DOI: 10.15669/pnst.8.363

Progress in Nuclear Science and Technology
Volume 8 (2025) pp. 363-367

ARTICLE

Nearly 50 Years of Education and Training on the Operation and Dismantling of Sodium and Liquid Metals Facilities

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The French sodium and liquid metals School was founded nearly 50 years ago within the CEA Cadarache to meet the training needs of French manufacturers in the sodium fast reactor sector. It subsequently opened up to foreign partners and manufacturers and extended its field of expertise to other liquid metals. Its mission is to ensure the training of CEA and external personnel in controlling the risk of sodium and other liquid metals, in the operation and maintenance of installations, and in the dismantling of devices containing sodium. Its objective is to ensure the transmission, maintenance and renewal of the skills of personnel working in the field of sodium and liquid metals. It is a major element in the sector for transmitting knowledge, know-how and interpersonal skills linked to the operation and dismantling of sodium facilities taking into account the knowledge and skills of its training leaders and lecturers. Recent changes in industrial needs have made it possible to offer training on other liquid metals in recent years. Other developments are planned to enable teaching on the operation and dismantling of facilities using advanced heat transfer fluids such as molten salts.

KEYWORDS: education and training, knowledge, lessons learned, liquid metals, sodium technology

I. Introduction

The French sodium and liquid metals school was founded nearly 50 years ago within the CEA Cadarache in order to train professionals working in the field of sodium fast reactors, from the industry and the research units. At that time, RAPSODIE was in operation for eight years, PHÉNIX's start-up had taken place two years earlier, and SUPERPHÉNIX had been announced one year before. Since its beginning, education and training was proposed in the French sodium school, in order to train operators that were about to operate those reactors, but also to train the PhD students, engineers and technicians who worked to find innovative and efficient technologies for sodium facilities.[1-3)]

It is now dedicated to the training of engineers, technicians and operators on sodium and liquid metals technologies, the operation of sodium facilities, and the handling, in-service inspection and repair of sodium components and sodium instrumentation.[2,4)] The school trained more than 6 000 participants coming mainly from France, but also from countries such as USA, Europe, Latin America, Japan, China, India, Russia.

II. Organization of the School

The French Sodium School is located in Saint-Paul-lez-Durance, south of France, at half an hour from Aix-en-Provence, in the CEA centre of Cadarache. Cadarache houses RAPSODIE reactor, the first French experimental sodium-cooled fast reactor. The training courses are delivered in a building dedicated to the School. This building contains a classroom, two changing rooms, an exhibition hall and a sodium loop dedicated to research and development and education and training called SUPERFENNEC, where a great part of the practical exercises take place.

The remaining of the practical exercises take place in CEA research and development facilities and cells.

The school is managed by a Director and a deputy Director, that are attached to the technology of components and processes Division, in the Department of nuclear technology of CEA Cadarache. The Director and deputy Director work with training leaders that are responsible for training courses. The content of each training courses, as well as the name of the lecturers, are determined by the training leader. A pedagogical council reunites when necessary, and at least every two years, the direction of the school, the training leaders, the project managers that support financially and materially the school, the secretaries and the managers of the Division.

The training courses can be separated in two main fields: operation and dismantling, with a common core, the security aspects.

III. Educational Means Used in the French Sodium School

All the lectures are given by the experts in their fields that share with the participants their knowledge and their feedback. Most of the lecturers come from CEA, and especially the Department of nuclear technology. They present, in a pedagogical way, the knowledge they have acquired when working on sodium facilities, design of components or

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operation of processes (**Fig. 1**). Some other lecturers come from PHENIX, SUPERPHENIX or RAPSODIE reactors, or from the CEA Department of reactor studies.

Fig. 1 Lecture on sodium chemical properties at the French Sodium School ©A.Aubert/CEA

The lectures contain a great part of active training. Lecturers integrate tutorials and real case studies in the major part of the course. It allows the participants to build and deepen their knowledge. The real case studies enable the teachers to share the lessons learned by CEA with the participants concerning the operation of a liquid metal facility, the safety issues they encountered, the technologies, instrumentation, sensors and processes they use for sodium and liquid metals facilities. In addition to tutorial and real case studies proposed by the lecturers, participants are encouraged to share the difficulties they encounter with the teachers and the other participants in order to discuss those difficulties. The most interesting cases are chosen by the teachers, and all the participants have a reflexion, in small groups or with the whole classroom, about the problematics and they try to bring answers to help solve the problem. Scenario of incidents and accidents can be presented and analysed; hypothesis for overpressure calculations can be discussed; participants' problematics can be studie.

As said previously, the practical exercises are done on facilities used both for research and development and for education and training. The sodium school training loop, SUPERFENNEC, shown in **Fig. 2**, is the main education and training facility. It was built to train the operators who worked on the start-up and operation of SUPERPHENIX and was then called SUPERFENNEC for "SUPERPHENIX Ecole" (SUPERPHENIX School). Using this loop, the trainees learn how to start-up, fill-in, operate, intervene in, and shutdown a sodium facility. This loop is also used to learn how to conduct a purification campaign in a sodium facility.

Other facilities or devices are used to train learners. Devices, in a dedicated hall, are used in order to learn how to intervene on a sodium loop, with the aim of cutting a pipe, scraping the sodium contained in the pipe, and then realize a welding. Specific facilities, used mainly for R&D, can be used to realize practical exercises of sodium cleaning. The same functions as industrial cleaning pits or treatment facilities can be found in those cleaning facilities (spraying of liquid or vapour water, possibility to realize an immersion, possibility to carbonate sodium hydroxide when produced). Inert gloveboxes can be necessary to prepare the experimental devices that need to be cleaned or treated.

Fig. 2 Practical exercise on SUPERFENNEC facility ©A.Aubert/CEA

Recently, two pedagogical benches have been designed in order to study firstly the sodium-water reaction, and secondly the sodium treatment processes (cleaning process and carbonation). The first bench enables the reaction of half a gram of sodium with liquid water. The hydrogen gas formed during the reaction is captured in order to measure its volume and then do some calculations. A coloured indicator, the phenolphthalein, shows that the reaction produces a basic compound. The second bench enables to realize two operations: a cleaning operation, the reaction of one gram of sodium with a spray of liquid water; and a treatment operation: the carbonation of one gram of sodium.

The sodium school also uses cutaway mock-ups of a sodium loop, of components such as liquid metals valves, pumps, plugging-meters, cold traps. The cutaway sodium loop has the particularity to possess all the instrumentation and components that are necessary in a real sodium loop. In addition, real sensors, real instrumentation and real components are presented and studied during the lectures. The instrumentation and components are often developed by the CEA R&D engineers and tested in CEA sodium facilities.

Two simulators are also used in the lectures. The first one is SUPERFENNEC simulator and is used in order to learn the operation of a sodium loop, to conduct purification campaigns, to test procedures, etc. The second one is SIRENa simulator,

developed by the CEA Department of reactor studies, in order to learn how to operate a sodium fast reactor.[5] Both simulators enable the trainees to learn while being allowed to make mistake and see how the loop or the reactor will behave.

To finish, visits of sodium or other liquid metals facilities in CEA Cadarache (NaK alloy, lithium, or lead-bismuth eutectic) are proposed in the training courses. They allow to become aware of components and loops dimensions, to see in a real environment the components, sensors and other instrumentation, to see liquid sodium (**Fig. 3**) or to see cleaning pits, in-air treatment cells and carbonation skids and vessels. For some specific training courses, visits of RAPSODIE, PHENIX and SUPERPHENIX reactor can be proposed.

Fig. 3 FONTANA facility: a sodium fountain that allows to see liquid sodium ©A.Aubert/CEA

IV. Partnerships

1. INSTN

A partnership has been existed between the French sodium school and the INSTN (National institute for nuclear science and technology) since 1995. The INSTN, an education and training institute belonging to the CEA, carries the French sodium school training offer. The sodium school and the INSTN work together on the pedagogical specifications of each training course, and the description of the courses are available on the INSTN website. The INSTN course manager is responsible for the pedagogical specifications and the quality certification. The participants register with a secretary of the INSTN. The INSTN pedagogical secretary does the major part of the logistics, bookings and administrative documentation for the training courses. INSTN is a member of the school pedagogical council.

2. FROSS

The French sodium school collaborated with the FROSS (Fast Reactor Operation and Safety School), that was created in 2005 at PHENIX, for the training of engineers and future operators of the plants under construction of CAEA (China Atomic Energy Agency, China) and IGCAR (Indira Gandhi Centre for Atomic research, India).[6] PHENIX was operated by both CEA and EDF, the French electrical utilities. The FROSS was created to answer the training needs of other international partners involved in the development of sodium fast reactors. The training objectives of the FROSS was to share PHENIX feedback over more than 35 years of experience, at that time, of a fast breeder reactor operation, and provide, in English, lectures on safety and organizational aspects of a sodium fast reactor operation; sodium technology; circuit and plant operation, with emphasis on safety and commissioning aspects; normal, incidental and accidental instructions. For all the aspects lined with sodium safety and technology, the FROSS was associated with the French sodium school, where part of the training took place. Depending on the initial knowledge and experience in managing installations with sodium coolant, training sessions of 2 and 3 weeks were organized. The latter includes 6 days (instead of 2) at Cadarache.

To fulfil its training objectives, FROSS based the contents of the training courses on three main components: PHENIX own training programme for its operators; operating instructions validated and improved by more than 35 years of operation and intensive use of SIMFONIX simulator, which was PHENIX simulator, with over 16 years of teaching experience (**Fig. 4**).

SIMFONIX was a system that simulated the basic principles of PHENIX power plant. Even if it was not a full-scale simulator, it allowed a good display of the main parameters and interactions between physical phenomena. It was then used to train PHENIX operators how to operate the reactor under normal and incidental conditions.

Fig. 4 FROSS training room with SIMFONIX simulator ©PHENIX/CEA

V. Recent Activities

Since 2016, the school has opened up to the international market again. Industries, previously unknown to the school, have contacted the school so that it can meet their training needs. This is how a training course on NaK alloy was created in 2016, for two European clients, with the new particularity that at least one of the clients did not work in the nuclear field but in the automobile sector. This constitutes an important change and a major shift that the school has been able to take, just like the R&D on liquid metals at the CEA. In this context of being able to meet non-nuclear needs, a training course dedicated to the operation of sodium installations (not specifically nuclear reactors) was developed in 2017. These training courses, proposed in English for international clients, are made visible on the INSTN website and help to attract future clients working with liquid metals in sectors other than nuclear reactors. Clients working on concentrated solar power plant projects using liquid sodium as a heat transfer fluid have been trained at the French sodium school (Swedish company in 2021) or plan to do so in the coming months (Australian company).

In addition, new international training courses have been developed since 2018 in order to answer international training needs. These courses are focussed on sodium loop operation and technology, have a focus on PHENIX and SUPERPHENIX operation feedback and one of the training courses have a large part dedicated to sodium fast reactors operation, using SIRENa simulator, that has been developed by CEA in order to replace SIMFONIX simulator after the shutdown of PHENIX power plant.

Concerning the training courses dedicated to decommissioning and dismantling sodium power plants, due to the shutdown of RAPSODIE, SUPERPHENIX and then PHENIX, training requests have increased recently. Participants mainly come from French industry: welders, pipe fitters, operators, project managers working mainly on PHENIX dismantling, but also in the two other reactors dismantling.

VI. The School in the Future

The new R&D studies linked to the current nuclear recovery plan should also contribute to a more or less similar evolution of the school's training needs. There are important prospects for training needs on liquid metals (sodium, lithium, lead) and advanced coolants (molten salts) following the nuclear industry recovery plan and the emergence of start-ups on small reactors cooled with liquid metals and molten salts.

In addition to this change, the number of requests received for training on lithium operation safety and technology have increased and two training courses have been delivered on this coolant these past years. These training courses echo several current R&D programs (CEA, ITER, Eurofusion, start-up…).

Since the nuclear recovery plan put in place in 2022, new concepts of nuclear reactors have emerged, such as molten salt reactors. These concepts, which will require technological developments, will lead to the establishment of specific training for future operators.

The main objective of the school in the future years will then be to increase its educational offering, in addition to its historical courses on sodium technologies, to strengthen it in the field of other liquid metals, to offer training in the field of advanced heat transfer fluids to meet the needs of future industrialists in the sector and to adapt its educational means.

To be able to answer the new needs identified, the sodium school will have to continue its modernization. In addition, on the content of the training courses, the effort will be put on:

- maintaining the training offer on sodium technologies and its derivatives, in particular the NaK alloy, on a national and international scale (dismantling and safety);
- strengthening skills on other liquid metals such as lead, lead-bismuth eutectic and lithium, with the aim of increasing the training offer on these heat transfer fluids, based on the model currently offered for sodium;
- creating a training course on advanced heat transfer fluids, such as molten salts, to meet the training needs of operators, technicians and engineers who will operate the facilities and reactors of tomorrow.

VII. Conclusion

The French sodium school has trained more than 6,000 people since its creation nearly 50 years ago. It has been able to adapt to changes in the nuclear sector and meet industrial needs, both in France and internationally. The development of the school planned for the coming years will meet emerging needs following the nuclear of the future sector recovery. Its organization will probably have to evolve to adapt to these developments, and its name will have reflect these changes.

Acknowledgment

The authors want to thank the past and present training leaders and lecturers of the School, the project managers who have supported financially and materially the School, the secretaries, the managers and former directors of the School and the INSTN, which carries the training offer.

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