DEVELOPMENT OF EDUCATION AND TRAINING PROGRAMS USING ISIS RESEARCH REACTOR

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Abstract

As a part of the French Alternative Energies and Atomic Energy Commission (CEA), the National Institute for Nuclear Science and Technology (INSTN) carries out various education and training programs on nuclear reactor theory and operation. These programs take advantage of the use of an extensive range of training tools that includes software applications, simulators, as well as the use of research reactors. After a presentation of ISIS reactor, we present the training courses that have been developed on ISIS reactor and their use in education and training programs developed by INSTN. We report on how the training courses carried out on ISIS research reactor ensure a practical and comprehensive understanding of the reactor principle and operation, bringing tremendous benefit to the trainees. We also discuss the future development of education and training programs using the ISIS research reactor as a very powerful tool for the development of the human resources needed by the nuclear industry and the nuclear programs.

1. INTRODUCTION

As a part of the French Atomic Energy Commission (CEA), the National Institute for Nuclear Science and Technology (INSTN) is a higher education institution under the joint supervision of the Ministries in charge of Education and Industry. The institute was created in 1956 with the objective of providing students and professionals a high level of qualification in disciplines related to nuclear engineering. In this frame, INSTN carries out education and training (E&T) programs on nuclear reactor theory and operation. Its strategy is to complete theoretical courses by training courses and laboratory works carried out on an extensive range of training tools that includes software applications, simulators, as well as the use of research reactors.

Since 2007, according CEA’s policy, ISIS research reactor is mainly dedicated to E&T activities. For this purpose, the reactor went through a major refurbishment from 2004 till 2006. We present here the characteristics of ISIS reactor and the training courses that were developed on this reactor. We present the E&T programs carried out by INSTN. We discuss the benefit brought by the training courses that ensure a practical and comprehensive understanding of the reactor principle and operation. We also discuss the future development of E&T programs that use the research reactor as a very powerful tool for the development of the human resources needed by the nuclear industry and the nuclear programs.

2. ISIS REACTOR CHARACTERISTICS

ISIS research reactor is located on the CEA Saclay site. It belongs to the same nuclear facility as OSIRIS reactor. Both reactors are open core pool type reactors and exhibit the same core characteristics (size and configuration of the core, fuel and rod characteristics). However, from the thermo-hydraulic point of view, ISIS reactor has a nominal power of 700 kW, while OSIRIS can be operated up to 70 MW. The schematic of ISIS reactor pool is shown in Figure 1-a. The pool of ISIS reactor is 7 meters deep. At the bottom of the pool, a big metallic piece, called the base, sustains the core of the reactor (n°12 in Fig. 1-a). An array of holes in the base can be used to insert experimental devices in different location around the core (n°11). The core has a horizontal section of 62 cm x 70 cm and a height of 65 cm. It is composed of an aluminum box with 56 cases which is enclosed in a zirconium alloy container (n°10). The core contains 38 fuel assemblies (n°18), 6 control rods (n°17), 7 beryllium assemblies (n°19), as well as 5 experimental cases (see Figure 1-b). The MTR (Material Testing Reactor) type fuel, in silicide U_3Si_2Al form, is enriched at 19.75 %.

The control rods are moved through mechanisms that are placed above the pool (n°2). They have a particular design since they include a lower part that contains fuel plates in addition to the upper part that contains hafnium used to capture neutrons. Thus, when moving up a rod out of the core, the removal of the rod results both in the removal of absorbing material and the introduction of extra fuel in the core. The beryllium assemblies, placed on one side of the core, are used both as a neutron reflector, to reduce the neutron leakage, and as the starting neutron source, through (γ,n) reactions with beryllium. In addition, this beryllium wall, coupled with the fuel load, is used to obtain a non uniform neutron energy spectrum in the core, i.e. a larger contribution of slow neutrons in the vicinity of beryllium. The experimental cases can be used to place devices to be irradiated or tested (instrumentation, samples to be activated, test fuel, etc). In their basic state, the case is filled with a plain aluminum box which exhibits the same dimension as a fuel assembly and contains four plain aluminum cylinders (28 mm in diameter).The cylinders can be removed separately to introduce small samples or devices in the core.

The reactor is equipped with 4 neutron detection systems that are placed in metallic tubes found above the top of the core on the beryllium assembly's side (n° 20). The low level detection system (BN1 & BN2), equipped with fission ionization chambers working in pulse mode, can be operated from source level up to a power of 40 W. The high level detection systems (HN1 & HN2), equipped with boron ionization chambers working in current mode, can be operated from about 1 W up to the nominal power. Extra detectors can be installed in an additional tube found between HN1 and HN2 or in tubes that can be inserted in or around the core.

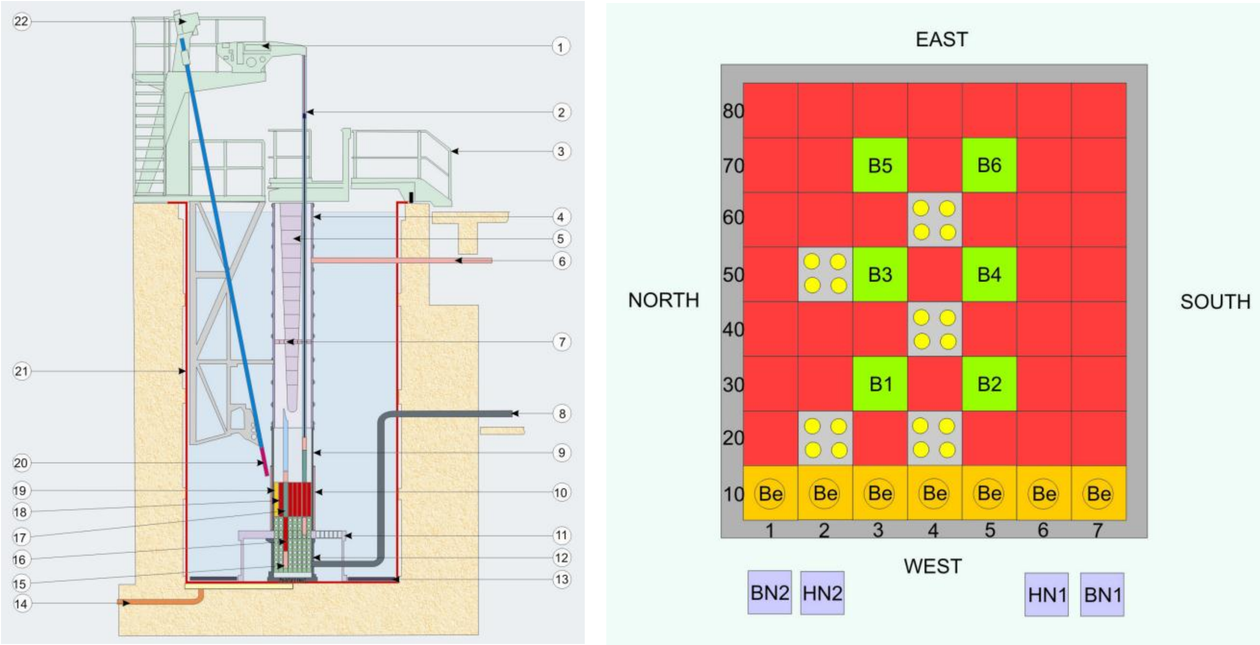

FIG. 1. Schematic of the ISIS reactor pool (a – left hand side) and core (b – right hand side).

Above the core a stainless steel chimney separates the water from the primary water loop from the rest of the pool (n°4). A gate (n°5), which is placed on one side of the chimney, can be removed to load or unload fuel assemblies or experimental devices between the pool and the core. The water of the primary circuit flows from the bottom to the top of the chimney, passing between the plates of the fuel assemblies, at a rate of 50 m^3/h. It is cooled by two heat exchangers from the secondary loop. At the nominal power, the primary water inlet and outlet are typically at 35 and 45 °C, respectively. At low power, i.e. below 50 kW, the reactor can be operated in natural convection. Figure 2-a shows a photo of the top of pool, during the presentation of the reactor to the students. The vertical metallic tubes seen in the middle of the picture are the mechanisms of the control rod.

3. ISIS REACTOR CONVERSION TO E&T ACTIVITIES

From 1967 (first start up) until 2004, ISIS reactor was mainly used for the qualification of core configurations or experimental set-ups to be installed on OSIRIS reactor, as well as for the supply of neutron or gamma fluxes for experiments carried out on ISIS. In 2003, the decision was taken to concentrate the CEA’s E&T activities on ISIS reactor in Saclay. This was following the shutdown of SILOETTE reactor at CEA in Grenoble (in 2002) and the decision to shutdown ULYSSE reactor operated by INSTN at CEA in Saclay (in 2007). For this purpose a working group was created with the objective of converting ISIS reactor to E&T activities. This project was carried out on the basis of:

— The pedagogic background gained on ULYSSE reactor, which was ran by the INSTN, from 1961 mainly for E&T activities;
— The results of experiments carried out on ISIS reactor, before the refurbishment, in order to evaluate its potential for E&T activities;
— Safety analysis of new types of experiments that could be conducted and were not covered by the license of ISIS reactor;
— An ergonomic study of the control system and control room for their use by the regular operators and by the trainees.

All these aspects were used to define modifications of the control system and control room that were specific to E&T activities and came in addition to more standard changes done in the frame of the control system refurbishment. The modifications concerned, in particular, the logic of the safety system, the control system hardware, the ergonomics of the control board and control room, as well as of the development of a supervision software.

FIG. 2. Photos of: a – Reactor hall during ISIS presentation to the trainees, b- Control room.

For example, the logic of the safety system was modified to enable the individual drop of each rod during standard reactor operation. A specific operation mode was created for E&T activities, with a power limit fixed to 50 kW and allowing reactor operation in natural convection. A major improvement also concerned the extraction of the measured signals during reactor operation for their use by a supervision system that displays different screens showing the evolution of chosen reactor parameters for each type of experiment done on the reactor (see example of a supervision view in Figure 2-b & 3-a). The control room layout was organized in order to welcome up to 10 trainees, in addition to the operating staff of the reactor and to the instructors (see Figure 2-b). The control room is located on one side of the reactor hall. It is separated from the hall by a glass partition that allows a direct observation of the operations taking place in the reactor hall. A CCD camera placed in the chimney of the pool is used to get a close view on the core during fuel or device loading as well as during reactor operation (observation of water convection or Cherenkov effect). A large screen is used to follow the evolution of the reactor parameters, choosing the desired set of parameters to be shown for each experiment. Finally, with a power limited to 50 kW for E&T activities, there is no particular restriction to be applied to the trainees from the point of view of radiation protection in the control room, nor in the reactor hall.

From 2004 till 2006, the reactor went through a major refurbishment of the control system and the control room in order to use ISIS reactor for E&T activities. After refurbishment and testing, the reconfigured ISIS reactor was licensed by the regulatory body at the end of 2006. Thus, from March 2007, ISIS reactor became the main reactor used by CEA for E&T activities.

4. EXPERIMENTS CARRIED OUT ON ISIS REACTOR

Taking advantage of the refurbishment of ISIS reactor that was specifically carried out to convert the reactor to E&T activities, a large panel of experiments have been developed for the E&T programs organized by the INSTN. The experiments include:

— The survey of the core reactivity during fuel loading;
— The approach to criticality;
— The reactor start up;

- The study of the influence of devices placed on the core reactivity;
- The demonstration of the role of precursors in power stabilization;
- The control rod calibration;
- The evaluation of total worth of the rods by the rod drop technique;
- The study of the temperature effects;
- The study and setting of the neutron detection systems used for reactor control;
- Radiation protection applied to reactor facilities;
- Neutron cartography.

For each experiment, the evolution of a specific set of parameters can be shown on a screen in front of the trainees using the supervision system. For example, Figure 3-a shows the screen exhibited when carrying out the approach to criticality by moving up the rod number 6 (BC6).

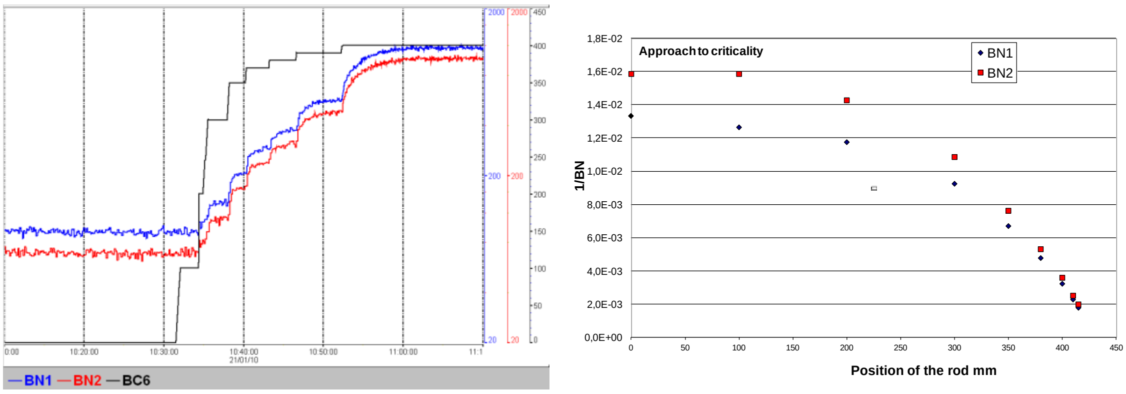

FIG. 3. Approach to criticality: a-(left) Recording of the counting rates BN1 and BN2 BC6 position as a function of time ; b-(rigth); Curve 1/BN as a function of BC6 position.

The counting rates of the two level detection systems BN1 and BN2 together with the position of the rod are recorded as a function of time. The data recorded by the supervision system can easily be extracted and used in a software application to make calculations and to draw curves. Figure 3-b is the curve of 1/BN1 and 1/BN2 as a function of the position of the rod BC6 during the approach to criticality. This curve is shown on the screen in front of the trainees when moving up the rod step by step so that the trainees can check at each step that the rod can be moved further up without over passing the criticality.

In prelude to the course, a presentation of the reactor is made. It includes the description of the reactor on a PowerPoint presentation and a visit in the reactor hall to show the structure of the pool and the core. It can be completed by a visit of the 70 MW OSIRS reactor hall and control room, as well as the hot cells which are used for the manipulation of irradiated materials. Nine different courses, with 3 hours duration, have been developed on ISIS reactor. They are integrated to the E&T programs developed at INSTN. Depending on the public and on the pedagogic goals, the trainees can follow programs that exhibit from 3 up to 24 hours of training courses on ISIS reactors.

Every year, about 400 trainees participate to the training courses on ISIS reactor. E&T activity on ISIS research reactor represents about 360 hours distributed over 70 working days. One third of this activity concerns international courses that are taught in English. With an increase in the need for E&T, especially at an international level, the E&T activity on ISIS reactor could easily be increased up to 600 hours distributed over 120 working days.

5. E&T PROGRAMS USING ISIS REACTOR

Since 1956, INSTN has always promoted the use of laboratory work and training courses carried out on nuclear facilities in order to complete theoretical courses. It was established that from a pedagogical point of view training courses on nuclear facilities and on nuclear reactors in particular was needed to ensure a practical and comprehensive understanding of the reactor principle and operation. Moreover, empathies being given to the impact of each operation and effect on the safety and security of the reactor design and operation, the training courses enhance the background of the trainees in nuclear safety. Thus, whenever it is needed training courses on ISIS reactor are integrated in E&T programs from INSTN.

INSTN is involved both in academic degree programs and continuing education courses for professionals. Concerning the academic degree, training courses on ISIS reactors are addressed to students and employees from different institutions at a national and international level. This includes courses carried out in the frame of:

- An international master in Nuclear Energy which is organized at INSTN in collaboration with other universities and engineer schools;
- A one year specialisation course in Nuclear Engineering which was developed by the INSTN in 1956 and contributed to the qualification of up to 140 engineers every year since this date;
- Nuclear engineering modules of various master and engineer degrees in which the INSTN is involved;
- A collaboration agreement between Sweden and France that ensure the financial support for the organization of up to 12 training sessions (2,5 days) on ISIS reactor for students from Swedish universities (Chalmers University of Technology, KTH Royal Institute of Technology, Uppsala University).

Concerning the continuing education for professionals, training courses on ISIS reactors are addressed to a very wide public including researchers, engineers and technicians. This includes training courses carried out in the frame of:

- A 8 weeks course which is compulsory in the qualification process of the operators of the French research reactors;
- Different courses (taught in English or French) organised on a regular basis (at least once a year) and related to the principle, the operation, the safety and the neutronics of nuclear reactors;
- Different courses organised by INSTN to respond to the specific need of the nuclear industry and nuclear programs, which includes courses for the personal of the French regulator body, for young engineers from the Italian company ENEL, for project managers of the Vietnamese company EVN (Electricity of Vietnam), or for teachers and professors from several Polish Universities (training of the trainees).

Depending on the pedagogic and qualification goals, the trainees follow different training programs (3 to 24 hours) on ISIS reactor that can be completed at INSTN by training courses carried out using other tools such as software applications (APOLLO, FLICA, TRIPOLI, MCNP, …) and reactor simulators (normal and accidental PWR operation). Two examples of E&T program using ISIS reactor are detailed bellow.

The first example is the 2,5 days training course on ISIS reactor organised for the Swedish universities. For this program, all the theoretical courses on the reactor principle and neutron kinetics are ensured by the universities prior the venue of the students on ISIS reactor. The content of the training course on ISIS reactor is as follow:

- 1st ½ day : presentation of ISIS and OSIRIS reactor, presentation of the content of the course, visit of the facility (the 2 reactors and the hot cells);
- 2nd ½ day : survey of the core reactivity during fuel loading (mix of fresh and burned fuel), observation of the loading process, approach to criticality for the determination of the critical configuration of the rods;
- 3rd ½ day : reactor start up and stabilisation at low power (no temperature effect), study of the change in core reactivity when removing aluminum devices from the core (change in the moderation factor), drawing of rod calibration curve (measurement of the doubling time);
- 4th ½ day : evaluation of the global worth of a rod (rod drop technique), study of the shadow effect, study of the temperature effect (Doppler and dilatation, self stabilization), determination on the temperature coefficient;
- 5th ½ day : study of the role of precursors in power stabilization (during a fast transient in reactivity), operation of the neutron detection systems of the reactor (signal, operating range, use for the reactor control and for the safety system including reactor SCRAM).

This intensive training course gives a very good overview of the reactor operation and its practical and theoretical aspects: neutron and precursor kinetics, sub- and over-moderated regime, neutron distribution in the core, temperature feedback effect, etc. In each experiment, emphasis is given to the safety aspects, by conducting a practical safety analysis of the operations that are carried out on the reactor , taking into account normal and incidental conditions.

The second example is the 8 week course which is compulsory in the qualification process of the operators of the French research reactors. This training program and the overall qualification process are in good accordance with the Safety guide NS-G-4.5 from IAEA, which describes the good practice in the recruitment, the training and the qualification of the personal of research reactors. Thus, along a whole qualification process that has duration of about one year, the trainees spend 8 weeks at INSTN to follow theoretical and practical courses on nuclear physics, reactor physics, neutronics, thermohydraulics, radiation protection, safety and reactor operation. Examination is conducted both on the theoretical and practical aspects of the program. For this 8 week course, in addition to 2½ day program described above, the course also contains:

- The study of the neutron detection system, including their setting (bias voltage, discrimination level, calibration factor) and the follow up of the detector characteristics (impact of detector ageing on the signal and settings);
- Radiation protection applied to reactor operation including neutron, beta and gamma dose rate measurements on the facility, as well as the measurement of the neutron flux by the analysis of activated samples;
- A sequence during which the trainee operates ISIS reactor under the supervision of the normal operating staff.

For the later one, the trainee has to learn some basic knowledge (including operating procedures) on ISIS reactor operation. He follows the reactor operation by an regular operator or another trainee, makes all the calculations necessary to operate the reactor (position of a rod to obtain a doubling time of 30 s, for example) and finally operate the reactor. The operating sequence includes for example: the reactor start up, the switch from the low level of power neutron detection systems to the high level ones, the reactor power stabilisation at 500 W, the search for another critical configuration of the rods by inserting one rod and compensating it by the extraction of another one. During this sequence, the instructor from INSTN checks the trainees knowledge and skills to operate the reactor, including its response to stress. This first experience in the operation of a reactor is an important step in the qualification process of the trainee who is going to go through on the job training on its own facility for a few months before being licensed.

6. FURTHER DEVELOPMENT OF THE E&T PROGRAMS

Further development of the INSTN E&T programs using ISIS research reactor will be carried out through three major routes detailed below.

International courses will be developed on the basis of the IAEA standards as well as on the basis of courses that are regularly taught in French. As an example INSTN could propose by 2013 a course for the operators of the research reactors, taught in English, similar to the 8 week course described in § 5 and in accordance with the Safety guide NS-G-4.5 from IAEA. Such a course will include 24 hours of training course on ISIS reactor.

To respond to the needs of the nuclear industry or the nuclear programs, specific international courses can be developed by INSTN. This type of course can be organised for industry, for academy or for the regulatory body with different pedagogical objectives depending on the level of the nuclear specialization of the human resources. INSTN has recently developed specific courses in the different level of specialization and with durations ranging from 1 to 12 weeks. From the point of view of the teaching language, different organisation can be organized. Courses can be taught in English and can include simultaneous translation in specific languages (Vietnamese, Chinese, etc). Such courses can be developed on request, the objectives, the language organisation and the volume of training course on ISIS reactor being defined by the requesting organization.

In addition, complementary pedagogic techniques such as the mix of distance and face to face learning techniques can be used. Indeed, some of the theoretical content of the course as well as, to some extent, lab works on software applications, can be carried out through e-learning techniques. Face to face courses can then be limited to the courses that need a close interaction between the lecturer and the trainees, as well as to lab work carried out on nuclear facilities. The mix of the different techniques exhibits some advantages. For example, distance learning, with proper pedagogic tools, allows the trainees to acquire and to check basic knowledge in their country. This limits the time the trainees have to spend in face to face phases, where they can focus on the most practical aspects of the courses, including the training courses on nuclear facilities. Thus the use of the distance learning techniques will be promoted in the next year by INSTN.

7. CONCLUSION

The training courses carried out on ISIS reactor are addressed to a wide range of public, including engineers, researchers, operators of nuclear reactors and employees from the French regulatory body. The feedback obtained from the trainee's shows that the training courses carried on a research reactor ensure a comprehensive understanding of the reactor principle and operation that cannot be gained only with theoretical courses associated with the use of simulators. In addition, empathies being given to the impact of each operation and effect on the safety and security of the reactor operation, both in normal and incidental operation, the courses contribute to a significant improvement in the safety culture of the personal involved in reactor operation. With this feedback, INSTN is continuously promoting the use of the training courses on ISIS reactor in its E&T programs as they appear to be a very powerful tool for the development of the human resources needed by the nuclear industry and the nuclear programs.