engineers was further reduced and the distance between society and nuclear technology could not be decreased in the last decade, although frameworks to conduct mutual communication was nominally established and deployed (Fig. 20.2).

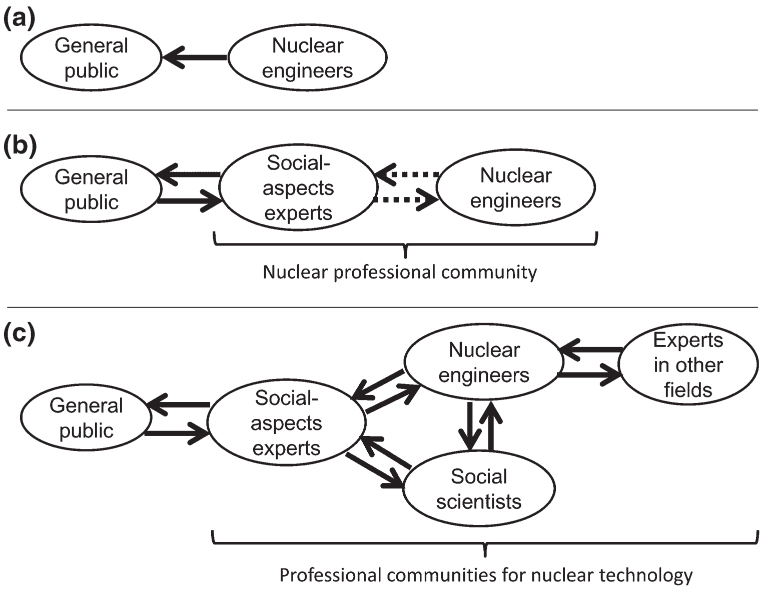


Fig. 20.2 Three structures for nuclear technology communications: **a** enlightenment-type one-way communication with society, where information as knowledge is transferred from engineers (experts) to the general public; **b** mutual communication with society via social-aspects experts (including communicators), where miscommunication occurred between social-aspects experts and nuclear engineers; **c** an effective mutual communication with society which I propose in this chapter

20.6 Is Communication Essential for Advancing Nuclear Engineering?

There is no doubt that nuclear engineers recognize the importance of social aspects including mutual communication with society, as can be seen in the education reform programs, the round table discussions, and the establishment of the SES subcommittee in AESJ. However, in reality, it is not completely clear or convincing for engineers whether mutual communication will really contribute to the safe utilization of nuclear technology and the advancement of nuclear engineering. This is one of the key reasons why nuclear engineers have not been positively involved in mutual communication. Many engineers think that the communication does nothing for the performance and advancement of nuclear technology but is just required to let the general public know the importance of nuclear technology and make them accept nuclear technology. In this sense, the communication with society is often considered to be a reluctant obligation and an additional burden for engineers, and its purpose to change the public perception.

Citizens usually do not think that they have to change; rather they think engineering or experts (community) as well as the governance of technology need to change, especially when they participate in mutual communication. The goal of engineers is to change society, while the goal of the general public is to change nuclear engineering and the nuclear expert community. Thus, in most events of mutual communication, both sides cannot achieve what they want; engineers cannot foster public acceptance, while the general public cannot have any changes in the technology and the expert community so as to make them more acceptable to them. Repeating such fruitless communication makes engineers tend to keep a distance from the communication.

However, when we see the significance of the communication from a different direction and appropriately define it, mutual communication with society seems vital to safely utilize nuclear technology and to advance nuclear engineering. I hereafter discuss this point from three viewpoints: (1) legitimacy, (2) introspection, and (3) trust.

20.6.1 Legitimacy

Historically, the civil use of nuclear technology has not been separable from the military use of nuclear technology, politically and socially. Related to this fact, there are many features that make nuclear technology distinct from other technologies. For instance, nuclear non-proliferation has been one of the main international political issues after World War II. The transparency on nuclear technology needs to be limited. National governments participate deeply in the development and utilization of nuclear technology under the international non-proliferation regime. Nuclear security concerns, which have been largely escalating during this decade, also require a decrease in transparency.

Economically, in comparison with other methods of electricity generation, the percentage of initial investment (capital costs) is higher and designing an insurance system is more difficult due to the large uncertainty in calculating possible damages from potential accidents, which requires some support from the government. There are also issues on waste disposal whose radioactivity lasts a very long time, which requires responsible involvement from the government.

Such characteristics of nuclear technology increase government commitment to the technology in its development, utilization, and evaluation. It is hard to put nuclear technology under a full market mechanism, which can act as a kind of screening process for technology in society. If a product does not fit society, the product is swept out from the market or is modified so as to become one more acceptable to society. In many countries, products made with nuclear technology, such as nuclear power plants, are nearly fully detached from the market mechanism. Someone may claim that there are market mechanisms within the nuclear industry, like nuclear export competition, bidding in procurement of fuel, etc. However, it is competition after the decision for nuclear technology utilization has been made by the government or by a semi-governmental utility company in most cases. Nuclear power plants are there whichever company wins the contract.

In history, we can find clear traces of such extensive government participation. For example, Japan built 1–2 nuclear power reactors every year since the beginning of the introduction of nuclear power in 1960s, until the mid-1990s, when the power demand declined because of the economic recession [11]. Partly thanks to this, electricity has been stably supplied, the economy rapidly grew, and Japan has established and maintained a high standard of technology for the manufacture of nuclear power plants. The long-term steady promotion and development were approvingly and proudly related in the field of nuclear engineering education before the Fukushima Daiichi accident. However, considering that there have been anti-nuclear movements since 1970s, and that the Chernobyl accident in 1986 stopped new construction of nuclear reactors in most Western countries, it is quite unusual to have the steady increase of nuclear power plants in Japan. Such a situation would not happen for other engineering products which are put under the market mechanism.

While the fleet of commercial nuclear power reactors expanded steadily, research and development (R&D) of advanced reactors was not so successful in Japan; the development of the advanced thermal reactor (ATR) was not realized, and the development of the fast breeder reactor (FBR) did not proceed according to expectations in spite of huge R&D outlays [11]. These unsatisfactory R&D results seemed to be overlooked, probably because they were a part of national policy.

These facts mean that nuclear technology and its expert community did not go through the usual procedure to obtain social legitimacy in comparison with other technologies; a pseudo-legitimacy was given and endorsed by the government. This may be one of the reasons why nuclear technology has often suffered strong negative reactions from society. Most citizens may not necessarily explicitly think about the legitimacy issue; however, they may feel some uneasiness in the fact that the government, not the citizens, made the decision, different from other products.

It is hoped that mutual communication with the public will enable its opinions to be reflected in the development and utilization of technology, and lead to social legitimacy. It should be noted that there must be feedback and adjustment after listening to the public; otherwise mutual communication is no different from one-way communication.

20.6.2 Introspection

Having these historical circumstances, nuclear engineers made light of the opinions of society and citizens, and made much of governmental decisions and the harmonization of the professional community. As a result, the nuclear expert community turned to be inner-looking and closed, regarded as it is as a "nuclear village," "nuclear mafia," etc.

The Fukushima accident reports [12–14] mentioned that although there were some technical issues related to the safety of nuclear power plants, nuclear engineers unconsciously took no measures to deal with those issues. Moreover, many of the issues pointed out in the accident reports were relatively easy to be solved technologically. For example, although scientific uncertainty existed in risk assessment of tsunami, possible counter measures to tsunami, like increasing the water tightness of the reactor building, were technically simple and doable. In addition, there was no clear indication that the safety measures had been denied due to financial reasons [12]. Thus, this problem is not fully technological, but also includes some judgment on what needs to be treated. Significant risks were mistakenly ignored and considered as non-urgent, which was said to be "out of the expectation" [12–14]. The accident reports claimed that this out-of-the-expectation mistake resulted from the non-proactive attitude of the power plant owner and non-independence and from insufficient competency of regulatory body, both of which are largely related to the inward-looking and closed nature of the nuclear professional community [12–14].

Indeed, there are facts indicating that some scientists and citizens showed a concern about possible damages due to tsunami [12–14]; however, these opinions were not valued sufficiently. This indicates that the nuclear professional community persisted in their belief in nuclear safety and assessed opinions as to who had given the opinion. Of course, it is not wise or fair to judge such a fault after its occurrence. In addition, it is a common practice for engineers to prioritize possible concerns according to their significance and solve them one by one. However, the order of the priority may have been biased and inappropriate from the standard of engineering practices.

In order to suppress the inward-looking nature, which comes from intrinsic characteristics of nuclear technology as described above, and then to minimize adverse effects from it, nuclear professionals should listen to opinions and criticisms from the outside, such as those from citizens and experts in other realms. Nuclear professionals need to respect these opinions and criticisms, and then reflect them in their work if needed. This is a kind of introspection function of the nuclear professional community so that adverse effects of nuclear technology characteristics to engineering itself can be minimized. To achieve this, mutual communication with those outside the nuclear professional communities, especially with experts in other fields, is important.

20.6.3 Trust

Frequent concern has been raised on issues of public trust on nuclear technology and the expert community. In the discussion of trust in science and technology and in the professional community in general, the decrease in trust of society and citizens is often emphasized. Possible reasons for the degradation of trust are anxiety of citizens about the closed expert community and disappointment due to that opinions of society not being reflected in the technology utilization and the governance of the professional community. Moreover, there is another point that we should not miss: not only is there public distrust toward technology, engineers, and their community, but also engineers' distrust toward society and citizens. There has been a structure of mutual distrust of each other.

Some engineers may claim that this is because some people and mass-media have irrationally criticized engineers and technology due to lack of knowledge and a biased standpoint. Indeed, there were a number of cases where the "deficient model" can explain the situation, although we should recognize the insufficiency of the "deficient model" in many cases. Engineers are also human beings after all, and thus painful experiences such as receiving irrational criticisms were deeply and subconsciously inscribed in their minds. In addition, it was transferred to younger generations via education and as culture.

Consequently, there are quite a few experts who believe that they have to promote nuclear energy utilization even without endorsement and appreciation from society, because they are convinced that nuclear energy is really needed. Some experts even ignore skepticism and criticism of citizens, relying on the own belief. However, it should be recognized that this attitude is quite inappropriate for professional engineers, and that this attitude further enlarges distrust, disappointment, and opposition of citizens toward the nuclear professional community.

The trust from the general public may facilitate the utilization of nuclear power plants, the site selection of radioactive the waste disposal facility, etc. However, if this is all that is intended, trust cannot be achieved in most cases. Rather, more importantly, public trust is essential for engineers to work positively and proactively. And such positive and proactive attitudes are essential for nuclear experts to deal with a high-risk technology, which the accident reports require that TEPCO and the regulatory body have. In this sense, "trust" can be replaced with "respect." A professional community which is not respected and is not appreciated for its outcome due to distrust and which distrusts the society which they should serve is not a professional community which proactively and continuously makes progress so as to increase the safety level. The degree of public trust is an index of the healthiness of the professional community. To heighten it, active mutual communication—in practice (1) understand public opinion, (2) come up with measures based on it, and (3) show the measures to the general public, and then (4) again listen to and understand public opinion—is important.

Legitimacy, introspection, and trust are inter-related. Being trusted/respected is needed to proactively work, which results in increase of legitimacy. However, due to the nature of nuclear technology, there is a driving force that makes the nuclear expert community inward-looking more than the other technology communities. Thus, an introspective attitude is needed to keep the community open and more active, which results in increase of trust and legitimacy. All of these three aspects may be underpinned by mutual communication with society including experts in other science and engineering fields.

20.7 Effective Communication

20.7.1 Communication with Society and the General Public

Even after recognizing the importance of mutual communication, it is not easy for nuclear engineers to understand and catch up with the general public that has different beliefs, preferences, cultural backgrounds, and often negative views on nuclear technologies. Nuclear technology has an intrinsic complexity regarding social context; and agreement/disagreement on the technology itself may become a topic of dialogue.

Public opinions are also complex. They cannot be understood by asking simple questions, such as "Do you support nuclear power utilization?" We nuclear engineers should not readily think that we can draw out these opinions ourselves. There should be experts who can analyze the raw data from opinion polls and interpret them in societal and historical contexts. Such experts are expected to indicate what people's desires and concerns are so that nuclear engineers can utilize the findings in developing their technology.

To realize this, engineers should acknowledge public opinion and have basic knowledge of social sciences, which is not the case in the current situation, so that they can adequately communicate with experts in these fields. I recognize that this is the central motivation for considering nuclear engineering education that highlights social-scientific literacy.

20.7.2 Communication with Experts in Other Fields

As nuclear engineering consists of systems engineering, there are many connections with other disciplines. It is advisable and natural to deepen the communication with other experts through such connections. In order to activate such communication and collaboration, nuclear engineering needs to be scientifically and technologically attractive. However, the level and quality within each sub-discipline field are not as high as those in its parent field, although a relatively large research budget has been funded for nuclear technology utilization and development. This could be due to lack of competition and openness. Indeed, pursuing scientific originality and frontier research are often incompatible with pursuing technology development specialized for nuclear engineering. Nevertheless, it is of crucial importance, especially for academia, to recover superiority in scientific originality in the nuclear engineering field, for activating competition and communication with other fields of science and engineering, which will ultimately help restore public trust.

20.8 Reform of Education

Most nuclear engineers are not ready to carry out the communication methods described in Sect. 20.7 at present. In addition, the Fukushima Daiichi accident indicated that even natural-scientific and technological standards of nuclear professionals are not adequately high. To improve the situation, nuclear engineering education needs to be reformed. I here propose the following 4 reform items.

20.8.1 Standardization and Internationalization

Even if social aspects are essential and need to be taught to nuclear engineers, natural-scientific and technological knowledge and disciplines are always the core of nuclear engineering. Without a high standard of these, nuclear safety cannot be ensured, social legitimacy and trust will never be achieved, and mutual communication and collaboration with experts in other fields cannot be activated. To make fulfilling a high standard of technological expertise and cultivating social-scientific literacy compatible in nuclear engineering education, the thoroughness and the effectiveness of education on the core technological expertise must be adequately heightened.

The core technological expertise includes reactor physics, radiochemistry, fluid dynamics, materials engineering, nuclear fuel cycle engineering, etc. Although these contents are taught as mandatory subjects in most universities, each subject may not necessarily be well optimized for each university. For example, when I teach materials science related to nuclear materials, even if I am careful, the contents are biased by my expertise and converged around my specific expertise. If the contents are common basics and the core for experts, they should not be too biased by the expertise of the lecturer but be more generalized and normalized so that nuclear professionals can share fundamental expertise independent of universities and nations where they have received their education. As an increasing number of countries plan nuclear power plant construction, developing and sharing standardized course materials is also beneficial to maintain the quality of nuclear professionals all over the world.

20.8.2 Transparency and Sharing

In addition to the core contents, advanced and applied contents are important. In this aspect, the feature of each university should emerge. In these contents, a variety of expertise and knowledge should be maintained. Some contents which let students experience trials and errors may be intentionally involved. Here, the most important point is to clearly show its pedagogical meaning to students, experts inside and outside the community, and to society. There are 3 reasons to do so.

1. Society can see what the nuclear professional community aims at in education. The curriculum is a kind of design sheet on how to nurture professionals. To show the design sheet is a social responsibility of the university. Responding to this accountability also helps to make the purpose of education clearer. It is also effective to increase the transparency of the expert community and then increase trustworthiness and introspection.
2. Each university can see the educational resources of other universities. As scientific disciplines involved in nuclear engineering are vast, it is difficult for one university department to sufficiently cover all the necessary subjects. If the educational resources are open to other universities, it would foster collaboration.
3. Universities can mutually monitor the status of other universities' (and thus other countries') education. Also experts in other fields can check the educational conditions. The Fukushima Daiichi accident re-confirmed to us that the consequences of nuclear technology including accidents are intrinsically international. Knowing about the situation of other universities would spur us to work hard together with each other, and also would function as introspection. This is also a responsibility to nuclear experts in other countries as well as to the public in other countries.

20.8.3 Social-Scientific Literacy Education

The importance of understanding the opinion of society was described in above sections. For to-be-experts, they first need to realize this importance as their own feeling and then recognize that its consideration and reflection are highly important to safely utilize nuclear reactors and to advance nuclear engineering. Then, they need to cultivate social-scientific literacy through education about engineering ethics, philosophy of science, history of science, science and technology and society (STS), social psychology, politics, economics, organizational theory, cultural theory, etc. As a result, the ability to collaborate with experts in social sciences as well as communicators to engage citizens can be fostered. To my knowledge, most nuclear engineering curriculums only include some of these subjects in a piecemeal fashion. There is no consensus which contents are more relevant and important for engineers.

Personally, I believe education on nuclear history is effective. This must involve not only positive history such as how nuclear R&D succeeded and technologies were developed, but also negative history such as failures in R&D, scandals, accidents, and how mutual distrust between society and engineers have come about. As mentioned above, nuclear technology has some unique features that other technologies do not usually have. Studying and knowing history also reminds us of this nature of nuclear technology.

In education of social aspects, international collaboration is also important. On societal issues in the community or in the society where one belongs, it is hard to be fully objective: sometimes one becomes too critical or too defensive. If the issues are of other nations, one can be more objective and keep an appropriate distance from the issue. For example, if international collaboration is made on nuclear history education, students would discover similarities and differences in these histories, and can find that many countries follow the mistakes of advanced countries. Whether good cases or bad cases, histories and situations of other countries teach a lot.

20.8.4 Faculty Development and Evaluation

Most education reform attempts focus on evaluation of students: e.g., how many times students attended research conferences, what papers were published, etc. This is quality control at the exit of an educational system. We should pay more attention on the system itself, specifically evaluation of faculty and facilities.

While the speed of social advancement/change has been increasing, the work period of an engineer has been extending. Even for nuclear engineering whose development speed has become relatively slow, technologies are largely renewed within the work period of an engineer. To construct an effective education system, it is imperative for the faculty, especially senior faculty, to put themselves in the forefront, update their knowledge, and continuously learn. Such activities by faculty should be systematically supported by the university. When all faculty members have such an attitude and update their knowledge as well as their views on the role and position of nuclear technology in society, the accumulation of these knowledge and views would form the basis of an appropriate education system.

Regarding evaluation of faculty, it should not be so straightforward and simple. Although some outsiders should be involved in the evaluation, it cannot be done mainly by outsiders. As the complexity of technology increases, indeed due to that, the importance of experts and their knowledge is more keenly highlighted, particularly in the case of balancing and managing multiple different disciplines relevant to technology utilization. Hence, it is better that the details of faculty development support and faculty evaluation criteria are discussed and determined primarily by the nuclear engineering department at each university and then shown to society and experts in other fields so as to reflect outsiders' viewpoints. In the discussion, the aforementioned 3 viewpoints, i.e., standardization and internationalization, transparency and sharing, and social-scientific literacy education, should be considered.

20.9 Concluding Remarks

This chapter was devoted to nuclear engineering education for the post-Fukushima Daiichi accident era. Prior to education itself, the knowledge and attitudes required of nuclear engineers were discussed with focus on the social aspects of nuclear technology.

First of all, we should clearly recognize that nuclear technology has some intrinsic differences from general technologies, which come from its relation to weapon technology, potential risks of reactor accidents, long-lasting radioactivity of spent fuel, etc. Most of these features require government commitment. Thus, in most countries, nuclear technology has not achieved much social legitimacy, which makes the social context of nuclear technology complex. Consequently, we nuclear engineers are required to communicate with society more thoroughly and more openly than engineers in other technologies. One may feel that this additional requirement for nuclear technology is "unfair," but we should realize it is an essential characteristic of nuclear technology.

To achieve social legitimacy, mutual communication with society, which includes communication not only with the general public but also with experts in other fields, seems vital. In addition to social legitimacy, it is hoped that mutual communication will foster an introspective attitude in the professional community and will help nuclear technology and the professional community regain public trust. It must be clearly understood that these points are not only needed for smooth utilization of nuclear technology, but also, and more importantly, for enhancing the safety of nuclear technology utilization and advancing nuclear technology to provide more benefits and welfare for society.

Finally, I proposed 4 items for education reform, which are mainly designed to make mutual communication with society more effective while maintaining a high level of technical expertise: standardization and internationalization, transparency and sharing, social-scientific literacy education, and development and evaluation of faculty. These ideas are not necessarily concrete, and may be nothing new. Most universities may already have taken some actions to materialize these ideas. However, what they are doing now is mostly insufficient to fully realize its purpose. If they just think it is needed to do so formally or to make their departments look better to attract the next generation, its aim may have been achieved. However, if the purpose is to acquire social legitimacy, to cultivate an introspective attitude in our community, and to gain trust for nuclear technology and the nuclear professional community, the contents are far from satisfactory and thus should be redesigned and then reconstructed.

Most engineers have been deeply involved in responding to the Fukushima Daiichi accident for the last 3 years. Now should be the time to deeply consider what kind of professionals we want to be and what nuclear engineering education should do to achieve it. I hope that this chapter will stimulate discussion in the nuclear professional community and draw more attention to nuclear engineering education on the part of the general public and experts in other fields.

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