Proceedings of the Reactor Physics Asia 2015 (RPHA15) Congerence
Jeju, Korea, Sept. 16 - 18, 2015

Nuclear Engineering Education at the University of Fukui

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1. Introduction

Fukui Prefecture in Japan has a long and rich history in nuclear power. Fukui is home to the first LWR in Japan (Tsuruga-1) which started in operation in 1970, and at present there are 13 commercial reactors in the prefecture. Fukui is also home to the experimental reactors "Fugen" (pressure-tube type reactor, under decommissioning) and "Monju" (Liquid Metal Fast Breeder Reactor). In Fig. 1 an overview is given of the main nuclear facilities in Fukui Prefecture.
The University of Fukui is a Japanese national (public) university and the only academic institution in the prefecture. The university has three campuses and consists of four main pillars:

- Medical School
- School of Education and Regional Studies
- School of Engineering
- Research Institute of Nuclear Engineering (RINE)

Education in nuclear engineering was formally introduced in 2004, when the *Nuclear Power & Energy Safety program* started in the Graduate School of Engineering. In 2009 the *Research Institute of Nuclear Engineering* was opened, and in 2016 nuclear education will start at the undergraduate level in the School of Engineering.

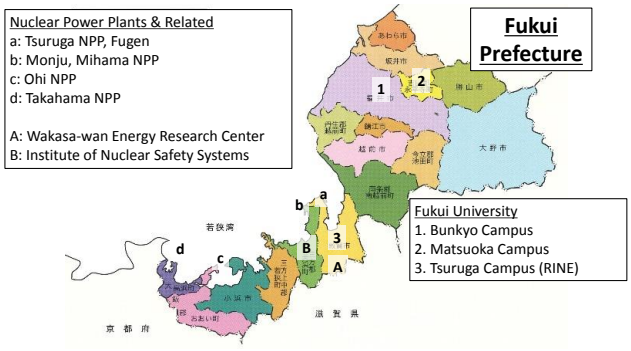

Figure 1. The campuses of the University of Fukui and the main nuclear facilities in Fukui Prefecture.

2. The Nuclear Power & Energy Safety program, and the Research Institute of Nuclear Engineering

The Nuclear Power & Energy Safety program educates students to a graduate degree. The program takes two years for an M.Sc. degree and another 3 years to add a Ph.D. degree. The program started in the Graduate School of Nuclear Engineering at the Bunkyo Campus (Fig. 2) in 2004. Education and research focuses on a wide range of topics which are related to nuclear power, such as computer science, radiation detection, biological effects of radiation, building engineering, etc.

Figure 2. The Bunkyo campus in Fukui City.

In 2009 the university inaugurated the Research Institute of Nuclear Engineering, which is housed at the Tsuruga Campus (Fig. 3). The focus of the research activities in the Research Institute of Nuclear Engineering was initially twofold: one, support of the prototype FBR Monju, the R&D for a future, commercial-size breeder reactor and the related nuclear fuel cycle. Two, research into aging of nuclear systems and decommissioning research in cooperation with Fugen. RINE has a close relationship with JAEA although we are separate entities. Following the accident at the Fukushima NPP the institute has diversified the research portfolio. Presently, the institute comprises the following departments:

Figure 3. The Research Institute of Nuclear Engineering at the Tsuruga campus.

- *Reactor Physics Department.* Fast reactor physics, transmutation, and advanced reactor design & analysis

- *Thermal-Hydraulics Department*. Liquid metal and water-cooled systems, CFD.
- *Nuclear Fuel & Materials Science*. Focus on advanced fuel forms, structural materials for thermal and fast reactors, aging of components.
- *Nuclear Reactor Construction Systems & Decommissioning Department*. Development and formalization of technology, knowledge and skills related to decommissioning.
- *Nuclear Accident Prevention & Risk Management Department*. Support for the local community in the areas of nuclear accidents, risks, radiation protection, and related topics.
- *International Cooperation & Advanced Human Resource Development Department*. International exchanges, improvement of curriculum, internships.

As of 2015, the institute comprises 7 full professors, 2 associate professors, 2 assistant professors, and about 15 professors-in-residence.

3. Recent research activities

An overview of recent research activities.

Reactor Physics Department

The research efforts in this department can can be classified into three broad topics. The first topic covers research efforts for the high fidelity simulation of (existing) PWRs. The second research topic is in fast reactors: development of core analysis methods and investigations into transmutation of Minor Actinides. Finally, in the area of advanced reactor concepts, the Molten Salt Reactor concept is investigated both a small-scale modular reactor and as an actinide transmutation reactor.
In the area of PWR research, the main focus of research is the improvement of core analysis methods. An examples is the issue of sensitivity coefficients in LWR pin cell calculations. In the multi-group approach, an error is introduced because a change in the density of nuclide I would change the self-shielding for all other nuclides. A correct treatment of this effect is of vital importance for LWR core analysis [1, 2]
In the area of fast reactor research, research efforts focus on core analysis methods. An example is the treatment of leakage in cell calculations for LMFBR analysis [3] and treatment of transients in large LMFBR cores [4]. Since the Fukushima accident, and the subsequent discussion about the future of nuclear power in Japan, a research program was started on transmutation in sodium-cooled reactors [5]. Typical for the work in the area of Molten Salt Reactors (MSR) is presented in references [6] and [7]. In the first reference, a passive air cooling system for criticality safe fuel dump tanks for a small MSR is discussed, and in the second reference an uncertainty analysis is presented for neutronic parameters of a transmutation MSR.

Thermal Hydraulics Department

The research efforts can be classified broadly in two areas. One area of research are liquid-metal cooled systems, the other research area concerns LWRs, specifically focusing on safety behavior under accidental conditions.
In the area of liquid metal cooling, the institute has successfully participated in several IAEA benchmark exercises on liquid-metal cooled reactors (Phńix, Monju, EBR-II). Recent references are [8, 9]. Also the phenomena related to anomalous heat exchange in a large liquid-metal cooled system are investigated [10].
On LWR safety, since the Fukushima disaster a strong focus on Station Black Out conditions has emerged. To prevent an accident like the accident at the Fukushima-1 nuclear power station, air cooling for LWRs is investigated [11], as well as the conditions in the Spent Fuel Pool under conditions of long term loss of power [12]

Nuclear Fuel & Materials Science

Folllowing the Fukushima accident, a renewed focus on severe accidents has emerged in Japan. In cooperation with the Japan Science and Technology Agency and the Ministry of Education, Culture, Sports, Science and Technology (MEXT), a multi-year research effort on the prediction and evaluation of core melt accidents in sodium-cooled reactors was initiated [13].
A good example of cooperation within our institute is found in the research on MSR, where investigations on the behavior of the fuel salt in a severe accident are ongoing [14]. In the area of materials science, research is conducted both in the areas of traditional nuclear materials [15], as well as advanced applications [16].

Nuclear Accident Prevention & Risk Management Department

While the name of this department evokes engineering, a main focus in recent research activities is concerned with risk communication, such as the work by Yamano [17, 18]. The softer side of nuclear engineering education is also illustrated by the development of teaching materials for primary and secondary schools. These materials are not written by our staff, but by primary school teachers, PTAs (Parent Teacher Association) and other interested parties, where our institute provides a study environment and acts as a consultant on the technical content of the teaching materials. Another activity is cooperation with the local authorities on issues related to nuclear accidents and risk management. For example, the institute provides education & training for the local emergency response units.

4. Academic education in nuclear engineeing

The University of Fukui is a member of JNEN, the Japanese Nuclear Education Network. This is a consortium of 14 Japanese universities with nuclear departments (see Fig. 4). Each university of JNEN has an online classroom system, which is used, amongst other, for nation-wide seminars. Typically, 5 or 6 seminars are organized throughout the academic year, and each seminar attracts about 120 students on average. It should be noted that these seminars are (of course) also open to students with a non-nuclear background.

Figure 4. The 14 universities involved with the JNEN network.

RINE puts a strong emphasis on internationalization. Every year we send students to academic and research institutions abroad for (part of) their thesis research, and every year we host several students who do (a part of) their thesis research in our institute. Besides these academic exchanges the institute also hosts several international trainees and researchers every year, mostly from Asian countries. Traineeships vary in length from a few weeks to 6 months and in some cases longer than 6 months.

In 2015 EUJEP2 program was launched (EU Japan Education Program 2). The Japanese partners are TokyoTech, JAEA, Kyoto University, and the University of Fukui. An important aspect of EUJEP2 is that one of the European partners is ENEN, the European Nuclear Education Network, an association of institutions in the area of nuclear education. EUJEP2 allows students from all ENEN members to come to Japan for a research internship, and it allows students from the Japanese EUJEP2 partners to do internships at any of the ENEN members. The EUJEP2 program provides sufficient funds for students to travel to Japan and perform an internship of up to 6 months, and vice-versa, students from the Japanese EUJEP2 members have funding to perform (part of) their thesis research in Europe.

5. Future: start of undergraduate nuclear engineering

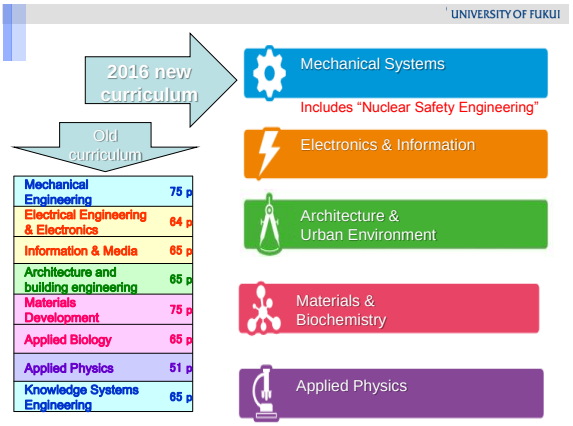

Figure 5. Curriculum reform in the undergraduate School of Engineering in 2016.

From April 2016, when the new academic year starts, the undergraduate part of the School of Engineering at the University of Fukui will be re-organized (see Fig. 5). The number of courses is reduced from 8 to 5, and within each course there are several specializations. One of the new specializations is *Nuclear Safety Engineering*. There are several reasons underpinning the start of this new curriculum: the aging of the workforce which is particularly vehement in the nuclear disciplines, the expected expansion of nuclear power as an export product to Asian countries, but also the decommissioning of nuclear power plants. Decommissioning activities are not only related to the Fukushima NPP. Following the recently updated nuclear regulations, operators have decided to decommission three reactors in Fukui Prefectures (Tsuruga-1, Mihama-1 and -2). Besides these three units, Fugen, the units Hamaoka-1 and -2, and of course the damaged reactors at the Fukushima NPP will be decommissioned in the coming decades. For several more reactors, a decision for decommissioning is likely in the near future. Thus in the coming decades, the decommissioning of nuclear power station and the required workforce will be an important topic in nuclear education.

6. Conclusions

The University of Fukui is committed to a well-supported curriculum in nuclear engineering, in both the undergraduate and graduate phases. The accident at the Fukushima NPP has put a shadow over the nuclear industry in Japan. However, whatever the future will bring, there is a great demand for a skilled nuclear workforce in Japan in the coming decades. Existing nuclear power plants need to be brought up to the new safety standards; license applications must be reviewed and analyzed; existing aging nuclear power plants need maintenance and upgrades; and, last but not least, the aging of the workforce implies that many young workers are

needed to replace the older generation. With our educational program in nuclear engineering, we hope to support the future of the peaceful use of nuclear power in Japan.

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