ELECTRA-FCC: A Swedish R&D centre for Generation IV systems

Janne Wallenius[a], Erdenechimeg Suvdantsetseg[a], Sara Bortot[a], Mikael Jolkkonen[a], Merja Pukari[a], Jesper Ejenstam[b], Peter Szakalos[b], Roman Thiele[c], Antoine Claisse[a], Kyle Johnson[a] and Christian Ekberg[d]

[a] Reactor Physics , Kungliga Tekniska Högskolan, Stockholm, Sweden

[b] Surface and Corrosion Science, Kungliga Tekniska Högskolan, Stockholm, Sweden

[c] Reactor Technology , Kungliga Tekniska Högskolan, Stockholm, Sweden

[d] Nuclear Chemistry, Chalmers Tekniska Högskola, Göteborg, Sweden

Abstract. ELECTRA-FCC (European Lead Cooled Training Reactor – Fuel Cycle Centre) is intended to function as an R&D centre for Generation IV systems. It consists of a 0.5 MW fast reactor with (Pu,Zr)N fuel, cooled by natural convection of liquid lead, a facility for separation of spent LWR fuel with a capacity of 4 ton/year and a fuel fabrication facility with a capacity of one fuel pin per day. The centre is intended to function as a training facility in support of other European fast reactors, such as MYRRHA and ALFRED. It will also permit to carry out highly innovative research on fast reactor dynamics and fuel cycle processes. The suggested location of the centre is Oskarshamn, in direct conjunction to the Swedish intermediate spent fuel repository and the OKG nuclear power plant. In the present paper, the technological choices for ELECTRA-FCC are discussed and a roadmap for R&D and licensing activities is presented.

INTRODUCTION

Lead cooled fast reactors (LFR) offer major advantages in terms of passive safety. Among these one finds the lack of rapid exothermic interaction with water, a high boiling temperature, excellent potential for heat removal by natural convection, chemical retention of fission products in the coolant and inherent shielding of gamma radiation. These features form the basis for the safety case of LFR concepts such as BREST [Adamov 1997], ELSY [Alemberti 2011] and SUPERSTAR [Bortot 2011]. In comparison with lead-bismuth cooled reactors [Gromov 1997, Abderrahim 2010], pure lead ensures a much lower source term due to Po-210, but faces a considerably higher risk of coolant freezing under deviations from normal operation. Considering that passive safety features are likely to be indispensable when licensing new reactor systems for commercial deployment, Russia has taken a strategic decision to develop and construct the BREST-300 reactor in the region of Tomsk, for intended operation in 2020. The BREST concept relies on the use of nitride fuel, which allows to reduce the reactivity swing and improves margin to failure during over-power transients [Adamov 1997]. In addition, safety margins are less sensitive to incorporation of americium in the fuel than for the corresponding oxides, which makes the nitride fuel option particularly attractive in the context of Generation-IV systems [Wallenius 2011].

Whereas Russia has an history of 80 reactor years in operating lead-bismuth cooled reactors, the irradiation experience in other countries is limited to in-pile testing of structural materials in lead capsules [Gessi 2010, Van Den Bosch 2010] and the operation of the MEGAPIE spallation target [Wagner 2008]. No reactors have operated using pure lead as coolant.

In order to gain experience of lead cooled reactor operation, and to provide a unique facility for education and training, KTH is developing the ELECTRA concept (European Lead Cooled Training Reactor) [Wallenius 2012]. ELECTRA is a low power fast reactor cooled by natural convection of liquid lead. A very small core size (30x30 cm) is achieved by use of inert matrix (Pu,Zr)N fuel. The corresponding pressure drop is low enough to permit full heat removal by natural convection of the coolant during normal operation, for a vessel height of approximately three meters. The high reactivity loss resulting from use of fertile-free fuel is compensated by the rotation of 12 cylindrical drums with

B_4C sections located outside of the core [Suvdantsetseg 2012]. The geometrical configuration of the core and the rotating drums is depicted in Figure 1.

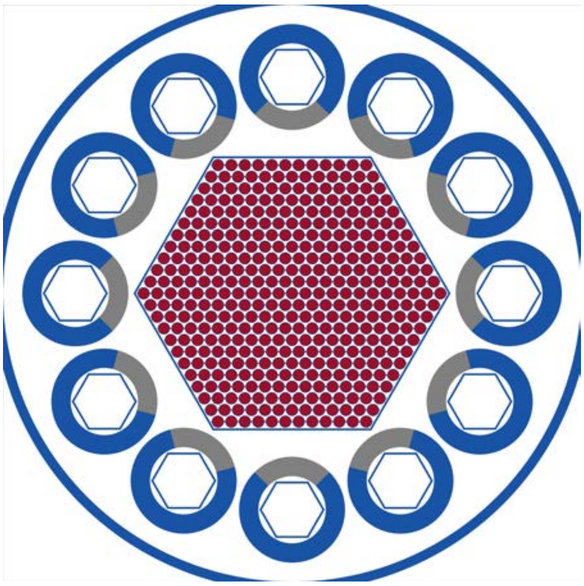


Figure 1: Configuration of core and control elements in ELECTRA

The small size of the core and primary system, in combination with the low power should make it possible to construct the reactor at a relatively modest cost. We may compare to the cost of the MEGAPIE experiment, which was a 700 kW LBE-cooled spallation target operated at PSI [Wagner 2010], which is estimated at 25 M€.

The fuel for ELECTRA may derive from two different sources. The primary choice is to construct a small recycle facility in direct conjunction to the Swedish intermediate repository CLAB in Oskarshamn. With a capacity of 4 tons spent LWR fuel per year, such a facility could separate the required inventory of plutonium within two years. The reference process for the separation is CHALMEX process, developed by the Chalmers University of Technology [Aneheim 2011, Aneheim 2012a, Aneheim 2012b]. CHALMEX is a global actinide extraction process. In the first step of this process, the uranium present in the spent fuel is separated. In the next step, all transuranium elements are extracted together. Thus there is no stream of pure plutonium. The setup will be based on centrifugal contactors developed at Chalmers, which results in a high throughput and good phase separation, but a small hold-up volume. This in turn has the advantage that there is no risk for criticality during operation. The throughput required to separate the fuel for ELECTRA within two years of operation is less than 2 kg of LWR fuel (200 grams plutonium) per day. These two facts together ensure that the facility can be made very compact, leading to a relatively modest cost.

The second potential source for the fuel is 900 kg of separated PuO_2 owned by the Swedish utility OKG, which presently is residing in Sellafield. This material was supposed to be used for MOX production, to be inserted into the Oskarshamn power plant. After the closure of the Sellafield MOX plant, the faith of this stock is uncertain. Currently, there is a moratorium for transport of pure plutonium powders in Europe, which means that the PuO_2 would have to be converted to MOX before being transported to Sweden. Thus, in any case, a facility for separation of Pu will have to be erected in Oskarshamn.

A fuel fabrication facility would be located next to the separation facility. As the core of ELECTRA requires about 70 kg of plutonium and features 397 fuel pins, the requested capacity of this facility is one fuel pin per day, corresponding to a throughput of less than 200 grams of plutonium per day. Therefore, the manufacture can be accomplished in a conventional lab facility, such as the ones already in operation at PSI, NRG and other research institutes. In total, one would need seven manipulator operated and water shielded glove boxes for powder manufacture, powder analysis, pellet production by spark plasma sintering, grinding, pellet characterization, pin welding and waste management. The total cost for this facility, including building and ventilation system, may be estimated at 15±2 M€, the main uncertainty pertaining to the number of glove boxes to be installed.

The reactor itself may be located on the premises of the OKG utility, utilizing the existing physical protection and infrastructure of the power plant. In addition, the distance to the suggested fuel-cycle facility is negligible in terms of transport.

Technical innovations making the design of ELECTRA possible include the application of inert matrix nitride fuel and the use of alumina protected fuel cladding. Both of these technologies will require qualification in terms of quality assurance of the manufacturing process and irradiation testing under nominal and transient conditions. Moreover, the natural convection concept will be validated in an electrically heated one-to-one scale model of ELECTRA to be built at KTH.

In the present paper, the choice of these technologies is discussed and a general roadmap for licensing of ELECTRA-FCC and associated R&D is presented.

CHOICE OF FUEL

The choice of fuel for ELECTRA may be rationalized through the following arguments:

1) The introduction of lead coolant will increase the likelihood to achieve adequate passive safety performance in Generation-IV reactors
2) At present, materials suitable for use in pump impellers of lead cooled reactors remain to be qualified
3) In the near term (next ten years), full heat removal by natural convection will offer a short-cut to testing operation of lead cooled fast reactors
4) A very compact core with low pressure drop may be designed by application of inert matrix (uranium free) fuels
5) Among inert matrix fuels tested under irradiation, (Pu,Zr)N offers a unique combination of low swelling, low gas release, insignificant pellet-clad chemical interaction, high margin to melting or dissociation and high plutonium density.

Item (5) is based on the outcome of successful irradiations carried out in BOR-60 [Rogozkin 2011], JMTR [Arai 2006] and HFR [Wallenius 2009]. Additional out of pile data supporting our conclusions have been obtained in Switzerland, France, Russia and Japan [Streit 2005, Basini 2005, Shkabura 2006, Skupov 2006, Minato 2009, Takano 2009].

Hence, we argue that (Pu,Zr)N is the most adequate fuel option for a low power reactor functioning as a test bed for lead fast reactor technology in the near term. A detailed programme to qualify this fuel for use in ELECTRA is described elsewhere [Pukari 2012].

CHOICE OF FUEL CLADDING

Most fast reactors have used austenitic steels for fuel cladding tubes. In the late 60’s it was realised that this material is subject to swelling, seriously limiting the residence time of the fuel. Applying an adequate amount of cold work and optimising the composition of the steel, it became possible to raise the swelling threshold to above 100 dpa [Maillard 1992]. Ferritic and ferritic-martensitic steels are less sensitive to swelling [Garner 2000], but have poor creep resistance at high temperature. Since ELECTRA is intended to constitute a facility for research on reactor dynamics, a high margin to failure is desired. In addition, the estimated end-of-life dose to the cladding is less than 40 dpa. Therefore, austenitic 15-15Ti steel is selected as the reference cladding material. This class of steel was originally developed by Sandvik under the designation 12R72 [Egnell 1979], and was later modified for use in Phenix under the name AIM1 and in SNR-300 as 1.4970. An extensive body of irradiation data exist for this steel. Its resistance to corrosion in lead is poor above temperatures of 500°C [Müller 2004]. Hence, the surface has to be protected by a material that can protect the bulk steel components from dissolving into the lead, while not growing too thick due to oxidization resulting from the presence of oxygen in the coolant.

Alumina forming coatings, such as FeAl and FeCrAlY have been extensively tested on ferritic-martensitic steels, proving effective in preventing dissolution by formation of a thin and stable oxide layer [Weisenburger]. Earlier tests also have shown that surface alloying of FeCrAlY with 15-15Ti steels using the pulsed electron beam GESA technique ensures integrity of this steel at high temperatures (600°C) for at least 8000 hours [Müller 2000, Müller 2004]. The GESA technique is already today applicable for short cladding tubes as the ones foreseen for ELECTRA (total length of about 50 cm). Thus, it is considered as the reference method for surface protection of the fuel cladding tubes of ELECTRA.

Tests of GESA treated T91 tubes under proton irradiation have recently been carried out at PSI. The results show that the surface alloy remains intact after irradiation, but may crack if subjected to strains exceeding 2% [Dai 2012]. The reason for the apparent embrittlement of the coating may be formation of Cr-rich precipitates. In such a case, optimisation of the FeCrAl coating composition should be considered, to reduce the probability of strain induced cracking. This may encompass a reduction of chromium content as well as introduction of adequate reactive elements (RE). In any case, strains exceeding 2% of ELECTRA cladding tubes should be avoided by proper thermo-mechanical design of the core.

Neutron irradiation testing of 15-15Ti surface alloyed with optimised FeCrAl-RE compositions is foreseen to take place in BOR-60 as part of the qualification programme of the fuel-cladding system for ELECTRA [Pukari 2012].

CHOICE OF COOLANT CIRCULATION MODE

The choice of natural convection for heat removal in ELECTRA avoids the need for developing and qualifying materials for pump impellers. However, flow stability issues may arise. Therefore, the R&D programme for ELECTRA foresees the construction and operation of an electrically heated one-to-one scale model of the reactor. A three-dimensional visualisation of the primary system of this facility is displayed in Figure 2.

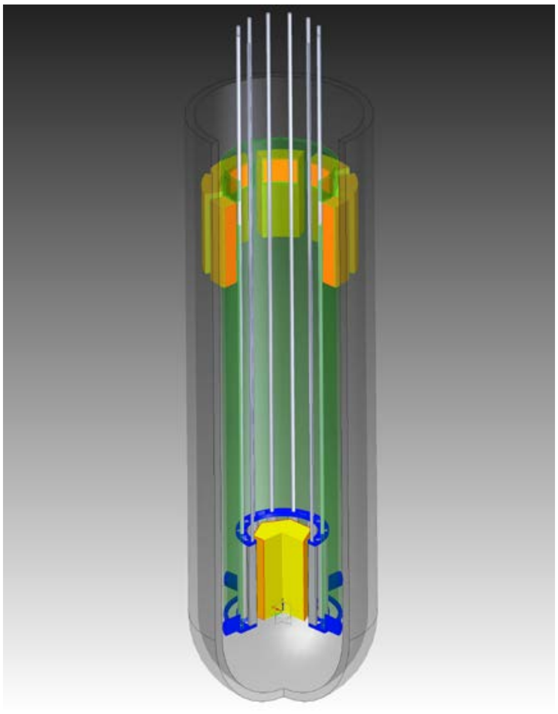


Figure 2: A model of the primary system of ELECTRA

In such a facility it will be possible test not only the integral behaviour of the system, but also to:

1) Generate experimental data for system code validation,
2) Validate models for natural convection under nominal and transient conditions,
3) Determine the ability to control oxygen concentration in a lead pool with natural convection flow,
4) Assess the corrosion performance of cladding, heat exchanger and structural materials under adequate thermo-chemical conditions,
5) Assess the need for lead purification systems,
6) Validate start-up and shut-down protocols,
7) Develop procedures for inspection of fuel rods under drained conditions, assuming decay-heat removal by natural convection of argon, helium or other suitable gas
8) Validate models for simulation of steam generator tube rupture, in terms of bubble transport to the core region and mechanical impact of lead sloshing.
9) Train operators of lead fast reactors

The cost for designing and building the electrically heated mock-up of ELECTRA has been estimated at 2.2±0.2 M€. The facility can be build and operated at KTH, where experience of operating the TALL LBE loop and a power supply of 1 MW is available.

ROAD-MAP

A tentative time-plan for R&D, licensing, construction and operation of ELECTRA and its associated fuel cycle facilities is presented in Figure 3. The program includes irradiation testing of fuel and cladding in materials test reactors.

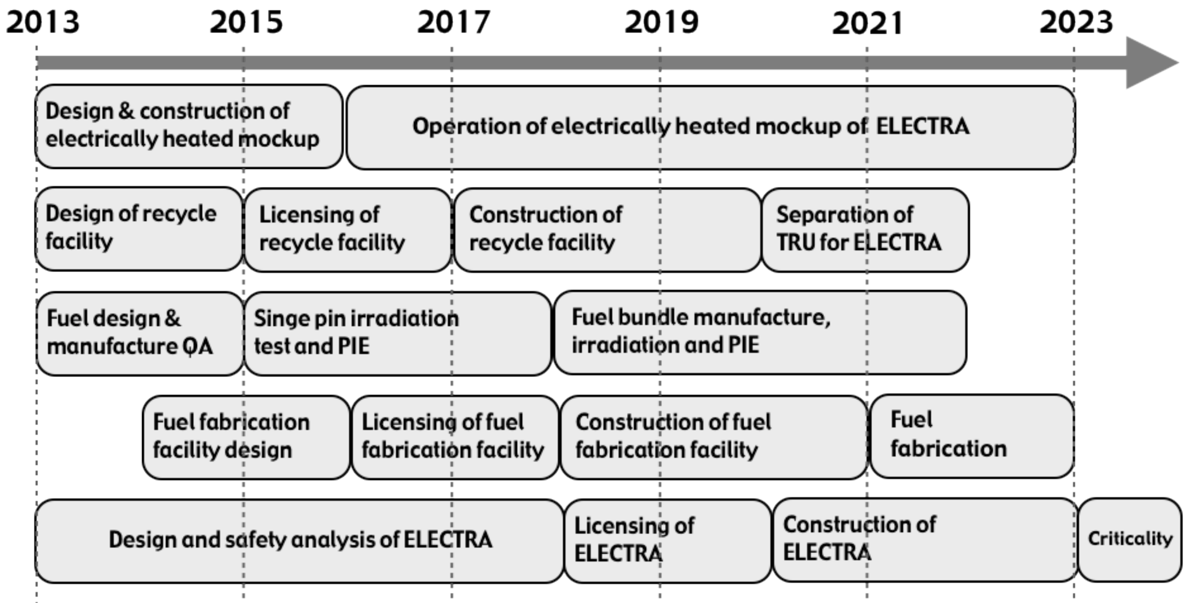


Figure 3: A best-case plan for R&D, licensing, construction and operation of ELECTRA-FCC.

The national R&D is carried out in collaboration between KTH, Chalmers and Uppsala University, in continuation of the GENIUS project. Industrial support is obtained from DIAMORPH AB, providing a unique facility and competence for Spark Plasma Sintering of nitride fuels, and Sandvik Heating Technology AB, assisting with development and characterisation of novel FeCrAl-RE alloys.

International collaboration is necessary to accomplish the program, and MoUs have been signed with ENEA and JAEA for work on qualifying the fuel and cladding for ELECTRA. Other organisations having expressed interest in collaborating include KIT, PSI, SCK•CEN, NRG, RosAtom, NNL, IFE and VTT. The use of ELECTRA-FCC as European facility for education and training on Generation IV systems is foreseen in the ESNII+ programme proposal, recently submitted to FP7 for evaluation.

Preliminary discussions on the licensing procedure have been conducted with the Swedish Radiation Safety Authority (SSM). The current legal framework is deemed to include sufficient provisions to carry out the licensing process, which includes submitting an environmental impact statement to the environmental court and a preliminary safety assessment report (PSAR) to SSM.

The implementation of ELECTRA-FCC is pending funding, which is currently sought from the Swedish government through the Swedish Research Council, Swedish nuclear industry and Oskarshamn's municipality through the "Added value agreement" with SKB. A total cost of 140±20 M€ is estimated for the suggested programme up to 2023, excluding costs for operation and decommissioning of ELECTRA-FCC.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Swedish Research Council (VR) under the GENIUS project and the PRIME planning grant, the Swedish Fuel and Waste Management company (SKB) and the EC FP7 projects LEADER and ASGARD. In-kind contributions from DIAMORPH AB and Sandvik Heating Technology AB are much appreciated.

REFERENCES

H. A. Abderrahim et al., *Nucl. Phys. News*, **20**, *1*, 24, 2010

E. Adamov et al, Nucl. Eng. Des. 173 (1997) 143.

A. Alemberti et al, Nucl. Eng. Des. 241 (2011) 3470.

E. Aneheim et al, Solvent Extraction and Ion Exchange, 29 (2011) 157

E. Aneheim, C. Ekberg and M. Foreman, Hydrometallurgy 115-116 (2012) 71

E. Aneheim, Development of a solvent extraction process for group actinide recovery from used nuclear fuel, PhD Thesis, Chalmers University of Technology, 2012.

Y. Arai, M. Akabori, and K. Minato, "JAEA's Activities on Nitride Fuel Research for MA Transmutation," *Proc. 9th IEM on Actinide and Fission Product Partitioning and Transmutation*, Nîmes, France, September 26–28, 2006, OECD/NEA 2007.

V. Basini et al, J. Nucl. Mater. 344 (2005) 186.

S. Bortot et al, Nucl. Eng. Des. 241 (2011) 3021.

D.C. Crawford et al, J. Nucl. Mater. 371 (2007) 232.

Y. Dai et al, J. Nucl. Mater. 431 (2012) 66.

L. Egnell et al, quoted in Andersson, T. et al, Structure and properties of a19Cr–25Ni–Mo–Ti steel. In Proc. of MiCon 78, ASM STP 672, 1979.

A. Gessi, Specifica tecnika prove LEXUR II, Report RdS/2010/105, ENEA, September 2010.

F.A. Garner, M.B. Toloczko and B.H. Sencer, J. Nucl. Mater. 276 (2000) 123.

B.E. Gromov et al, Nucl. Eng. Des. 173 (1997) 207.

M. Jolkkonen, M. Streit and J. Wallenius, J. Nucl. Sci. Techn. 41 (2004) 457.

A. Maillard et al: *Swelling and irradiation creep of neutron irradiated 316Ti and 15-15Ti steels*, Proc. 16th Int. Symp. Effects of radiation on materials, Denver, 23-25 June 1992, ASTM STP 1175, 1994, page 824

K. Minato et al, J. Nucl. Mater. 389 (2009) 23.

G. Müller, G. Schumacher and F. Zimmermann, J. Nucl. Mater. 278 (2000) 85.

G. Müller at al, J. Nucl. Mater. 335 (2004) 163.

M. Pukari, J. Ejenstam and J. Wallenius, A strategy for fuelling ELECTRA, In Proc. FR13, Paris, France, IAEA, 2012.

B.D. Rogozkin et al, Atomic Energy 109 (2011) 369.

I. A. Shkabura et al., “Study of Heat Conductivity and High-Temperature Creep of Nuclear Nitride Fuel with ZrN Based Inert Matrix,” VANT series, Material Science and New Materials, Issue 2, 67, 2006.

M.V. Skupov et al, ”Investigation of the thermal stability of nitride compositions being developed for minor actinide burning”, VANT series, Material Science and New Materials, Issue 2, 67, 2006.

M. Streit et al, J. Nucl. Mater. 319 (2003) 51.

E. Suvdantsetseg, J. Wallenius and S. Bortot, Nucl. Eng. Des. 252 (2012) 209.

M. Takano, et al, J. Nucl. Mater. 389 (2009) 89.

W. Wagner et al, J. Nucl. Mater. 377 (2008) 12.

J. Wallenius, CONFIRM final report, KTH 2009.

J. Wallenius, Transmutation of Nuclear Waste, Leadcold books and games, 2011.

J. Wallenius and E. Suvdantsetseg, Nucl. Techn. 177 (2012) 303.

J. Van den Bosch et al, J. Nucl. Mater. 398 (2010) 68.

A. Weisenburger et al, J. Nucl. Mater. 376 (2008) 284.

Knowledge passing on in France in the perspective of ASTRID realization

Dr. Philippe DUFOUR[1], Dr. Christian LATGE[1], Dr Leïla GICQUEL[2]

[1] CEA Cadarache, Nuclear Energy Directorate, 13108 Saint Paul lez Durance, France

[2] CEA Cadarache, INSTN, 13108 Saint Paul lez Durance, France

Abstract. Since several 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 to build a GENERATION IV prototype reactor by 2020, called ASTRID. This decision has motivated an important and rapid increase of R&D work, orientated toward design and concept evaluations. To answer to this demand, three new sessions were prepared successively since 2007, and launched, 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

This paper provides a description of these Education & Training activities, dedicated to the students, researchers, designers and operators involved in the development of Sodium Fast Reactors and related experimental facilities.
The duration of each Session is one week. They are dedicated to the orientations of the Generation IV forum, the main design options, operational feedback experience, circuit and plant operation with emphasis on transients, safety and commissioning aspects, and finally visit of the PHENIX reactor. These complementary sessions will be described, including the pedagogical approach and the tools.
In addition, European Sessions dedicated to Sodium Fast Reactors, have been organized within the frame of INSTN and the European Commission DG12, (CP-ESFR 7th Framework Project) in partnership with the Sodium School and PHENIX.

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

Key words: Sodium Fast Reactors, technology, safety, Education and Training

I. 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, the operation and also the decommissioning phases of several Sodium Fast Reactors (RAPSODIE, PHENIX and SUPERPHENIX reactors). Moreover, they have also strongly contributed to French projects such as EFR (European Fast Reactor) and more recently ASTRID prototype [2], [3]. Due to the specificities of sodium coolant, i.e. liquid metal, chemical reactivity, low density and viscosity,… their impact on the technology and the design, and new GENERATION-IV requirements, a dedicated strategy for Education and Training has been implemented in order to provide and share the knowledge obtained through design, R&D and operation of SFRs. CEA (the French Atomic Energy Commission) is in charge in France, within the frame of INSTN and ESML (School for Sodium & other Liquid Metals coolants) to develop specific courses and to propose dedicated Education & Training Sessions related to the Sodium Fast Reactors.

Two kinds of sessions are organized:

- Sessions focused on sodium technologies, for operation or decommissioning, organized by Sodium School (ESML), in partnership with INSTN,
- Sessions focused on SFR design and operation, organized by INSTN, in partnership with ESML. Three training sessions were prepared successively since 2007, and launched, within the frame of INSTN (French National Institute for Nuclear Science and Technology) and ESML:
    - SFR: History, main options, design and operational feedback
    - SFR: Functional analysis and design
    - SFR: Safety and operation

This paper provides a description of these Education & Training activities, dedicated to the students, researchers, designers and operators involved in the development of Sodium Fast Reactors and related experimental facilities.
In addition, European Sessions dedicated to Sodium Fast Reactors, have been organized within the frame of INSTN and the European Commission DG12, (CP-ESFR 7th Framework Project) in partnership with Sodium School and PHENIX.

II. 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 prototype 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 called ASTRID (for Advanced Sodium Technological Reactor for Industrial Demonstration) [4]. The whole SFR French program and development can be synthesized in one picture (see Figure 1). 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 programmed 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
2006	- 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 - 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 billion 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
2010	- 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

III. EDUCATION & TRAINING AT THE CADARACHE SODIUM SCHOOL

III.1. THE CEA SODIUM SCHOOL (ESML): MORE THAN THREE DECADES OF HISTORY

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

The initial objectives of the sodium school were to:

- Synthesize knowledge and to share it between the CEA experimental facilities operators and consequently support R&D activities,
- Teach operators able to work on Sodium Fast Reactors RAPSODIE and PHENIX,
- Form design engineers involved in SUPERPHENIX project,
- Train fire brigades.

Its role has always been to adapt its offer and its content to the changing demand for reactor operation, experimentation, for design, 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)
- From 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)
- From 2005: Training of CAEA (China Atomic Energy Agency - China), in partnership with Fast Reactor Operation and Safety School (FROSS)
- From 2005: Training of IGCAR (Indira Gandhi Centre for Atomic Research - India) engineers, future operators of the plant under construction PFBR, focused only on the safety, in partnership with Fast Reactor Operation and Safety School (FROSS)
- From 2005: Training of ROSATOM (BN600 operators), thanks to TACIS EU contracts, in partnership with Fast Reactor Operation and Safety School (FROSS)

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:

- Sodium physical and chemical properties, which influence strongly the technology and processes used in Research facilities and reactors.
- Processes necessary for an efficient and safe operation: filling & draining operations, sodium purification, cleaning prior to repair, inspection…, decontamination, sodium treatment…
- Instrumentation for operation and safety,
- Design rules for Research facilities,
- Sodium fires and sodium-water reaction…,
- Systems description (such as sodium power plant design and operating conditions).

The trainees usually belong 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 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, such as CIAE in China, IGCAR in India or ROSATOM in Russia.

III.2. 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: this strategy allows first to deliver a knowledge based on experimental feedback and secondly to initiate a fruitful contact between specialists and operators or designers. Administrative organisation and pedagogical support of the sodium school is provided by French INSTN (National Institute for Nuclear Science and Technology) which can deliver recognized diploma. Therefore the organization implies both INSTN and CEA Nuclear Energy Directorate, as indicated in Figure 1.

---

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

Fig. 1: The CADARACHE sodium school chart organization

All teaching activities are undertaken within the standards of ISO 9001: 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 called Superfennec, 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 days 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).

III.3. 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 fruitful 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".
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.

Fig 1: Trainees operating on a real sodium fire exercise and on the filling of a sodium loop

Fig. 2: Trainees preparing procedures before operating on the circuit

Since 1975, more than 5000 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). Due to the evolution of research activities related to the development of the future reactor, ASTRID, there is an increase of the needs for training operators of sodium facilities. Moreover, there is a large need to support the increase or activities related to the decommissioning and dismantling of SUPERPHENIX and PHENIX.

IV. EDUCATION & TRAINING RELATED TO SFR IN INSTN

Three training sessions were prepared successively since 2007, and launched, within the frame of INSTN (National Institute for Nuclear Science and Technology):

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

The duration of each session is one week.

Two other training sessions also exist in the INSTN catalogue:

- SFR: Core physics
- SFR: Beginning with the ERANOS code system

The duration of both sessions is one week. Respectively 21 and 35 trainees have followed this two training sessions between 2008 and 2011.

The following parts will focus only on the three first training sessions.

IV.1. SFR: HISTORY, MAIN OPTIONS, DESIGN AND OPERATIONAL FEEDBACK

A general one-week training session about sodium fast reactors, called “SFR: history, main options, design and operational feedback”, has been held in the INSTN since 2007. Around 160 trainees, which come mainly from French nuclear industry, followed this session, which occurs twice a year. Ten sessions were held in the INSTN Cadarache.

This session enables a trainee to discover the main options that exist concerning the SFR, learn the history of the different projects in France and in the world, and take into consideration the large number of feedbacks that exist in the world on SFR. Every lecture is made by an expert in the field. Lecturers come from the French electricity supplier EDF, the French plant designer AREVA, the French nuclear research commission CEA Cadarache and Marcoule, and the French safety research institute IRSN.

Dialogue takes a large place during the week. On the last day, a round-table conference takes place between the trainees and a representative from EDF, AREVA, IRSN and CEA. During this round-table conference, trainees can ask all the questions that remain.

Seven principal parts can be found. The first one is about the motivations concerning Generation IV International Forum and the new strategies emerging in the world, and the history of sodium fast reactors. The second part presents the main design options that remain, and the choices made in the past. Then, heat transfer is approached, with a part of thermodynamics and a part of sodium thermohydraulics. Fuel, core and materials are then presented in detail. An important place is released for the very important and valuable feedback earned during the operating of RAPSODIE, PHENIX, SUPERPHENIX and other SFRs around the world. Notions are then given on the fuel cycle. Finally, visits are organised including sodium school, Na facilities and PHENIX reactor.

IV.2. SFR: FUNCTIONAL ANALYSIS AND DESIGN

A second one-week training session was created in 2008. It is called “SFR: functional analysis and design”. It is much more specialised and oriented towards design of the reactor. Around 70 trainees, which come only from EDF, AREVA and CEA, followed this session, which occurs once a year. Five occurrences have been held in the INSTN Cadarache.

This session enables a trainee to discover all the required functions of the SFR. As for the first session, every lecture is made by an expert in the field, coming from EDF, AREVA and CEA.

The lectures are subdivided in functions. They are focused on nuclear heat source, with fuel design and reactivity control; sodium flow with mechanical pumps; heat extraction by primary loop; thermal exchange with sodium-sodium, sodium-water, sodium-gas and sodium-liquid metal exchangers; heat conversion; in service inspection and repair, handling of sub-assemblies and dismantling; control of sodium quality; minimization of dosimetry and safety.

Three visits are organised during the week. The critical mock-up MASURCA, sodium testing hall and sodium and cleaning laboratory are visited in detail.

IV.3. SFR: SAFETY AND OPERATION

A third one-week training session was created in 2010. It is called “SFR: safety and operation”. This session mainly relied on SIMFONIX, which is a PHENIX simulator (see chapter V) . It is based in PHENIX, Marcoule, but organized by INSTN Cadarache. Around 60 trainees, which come mainly from French nuclear industry, followed this session, which occurs thrice a year. Seven occurrences have been held.

The session is divided in two parts: the first one is lectures, such as safety general principles, description of PHENIX power plant, neutron physics; while the other one is oriented toward the operation. More than half of the training time takes place with the simulator. Because of that, the group cannot exceed 10 trainees.

Lecturers are a small team of former PHENIX operators and engineers. Their very important knowledge provides a lot to the training session. Trainees are put in situation in front of the simulator by instructors that play sequences as sub-critical approach, normal, incidental and accidental transients… The group of trainees forms a team that has to bring the power plant back to a normal operation.

This training session is very pedagogical. Indeed, the time passed with the simulator enables the trainees to learn faster and better how a sodium fast reactor behaves. It also enables comparisons between sodium fast reactors and pressurised water reactor.
PHENIX reactor is visited in details during the week.

V. SFR BASIC PRINCIPLES SIMULATOR

A nuclear reactor simulator is a tool that can meet both needs, training and education. If we stick to the training, the first historically required operator training, which has led to the realization of simulators called "full scope" reproducing perfectly control rooms of reactors to put operators in situation with respect to all possible steering scenarios.

It exists in the area of training a second need that meets simulators called " basic principles simulator " that are used in engineers courses as a complement to theoretical classes, practical work on simulator can help to understand the effects of constraints governing the operation of a reactor (inertia, feedbacks, regulations...) or put into practice the theoretical knowledge (eg. sub-critical approach). INSTN uses this type of simulators for training on PWRs and it is to meet this need vis-à-vis the SFR that the SIMPHONIX simulator of PHENIX is currently used.

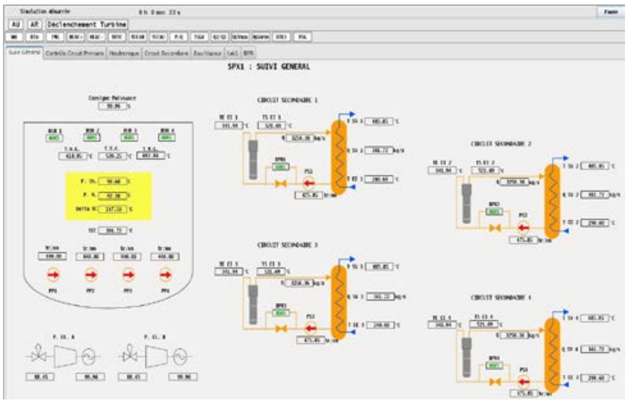
It should be noted that the use of a basic principle simulator for training can be extended for studies. Using this kind of simulator with configurable integrated monitoring and protection system provides an important benefit in the process of system design because it allows very rapid iterations between design and validation, both for system itself or then for the first operating procedures.

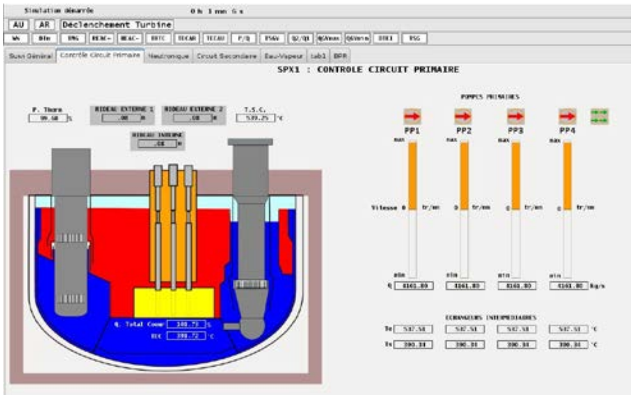
Due to obsolescence, the sustainability of the SIMFONIX simulator used today in the frame of INSTN training is not guaranteed, so it was decided to make a basic principle simulator. This easily configurable simulator will be deployed on multiple machines in a network and multi-screens in the INSTN, but may as well be deployed, as a tool for self-training, on a single PC for design engineers to acquire practical knowledge of the operation of sodium cooled fast reactors.

The self-training tool consists of basic principle simulator associated with a pedagogical folder containing a specific guide to handle simulator and a number of training records describing physical phenomena to be illustrated and exercises to achieve.

The operating code used as the core of the simulator is the CEA code DYN4G. The imagery is developed on the reactor SUPERPHENIX datasets which is fully available (regulation and protection system).
The simulator reproduces phenomena in real time and modeles the behavior of systems in all operating conditions: normal, incidental and accidental. The dynamic behavior of the material is reproduced in particular time constants of the measures, time of valves opening and closing, inertia of the rotating equipments.
Slow transients can be represented in accelerated speed.

Each modeled system is described by a screen showing the circuit and the physical quantities characterizing the state of the circuit: temperature, pump rotating speed, positions of control rods, sodium levels, etc. and also the commands that affect the circuit.
The user can switch between one screen at will.





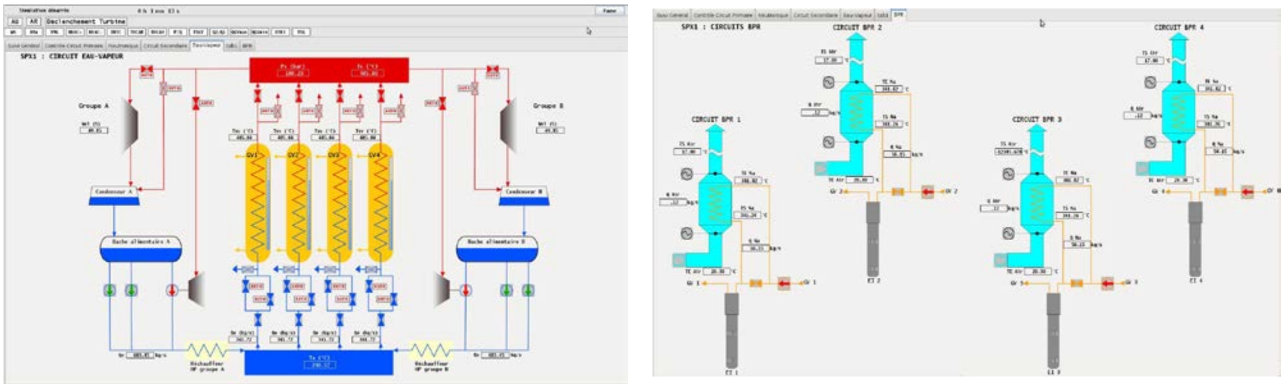


Fig 3: Mimic board, set up on a stand, graphically representing the main components of Superphenix plant

The following models are implemented:
• Core with calculated values of neutron flux, reactivity and power required for the representation of flux measurement channels in each range counting
• Primary circuit
• Intermediate circuit
• Energy conversion system
• Decay heath removal circuits
• Argon circuit balancing pressures of the intermediate circuits
• Control and Monitoring
• Protection system

The Initial states are: plant at 100% Pn, 90% Pn,75% Pn, 50% Pn, 30% Pn and divergence. Whatever the state of the plant, the core may be modelled by different states: new core, beginning of cycle or end of cycle.

Modelled transients have been developed, including: subcritical approach, ramp from 0% Pn to 100% Pn, change of load, and all incidental and accidental transients excluding situations of deterioration of the core but including piping failure and sodium leaks (vessel or piping)

The teaching notes are dedicated to the following items:

o TN1: Divergence of the reactor from the control panel of the primary circuit
o TN2: Operation regulations (rule, index test description)
o TN3: Starting the reactor:
  ♣ Curves of standard states
  ♣ Appointment points
  ♣ Ramp from 0 to 100% nominal power
o TN4: Incidental and accidental scenarios
  ♣ TN4.1: Scram, fast stop
  ♣ TN4.2: Triggering of primary pump
  ♣ TN4.3: Triggering of secondary pump
  ♣ TN4.4: Loss of intermediate circuit
  ♣ TN4.5: Loss of Flow
  ♣ TN4.6: Loss of Power station
  ♣ TN4.7: SG Isolation and Rapid Decompression
  ♣ TN4.8: Decay Heath Removal
o TN5: Normal shutdown

VI. EUROPEAN SESSIONS

In addition, European Sessions dedicated to Sodium Fast Reactors, have been organized within the frame of INSTN and the European Commission DG12, (CP-ESFR 7th Framework Project) in partnership with Sodium School and PHENIX.

In November 2009, a one week training session dedicated to SFR was held in Cadarache. This session was related to the following items: history of SFRs, thermal-hydraulics, technology and instrumentation, physico-chemistry, material, safety….Teachers came from CEA, EDF, AREVA, IRSN, Kalsruhe Institute of Technology, NRI-Praha (Czech Republik) and IPUL in Latvia. Thirty seven attendees came from 18 European organizations and Universities. These sessions allowed to increase the links between all European attendees.

In November 2010, a second session, focused on design methodologies, modeling tools and safety, was held in Cadarache. It addressed the following items: safety approach, core design, fuel, thermal-hydraulics, codification RCC-MRx, design of main components, continuous monitoring and periodical inspection, Na-water interaction, Na fires, impact studies, ASTRID project… Teachers came from CEA, EDF, AREVA, IRSN, Karlsruhe Institute of Technology, HZDR, and 44 attendees came from 19 organizations. Several visits were organized including control room of Rapsodie, Masurca reactor, Na and He facilities**….**

VII. CONCLUSIONS

Education and Training is a key element for the future of the development of Sodium Fast Reactors, and more particularly for the ASTRID project. Two entities are aimed to deliver Training sessions, Sodium School in Cadarache and INSTN-Cadarache. Within this scope, they are ready to collaborate with other foreign Education and Training Entities.

REFERENCES

[1] G. Rodriguez, et al., “The French Sodium School: Teaching Sodium Technology throughout the World”, Conference On Nuclear Training and Education CONTE 2007, Jacksonville, Florida, USA, February 4-7 2007

[2] C. Latge et al “The French Sodium School: Teaching Sodium Technology for the present and future generations of SFR users” Journal of Nuclear Science and Technology Special Issue 27 2010

Fast Reactor Knowledge Organization System: live demonstration

A.Pryakhin, S. Monti, J. de Grosbois

International Atomic Energy Agency

E-mail address of main author: A.Pryakhin@iaea.org

The loss of FR knowledge has been taken seriously and the IAEA took the initiative to coordinate the efforts of the member states in the preservation of knowledge in FRs. In the framework of this initiative, the IAEA intends to create an international inventory combining information from different member states on FRs and organized in the knowledge system in a systematic and structured manner.

Fast Reactor Knowledge Organization System (FR-KOS) is a web based application implementing IAEA methodology and approach for categorization of FR knowledge domain in connection with the repositories of FR knowledge bases. It supposed that a live demonstration of the FR-KOS system will be presented and discussed.

Live demonstration provides an overview and hands-on experience of the following functions and capabilities of the FR-KOS:

- Fast Reactors taxonomy
- Repositories
- Quesries
- Basic analysis of the resulting data sets

FR-KOS can be useful for national nuclear authorities, regulators, scientific and research organizations, commercial companies and all others who is really involved in Fast Reactor activities on national or international levels.

REFERENCES

[1] Fast Reactor Knowledge Preservation System: Taxonomy and Basic Requirements, IAEA Nuclear Energy Series No. NG-T-6.3

[2] International Fast Reactor Knowledge Organization System, FR-09 International conference on Fast Reactors, Kyoto, Japan, 2009, IAEA-CN-176-10-01.

Fast Reactor Knowledge Organization System: Implementation and challenges

A.Pryakhin, S. Monti, J. de Grosbois

International Atomic Energy Agency

E-mail address of main author: A.Pryakhin@iaea.org

For three decades, several countries had large and vigorous fast breeder reactor development programmes, which had their peaks by 1980. From that time onward, Fast Reactor (FR) development generally began to decline and efforts for FR reactor development essentially disappeared by 1994.

This development stagnation continued until 2003. In September 2003, in Resolution GC(47)/RES/10.B, the International Atomic Energy Agency (IAEA) General Conference recognised the vitality of nuclear knowledge.

The loss of FR knowledge has been taken seriously and the IAEA took the initiative to coordinate the efforts of the member states in the preservation of knowledge in FRs. In the framework of this initiative, the IAEA intends to create an international inventory combining information from different member states on FRs and organized in the knowledge system in a systematic and structured manner.

IAEA together with international subject matter experts:

1) developed a taxonomy as a systematic categorization approach for description of FR knowledge domain

2) produced FR Knowledge Organization System as an application, implementing FR taxonomy, search functions and other capabilities for effective access, navigation and search through selected repositories on the basis of pre-defined query

3) created a sample repositories of FR documents as FR knowledge base. Sample repository contains all documents provided by Member States and available at IAEA in the area of FR.

FR-KOS has many advantages and effective solutions. However, the following challenges can be noted:

1) Member States have different approach for document sharing and therefore MS' contribution should be re-considered

2) As many other software system, FR KOS requires training and background

3) Clear objectives should be identified before exploring repositories and searching knowledge base.

FR-KOS was presented first at the FR09 International Conference in Kyoto, Japan in 2009, where it was received positive feedback and interest from meeting participants.

This is the evidence that FR technology will undoubtedly play an important role in the future.

FR-KOS can be useful for national nuclear authorities, regulators, scientific and research organizations, commercial companies and all others who is really involved in Fast Reactor activities on national or international levels.

REFERENCES

[1] Fast Reactor Knowledge Preservation System: Taxonomy and Basic Requirements, IAEA Nuclear Energy Series No. NG-T-6.3

[2] International Fast Reactor Knowledge Organization System, FR-09 International conference on Fast Reactors, Kyoto, Japan, 2009, IAEA-CN-176-10-01.

The ENEN-III project: Technical Training on the Concepts and Design of GEN IV nuclear reactors

T. Berkvens[a], C. Renault[b], M. Alonso[c], R. Salomaa[d], C. Schönfelder[e]

[a] Belgian Nuclear Research Centre, Mol, Belgium

[b] Institut National des Sciences & Techniques Nucléaires, Saclay, France

[c] Universidad Nacional de Educación a Distancia, Madrid, Spain

[d] Helsinki University of Technology, Helsinki, Finland

[e] AREVA NP GmbH, Offenbach, Germany

Abstract. ENEN-III (European Nuclear Education Network Training Schemes) is a project within the 7th Framework Programme that falls under the Euratom Fission Training Schemes (EFTS) in all areas of nuclear fission and radiation protection. ENEN-III joins 19 partners from 12 European countries and its specific area is nuclear engineering. It covers the structuring, organization, coordination and implementation of training schemes in cooperation with local, national and international training organizations, to provide training to professionals in nuclear organizations or their contractors and subcontractors. The schemes provide a portfolio of courses, training sessions, seminars and workshops, offered to these professionals for continuous learning, for updating their knowledge and developing their skills to maintain their performance at the current state-of-the-practice and to anticipate the implementation of new scientific and technological developments. One of the generic types that is addressed is the training scheme for the development and pre-conceptual design of generation IV nuclear reactors. A training scheme for the design of these advanced nuclear reactors, including the large variety of topics to be covered, will be more research oriented and will have a broader and less specialized scope than other schemes. It is expected to respond to the current needs of the research communities and engineering companies in order to design and build the prototypes of the nuclear reactors of the future, taking into account that there is a shortage of engineers with a satisfactory background in nuclear disciplines. The paper will present this training scheme developed within ENEN-III.

1. Introduction

The ENEN-III project (European Nuclear Education Network Training Schemes) [1] is a 7th Framework Programme that falls under the Euratom Fission Training Schemes (EFTS) [2] in all areas of nuclear fission and radiation protection. The EFTS are not a simple training and mobility programme. They are dedicated to structuring both research training and researcher career development across the EU. The schemes address life-long learning and career development of experienced researchers, both in the public and private sectors. They target nuclear researchers and industrial experts at the postgraduate level, from doctoral students to senior visiting scientists.

One of the major objectives of the schemes is to facilitate the transfer of higher-level knowledge and technology between disciplines, sectors and countries. The ultimate goal is to develop a European passport for Continuous Professional Development (CPD), which relies on the principles of common qualification criteria, a common mutual recognition system, and the facilitation of teacher, student and worker mobility across the EU.

The specific area of ENEN-III is nuclear engineering. In parallel, four other EFTS programmes are in progress: ENETRAP II (radiation protection) [3], PETRUS II (radioactive waste and disposal) [4], TRASNUSAFE (nuclear safety culture) [5] and CINCH (nuclear and radio chemistry) [6].

The ENEN III project covers the structuring, organization, coordination and implementation of these training schemes in cooperation with local, national and international training organizations, to provide training to professionals active in nuclear organizations or their contractors and sub-contractors. The training schemes provide a portfolio of courses, training sessions, seminars, and workshops for continuous learning for upgrading knowledge and developing skills. The training schemes allow individuals to acquire qualifications and skills, as required by the specific positions in the nuclear sector, which will be documented in a training passport. The essence of such passport is to be recognized within the EU by the whole nuclear sector which provides mobility to the individual looking for employment and an EU wide recruitment field for the nuclear employers.

ENEN-III joins 19 partners from 12 EU countries and the project is coordinated by the ENEN association, the European Nuclear Education Network. Among the partners there are ten universities, six research insitutions and two industry partners.

Based on an analysis of training needs, schemes for the following profiles have been developed:

- **Type A)** Basic training in selected nuclear topics of non-nuclear engineers and professionals in the nuclear industry
- **Type B)** Technical training for the design challenges of generation III (GEN III) nuclear power plants
- **Type C)** Technical training for the construction challenges of GEN III nuclear power plants
- **Type D)** Technical training for the development and pre-conceptual design of generation IV (GEN IV) nuclear reactors.

This paper will address the general framework of the ENEN-III project and will use examples of training scheme D, without touching upon the details of the other training schemes.

2. A framework for life-long learning and mobility

The nuclear industry relies on highly trained people to safely run and maintain existing installations, as well as to build new ones. The ENEN-III project will help to preserve nuclear knowledge and skills in Europe by creating a range of training schemes designed to suit the needs of different professions in the nuclear sector.

There is a strong need for high level training of young specialists in the nuclear sector. This is due to the combination of a lack of young nuclear graduates and the ageing of the actual manpower. It is critical to maintain the safety and efficiency of the existing nuclear installations and to build and prepare the development of the next generations of facilities. Well designed training of the workforce is therefore necessary, allowing the handling of the technical challenges with all safety assurances.

Major industrial organisations have the means, both in terms of expertise and finances, to hire young engineers and to train them for their specific duties, through a combination of in-house programmes, training courses available on the market, and, not to be neglected, on-the-job training. It is much more problematic for smaller organisations and in countries where recent policies with respect to nuclear energy has led to the decrease in nuclear education and research funding. It is in this context that the ENEN-III project wants to propose a framework that is sufficantly flexible to accommodate to the education & training (E&T) needs of different scientific disciplines, other training schemes and to be aligned with other frameworks that are being developed for the nuclear industry (for example the other EFTS).

The bulk of the framework proposed by ENEN-III focusses on CPD courses to promote life-long learning. It is however imperative that the professionals/engineers taking part in the training schemes have acquired the appropriate level of education, necessary to be able to undertake the training schemes. This academic qualification of the trainees will not be subject of the ENEN-III framework, as it will be internationally recognised when it was obtained from an accredited association. The European Credit Transfer and accumulation System (ECTS) [7] is a tool that helps to design, describe and deliver such academic programmes and award higher education qualifications.

When training nuclear professionals, the nuclear community has shown signs that it wants to adopt the concept of ‘Competence Building’ as a step beyond the traditional E&T and knowledge management activities. More generally: competence building is the result of traditional education plus life-long learning, non-traditional learning, and other forms of educational experiences, relying, in particular, on borderless mobility across the EU and abroad to get acquainted with various sectors.

Within the EU the demonstration of professional know-how and the international recognition of competencies become thus key issues. The principal question asked by the graduate or the young professional will therefore no longer be “*What did you do to obtain your degree (or your qualification)?”* but rather “*What can you do now that you have obtained your degree (or your qualification)?”* As a consequence, a new concept is emerging in the Vocational Education and Training (VET) community, including also academic experts, namely: the "learning outcomes", assessed and recognized throughout the EU.

Learning outcomes are gaining in importance compared to the traditional input-led evaluation, based on textbook knowledge or end of course examination. In practice, learning outcomes refer to specific competencies and therefore consist of a mix of *Knowledge* (Learning to know), *Skills* (Learning to do) and *Attitudes* (Learning to live together and/or Learning to be), to be defined by all stakeholders involved. The above reflections are at the basis of the European Credit system for Vocational Education and Training (ECVET) [8], with central objective to promote mobility in VET in Europe. ECVET is aimed at facilitating the transfer, recognition and accumulation of assessed learning outcomes of individuals on their way to achieving a qualification. It is in this context that the ultimate objective of each EFTS is to use the ECVET approach to provide the trainees with a “European passport”, a portfolio of learning outcomes.

3. The ENEN-III training scheme approach

To develop training schemes for the four different target groups mentioned in the introduction, the project partners have developed a specific approach, which is based on the Systematic Appraoch to Training (SAT). The SAT is a useful concept initially introduced for the preparation and implementation of training programmes and the evaluation of training programmes and trainees at nuclear power plants [9]. Its approach can also be used for the design of training courses for different target audiences, like the ones proposed in the ENEN-III project. The SAT includes the following five phases:

- Analysis: The analysis phase comprises the identification of training needs and of the competences necessary to perform a particular job.
- Design: In the design phase, the identified competences are converted into learning outcomes. These outcomes are organized into a training plan.
- Development: The development phase comprises preparation of all training materials so that the learning outcomes can be achieved.
- Implementation: In the implementation phase, training is conducted using the training materials that have been developed.
- Evaluation: In the evaluation phase, all aspects of the training programme are evaluated on the basis of the data collected in each of the other phases. This is followed by suitable feedback, leading to improvements in the training programme.

The definition of the required competences is a crucial step in the process. A competency analysis represents the basis for creating and developing learning outcomes for the different training schemes. When available, existing job profiles of the different end users should be used for this analysis. As an alternative, interviews with the relevant stakeholders (for example division heads, research managers, …) should be conducted. An overview of the ENEN-III approach is given in Figure 1.

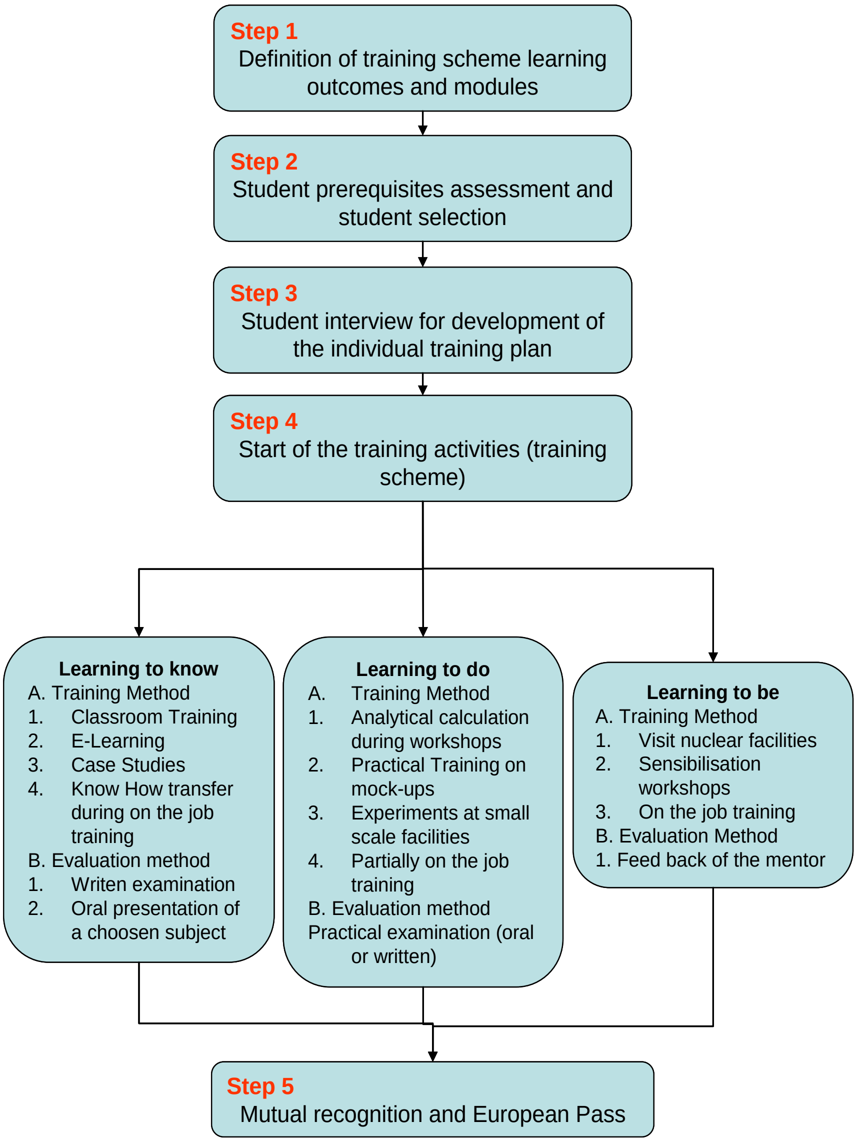


FIG. 1. The ENEN-III approach.

4. Training scheme for the development and pre-conceptual design of generation IV nuclear reactors

The Strategic Research Agenda (SRA) of the Sustainable Energy Technology Platform (SNETP) outlines the goals and visions up to 2050 for new sustainable nuclear energy systems [10]. The central research & development (R&D) topics in GEN IV systems and concepts involve new reactor types with enhanced safety and security, improved economy and minimized waste accumulation. New nuclear technologies with improved materials and fuels, innovative heat conversion systems, advanced operation and control systems have to be developed. GEN IV reactor designs are closely related to the choice of the nuclear fuel cycle with potential use of reprocessing and waste transmutation. Non-electric process heat applications are envisioned because of the availability of very high operating temperatures.

For the realization of the GEN IV visions listed in the SRA, with large demonstration plants and numerous supporting infrastructure projects, research facilities and the nuclear industry partners must obtain sufficient financial, material and human resources (HR). The ENEN-III project addresses the E&T efforts to respond the HR needs.

The learning outcomes for the training of engineers that are involved in the development and pre-conceptual design of GEN IV nuclear reactors were developed as a deliverable in ENEN-III [11]**.** The training scheme includes areas of interest that would give the trainees the possibility to find answers to the R&D challenges mentioned in the SRA.

All six GEN IV reactor types are targeted in this training scheme: the Sodium-cooled Fast Reactor (SFR), Lead-cooled Fast Reactor (LFR), Gas-cooled Fast Reactor (GFR), Very High Temperature Reactor (VHTR), SuperCritical Water Reactor (SCWR) and Molten Salt Reactor (MSR).

The domains where knowledge, skills and attitudes have to be developed are the result of a competency analysis and are listed in Table 1.

Table 1. Competency analysis for a GEN IV engineer

Knowledge	
	General knowledge on GEN IV systems and technology
	Design specific knowledge for the LFR
	Design specific knowledge for the SFR
	Design specific knowledge for the GFR
	Design specific knowledge for the VHTR
	Design specific knowledge for the SCWR
	Design specific knowledge for the MSR
Skills	
	Developing engineering tools necessary for the analysis of the design
	Working with Self-developed Engineering Tools or Off-the-Shelf Tools
	Working with nuclear design codes
	Cost Estimates (costs, time) for the Engineering Work
	Order Processing (Project Management)
Attitudes	
	Self-reliant in gathering knowledge
	Ability to transpose experience and knowledge from one specific technology to another technology
	Formal Quality Control of Result Reports
	Individual, Critical Examination of the Tasks
	Presentation and Documentation of Work Results
	Teamwork/Communication

According to experts, engineers involved in research into GEN IV reactor types need to have a basic training on the general aspects of GEN IV systems and technology. This knowledge area is relatively independent of the specific reactor type the engineers will be working on and is designed to give the trainee an overview of the challenges that exist in GEN IV design.

Next to this, for each reactor type (SFR, LFR,…), the learning outcomes for design-specific challenges were elaborated separately. Trainees could focus on the reactor type he or she is working on, but since the existing knowledge is limited and often issues are found to be common to the different systems, it can be of interest to study related systems in order to discover pitfalls in the design.

However, additional areas of interest have been considered as critical cross-cutting areas such as safety, materials, fuels and fuel cycle. As an example, for a job profile such as design engineer in material (or component) development or qualification, high level competences in structural materials may be needed, irrespective of any particular reactor family. Such engineers may have to shift their activity from one reactor type (Gen II, Gen III and Gen IV) to another one, according to industrial or R&D priorities.

The competence analysis represented in Table 1 was subsequently refined. The general knowledge area was devided into 11 areas of interest, listed in Table 2, whereas the design specific knowledge areas have been treated similarly for each GEN IV reactor type, focussing on the following five areas of interest:

- Core design
- Material challenges
- Primary Circuit design
- Instrumentation techniques
- Safety issues related to the coolant.

Table 2. Areas of interest for general knowledge on GEN IV systems

General knowledge on GEN IV systems and technology
Introduction to GEN IV systems and technology
Introduction to the LFR
Introduction to the SFR
Introduction to the GFR
Introduction to the VHTR
Introduction to the SCWR
Introduction to the MSR
General safety features of GEN IV systems
Structural materials for GEN IV reactors
Fuels for GEN IV reactors
GEN IV and the closed fuel cycle

As a final step, learning outcomes for every area of interest needed to be developed, taking into account the fact that learning outcomes have to describe a concrete and measureable behaviour (*What is the trainee able to know/do after completing the module?*). In the ENEN-III project, the Bloom taxonomy [12] has been used to generate learning outcomes in the cognitive (knowledge), psychomotor (skills) and affective (attitudes) domains.

An example of the learning outcomes for the first area of interest is given in Table 3.

Table 3. An example of learning outcomes in the ENEN-III project.

Area of interest	**Learning outcomes**
Introduction to GEN IV systems and technology	1. Describe the different generations of nuclear reactors 2. Explain the need for GEN IV reactors 3. List the main issues assigned to GEN IV reactors 4. Describe the 6 main concepts selected by the GIF. In particular, for each of them, indicate neutron spectrum and the nature of primary coolant. Comparison of the advantages and disadvantages of the different systems. Open issues in the development of the different technologies. 5. Compare GEN IV with GEN II and GEN III reactors. 6. Compare the potential of the 6 GEN IV systems in terms of economics, safety, sustainability and proliferation resistance. 7. Asses the economic aspects of GEN IV systems 8. Give an overview of international networks and research infrastructures for GEN IV systems 9. Discuss the different construction codes that can be used to design these systems with their advantages, disadvantages and shortcomings.

In parallel to the knowledge domain, the skills and attitudes domains have also been divided into several areas of interest for which learning outcomes have been developed (see Table 1.) The skills categories can also be summarized in the following areas:

— Analytical Skills

Engineers working on GEN IV should be able to solve analytical complex thermo-hydraulic problems. The capability of using advanced tools like Vantage Plant Engineering Systems for example CATIA or thermo-hydraulic codes like RELAP (CATHARE,…) should be a self-understood skill for this category of engineers. Or the engineers should be able to develop their own tools or improve/adapt existing codes in case that existing tools do not exist or are insufficient to solve the specific problems.

— “Hands On” Skills

The learning outcomes in the area of “Hands On” skills are most suitable to be achieved during experimental work and practical training at small scale facilities and simulators.

— Communication and Organizational Skills

In an R&D environment, communication and organizational skills are essential in order to promote successful collaboration between researchers that are part of different units or institutes. The GEN IV projects generally are complex projects dealing with cross-cutting disciplines, involving partners from different countries. All engineers working on these projects will benefit from acquiring the skills addressed in this area of interest.

The different learning outcomes for every area of interest will not be explained in detail in this paper, but can be consulted in [11].

5. Implementing the training scheme

The technological challenges characteristic to the design of all different GEN IV reactor types are highly complex and demand specialised, multidisciplinary and cross-cutting knowledge and skills. Therefore the training scheme can only be open to at least nuclear engineers or engineers with an additional nuclear education. It should be noted that the best training scheme may differ from one job profile to another. The different areas of interest should thus be considered as elementary modules to be assembled in an optimized manner.

After the defnition of the learning outcomes for each area of interest, a survey was conducted to identify possible training activities among the project partners that could be used in the training schemes. The available courses were collected for each of the four training schemes and displayed in a database.

Within the ENEN-III project, 14 trainees among the different project partners are identified to test the proposed training scheme on GEN IV reactors. These trainees are allowed to attend different training activities in the framework of their CPD. Several documents have been created to monitor the participation of the trainee in the training scheme. The porfolio of documents for each trainee consists of:

(1) *The Europass CV* [13]
A document which gives a comprehensive picture of the competences and qualifications of a trainee.

(2) A document called *'My Learning Outcomes'*
In this document, the learning outcomes for the chosen training scheme are evaluated with respect to the background of the trainee. Each of the learning outcomes needs to be listed as 'achieved' or 'to be achieved'. This is done using face-to-face interviews with the trainees and their supervisors.

(3) A document called *'My Action Plan'*
Where training activities are listed that should lead to the development of missing learning outcomes. These activities could be: theoretical training sessions, practical training sessions, seminars, workshops, case studies, technical visits, on-the-job training, ...

In addition, each portfolio should be completed with the relevant certificates of attendance, test results, reports, etc. This portfolio will form the basis to move towards an accreditation structure for the recognition of the acquired learning outcomes.

The ENEN-III project is scheduled to end in April 2013 and therefore only preliminary conclusions on the implementation and evaluation of the training schemes can be made.

An important observation is the fact that training courses on specific GEN IV topics are very rare. From our survey on existing training courses among the 19 project partners, it was shown that basic courses in nuclear engineering and courses targeting issues related to GEN III nuclear reactors are regularly offered, especially for the knowledge domain. Training courses on GEN IV are offered only seldom, mainly because this subject is still much more research oriented and the relevant competences are scattered among very few research institutions or universities. Cutomized training courses should therefore be developed, but this is a time and resource consuming activity, that not all institutions want to take up.

6. Conclusions

In a world of dynamic markets and with an increasing need of mobility of nuclear professionals, a coherent and harmonized approach of training practices and skills recognition is crucial. The technological challenges, corresponding to the construction and design of novel nuclear reactor systems (GEN III and GEN IV), are driving the need for competent and highly qualified nuclear professionals. Novel E&T programmes need to be developed by the nuclear stakeholders, to ensure that life-long learning is promoted among the workforce.

Essential in such an approach is the use of learning outcomes instead of learning objectives to develop training schemes. They will enable training course designers to develop their courses with a direct link to job profiles and they can improve the transparency of qualifications. They contribute to the mobility of professionals by facilitating the recognition of competences.

The ENEN-III project has proposed and tested a framework for the development of such training schemes, based on a consensus between academic and research institutions and industrial partners. The first results have shown that the development of knowledge can be easily achieved within existing frameworks. However, the development of skills and attitudes are much more demanding, since they are linked to the psychosocial and emotional profile of a trainee.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the European Commission for funding the ENEN-III project through the 7th Framework Programme Theme: Fission-2008-5.1.1, Grant Agreement no. 232629. They also would like to thank all ENEN-III project partners for their valuable contributions and support.

REFERENCES

[1] http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/enen-iii.html
[2] http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7.html
[3] http://enetrap2.sckcen.be/
[4] http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/petrus.html
[5] http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/trasnusafe-fp7.html
[6] http://cinch-project.eu/
[7] European Credit Transfer and Accumulation System (ECTS), ISBN 92-894-4742-7, EC 2004
[8] Official journal of the European Union, *Directive 2006/962/EC on key competences for life-long learning*, 2006
[9] IAEA, *Nuclear Power Plant Personnel Training and its Evaluation*, Technical Reports Series No. 380, IAEA, Vienna (1996)
[10] www.snetp.eu 'SRA: Executive summary', May 2009
[11] T. Berkvens, C. Renault, ENEN-III, Grant Agreement no. 232629, Deliverable 1.5, *Training scheme for the development and pre-conceptual design of generation IV nuclear reactors*, May 2011
[12] D. Kennedy, Á. Hyland, N. Ryan, *Writing and Using Learning Outcomes: a Practical Guide*, EUA Handbook 03/20/2009
[13] http://europass.cedefop.europa.eu/en/documents/curriculum-vitae

SAFE MANAGEMENT OF FAST REACTORS: *towards sustainability*

Andrejs Dreimanis

Radiation Safety Centre of the State Environmental Service
Riga, Latvia

Abstract. An interdisciplinary systemic approach to socio-technical optimization of nuclear energy management is proposed, by recognizing a) the rising requirements to nuclear safety being realized using fast reactors (FR), b) the actuality to maintain and educate qualified workforce for fast reactors, c) the reactor safety and public awareness as the keystones for improving attitude to implement novel reactors.

Knowledge management and informational support firstly is needed in:

1) technical issues**:** a) nuclear energy safety and reliability, b) to develop safe and economic technologies;
2) societal issues: a) general nuclear awareness, b) personnel education and training, c) reliable staff renascence, public education, stakeholder involvement, e).risk management.

The key methodology - the principles being capable to manage knowledge and information issues: 1) a self-organization concept, 2) the principle of the requisite variety.

As a primary source of growth of internal variety is considered information and knowledge. Following questions are analyzed indicating the ways of further development:

a) threats in peaceful use of nuclear energy,
b) basic features of nuclear risks, including terrorism,
c) human resource development: basic tasks and instruments,
d) safety improvements in technologies,
e) advanced research and nuclear awareness improvement

There is shown: public education, social learning and the use of mass media are efficient mechanisms forming a knowledge-creating community thereby reasoning to facilitate solution of key socio-technical nuclear issues: a) public acceptance of novel nuclear objects, b) promotion of adequate risk perception, and c) elevation of nuclear safety level and adequate risk management resulting in energetic and ecological sustainability.

1. Introduction

Today, together with a common rising tendency of globalization of our world there also appear crucial global changes in nuclear energy activities, aimed to increase the scale, efficiency and safety of peaceful use of nuclear energy with the final goal to contribute to further sustainable development of our world.

Taking into account that production fossile-based energy progressively leads to degradation of our global environment, one of reliable ways towards sustainable development seems to increase the relative weight of the nuclear energy. As the next generation fast nuclear reactors, owing to their design safety and economic advantages, seem to be the most efficient candidates in strengthening energetic sustainability, the development of fast reactors should be guided – first of all, at increasing their operating safety [1]. On the other hand, nuclear energy also brings real as well as imagine risks to global security and environmental safety, controversies of various nature emerged due to the use of nuclear energy in various peaceful and warlike aims.

Furthermore, high complexity and specific characteristics of nuclear energy and its management modes leads to aggravated public perception of associated risks, and such public perception of nuclear risks essentially differs from their scientific evaluation. Moreover, one of the main features of nuclear risks – low probability of accidents, together with their heavy global character with long-term harm effects. Such permanently growing public concern about possible nuclear risks and decision making policy in nuclear areas may endanger forthcoming development of novel projects of efficient use of nuclear energy.

Such real and supposed nuclear risks and the growing complexity of nuclear energy management on the whole forces us to develop novel forms of complex problem solution, decision making and social communication approaches with the final aim to gain public confidence to find reliable and confident solutions of forthcoming use of nuclear energy, thereby, strengthening the basic conditions of sustainable development of mankind and assuring the global society in the safety of nuclear energy activities.

As a possible way towards solution of these problems one can propose to develop an interdisciplinary systemic approach to societal optimization aspects of nuclear energy management, including risk perception communication Recognizing a key role of education, communication and knowledge about nuclear energy issues in improving public attitude we propose a synergetic approach to societal-technical optimization of nuclear energy management together with considering the further development of basic components of nuclear energy sustainability [1].

2. Current problems and threats in peaceful use of nuclear energy

2.1. Operational safety and accident prevention

A series of fundamental problems and controversies of various nature emerged due to the use of nuclear energy in different peaceful and military purposes, including: a) political and environmental inter- and intra-national concerns about nuclear power plant safety, b) the treat of proliferation of weapons of mass destruction and to global security, c) environmental and security problems related to safe transport and disposal of radioactive waste, d) psycho-social problems of risk perception and acceptance of official nuclear energy management policy and projects.

The basic issue and aim of nuclear power plant (NPP) safety consists, first of all, prevention of nuclear accidents and incidents, in order to ensure people life and health, environment and economics. They can have also significat transboundary effects (as in the Chernobyl case) and raise the concerns of the public about the safety of nuclear energy and the radiological effects on people and the environment [2]. Among the main components of the NPP operational safety failures one should accent following ones –

a) external disasters (earthquakes, tsunami, floods),
b) human factors: errors, human resources with the knowledge, skills and access to information enabling them to perform effectively, and
c) technical incompleteness (hydrogen formation in light-water reactors; probable recriticality and core disruptive accidents in developing sodium fast reactors) [3].

2.2. Nuclear terrorism threats

Nowadays the nuclear threats have following significant forms: a) a set of heavy hazards caused by the attack on, or sabotage of, nuclear facility or a transport vehicle; b) the acquisition of nuclear weapons by the theft; c) manufacturing explosive devices using stolen nuclear materials; and d) the use of radioactive material in radiological dispersal devices.

Due to the increasing globalization tendencies, in particularly, global communication activities and the spread of secure nuclear information and technologies, a remarkable part of countries have potential capability to acquire nuclear material and technologies and, thereby, in future to become even a new nuclear proliferation centre to other new countries.

Attacks on nuclear power plants, research reactors, nuclear fuel processing and storage facilities - could bring about heavy damages and disruptions, large economic losses, and have potentially very significant health impacts, bringing giant releases of radioactive material into environment. Besides, attacks on facilities such as spent-fuel storage sites may endanger the nuclear safety and security also due to the fact that such storage areas are generally in a lesser extent protected against various attacks and impacts in comparison to NPPs.

2.3. Transportation threats of nuclear materials

Among the nuclear threats and risks, the transportation of nuclear materials pays especiall attention in order to protect them from the probable attacks and consequent theft**,** taking into account relatively weak possibilities to protect radioactive material when it is on the road. Besides, plutonium reprocessing from spent fuel and its recycling also requires intensive security measures, because these activities create much higher risks in comparison to those when the plutonium is located in massive fuel assemblies in the NPP reactor core zone having multiple radiation and physical protection

2.4. Environmental pollution – nuclear discharges and waste management.

Always an aggravated nuclear safety concern were the actual and potential releases (especially uncontrolled) of radioactive material, leading to off-site contamination of environment as well as radiation exposure of people. While planned radionuclide emissions during NPP routine operation regime are controlled and restricted to prescribed levels via all available technical and legal instruments, a serious problem still remains exceptional emissions of radioactivity during NPP accidents, thereby endangering the human health and their life quality by polluting environment and finally – worsening public attitude to peaceful use of nuclear energy.

Currently a still unsolved technical and societal issue remains safe mangement and disposal of the spent nuclear fuel and high-level radioative waste (HLW) originating the NPP operation. Besides the necessity to develop geogical repositories for the spent fuel and HLW safe and secure disposal, the international context of the spent fuel transportation for reprocessing as well as forthcoming anticipated shipments to regional geological disposal sites often provokes serius resident objections and potentially – even intergovernmental discrepancies.

2.5. Human factors

The known NPP nuclear accidents emphasized the high importance of maintenance and developing also appropriate human resources in the nuclear safety and nuclear emergency preparedness. Only highly qualified and regularly trained personnel is able to ensure the performance of NPP operation without human errors. On the other hand, the growing public concern about possible nuclear risks manifesting in real risks and nuclear threats as well as imaginary risks nuclear fear originated due to inadequate risk perception - may endanger forthcoming acceptance and development of novel advanced projects of efficient use of nuclear energy.

3. Societal optimization of nuclear activities - methodology

3.1. The necessity of societal approach

Large experience accumulated in nuclear energy management and the studies on societal issues in this area show that nowadays there is difficult to perform main tasks of nuclear energy management and, especially – to develop and implement novel nuclear facilities (NPPs, radioactive waste (RW) repositories, etc.) without involving society. On this basis one can suppose predominance of societal factors in solving the nuclear energy issues, especially those related to siting of nuclear objects. Thus, as a key to modern governance of nuclear energy management could be considered stakeholder involvement, having been already widely acknowledged in international binding documents [3-5], forums and research studies [6-8].

However, in parallel with implementation and observing legislative instruments – national and international – efficient involvement of various groups of stakeholders having different interests and, thus, development of socially favourable and technically advanced nuclear projects requires to promote approaches, based on stakeholder education, information, communication and interactions.

3.2. Stakeholder awareness level – the key parameter of societal optimization

Inter-disciplinary complexity and special characteristics of nuclear energy management leads to aggravated public perception of associated risks and such public perception of nuclear risks markedly differs from scientific assessment of these risks. The important role of public education, distribution of all relevant information and development of communication options in the areas of the spent nuclear fuel and RW management safety has been underlined, in particular, via setting up a requirement to make information on the safety of nuclear objects available to public [3, 4].

Being aware of decisive role of public learning and informing as well as society participation, our approach to societal optimization of nuclear energy management is to analyze the role of knowledge and information in the development of solutions to the complex socio-technical problems of the management safety. For our approach, let us take into account that: i) the public awareness and knowledge level about nuclear energy management problems is different, and ii) the inherent incompleteness in data on nuclear safety. On the basis of these premises, as the key principles in our approach we choose the principles which could manage with the qualities knowledge and information qualities: a self-organization (SO) concept, 2) the principle of the requisite variety.

3.3. Synergetic and the principle of requisite variety

As nuclear energy management problem nowadays has acquired a multidisciplinary nature, thus, can be considered as an object of an interdisciplinary science – synergetic [9] being a tool for description of complex system evolution. Due to growing social activity also in the nuclear area, there is swelling such global tendency of as a shift from relations based on separation, control and manipulation towards participation, appreciation and SO [10]. It is well known that development of qualitatively novel structures is associated with SO processes - spontaneous creation of a collective order out of the local interactions between initially independent components, and basic mechanisms of SO [11] can be attributed also to information phenomena [12]. Taking into account the decisive role of information and knowledge in the management of stakeholder involvement and participation, our task could be specified as to apply the synergetic concept, namely – SO – to information and knowledge aspects [12], with the aim to consider the key societal nuclear energy management issues.

For our aims we use also the relevant *"principle of SO"* [13] stating that „a dynamical system, independently of its type or composition, always tends to evolve towards a state of equilibrium". Thus, the further step in our approach we will base also on the adaptation concept: „if we consider a particular part of the original, self-organized system as the new "system", and the remainder as its "environment", then the part will be necessarily adapted to the environment" [13].

Using such a self-organized nature of adaptation as a basic criterion of social optimization we choose the principle of requisite variety, stating: *for successful development of a given system (e.g. human being(s)) in external environment its inherent variety should exceed the variety of its environment"*. In such an approach enabling us to consider the problem of social optimization as a problem of social adaptation we should to specify a real content of the meanings of: i) *external environment*, ii*) internal complexity*, iii) a *given system*.

3.4. Self-organization of Stakeholder Community

Taking into account the drastic expansion of the problem area related to nuclear energy management, in particular, the marked changes in the societal environment for decision making in siting of nuclear facilities [14], let us define - in the analogy with the concept of human's three worlds [15] the concept "external environment" as an non-equilibrium creation including: (1) the natural environment, (2) the social world, (3) artificial environment – a set of objects and conditions emerged as the result of human activities. In such an extended definition the concept "external environment" includes a set of physical, ecological socio-economic and other factors. Thus, a necessary condition of successful adaptation to a changing *external* environment and optimization of interactions with such environment will be the predominance of humans' internal complexity over the environmental complexity.

The growing complexity of the external environment markedly displayed in the decision-making on siting of facilities, demands to develop approaches to manage the societal requirements to the siting of new nuclear facilities. Emphasizing here two key factors - information and knowledge - via which we relate to our environment by SO processes [16] and taking into account that the knowledge about the world contains possible interactions between subjects, we can propose to reveal relations between different stakeholder groups and their concerns and to find out possible forms of SO of such stakeholder groups into a joint stakeholder community having common strategic aims. Such a joint stakeholder community including all involved parts participating in decision making is considered as the *given system*.

4. Social learning and optimization of risk management

4.1. Social learning – basic mechanisms and tools

Accordingly, our task of optimization of stakeholder involvement can be formulated as the need to develop activities increasing the internal complexity of the joint stakeholder community. Viewing knowledge as a complexity factor, all available forms of stakeholder involvement, their education and mutual interactions can be classified as mechanisms of societal optimization, increasing the internal complexity. First of all, it can be achieved via social and mutual learning, thereby activating and diversifying interaction between stakeholders. A key mode of this interaction can be seen as the recognition by operators and regulators of the need to contact other stakeholder groups - to increase their knowledge level and to enhance mutual understanding. As the knowledge itself is able to self-organize [17], the whole process of mutual learning and educating of stakeholders can emerge in a *knowledge creating stakeholder community* being capable to use novel communication and knowledge management forms [18], for example, the Internet, being a global socio-technical system, where humans permanently recreate the global knowledge storage mechanism by producing new informational content [19].

Due to giant complexity, these global web networks have certain SO properties, including self-adaptation to changes in operating environment, to self-healing, and – just the internet will facilitate SO of a social community in a self-organized social network. Thus**,** Internet as a modern communication networks can be considered as an important case of SO, thereby facilitating [11] information retrieval. In particular, for the case of geological repository development such web-based approach, being an advanced way for all stakeholders to access permanently updated data, has already been developed and applied with the aim to provide socially informed decision making [18].

4.2. Optimization of risk perception

The role of social learning soundly appears in risk communication. So, importance of uncertainties management displays in: 1) confidence building for safety assessments, 2) in the decisive role of the unknown factors [20] in determining risk perception by the public, 3) in the social learning where the basic component of social learning can replenish – adaptation – by handling uncertainty [21] – deficiency in the necessary information. Thus, as the perceived risk of a nuclear facility could be regarded as a function of the knowledge of facility issues [20], the role of social learning in solving risk perception issues can be shown in the following way: the unknown factor of perceived risk can be diminished via social learning where affected communities become familiar with nuclear issues.

There is also another side of social learning: the ability to understand how the community perceives all possible as well as imaginary risks. To reach such understanding one could propose a program aimed to identify public and other stakeholder concerns. This could be achieved by increasing – via versatile communication and stakeholder involvement – the levels of such trust components [22] as openness, caring and competence enabling to include these items in the decision-making mechanism and raising the decision-making capacity of stakeholder community and public acceptance.

In addition, efficient risk management requires to maintain a deliberate balance between nuclear safety and nuclear security, thereby protecting the security of classified information while ensuring the necessary safety level, besides providing transparency of all essential safety issues as well as the wide presentation of all lessons learned, relating to both safety and security, are shared for the benefit of the entire nuclear community.

4.3. Further development of human resources

The Fukushima NPP accident has re-emphasized the vital importance of developing human resources in the fields of nuclear safety and nuclear emergency preparedness in order adequately to react to a potential NPP accident. In line of the elaborated concept of information and knowledge role in optimization of risk management and finally – fostering safe management of nuclear energy, exclusively important task consists in preparing and preserving for NPP and other nuclear facilities highly professional personnel having advanced reliable knowledge and skills allowing the personnel to operate effectively.

This aim seems to be achieved mainly via following means [23]:

a) education at all levels, using modern education networks, as the European Nuclear Education Network, the European Nuclear Energy Leadership Academy, the World Nuclear University;
b) training – for all categories and ages of nuclear workers, in the frame of International Atomic Energy Agency (IAEA) training courses; besides, in Europe – in four European Fission Training Schemes projects: for nuclear engineering, for radiation protection, for geological disposal of radioactive waste and for the nuclear safety culture;
c) research and knowledge management, using contemporary international databases, electronic communications portals and capabilities of specific projects, e.g., in the frame Euratom Framework Programmes, as well as other research projects.

In line of the general concept of human resource development in nuclear technologies containing a requirement to maintain knowledeges and competences in current technologies as a basis of their furher improvemt and development [24], a specific Fast Reactor Knowledge Preservation (FRKP) Initiative [25] has been launched by IAEA with the to develop and preserve Fast Reactor Data and Knowledge and finaly to create an International Knowledge Base for fast reactors

5. Techical development of nuclear technologies

Crucial progress in improving safety level of nuclear energetics consists in currently developing new generations of nuclear reactors, namely, third and fourth generation. Quite important characteristic of these novel generation types of nuclear reactors - they have in common is passive safety systems, requiring no operator intervention in the event of a major malfunction [3].

In particular, the third-generation reactors EPR (European Pressurized Reactor) have such essential safety improvementsas : a) double containment of the reactor building with ventilation and filtration, b) core catchers; c) reduced possibility of core melt accidents; d) containment heat evacuation system; e) redundancy: four trains of the main safeguard systems.

Recently OECD/NEA [26] has pointed out that the theoretically-calculated frequency for a large release of radioactivity from a severe nuclear power plant accident has reduced by a factor of 1600 between the early Generation I reactors as originally built and the contemporary NPPs.

Further development of nuclear energy sustainability – already in the frame of the fourth generation nuclear reactors – together with elaboration of new concepts for extension of fuel life and effectiveness, will proliferation resistance and the waste amount decrease includes also a new safety risk informed approach for the new generation reactors [27], with three goals for the 4-th genearation reactors in terms of safety and reliability [28] and four Safety Basic Principles, in particular, emphasizing the necessity to meet the safety requirements for the new generation reactors for the aims of their forthcoming commecialization [29].

6. Multilevel confidence building in nuclear activities

The world-wide scale of nuclear activities actualizes the importance of multi-level confidence building multi-level confidence building at:

1) global level, via
    a) United Nations activities aimed at reaching political settlement of controversies and discrepancies related to the use and proliferation of weapons of mass destruction, with a possible use of a novel approach – based on social self-organization – of minimization of controversies,
    b) IAEA activities aimed, in particular, at reaching safety and security of the use of nuclear energy and materials, at assurance of international community of peaceful use of nuclear materials as well as at efficient interaction and feedback with society;
2) regional level – seeking – via a two-way information exchange – for optimal solutions of safe management of nuclear power plant running, decommissioning and radioactive waste disposal, particular case studies being included in the Euratom Framework Programmes;
3) national level.

In the area nuclear energy management, just the IAEA activities are aimed at reaching safety and security of the use of nuclear energy and materials, at assurance of international community of peaceful use of nuclear materials as well as at efficient interaction with society. Activities of such bodies (established by IAEA) as the International Nuclear Safety Group (INSAG), the International Nuclear Information System (INIS) highly promote a) multinational cooperation, aimed to harmonize the global safety approaches and to improve the transparency of nuclear safety legislation, b) wide participation of stakeholders in the decision-making in nuclear matters, in order to maintain public confidence and to provide stability in decision-making, c) the increase of the nuclear knowledge and „awareness" levels about the use, safety, security of nuclear energy.

In order to strengthen nuclear safety, emergency preparedness and the people health and the environment worldwide, under the leading role of the IAEA has been commenced , the process of learning and acting upon lessons following the accident at Fukushima Daiichi Nuclear Power Station, having resulted, in particular, to acceptance of the IAEA Action Plan on Nuclear Safety [30] emphasizing, inter alia, that:

a) the necessity to ensure the highest standards of nuclear safety and for providing a timely, transparent and adequate response to nuclear emergencies, including addressing vulnerabilities revealed by accidents,
b) that the IAEA Safety Standards provide the basis for what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation, and will continue to be objective, transparent and technologically neutral,
c) transparency in all aspects of nuclear safety through timely and continuous sharing and dissemination of objective information, including information on nuclear emergencies and their radiological consequences, is of particular importance to improve safety and to meet the high level of public expectation. Nuclear accidents may have also serious transboundary effects; therefore it is important to provide adequate responses based on scientific knowledge and full transparency.

7. Conclusions

On the basis of contemporary non-linear science concepts, the decisive role of information and knowledge in the societal optimization of nuclear energy management area has been outlined. There are indicated possible ways to enable social learning, the recognition of stakeholder concerns as well as efficient risk communications. The following theses as a possible interdisciplinary approach towards societal optimization and confidence building in nuclear activities are forwarded and developed:

a) self-organized social learning, knowledge and risk management could promote adequate perception of risk and prevent, by diminishing uncertainties, social amplification of an imagined risk, as well as to increase the trust level and facilitate more adequate equity perception;
b) knowledge management, social learning and self-organized communication of all stakeholders will provide a reliable basis for a new integral type of thinking being so actual for successful realization of advanced nuclear projects being keystones of sustainable development.

The proposed approach could enable further systemic approach to social harmonization of nuclear issues, enhance the participation of society in decision-making processes and build public confidence.

At last, today, in conditions of growing potential treat of nuclear terrorism to global security as well as increasing range of use of nuclear energy and globalization tendency of such nuclear projects (e.g. international repositories for deep disposal of radioactive waste), one can argue that only on the basis of indicated above development of the inner humane variety it seems possible further successful advancement in developing the integrative system thinking approaches also to peaceful and humane application of the contemporary knowledge, in particular, in peaceful use of nuclear energy management, in order to fully comprehend the ideas of the Russell-Einstein Manifesto being now implemented by activities of United Nations, IAEA, European Commission and many other public institutions and organizations, aimed, in particular, at reaching safety and security of the use of nuclear energy and materials, at assurance of international community of peaceful use of nuclear materials.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems. INPRO Manual — Overview of the Methodology, IAEA-TECDOC-1575 Rev.1, vol.1, IAEA,Vienna (2008).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Declaration by the IAEA Ministerial Conference on Nuclear Safety in Vienna on 20 June 2011, *INFCIRC/821*; 2011.

[3] WORLD NUCLEAR ASSOCIATION, Safety of Nuclear Power Reactors, http://www.world-nuclear.org/info/inf06.html; 2011

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Convention on the Safety of Spent Fuel Management and on the Safety of RW Management, INFCIRC/546, IAEA, Vienna (1997).

[5] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, Århus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, (1998).

[6] OECD NUCLEAR ENERGY AGENCY, Stakeholder Involvement Techniques: Short Guide and Annotated Bibliography, Forum of Stakeholder Confidence, No. 5418, Paris (2004).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, “Nuclear Power for the 21st Century” (Int. Ministerial Conf.., Final Statement), Paris (2005).

[8] UNITED NATIONS, Report of the UN Conf-ce on Environment and Development (Rio de Janeiro, 1992), Annex I – ”*Rio Declaration on Environment and Development*”, *http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm*, 1992.

[9] MISHRA, R.K., et. al., eds., On Self-Organization: an Interdisciplinary Search for a Unifying Principle (Springer Series in Synergetics), Springer, Berlin (1994).

[10] STERLING, S., “Whole Systems Thinking as Basis for Paradigm Change in Education: Explorations in the Context of Sustainability”, Doctoral Thesis, htpp://www.bath.ac.uk/cree/sterling.htm

[11] HEYLIGHEN F., “The Science of self-organization and adaptivity”, *http://pespmc1.vub.ac.be/Papers/EOLSS-Self-Organiz.pdf*.

[12] HAKEN, H., ed., Information and Self-Organization: an Interdisciplinary Search for a Unifying Principle (Springer Series in Synergetics), Springer, Berlin (2000).

[13] ASHBY, W.R., Design of Brain – The Origin of Adaptive Behavior, Chapman & Hall, London (1952).
[14] OECD NUCLEAR ENERGY AGENCY, “Stepwise approach to decision making for long-term RW management: experience: guiding principles”, Forum of Stakeholder Confidence, No. 4429 (2004).
[15] POPPER, C., ECCLES, J., The Self and Its Brain, Springer, Berlin (1977).
[16] KEEL-SLESWIK, R., “Artefacts in software design”, Software Development and Reality Construction., (FLOYD, R., BUDDE, R., ZULLIGHOVEN, H., eds.), Berlin, Springer, (1992) 168-188.
[17] KOBSA, A., “Knowledge representation: a survey of its semantics, a sketch of its semantics”, Cybernetics and Systems, **14** (1984) 41-89.
[18] TAKASE, H., et.al.,”Development of on-line performance assessment system”, Environmental Remediation and RW Managm. (Proc. Int. Conf. Oxford (2003) (CD-ROM file ICEM03-4874).
[19] FUCHS, C., “The Internet as a Self-Organizing Socio-Technological System”, Cybernetics and Human Knowing, **12** (2005) 57-81.
[20] DESVOUSGES W. H., et. al., „Perceived risk and attitudes toward nuclear wastes: national and Nevada perspectives”, Public Reactions to Nuclear Waste (DUNLAP, R. E., et. al., eds.), Duke University Press, Durham (1993) 176-208.
[21] CONRAD, M., Adaptability, Plenum Press, New York (1983)..
[22] PETTS, J., “Trust and waste management information: Expectation versus observation”, J.Risk Research, **1** (1998) 307-320.
[23] YOSHIMURA, U., “Two questions to…”, Eurosafe Tribune - Innovations in nuclear safety and security, **19** (2011) 32.
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Status and Trends in Nuclear Education, Nuclear Energy Series No.NG-T-6.1, IAEA, Vienna (2011).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical Working Group on Fast reactors, Consultancy on „IAEA initiative to establish a fast reactor knowledge base”, Vienna 8-10 Dec 2004, TWG-FR—121, IAEA, Vienna (2011).
[26] OECD NUCLEAR ENERGY AGENCY, “Comparing nuclear accident risks with those from other energy sources”, No. 6861 (2010).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Proposal for a Technology-Neutral Safety Approach for New Reactor Designs, IAEA-TECDOC-1570, IAEA, Vienna (2007).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY - The Risk and Safety Working Group of the Generation IV International Forum, “Basis for Safety Approach for Design & Assessment of Generation IV Nuclear Systems” (2008).
[29] NAKAI, R., “Design and assessment approach on advanced SFR safety with emphasis on the core disruptive accident issue”, Fast Reactors and Related Fuel Cycles : Challenges and Opportunities (FR09) (Proc. Int. Conf. Kyoto 2009), IAEA, Vienna (2012) 207-220.
[30] INTERNATIONAL ATOMIC ENERGY AGENCY, „Draft IAEA Action Plan on Nuclear Safety”, Board of Governors General Conference. Report by the Director General. Summary item 3(b) of the Board's provisional agenda, (GOV/2011/46) (2011).