Teaching Sodium Fast Reactors in CEA

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Abstract

Among the Fast Neutron Reactor Systems, the SFR has the most comprehensive technological basis as result of the experience gained from worldwide operation of several experimental, prototype, and commercial size reactors since the 1940s. This experience corresponds to about 402 years of operation by end of 2010. Six reactors are in operation: BOR60, BN600 and BN800 in Russia, Joyo in Japan, FBTR in India and CEFR in China. One reactor is being commissioned: PFBR (500MWe) in India and several projects are currently developed: FBR1 and 2 in India, BN1200 in Russia, JSFR in Japan, PGSFR in Korea, CFR-600 in China and ASTRID in France. In order to support operation of existing reactors, design activities for new projects and decommissioning of old reactors, it is mandatory to develop skills, more particularly among the young generation, who will operate these new reactors. In addition, education and training is also essential to share the knowledge among the teams involved in Research and Development. Several strategies are developed at the national level, or within multilateral framework, like EU or IAEA to support development of Fast Reactors.

In France, to answer to this increasing demand of Education & Training, four sessions are proposed, within the frame of INSTN (French National Institute for Nuclear Science and Technology):

- SFR: History, main options, design and operational feedback
- SFR: Functional analysis and design
- SFR: Safety and operation
- SFR: Sodium structures interactions

The French Na School (ESML) provides since 1975 also several sessions dedicated to Na facilities design, safe operation, handling, and also decommissioning and sodium treatment. Beside courses, practical exercises are organized during each session. 10 different modules are available, ranging in length from 1 to 5 days.

CEA contributes also to the organization of European Sessions dedicated to Sodium Fast Reactors, organized within the frame of the European Commission (CP-ESFR, ESNII+ , ESFR-SMART)

This Education and Training strategy is a key element for the future of the development of Sodium Fast Reactors, and more particularly ASTRID project. CEA is ready to share training experience and to collaborate with other foreign Education and Training Entities.

I. INTRODUCTION

Among the Fast Neutron Reactor Systems, the Sodium Fast Reactor (SFR) has the most comprehensive technological basis as result of the experience gained from worldwide operation of several experimental, prototype, and commercial size reactors since the 1950s. This experience corresponds to around 420 years of operation by end of 2017. Six reactors are in operation: BOR60, BN600 and BN800 in Russia, Joyo in Japan, FBTR in India and CEFR in China. One reactor is being commissioned: PFBR (500MWe) in India and several projects are currently developed: FBR1 and 2 in India, BN1200 in Russia, JSFR in Japan, PGSFR in Korea, CFR-600 in China and ASTRID in France,, in partnership with Japan. In order to support operation of existing reactors, design activities for new projects and decommissioning of old reactors, it is mandatory to develop skills, more particularly among the young generation, who will operate these new reactors. In addition, education and training is also essential to share the knowledge among the teams involved in Research and Development. Several strategies are developed at the national level, or within multilateral framework, like EU or IAEA to support development of Fast Reactors [1]

In France, the new objective is to build a GENERATION IV reactor prototype so-called ASTRID. This decision has motivated an important and rapid increase of R&D work, orientated towards the design and conceptual evaluations. Two reactors are currently being dismantled, Phenix and Superphénix. It was therefore necessary to support these activities and promote Education and Training Initiatives. To support this requirement, ESML (Ecole du Sodium et des Métaux Liquides), EC (Ecole des Combustibles), both located in CEA-Cadarache and INSTN (Institut des Sciences et Techniques Nucléaires) are the key schools to support the development of Sodium Fast Reactors.

II. Education and Training at ESML

The objectives of the Sodium School (ESML) are to synthesize knowledge, to share it between CEA experimental facilities operators and consequently to support R&D activities, to train operators able to work on Sodium Fast Reactors, to train design engineers involved in SFR projects and to train fire brigades. Its role has always been to adapt its offer and its training content to the changing needs for reactor operation, experimentation and for design activities. Trainees usually belonged to French companies such as CEA, EDF, AREVA and IRSN, or any companies involved in sodium activities belonging or not to the nuclear industry. At the early stage of its creation, ESML intended to be opened to foreign countries. Specific training sessions were provided for German operators for SNR300 (1983), Japanese operators for the first start-up of Monju reactor (90's) or in support to the PFR and DFR decommissioning projects (UK). More recently, ESML in association with PHENIX plant operator has extensively increased its opening to foreign institutes, such as trainees from CIAE in China, ROSATOM in Russia on Reactor technologies, safety and operation, or IGCAR in India dedicated to Safety. ESML provided also specific sessions to Chemical industry, such as UOP (USA).

The pedagogical approach consists in a combination of various educational means: lectures, discussions and Training on a Sodium loop. Since 1975, more than 6000 trainees have received a training at the Sodium School. The following items are currently addressed: physico-chemistry of sodium coolant (physical and chemical properties), purification, corrosion, contamination, cleaning and decontamination…
Sodium technology, description and operation of components, instrumentation, visualization, inspection and repair, are also presented in dedicated sessions; during these sessions, exercises involving operation and intervention procedures on the sodium loop are organized. Sodium safety is always a key part of the sessions. Specific hazards induced by the chemical properties of sodium are described:

sodium-water reaction and hydrogen risk assessment, sodium fires, safety rules, prevention, intervention, exercise on a real sodium fire… In support to the processes used for decommissioning SFRs, ESML lecturers present and address the following items: some specific risks, dismantling techniques, sodium treatment, sodium waste storage, decommissioning of Na-K facilities….

Currently, nine theoretical and practical modules are proposed (the duration of each module depends on the topic):

- Na risk management and safety (1 day)
- Na hazard basics validation (0,5 day)
- Na circuit operation & maintenance (5 days)
- Na facilities decommissioning (5 days)
- Practice of component cleaning and decontamination (3 days)
- Management of Na-K (sodium-potassium) and associated hazards (3 days)
- Intervention on Na facilities (2 days)
- Practice of Na circuit operation (3 days)
- Practice of sodium purification (3 days)

Every year, ESML organizes about 15 sessions, which represent about one hundred trainees.

Devices and facilities are available to conduct practical exercises or experiments:

- Na facility designed for training participants in sodium circuit operation (SUPERFENEC loop). (Fig.1)
- Cleaning pits for the treatment of components containing sodium (MININANET, PEELA facilities).(Fig.2)
- Observation of a sodium fire, hydrolysis of sodium by spraying water in shielded cell (VAUTOUR facility). (Fig.3)
- Cutting operations of sodium components, …

Figure 1: Superfennec Na loop.

Figure 2: MININANET facility

Figure 3: Na fire extinguishing exercise

<u>New pedagogical tools for the Na School:</u>

New pedagogical tools for the Na School are currently set-u To improve our pedagogical means, four new educational tools are presently developed and are dedicated to the following main phenomena involved in Na technology:

- US transmission
- Magneto-hydrodynamics
- Na-Water reaction
- Na fire

Four benches will allow the Sodium School to up-date the pedagogy and contribute to improve the offer of training sessions and the skills acquired by the trainees. These educational tools will be dedicated to training but also used for communication purpose to improve the public acceptance.

Bench N°1: Ultrasound imaging technology
In-service inspection and repair (ISI&R) is considered as a challenge for Generation IV sodium-cooled fast reactors, due to sodium coolant opacity, chemical reactivity. ISIR mainly focus on the inspection of reactor block structures, immersed in sodium at about 200°C: telemetry, under-sodium viewing, crack detection….In order to illustrate the potentialities of Ultra-Sounds (US) technologies, telemetric measurements, creation of images from simple shapes, use of Transducers Ultra-Sound able to be operated at High Temperature (TUSHT®), some dedicated laboratory devices will be implemented, at ESML

Bench N°2: Magneto-hydrodynamics (MHD)

Due to their high electrical conductivity, liquid metals, and in particular sodium and its alloys like Nak, allow the use of magneto-hydrodynamic devices as actuators and sensors. Electro-Magnetic Pumps (EMP), Eddy Currents Flow Meter (ECFM) are one of the most widely used devices in liquid sodium circuit. In both cases, working principle is based on the interaction of an electrical current density, a magnetic flux density and the velocity field of the liquid metal. Understanding, implementing and using of such devices in liquid metal facility needs specific knowledge on applied electrotechnics and magneto-hydrodynamics (MHD). Dedicated benches will be proposed to support dispensed courses based on more theoretical notions.

Bench N°3: Na-water interaction

Hazard induced by the potential large interaction of Na and water in a Steam Generation Unit or a cleaning pit is often underlined: there is one discontinuous source of hydrogen and sodium hydroxide, inducing related hazards.
Nevertheless, this reactivity with water is commonly used for the development of cleaning processes for structural material wetted with sodium, during handling operations and moreover for the conversion of the large amounts of sodium into sodium hydroxide, at the end of the reactor operation, during the decommissioning phase. A process, called NOAH, has been developed in CEA Cadarache and applied successfully to convert the primary sodium from Rapsodie, PFR, KNK-2 and Superphenix. It will be used also to process the sodium from Phenix. Thus, it has been decided to design and set-up two Sodium Water Reaction benches: a device for educative practical works (Figure 5) and another one for a demonstration of sodium treatment by hydrolysis with water.

This first educational facility (geometries and volumes of the glass equipment) will be optimized with regards safety standards and designed for a pressure resistance of about 1.5 bar. abs.

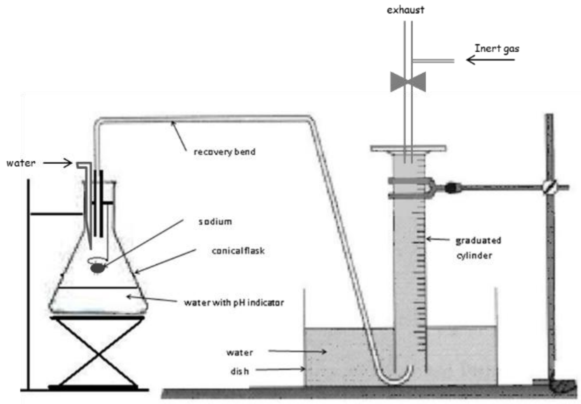

Figure 4 Bench dedicated to the characterization of Na-water interaction

Bench N°4: Sodium fire

A dedicated bench will be devoted to the design of a spray fire device to carry out small-scale sodium fire experiments (Figure 5). It will be limited to a few grams of Na of sodium (10 g max).. Thermocouples are located inside the combustion chamber for measuring the spray temperature. High-speed camera and thermal imaging can be used to visualize the sodium fire combustion, in particular the distribution of the particles sizes in the jet during combustion, the temperature distribution, effects of sodium temperature and oxygen concentration.

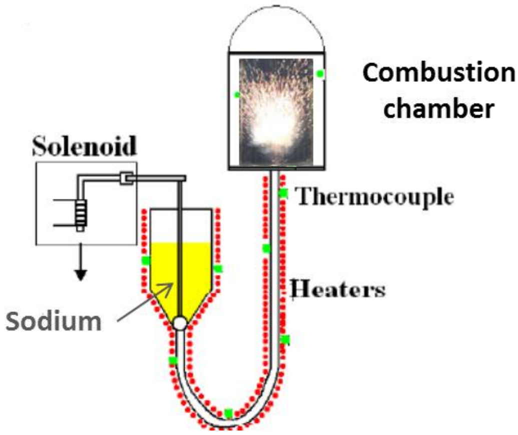

Figure 5: Basic principle of spray fire demonstrative facility

III. Education and Training at INSTN

Within the frame of INSTN (Institut National des Sciences et Techniques Nucléaires) (www-instn.cea.fr), several sessions are currently provided:

- SFR history, main options, design and operational feedback
- SFR functional analysis and design
- SFR safety and operation, and
- SFR: interaction between Na and structures
- SFR: Core physics
- SFR: ERANOS code

In addition, the INSTN (*Institut National des Sciences et Technologies Nucléaires*), develops its own Nuclear Engineering Master level (or specialization) degree and a catalogue of more than 200 vocational training courses.

INSTN is partner of ENEN (European Nuclear Energy Network). (www.enen-assoc.org)

To address more particularly SFR training needs related to the operation of SFR, it was intended to
develop a SFR simulator, including the Energy Conversion System. The SIRENa simulator, developed by Reactor Studies Department, in Cadarache Research Center (France) (Figure 6) is used in engineering courses as an adjunct to lectures on safety and operation and can be used for human factor studies and human machine interface design. Training on such a simulator permits to perceive the effects of constraints governing the operation of a reactor (inertia, cons-reactions, regulations ...) or to apply theoretical knowledge (eg sub-critical approach). Within this project, the main functional specifications of the simulator and the needs of development of dynamic models, have been defined.This simulator represents a "Pool type" SFR, the most common concept selected for large SFRs. The design consists of a safety vessel, which contains the primary vessel, reactor core, intermediate heat exchanger (IHX), secondary heat exchange, control rods, balance of plant and intermediate circuit pipework. Core cooling in SFR may be achieved by forced or natural circulation. The user can modify plant parameters, to adjust various aspects of the plant configuration and to accommodate differences between specific designs. An example of one such variation could be in the number of intermediate heat exchangers that are contained within the pressure vessel, the inclusion of coolant pumps onto the pressure vessel, In pool-type SFRs, the sodium in the primary circuit does not directly exchange its heat with the coolant of the Energy Conversion System (ECS): water if the Rankine cycle is selected, gas if the Brayton cycle is selected. The main components with their associated models are included in the simulator: pumps, heat exchangers, Plant control and protection systems, Purification Systems and their cold traps, Decay Heat Removal Systems….

The simulator is capable of simulating the following standard operational events:

- Power Increase and Decrease, in this mode user can change power with ramp in range among 0% to 100% by control rod
- Reactor Scram and Restart
- Reactor Start-up and Heat up
- Reactor Shutdown and Cooling

Moreover, the user can change the speed of pumps; accordingly, simulator shows it effect on Primary heat transport, intermediate heat transport system and steam/ gas system.
Simulator allows also the user to change the material of fuel, cladding and shows it affects

(through thermal properties and reactivity coefficients).
Simulator is able of generating malfunction like pump shutdowns, valve failures, and regulation system failures…

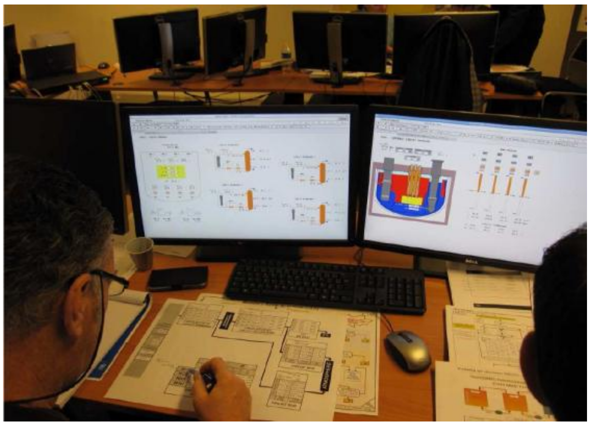

Figure 6: SIRENa simulator for SFRs

IV. Education and Training at I2EN

France has an important nuclear teaching platform organized around engineering schools, universities, involving also research laboratories, technical schools and also nuclear companies or dedicated entities, for professional training. In this context, I2EN, the *International Institute for Nuclear Energy* set up in 2010, is federating French entities delivering high level curricula in nuclear engineering and science related to the main following items:

- Nuclear safety and radiation protection
- Reactor physics & nuclear engineering
- Waste management, disposal, nuclear decommissioning & safety
- Materials science for nuclear energy
- Chemistry for nuclear energy & environment
- Instrumentation for nuclear industry …

Even if i2en provides mostly initiatives taylored to the needs of industry (mostly PWRs in France), several masters address Fast Neutron Reactors (essentially SFRs) and more particularly the main fields underlined previously. The list of initiatives is provided in the I2EN web-site: http://www.i2en.fr

V. CONCLUSION

To support the development of SFRs, an efficient Education and Training strategy is essential for the future of the development of Sodium Fast Reactors. Sodium School (ESML) and INSTN are key actors in France to develop new skills in support to SFR studies. A general consensus is to apply modern approaches to course design ie the application of the intended learning outcome (ILO) approach and the implementation of interactive methodologies.

CEA is ready to share training experience and to collaborate with other foreign Education and Training Entities.

Nomenclature

DHRS	Decay Heat Removal System
GIF	Generation IV International Forum
IHX	Intermediate Heat Exchanger
INSTN	National Institute for Nuclear Science and Technology
MHD	Magneto-hydrodynamics
SFR	Sodium Fast Reactor
SGU	Steam Generator Unit

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