The French Sodium School : Teaching Sodium Technology for the present and future generations of SFR users

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Abstract. This paper provides a description of the French Sodium and liquid Metal School (ESML) created in 1975 and located in France (at the CEA Cadarache Research Centre) and of the Fast Reactor Operation and Safety School (FROSS) created in 2005 at the Phenix plant. It presents their recent developments and the current collaborations throughout the world with some other nuclear organizations and industrial companies. The very recent courses implemented within the frame of INSTN, (French Nuclear Teaching Institute), in collaboration with the Sodium and liquid Metal School (ESML) to answer to the future needs of Generation IV SFR concept and design are also presented.

The sum of courses provided by CEA through its Sodium school and FROSS organizations is an unique valuable amount of knowledge on Sodium Fast reactor design, technology, safety and operation experience, decommissioning aspects and practical exercises. It is provided for the national demand and, since the last ten years, extensively opened to foreign countries. Over more than 30 years, this organisation has demonstrated its flexibility in adapting its courses to the changing demand in the Sodium Fast reactor field, and in association with the PHENIX and SUPERPHENIX plants, can adapt its teaching techniques using specific theoretical and practical courses and lectures. This paper is an up-to-date of the paper presented in 2007 in CONTE conference [1].

1. INTRODUCTION

Since the beginning of nuclear development, France has significantly contributed to the development of Sodium Fast Reactors and of Liquid Metal technology. Research programs have always accompanied the design, the manufacturing and the operation phases of several Sodium Fast Reactors (RAPSODIE, PHENIX and SUPERPHENIX reactors), or projects in France: EFR (European Fast Reactor) and recently ASTRID prototype [2], [3].

Due to the specificity of sodium technology, CEA (the French Atomic Energy Commission) is in charge of developing specific courses in order to teach and transmit the associated knowledge and practise. This paper aims at providing a description of the French Sodium School located in France since 1975 (at the CEA Cadarache Research Centre) and of the Fast Reactor Operation and Safety School (FROSS) created in 2005 at the PHENIX plant (CEA and EDF : the French electrical utilities). It presents their recent developments and the current collaborations throughout the world with some other nuclear organizations and industrial companies. This paper is an up-to-date of the paper presented in 2007 in CONTE conf. [1].

2. BRIEF HISTORY OF SODIUM FAST REACTOR DEVELOPMENT IN FRANCE

The very first tests conducted by the CEA using liquid metals date back to 1953. More than half a century later, the CEA has significantly progressed in the field of sodium-cooled fast reactor (SFR) technology. Such progress is reflected in the design, construction and operation of three fast breeder reactors: the experimental reactor : RAPSODIE; the demonstration reactor : PHENIX; the commercial-size prototype reactor : SUPERPHENIX; and the European project integrating feedback from operating fast breeder reactor plants in Europe – EFR, European Fast Reactor. Since 2007, an important program has been launched by the three partners CEA, AREVA and EDF in order to develop an innovative SFR concept. The purpose is to reach the construction of a prototype whose name is ASTRID (for Advanced Sodium Technological Reactor for industrial Demonstration) by 2020 [4]. The whole SFR French program and development can be synthesized in one picture (see Fig.1).

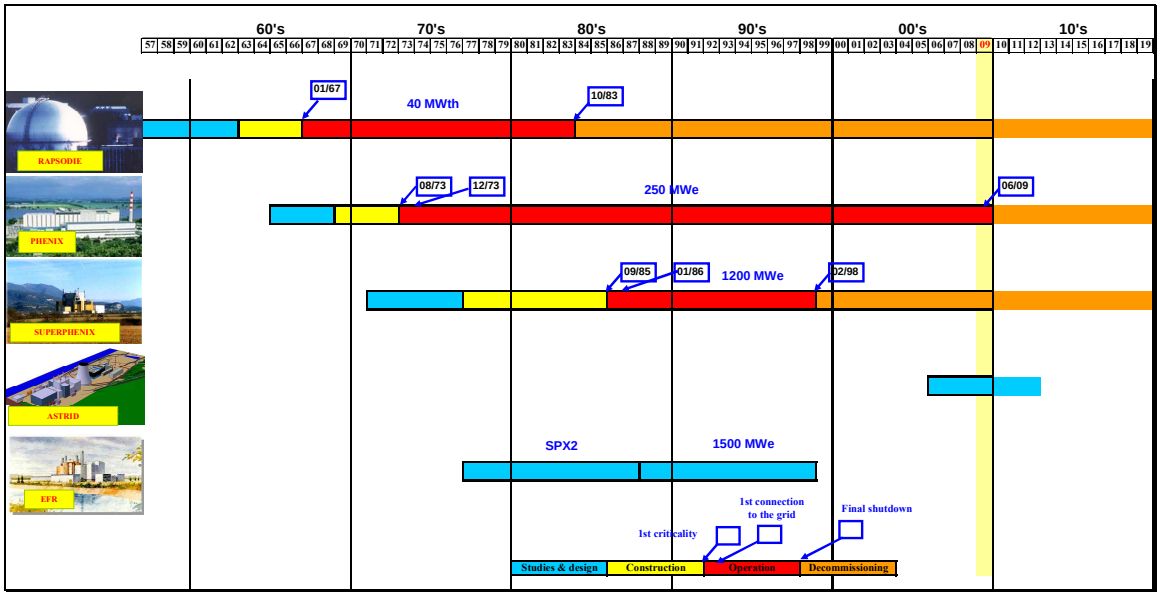

Fig. 1 : SFR development and operation in France

In addition Table 1 is providing the most relevant news from the past ten years.

	Reactors and project: RAPSODIE – PHENIX – SUPERPHENIX – EFR – ASTRID
1998	- 02/02: governmental decision to decommission SUPERPHENIX / End of EFR project - Authorization to conduct 50th cycle in PHENIX
1999	- September: SUPERPHENIX's primary pumps are definitively shut down - December: Beginning of unloading activities in SUPERPHENIX
2002	- The sodium-fast reactor concept (SFR) is retained by Generation IV forum. France participates to the project
2003	- From 1999 to 2003: Inspections and improvements in PHENIX - June: Beginning of 51st cycle in PHENIX - 19/03: End of SUPERPHENIX unloading activities (fissile and fertile assemblies)
2004	- August: end of 51st Cycle in PHENIX other operating cycles are planned before definitive shut down of the plant - Elaboration of the French contributions to the GEN IV SFR R&D programme
2005	- August: end of 52nd Cycle in PHENIX - October: Start of 53rd cycle in PHENIX - Intensification of the R&D on sodium fast reactors and governmental approval of a double track strategy (sodium and gas fast reactors) for industrial deployment in 2040
2006	- January: Declaration of President Chirac "*I have decided to launch, starting today, the design work by CEA of a prototype of the 4th generation reactor, which will be commissioned in 2020*" - June: End of 53rd cycle in PHENIX – Almost 25 billions kWh produced since 1974 - October : beginning of the 54th cycle : still three cycles to run - From 2002 to 2006 : Decommissioning of the 52 SUPERPHENIX small primary components
2008	- Carbonatation of the four SUPERPHENIX secondary sodium circuits - October : The next French prototype is officially named ASTRID : Advanced Sodium Technological Reactor for Industrial Demonstration
2009	- June : Final shutdown of PHENIX reactor – Start of End of life tests - September : Official ceremony for the PHENIX reactor end - July : The TNa facility designed to treat the SPX sodium is in operation - June : After a synthesis of the R&D performed since three year, the design of the ASTRID reactor is starting in particular with the definition of its operating power.

Table 1 : Key dates on the French SFR program

3. THE CADARACHE SODIUM SCHOOL

3.1. THE CEA SODIUM SCHOOL : MORE THAN THREE DECADES OF HISTORY

The initial objective of the sodium school was to be able to form engineers and operators able to work on sodium fast reactors or on supporting R&D activities. Its role has always been to adapt its offer and its content to the changing demand of reactors, for operation or dismantling.

The sodium school history can be resumed in key dates :

- 1975 : Creation of the Sodium School at Cadarache (Training of Phenix plant teams)
- 1980 : Accreditation by EdF (Electricité de France – French national electricity supplier) : Training of Superphenix plant teams
- 1984 : School opened to foreign companies or utilities (Training for SNR300 team - Germany)
- 1995 : Partnership with INSTN (French Nuclear Teaching Institute)[1]
- 1997 : Development of modular trainings (10 modules)
- 1998 : With the abrupt decision to stop the SUPERPHENIX reactor, the sodium school has defined a new set of modules more orientated towards decommissioning (theory and practice).
- 2000 : Cooperation with JAEA (Japan Atomic Energy Agency – Japan) to provide 37 lectures at Monju reactor (program scheduled on 1 week per year during 5 years) – see table 2.
- 2005 : Collaboration with FROSS : Training of CAEA (China Atomic Energy Agency - China) and IGCAR (Indira Gandhi Centre for Atomic research - India) engineers, future operators of the plant under construction.
- 2007 : A new module on GENERATION IV SFR (Sodium Fast reactors) history, and main options has been initiated, within the frame of INSTN, in partnership with the Sodium School.
- 2008 : A second module "Sodium Fast Reactor: Functional analysis and Design is available for French organizations and organized within the frame of INSTN, in partnership with the Sodium School (Duration: 1 week)

Title of CEA lecture	Lecture date
Pollutions sources	2002
Quality monitoring	2002
Sodium purification	2002
Operation of cold traps	2002
Hydrogen risks	2002
Cleaning of components after draining	2002
Interventions on circuits for repair	2002
In Service Inspection and repair : Strategy, recent developments	2002
Corrosion with sodium	2003
Contamination in sodium fast reactors	2003
Decontamination in sodium fast reactors	2003
Cold trap processing	2003
Theory of sodium fires.	2003
Fires consequences, protections of installations	2003
Safety on sodium facilities	2003
Safety exercise with trainee participation (movie)	2003
Chemical properties of sodium	2004
Physical properties of sodium	2004
Movies on Chemical and Physical properties of sodium and alkali metals	2004
Technology of circuits	2004
General instrumentation for sodium circuits	2004
Sodium circuit operation	2004
Risks induced on structural materials by cleaning operations	2004
Sodium waste treatment	2004
Interaction between sodium and hydrocarbons	2005
Hydrogen diffusion through walls	2005
Cleaning of subassemblies	2005
Training on cleaning processes (movie)	2005
Ultra Sonic monitoring in sodium	2005
Sodium/water reaction in Steam Generators, hydrogen detection	2005
Sodium leak detection	2005
Experimental feedback of RAPSODIE decommissioning	2006
Experimental feedback of PHENIX in operation	2006
Experimental feedback of SUPERPHENIX in operation	2006
Strategy of sodium fast reactor decommissioning	2006
Chemical and physical properties of NaK	2006
Handling of NaK and safety	2006

Table 2 : List of lectures provided to JAEA from 2002 to 2006

3.2. SODIUM SCHOOL TECHNOLOGY TRAINING OBJECTIVES

Teaching and training activities on sodium technology are devoted to the researchers, the designers, the operators and the decommissioning staffs, but also to firemen: they include technical knowledge on R&D items (such as sodium purification), system description (such as sodium power plant design and operating conditions), operation rules (such as sodium fire fighting) and feedback experience (such as sodium fires or sodium-water reactions).

The trainees are usually belonging to French companies such as CEA, EDF, AREVA, or Safety Research Institute (IRSN), or any companies involved in sodium activities (belonging or not to the nuclear

[1] : http://www-instn.cea.fr

industry). At the early stage of its creation, the sodium school intended to be opened to foreign countries. As an example, it can be highlighted some specific training sessions for German operators (1983) or for Japanese operators for the first start-up of Monju reactor (90's) or in support to the PFR and DFR decommissioning projects (UK). Some specific sessions were also provided to Chemical industry, ie UOP (USA), Moreover since 5 years, the Sodium school in association with PHENIX plant has extensively increased its opening to foreign institutes.

3.3. SODIUM SCHOOL MEANS

Sodium teaching is based on about 35 experts in their field coming from CEA (25), EDF (5) and AREVA (5). All the CEA people delivering courses at the sodium school are engineers and technicians involved in sodium activities in CEA Departments or at PHENIX plant. Teaching at the sodium school is voluntarily defined as a partial time job to keep a strong connection between recent R&D developments and teaching. Administrative organisation of the sodium school is assumed by French INSTN (National Institute of Nuclear Science and Techniques) which can deliver recognized diploma. Therefore the organization implies both INSTN and CEA Nuclear Energy Directorate.

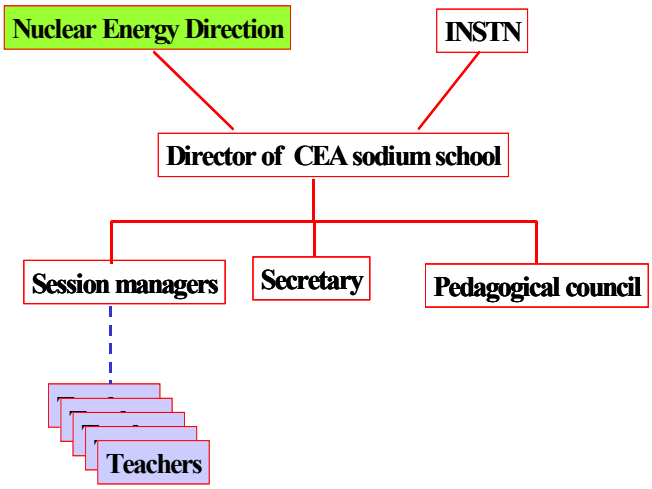

Fig. 2 : The CADARACHE sodium school chart organization

All teaching activities are undertaken within the auspices of ISO9001 : 2000 Quality Management system. Teaching premises are made of a modern teaching room (with video system, computer, internet connection) for the lectures, of several experimental devices (cleaning pit, sodium fountain, sodium dynamic loop, sodium fire cell, decommissioning hall) for exercise practising, and of a collection of technological specific SFR components plus mock-ups, posters, samples….

There are ten different sessions (from 1 to 5 day long), focusing on four main purposes :

- physico-chemistry of sodium coolant (physical and chemical properties, purification, corrosion, contamination, cleaning and analysis),
- sodium technology (commissioning and operation, description and operation of components, instrumentation, visualization, inspection and repair, exercises : operating and intervention on the sodium loop dedicated to Education & Training),
- sodium safety (specific risks : sodium-water reaction, sodium fires, safety rules, prevention, intervention, exercise on a real sodium fire),
- sodium decommissioning (specific risks , dismantling techniques, sodium treatment, sodium waste storage, decommissioning of sodium and NaK facilities).

The complete library of courses is made of about 80 documents, 40 of them being available in English. It is completed by a number of movies and pictures, and by the visit of existing R&D sodium platforms at Cadarache Center.

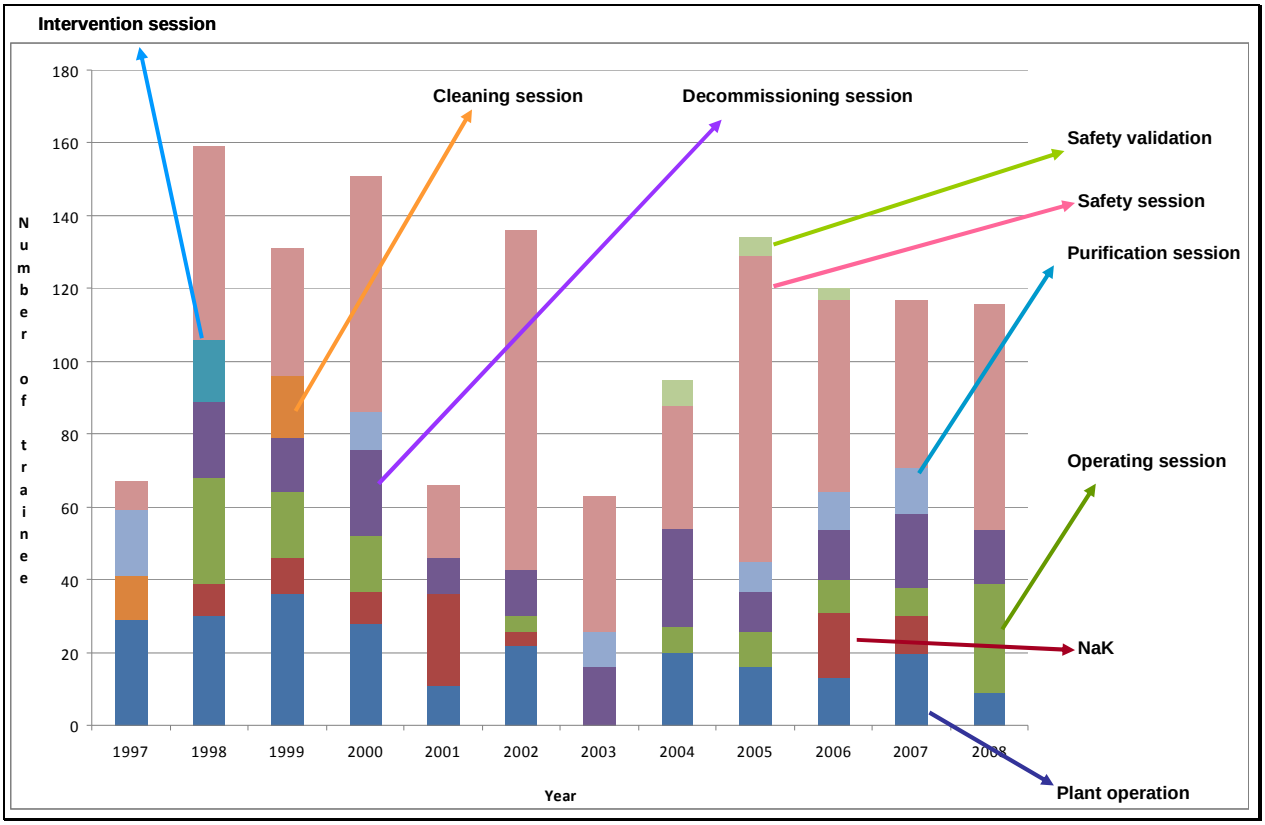

Fig. 3 : Number of trainees per year and per module

3.4. THE PEDAGOGICAL APPROACH

Teaching and transmitting the sodium technology knowledge is assumed both through theoretical lectures and practical exercises. The number of trainees is limited for each session: not more than 20 for lectures and not more than 12 for practical exercises. This allows easy and frequent exchanges and discussions between trainees and teachers: free time is also used for specific cases that the trainees would like to study. The final test of each session checks the proper improvement of each trainee knowledge and understanding of sodium technology.

The teaching activity of the sodium technology specialists is a small part of their job : for most of them, it doesn't exceed some dozens of hours per year. Of course, the trainees can remain in touch with any of them after the session.

Pedagogical quality is based on the interest of each teacher for the teaching art, but also improved thanks to specific "teacher training" : INSTN proposes such yearly sessions which really transform good scientist in good educators (!).

The Pedagogical Council is in charge of general education: direction and coherence of the teaching programs, quality of education (integration of feedback experience). It is composed of nine members (1 INSTN and 8 CEA from Nuclear Energy Directorate) who meet at least once a year.

3.5. LOCATION

The Sodium School is located at CEA Cadarache Research Centre which was opened in 1959 for nuclear fission activities: it involves three main Departments (Nuclear Reactor, Nuclear Fuel, Nuclear technology).

3.6. THE CADARACHE SODIUM SCHOOL IN PICTURES

Fig. 4 : Trainees operating on a real sodium fire exercise and on the filling of a sodium loop

Fig. 5 : Trainees preparing procedures before operating on the circuit

3.7. PRESENT AND FUTURE ACTIVITIES

Since 1975, more than 4500 trainees have received a training at the Sodium School : the present activity corresponds to about ten sessions per year (an average of 130 trainees per year).

Since two years there has been a new growing interest in the international nuclear community for Sodium Fast Reactor design. In France, a new objective has been defined by the French President to build a GENERATION IV prototype reactor by 2020. This decision has motivated an important and rapid increase of R&D work, more orientated at the moment to design and concept evaluation. To adjust to this new demand, two new sessions were prepared since 2007, and launched in 2008, within the frame of INSTN, in partnership with Sodium School :

- SFR: history, main options, design and operational feedback, and
- SFR: Functional Analysis and Design.

The duration of each Session is one week. They are dedicated on the orientations of the Generation IV forum, the main design options, design through 12 main functions (i.e. core, reactor design, fuel handling, energy conversion, etc…), feedback experience and visit of the PHENIX reactor.

In November 2009, 23rd to 27th, in Cadarache, a first new European Session dedicated to Sodium, including physico-chemistry, thermalhydraulics, technology, instrumentation, safety,…has been organized within the frame of INSTN and the European Commission DG12 (ESFR 7th Framework Project) in partnership with Sodium School and PHENIX reactor.

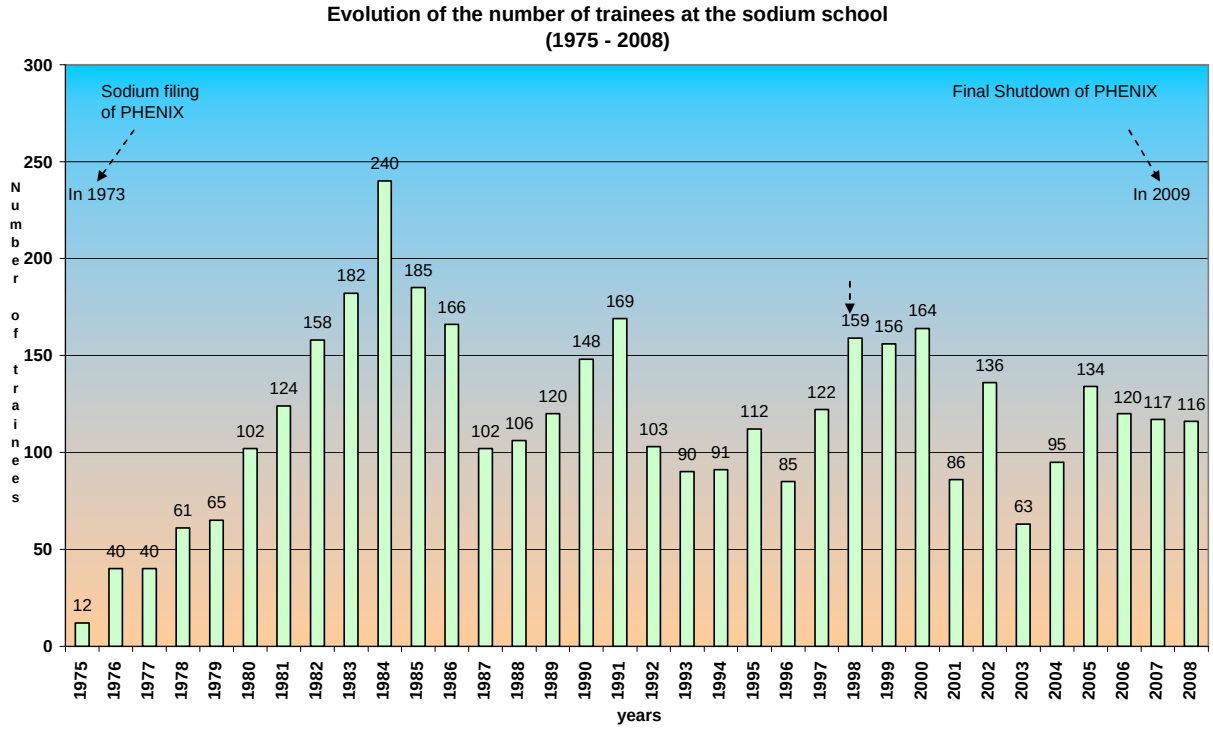

Fig. 6 : The CADARACHE sodium school trainee database from over 30 years

4. THE FAST REACTOR OPERATION AND SAFETY SCHOOL

4.1. PHENIX NUCLEAR POWER PLANT : OVER THREE DECADES OF HISTORY

Phenix is a prototype sodium Fast Breeder Reactor (FBR) which has been operated for over 35 years : first divergence took place in 1973, and Phenix delivered, on the French grid, its first kilowatt-hours in December 1973. The initial objectives for this prototype were to demonstrate that a FBR is a safe reactor, that it produces electricity efficiently, that it is capable of serving as a breeder reactor, and that it can serve as a tool for increased understanding and further development of this reactor type.

Recent years were marked by significant renovation work following several safety re-evaluations, and operating six cycles with the objectives of carrying out a program of experimental irradiations over a period of six cycles, in the field of transmutation and nuclear waste management, and to provide support for studies on future nuclear reactors (both for fuel and structure materials).

Since its inception, Phenix has been a joint program between the French Atomic Energy Commission (CEA) (80 %) and Electricity of France (EDF) (20 %). Both partners contributed proportionally to the plant's operating budget. The personnel (approximately 280 persons) were composed of mixed teams with agents from both companies. CEA manages the joint undertaking and is the nuclear operator.

4.2. FROSS TRAINING OBJECTIVES

To answer to the training needs of other international partners involved in the development of Sodium cooled Fast Reactors (SFR), the training objectives of Phenix-based FROSS are to share Phenix over 35 year experience of FBR operation and provide, in English, a formation on :

- Safety and organizational aspects of SFR operation
- Sodium technology
- Circuit and plant operation, with emphasis on safety and commissioning aspects
- Normal, incidental and accidental instructions

For all the aspects linked with sodium safety and technology, FROSS is associated with the French sodium school, created in 1975 at Cadarache CEA centre, where part of the training takes place. Depending on the initial knowledge and experience in managing installations with sodium coolant, training sessions of 2 and 3 weeks are presently organized. The latter includes 6 days (instead of 2) at Cadarache.

4.3. FROSS MEANS

To fulfil its training objectives, FROSS based the contents of the sessions on :

- Phenix own training programme for its operators
- Operating instructions validated (and improved) by more than 35 years of operation
- Intensive use of SIMFONIX simulator with over 16 years of teaching experience

SIMFONIX is a system that simulates the basic principles of the Phenix power plant. Even if it is not a full-scale simulator, it allows a good display of main parameters and interactions between physical phenomena. So it is used to train Phenix personnel how to operate the reactor under normal and incidental conditions.

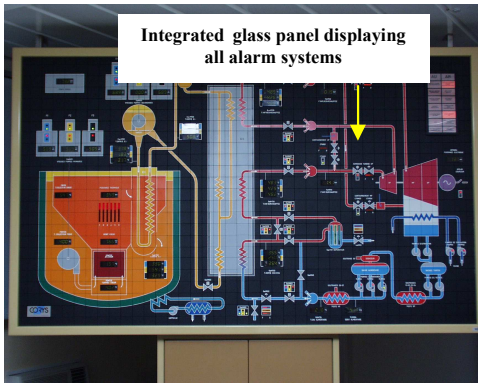

Fig. 7 : Mimic board, set up on a stand, graphically representing the main components of Phenix plant

Examples of simulator training courses

- Subcritical Approach and Criticality
- Reactivity step
- Rod calibration
- Reactor protection
- Feedback effects
- Plant start-up (steam generator in operation)
- Load reduction and normal shutdown
- Scram procedures
- Action to follow in the event of primary coolant pump failure
- Neutronic incidents
- Primary cooling system incidents
- Secondary cooling system incidents

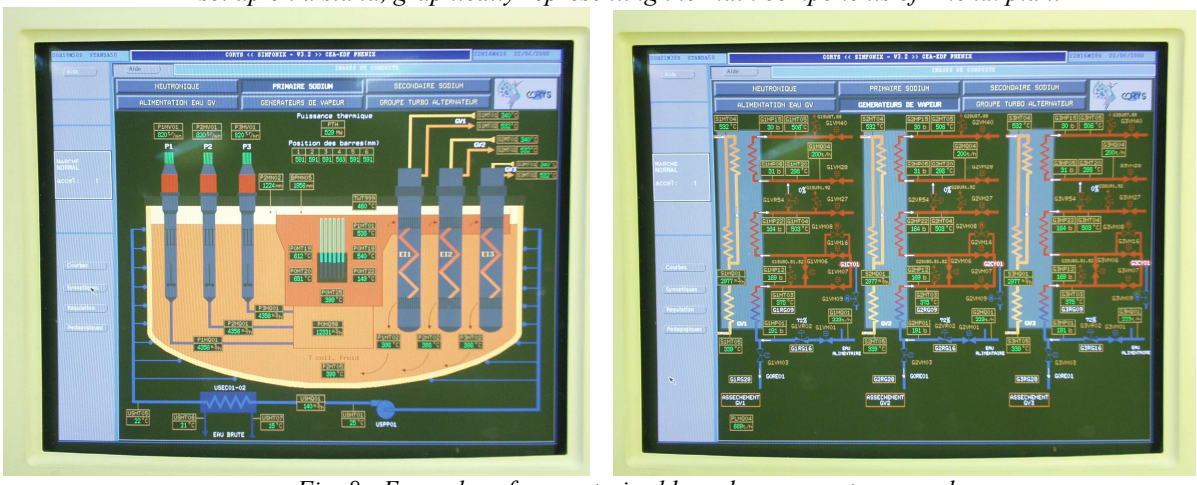

Fig. 8 : Examples of computerized boards on operator console

4.4. THE PEDAGOGICAL APPROACH

It consists of a combination of various educational means:

- Lectures, associated with discussions, by Phenix specialists
- Meetings with plant section managers and staff
- Demonstrations
- Simulator exercising
- Periods with Phenix operating teams
- Visits of the plant and some premises

As for the Sodium school, the teaching activity of Phenix specialists is a small part of their ordinary job, and here also, the trainees can remain in touch with any of them after the session. The number of trainees is ideally of 6 persons (with a maximum of 8) due to practising on simulator.

Typically, a session includes the following modules :

- ***Welcome***
  - *General presentation of Phenix, plant tour*
- ***Module 1 Plant organization***

- *Presentation of the plant sections : Operation, Maintenance, Handling, Physics, Safety and Quality, Engineering : presentations of each section activities followed by a discussion with the head of the section*
- *Additional lectures such as : Organisation of maintenance, Overall surveillance, Organisation of Safety, On-site Emergency plan organization*

- ***Module 2 Plant Operation***
  - *Presentation of operating instructions*
  - *Exercises on Phenix simulator: "Simfonix"*
  - *2 half days with the operating shift teams*
- ***Module 3 Sodium safety technology***
  - *This training is provided at the Cadarache Sodium School. It is composed of lectures of general safety aspects of sodium cooled FR : Presentation of Sodium School, odium fire, Technology, Theory of Na fire, Fires consequences, protections, Safety technology, Na/water reaction in Steam Generators, H_2 detection, Sodium leak detection, Safety on sodium facilities, Possibility of visiting some Cadarache Center facilities.*
- ***Module 4 Phenix accidental instructions***
  - *The module consists of lectures on some of the Phenix accidental instructions related to module 3: Loss of Decay Heat Removal circuit accident, Loss of emergency cooling circuit accident, Sodium fire in controlled areas, Sodium fire in Steam Generator building, Sodium/water reaction in Steam Generators.*
- ***End of the training***
  - *Assessment of the training and visit of some Marcoule facilities*

4.5. LOCATION

The Phenix Power plant, located on the banks of the Rhone river, is an integral part of the CEA Marcoule nuclear site in the south east of France. Marcoule site, existing for more than 50 years, was the birth place of French nuclear industry with, among others, in 1956 the first from nuclear origin kWh in France with G 1 reactor, in 1958 the start-up of UP1 reprocessing plant and in 1969 the vitrification process pilot : PIVER. Now, the main R&D programmes are on the fuel cycle with researches on :

- Spent fuel treatment
- Waste management
- Cleaning-up and dismantling of old installations.

4.6. PRESENT AND FUTURE ACTIVITIES

Created in 2005, FROSS has, so far, welcome

- 6 sessions for Indian engineers, operator of FTBR and future operator of PFBR (26 engineers)
- 3 sessions for Chinese engineers, future operator of CEFR (24 engineers)
- 3 sessions for Russian engineers from BN600 reactor (14 engineers) in the scope of the European Commission TACIS program.

More sessions are planned for 2010.

5. CONCLUSIONS

The CEA sodium school is providing specific and detailed courses on sodium and other liquid metal technology since the very beginning of the national demand and in the last five years has extensively opened its qualification to foreigners. In nearly 35 years, this organisation has demonstrated its flexibility in adapting its courses and practical exercises to the changing demand in the Sodium Fast reactor field. Since 1975, more than 4500 trainees have joined the sodium school at Cadarache or FROSS School at Phenix and strong collaboration with INSTN. It is now able to provide courses for the coming GENERATION IV SFR technician, engineers and designers. The sodium School associated with FROSS are able to conceive and propose new sessions, adapted to the people involved in sodium technology throughout the international SFR community : proper lectures, exercises and visits can be easily selected among all the existing ones, and new ones can also be adjusted at demand on the basis of CEA's large data and experiences.

ACKNOWLEDGEMENTS

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