DE LA RECHERCHE À L'INDUSTRIE

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International Conference on FAST REACTORS AND RELATED FUEL CYCLES:
Next Generation Nuclear Systems for Sustainable Development
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Yekaterinburg, Russian Federation

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« Filling the gap; training Young people »

When there is necessity to « fill the gap »?

- When there are some changes in the policy of the Country/organization,
- When the « âge » pyramide induces important leaving flow from the organization

➔ Challenges for the organization:

- Preserve, transfer and share the knowledge (basic data and properties, processes, design rules, operational feedback...)
  - ➔ From Senior to Junior, skilled to newly involved
- Recruit young engineers - researchers
- Generate research activities in various scientific fields answering to the country's needs
- Generate interaction between young-new & skilled engineers – researchers
- ...

IN FRANCE (INCLUDING EUROPEAN PROJECTS SPX, EFR)

➔ Design & Operation: there was « continuity » from Rapsodie to Superphenix and EFR project: So, continuous process of knowledge transfer

1967-1983

Rapsodie

1973-2009

Phenix

2010-...

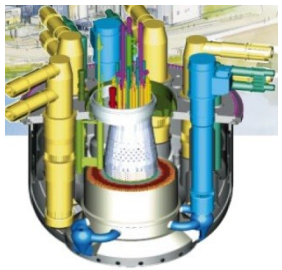
1985-1997

SPX

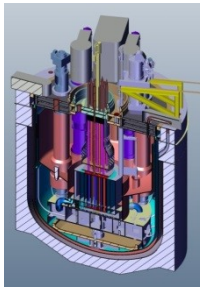
1998-...

1985-1998

EFR



ASTRID



2010-.....

➔ Decommissioning: continuity from Rapsodie to Superphenix & Phenix

➔ And also transfer of knowledge from operation to decommissioning and vice versa

1984-...

MAIN AXIS FOR KNOWLEDGE AND SKILLS MANAGEMENT 1/2

➔ **PhD studies, to develop the scientific skills of future CEA engineers-researchers**

➔ **Development of R&D programs on Phenix and associated feedback:**

Phenix: Material behaviour Assessment,

Safety Up-grading & Life duration extension

Irradiation program

End of Life Tests

(Ref JF Sauvage « PHENIX : 30 Years of history » , J. Guidez « Phenix: operational feedback »)

➔ **Mobility of young engineers from Cadarache to Phenix**

Participation to the Up-grading and the last years of operation (2005-2009)

➔ **Feedback from the Superphenix project** *(Ref J. Guidez, G. Prêle « SuperPhenix » Atlantic Press)*

SuperPhenix start-up operations and operation

SuperPhenix decommissioning

➔ **Mentoring of (young or newly involved) technicians (and engineers)**

Na facilities: qualification approach focused on operation, safety, for young/new technicians-operators

Transition from knowledge-based qualification system to the competence-based qualification

MAIN AXIS FOR KNOWLEDGE AND SKILLS MANAGEMENT 1/2

➔ **Involvement in other Generation IV systems : GFR, LFR, and ADS (ie Megapie...)**

Creating « bridges » and underlining commonalities between systems

➔**International collaboration :** China, Europe, India (Safety), Japan, Rep of Korea, Russia, USA; OECD, IAEA...

➔ **Education & Training :**

Na School (ESML), INSTN Cadarache: Sessions dedicated to Generation IV

EU projects, ENEN, Collaborations with JAEA (Na Schools), CIAE, IGCAR, Russia (TACIS), ...

IAEA Sessions (ICTP...),

GIF (Webinars)

➔**Knowledge preservation :**

CEA internal Data bases and French Nuclear partners data bases (ie SPX operational feedback)

Key rôle of OECD-NEA (Expert Groups, data bases, Hand-books, Books),

IAEA(INPRO, CRPs, LMFNS, FRKP portal..) Hand-books, NES, Tecdocs

GIF

PROGRAMS DEDICATED TO LIQUID METAL SYSTEMS

A key rôle for PHENIX between 1995 and 2010:

Phenix: Material behaviour Assessment:

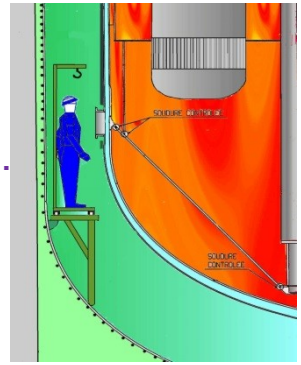
Evaluation of the performance of austenitic stainless steels:
satisfactory except Type 321 SS (cracks attributed to delayed preheat cracking).
Grades performing well include Types 304, 304LN, 316, 316L, and 316LN SS

➔ Feedback for material science & processes

Phenix: Safety Up-grading & Life duration extension

Given the evolution of the safety standards and construction rules:
2nd up-grading phase (from 01-1999 to 05-2003):
- Major seismic reinforcement, Na fire protection works
- Inspection of the conical shell, core cover plug...
- Adding a control rod (Complementary Shutdown System)
- Repair of the Steam-Generator modules....

➔ Feedback for ISIR, cleaning & decontamination, Na quality control...



Phenix : Irradiation program

- Irradiation programs : clad & structural materials, fuel, transmutation targets... ➔ Feedback for fuel cycle, scenarios, materials...

Phenix: End of Life Tests (next slide) **(open to international collaboration(CRP IAEA)**

➔ Feedback for Neutronics, Thermal-hydraulics, instrumentation..;

End of Life Tests in PHENIX: Objectives

- *Development of sodium fast reactors and their prototype ASTRID*
- *Additional validation of codes and investigations on Phenix negative reactivity transients*
- *Involvement of young engineers (TH, neutronics, instrumentation...)*

	Validation ERANOS DARWIN	Validation CATHARE TRIO_U	Validation GERMINAL	Investigations negative reactivity transients	Involvement of young engineers
Core physics (5 tests)	✓				✓
Thermal-hydraulic tests (2 tests)		✓			✓
Fuel test (1 test)			✓		✓
Negative reactivity transients tests (2 tests)				✓	✓

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BRIDGES AND COMMUNALITIES BETWEEN SYSTEMS (SIGNIFICATIVE IMPACT OF THE COOLANTS)

Scientific fields \ Coolant	Na	Pb-Bi	Pb	Gas
Materials				
Neutronics				
Thermal-hydraulics				
Mechanics				
Liquid metal chemistry				
Design rules, technology				
Instrumentation, ISIR				
Severe accidents				
Safety				

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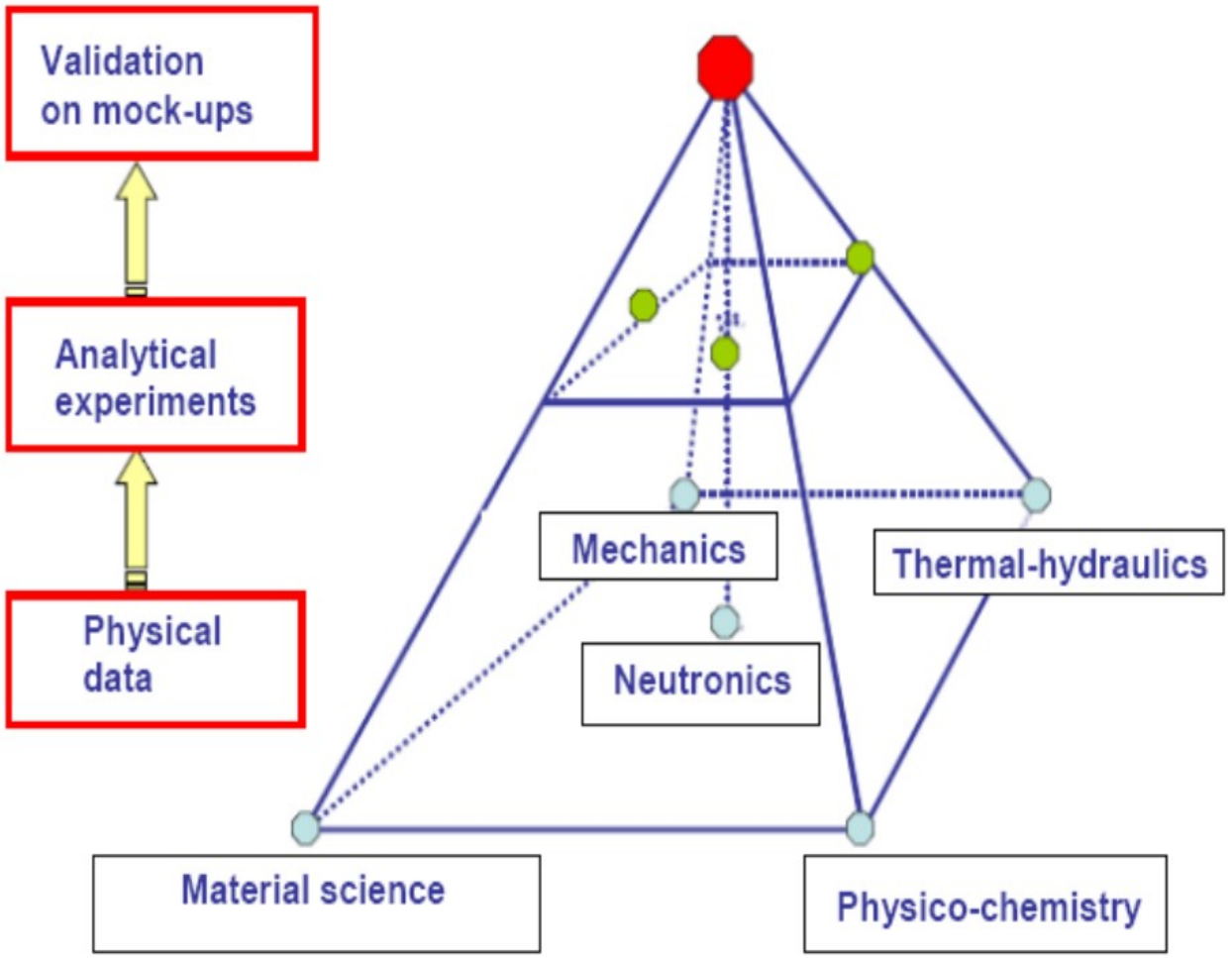


DEVELOPMENT OF SFR: STATUS

Reactor in construction phase

MBIR (Russia)
Multifunctional fast neutron sodium-cooled research reactor (2019)

Reactor in commissioning phase

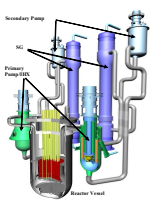
PFBR (India) 5OO Mwe (2017-18)

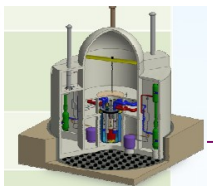
Reactor in decomissioning phase

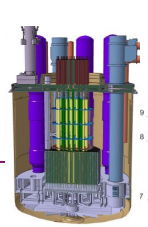
BN350 (Russia)
SPX, Phenix in France
MONJU in Japan

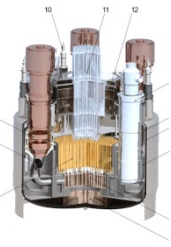
Reactors in operation

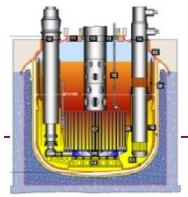
And new projects:
JSFR, CFR-600, PGSFR, ASTRID, BN1200, FBR1-2 ..









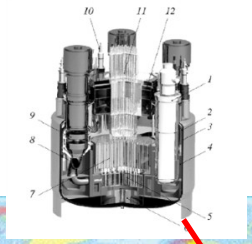


R&D COOPERATION IN SUPPORT TO SFR DEVELOPMENT

Europe : ASTRID

600 MWe

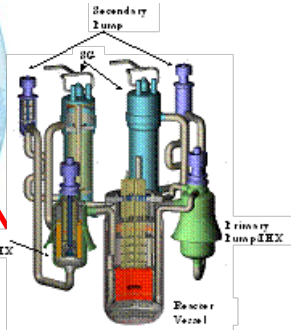
POCATOM



Russia : BOR-60, BN-600,

MBIR, BN-800, BN 1200

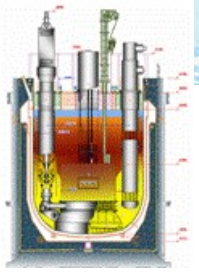
China : CEFR, CEFR-600, CDFR then CCFRs



JAEA

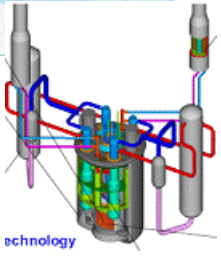
Japan : Joyo, Monju,

prototype JSFR



India: FBTR,

PFBR, then FBR1-2 (500 MWe)



Corea : KALIMER, PGSFR

KAERI

Korea Atomic Energy Research Institute

+ GEN IV International Forum

+ USDOE

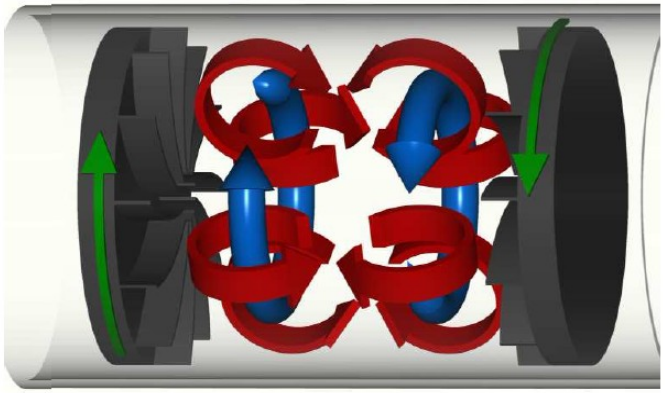
+ Europa (ARDECO)

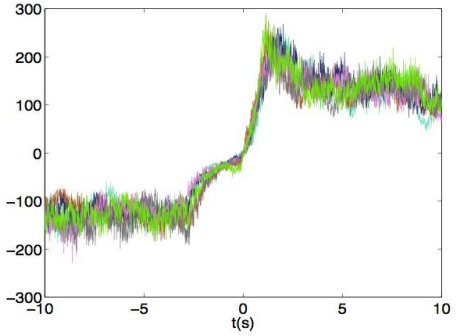
EERA

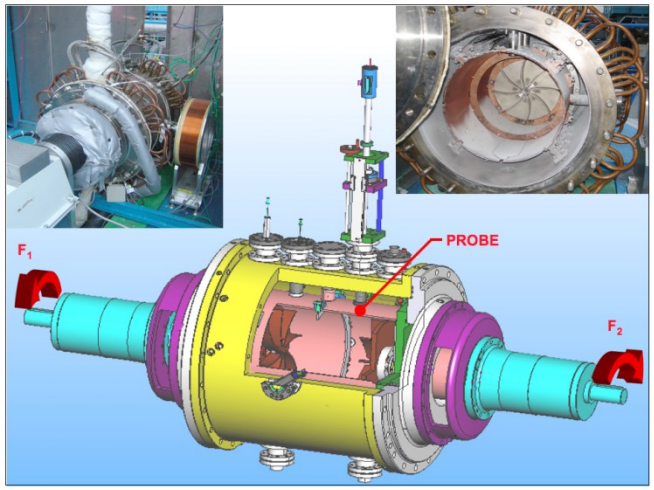
European Energy Research Alliance

Dynamo experiments with Na: VKS
a contribution also in CEA to keep theNa knowledge

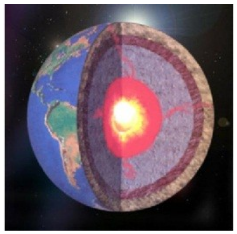
$R_m = 2\ \pi\ K\mu_0\sigma\ R^2 f$

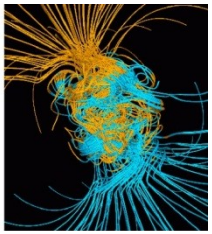


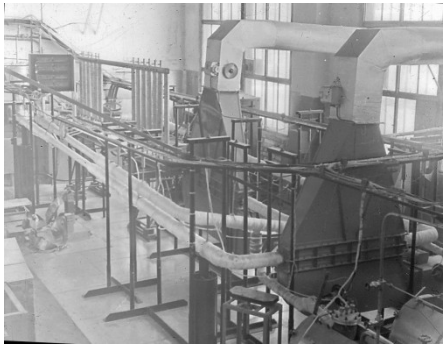




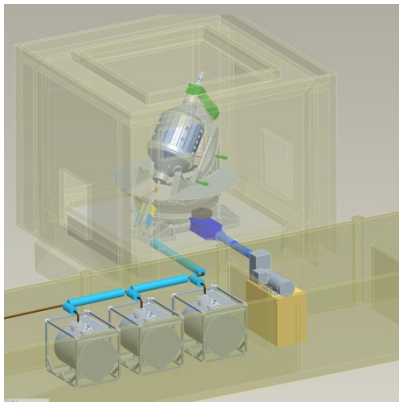
VKS in Cadarache





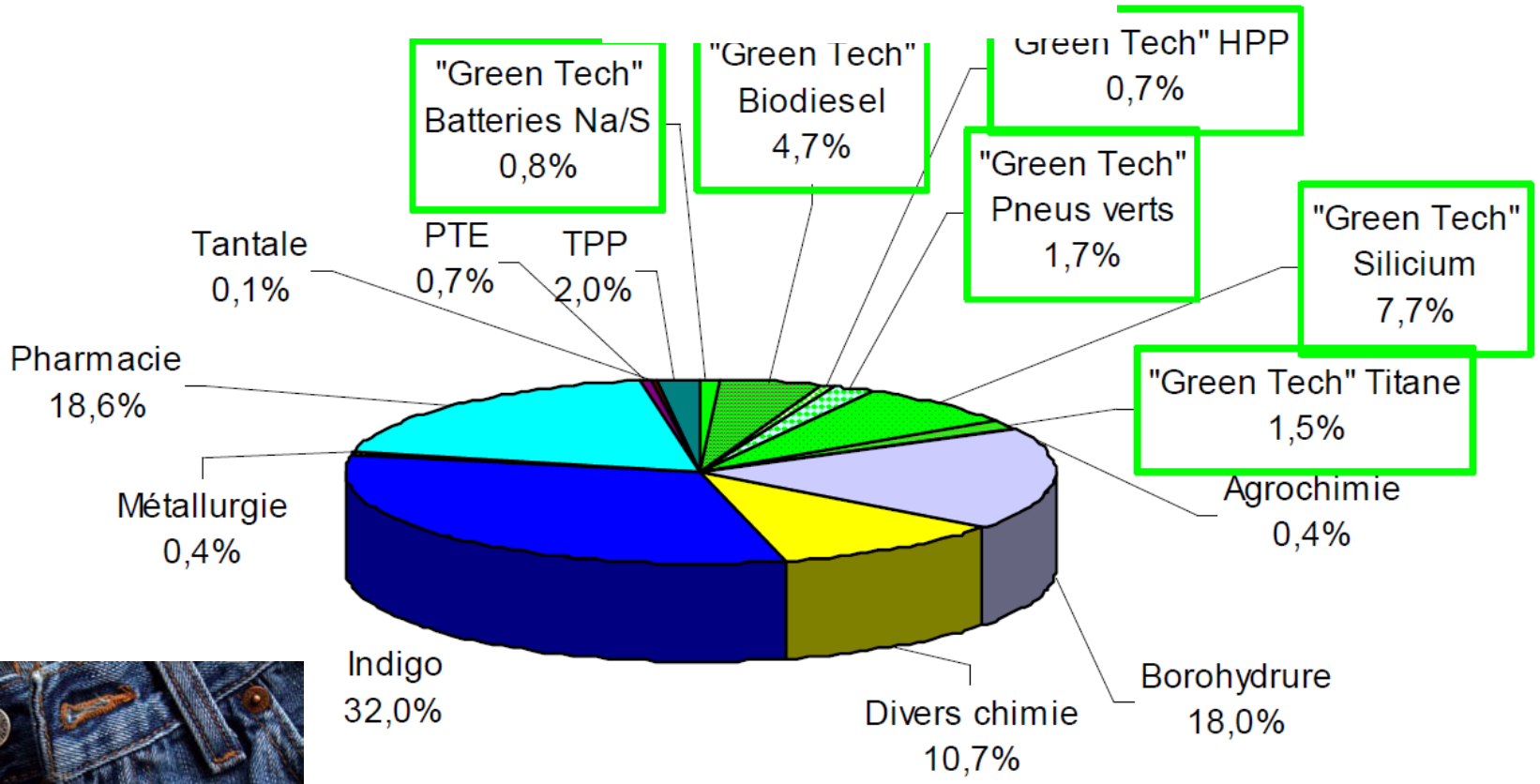


Na dynamo in IPUL (1991)



DRESDYN in HZDR

EXCHANGES WITH MSSA: SODIUM USES (COURTESY OF MSSA)
TECHNICAL EXCHANGES



Green Tech =17,2%

Some explanations:
-TPP triphenyl phosphine used for the synthesis of vitamin A
-HPP High Performance Pigment

Word production: ca 160 000 t/year

MAIN AXIS FOR KNOWLEDGE AND SKILLS MANAGEMENT

➔ **Education & Training :**

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EDUCATION & TRAINING - DISSEMINATION

- Na school (ESML-Cadarache)
- INSTN in CEA (Cadarache, Marcoule, saclay)
- European projects, ENEN, Collaborations with other « Na schools » (JAEA, IGCAR,..)
- Summer schools ie FJOH (KIT + CEA Cadarache), EU projects
- IAEA Seminars (dedicated sessions, ICTP Trieste...)
- Universities.....

Sodium School (ESML)

Initial goals of the Sodium School (ESML):

- **to synthesize knowledge**,
- **to share it between CEA Na facilities operators**,
- to train operators able to work on SFRs Rapsodie and Phénix,
- to train design engineers involved in Superphénix project and
- to train fire brigades.

➔ **Its role has always been to adapt its offer and its training content to the changing needs** for reactor operation, experimentation and for design activities, decommissioning….

Trainees from French companies such as CEA, EDF, AREVA, IRSN, operators & experts from foreign organizations (CEFR, MONJU, BN600, PFBR for safety…) or any companies involved in sodium activities belonging or not to the nuclear industry.

➔ **Since 1975, about 6000 trainees have received a training at the Sodium School**

Today: ten different sessions (from 1 to 5 days) focusing on main subjects:

physico-chemistry of Na coolant : physico-chemical properties, purification, corrosion, contamination, cleaning & analysis,

sodium technology: commissioning and operation, description and operation of components, instrumentation, visualization, ISIR, exercises : operating and intervention on the Na loop dedicated to Education & Training)

A school open to the world of SFRs:

At the early stage of its creation (1975), ESML intended to be opened to foreign countries.

Specific training sessions provided for:

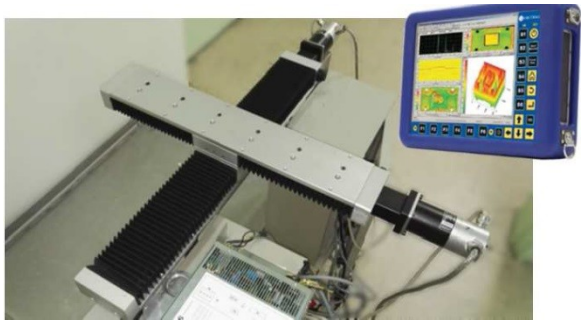
- German SNT300 operators (1983) (RFA),
- Japanese operators for the first start-up of Monju reactor (90's) (Japan)
- KEARI researchers (Rep of Korea)
- Chinese operators of CEFR (China)*
- IGCAR Researchers and operators (dedicated to Safety) (India)*
- BN600 Operators (TACIS project) (Russia)*
- PFR and DFR decommissioning project teams (UK).
- Chemical industry, such as Union Oil Products (USA)…

(* : in partnership with PHENIX Reactor)

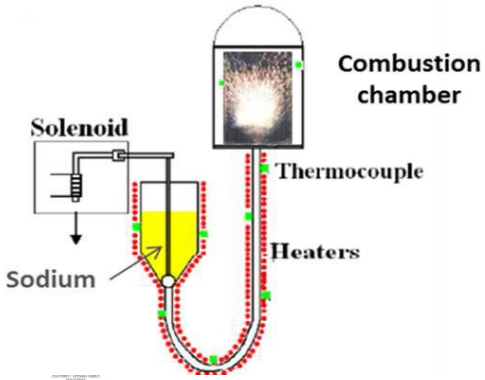
➔ The pedagogical approach consists in a combination of various educational means: lectures, discussions and Training on a Sodium loops.

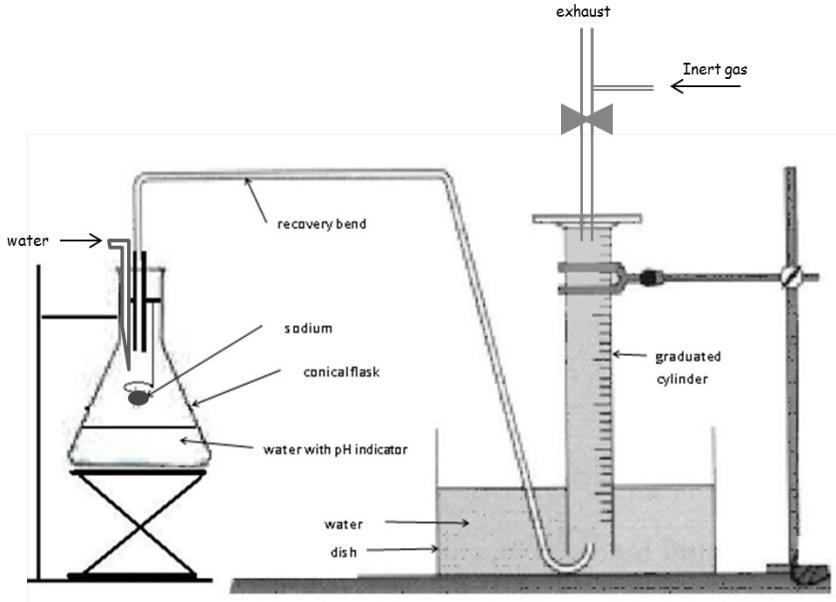
Since 1975, more than 5000 trainees from more than 50 companies or Institutions from France and abroad have received a training at the Sodium School.

Sodium School (ESML)



New benches





SODIUM SCHOOL IN CEA CADARACHE

Sodium School means

- ✓ **All the people delivering courses at the sodium school are engineers and technicians involved in sodium activities** in CEA Departments or at PHENIX plant
  - Quality teaching given by specialists
- ✓ **Teaching and transmitting the sodium technology knowledge is assumed both through theoretical lectures and practical exercises:**
  - Adapted means of communication
  - Practice exercise test rooms, using sodium circuits and specific instrumentation rooms
  - Sodium fire area, for training exercises
  - Cleaning area

INSTN & I2EN Education for students

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

➔ France has an important nuclear teaching platform organized around engineering schools, universities, research laboratories, technical schools and also nuclear companies or dedicated entities, for professional training.

In this context, I2EN, the *International Institute for Nuclear Energy* http://www.i2en.fr set up in 2010, is **federating French entities** delivering high level curricula in nuclear engineering and science and is promoting the French offer for education and training in partner countries.

Topics:

Safety, design and operation of nuclear reactors, materials, instrumentation and radioprotection, decommissioning, waste management, fuel cycle….

Education on SFR in INSTN-Cadarache

Within the frame of INSTN (Institut National des Sciences et Techniques Nucléaires) (http://www-instn.cea.fr),

➔ **Four sessions were successively prepared since 2007 and launched:**

- 1 SFR history, main options, design and operational feedback:
- 2 SFR functional analysis and design;
- 3 SFR safety and operation. (with SIRENA simulator)
- 4 SFR coolant-structure interactions

Sessions focused to the orientations of the Generation IV forum, operational feedback experience, functional analysis, design options and tools, circuit and plant operation with emphasis on transients, safety and commissioning aspects, visits (PHENIX, experimental facilities, Fuel laboratories…)

Sessions dedicated to EDF, CEA, AREVA, IRSN engineers, researchers, PhD….

The duration of both sessions is currently one week.

INSTN-Cadarache

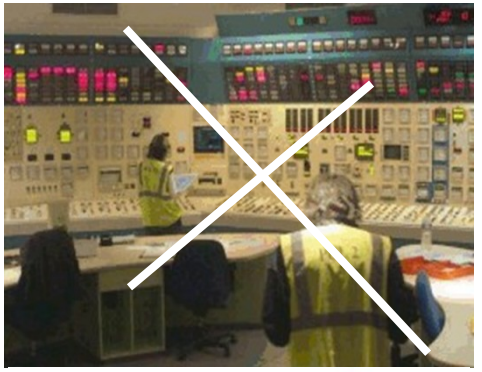
➔ **"Taylor-made" training sessions can be organized by INSTN in English for foreign partners**

➔ **INSTN-CEA/Saclay -** "GENERATION 4: Nuclear Reactor Systems for the Future"

- International courses on dismantling, waste management,…

SIRENA simulator

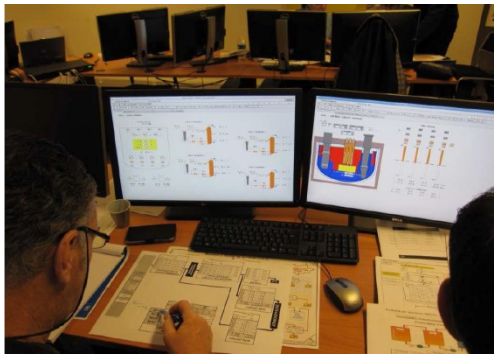
➔ **The SIRENA simulator: a tool for two needs: training of operators and/or students, studies (transient situations...)**
It is not a « full-scope » simulator (ie similar to a control-room)

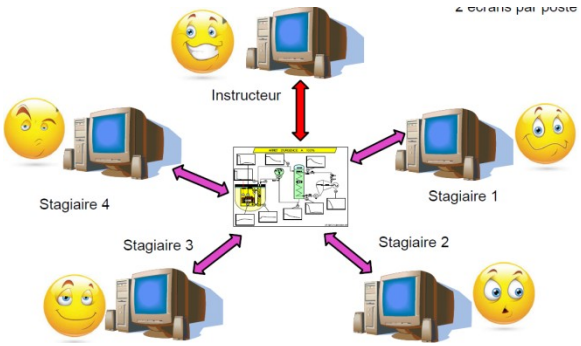


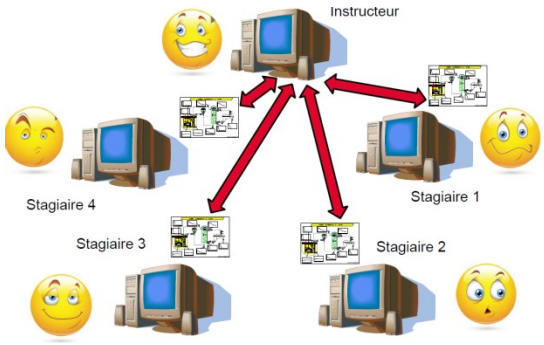
- Core with neutronic flux, reactivity, power,
- Primary circuit & intermediate circuits
- Energy Conversion System (1st Rankine cycle then Brayton cycle)
- Control rods, Safety complementary rods, Decay Heat Removal Systems
- I&C, regulation loops ...

➔ Steady-sate, normal and incidental transients

➔ One single or several distributed scenario



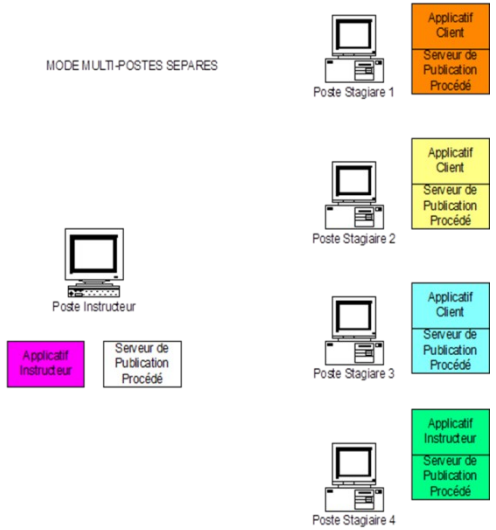


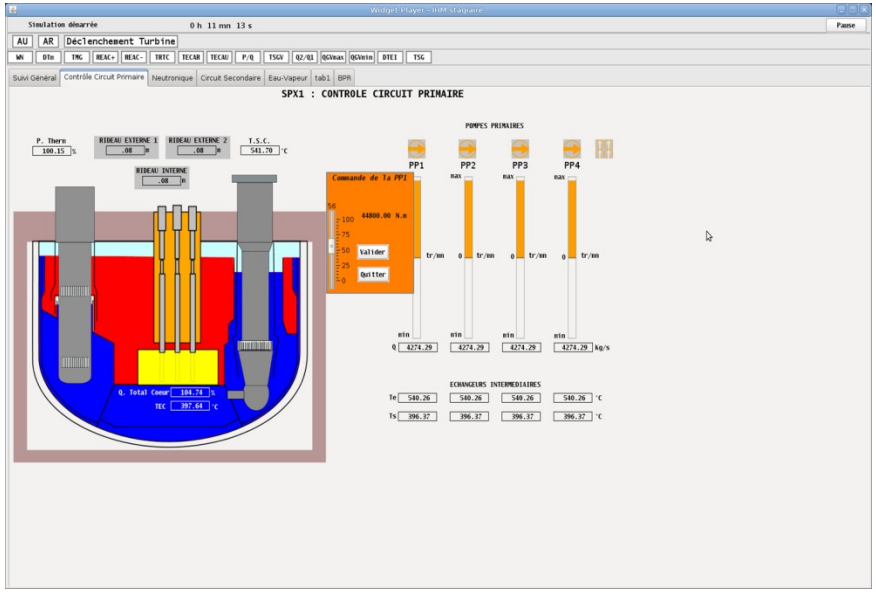


Full scope simulators

SIMFONIX, previously PHENIX simulator: a key tool during long term shut-down of Phenix

A nuclear reactor simulator is a tool that can meet both needs, training and education.
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.





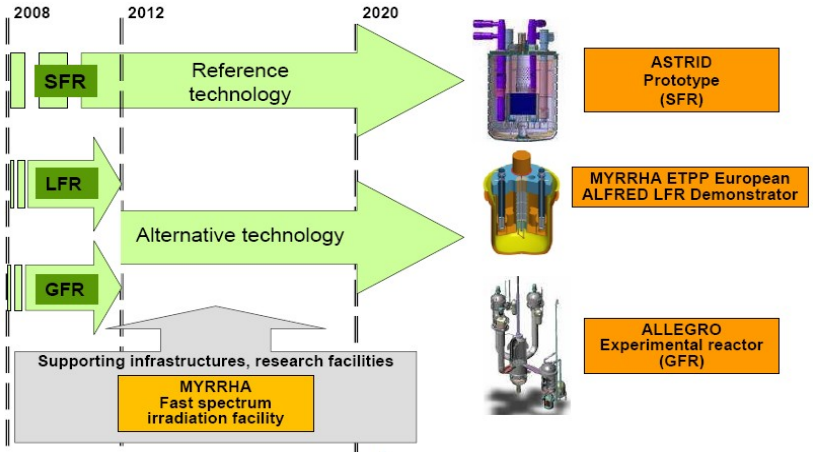
Europe (EU) : background

In Europe, the Strategic Research Agenda (SRA) of the

Sustainable Nuclear Energy Technology Platform (SNETP)

(100 stakeholders from industry and research organisations)

has selected **three Fast Neutron Reactor systems** as a key structure in the deployment of sustainable nuclear fission energy. ➔ **SFR is the reference technology.**



Several Education and Training initiatives are organized with the support of the European Commission to the **European Nuclear Education Network (ENEN),** and **within the frame of projects co-funded through the Euratom Framework Program (FP).**

➔ ENEN *Association*) http://www.enen-assoc.org (established in 2003) **to preserve and further develop expertise in the nuclear fields through higher education and training**

- ENEN currently has **over 60 members**, mainly in Europe. This objective is realized through the co-operation between universities, research organizations, regulatory bodies, the industry and any other organizations involved in the application of nuclear science and radiation protection.
- ENEN fosters student's mobility in Europe and beyond.

EU Education & Training initiatives within the frame of EU projects

ICN Romania

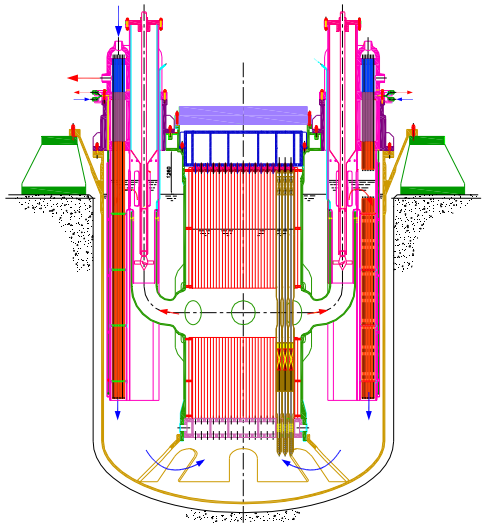
UJV Czech Rep.

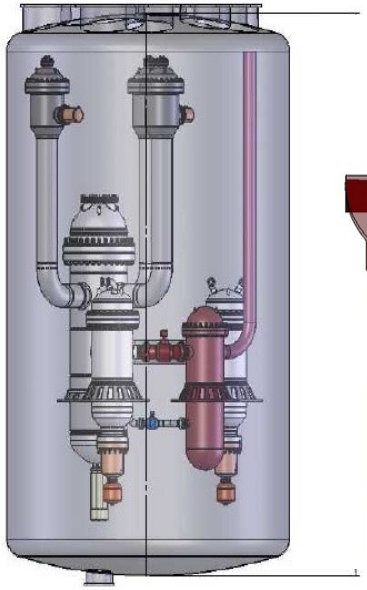
ESNII+ Seminars
➔ Favour exchanges between SFR, LFR GFR and ADS communities

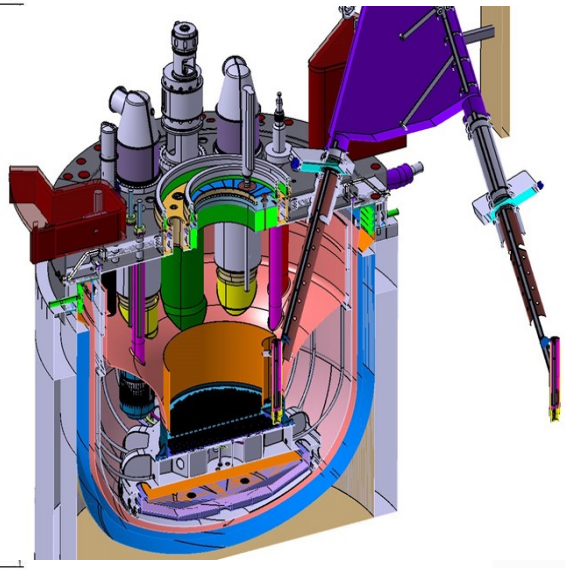
ENEA Italy

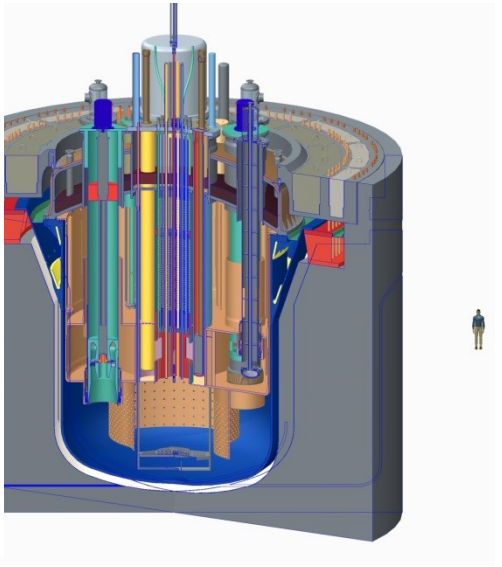
HZDR Germany

4 EUROPEAN PROJECTS









D ALLEGRO ASTRID MYRR

FALCON

Visegrad 4 for Generation IV
V4 G4
Centre of Excellence

Astrid

MYRRHA

Attendance to ESNII+ Events (2014-2017)

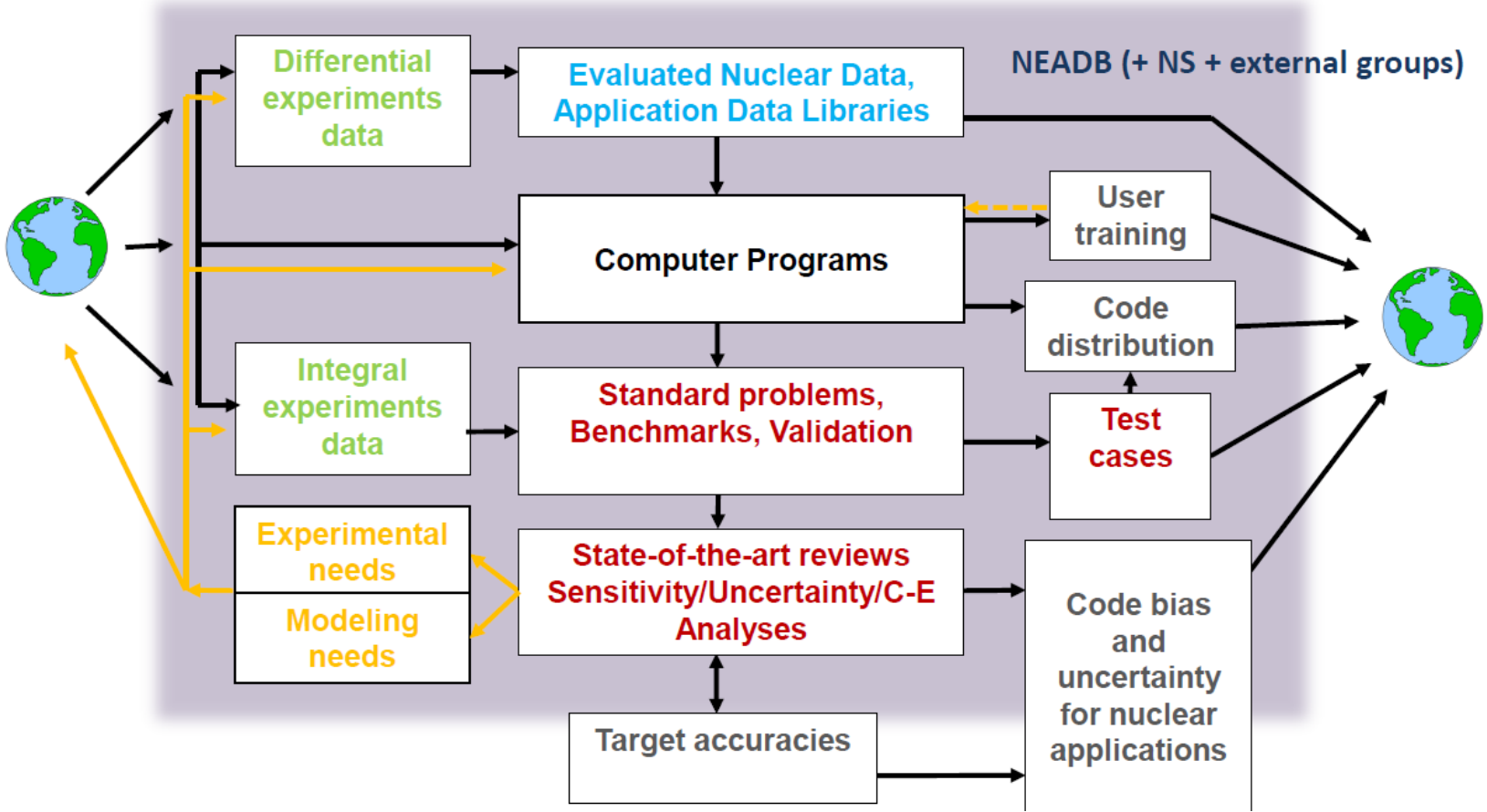
Event	Title	Place	Date	Organizer	Nb Attendees	Nb PhD, students
W1	Fuel properties	Aix-En-Provence (France)	2016 March 10-11	CEA (France)	51	5
W2	Core neutronic safety issues	Stocholm (Sweden)	2014 May 22-23	KTH (Sweden) CEA (France)	29	22
W3	Instrumentation for FNRs	Dresden (Germany)	2015 April 15-17	HZDR (Germany)	100	30?
W4	Thermal-hydraulics & thermomecanical issues	Brasimone (Italy)	2016 May 12-13	ENEA (Italy)	38	10
W5	Mitigation of seismic risks	Roma (Italy)	2017 May 09-11	SINTEC, ENEA(Italy)	22	3
W6	Chemistry & dosimetry	Rez (Czech Republik)	2016 Oct 05-07	UJV (Czech Rep.) CEA (France)	32	15
W7	Safety assessement of FNRs	Garching (Germany)	2017 July 10-12	GRS (Germany), SCK-CEN (Belgium)	17+?	?
W8	Severe Accidents	Karlsruhe (Germany)	2016 Nov 03-04	KIT (Germany), CEA (France)	28	9
W9	Sitting & Licensing	Pitesti (Romania)	2015 Nov 18-20	ICN (Romania)	35	5?
	TOTAL W				348+?	100+?
SC1	Summer School 1	Stockholm (Sweden)	2014 May 19-21	KTH (Sweden)	31	22
SC2	Summer School 2	Pisa (Italy)	2016 May 09-11	Univ. Pisa (Italy)	55	40
	TOTAL SC				86	62
	TOTAL W & SC				434+?	162+?

E&T ; GLOBAL INITIATIVES: OECD-NEA

OECD BETTER POLICIES FOR BETTER LIVES — Nuclear Energy Agency — NEA NUCLEAR ENERGY AGENCY

Provision of modelling tools along with the means to test, validate and improve them

Experiments, Nuclear Data, Computer Programs, Verification & Validation, Feedback, Users



E&T ; GLOBAL INITIATIVES: IAEA

Within the frame of its numerous activities in the field of Fast Reactors, several initiatives related to Education & Training have been carrying out;

As **biennial Education & Training course** in the field, the IAEA is organizing events at **ICTP-Trieste (Italy) ie**

-School on “Physics, Technology and Applications of Innovative Fast Neutron Systems”, in collaboration with ICTP, Trieste, 9 – 20 November 2009
-Workshop on “Codes & Standards for Sodium Fast Reactors”, Beijing in July 2010 ,
-a School on Physics, Technology and Applications of Innovative Fast Neutron Systems and Related Fuel Cycles, held at in September 2013.
-a School on Generation IV Systems in August 2016
and also
- An Education and Training Seminar/Workshop on Fast Reactor Science and Technology, San Carlos de Bariloche Argentina in October 2012
-An Education and Training Seminar/Workshop on Fast Reactor Science and Technology In Mexico-City in June 2015

CRP IAEA: NAPRO

➔ IAEA Coordinated Research Project (CRP) on " **Sodium Properties and Safe Operation of Experimental Facilities in Support of the Development and Deployment of Sodium-cooled Fast Reactors (NAPRO)**".

Three main goals:

- **Assessment of the consistency of the Na physical, physico-chemical and thermo-dynamic properties. Heat transfer and pressure drop correlations** (Need for a consistent and up-to-date handbook of sodium property data for use by IAEA Member States).
- **development of an international effort focused on obtaining and sharing design approaches and (main) guidelines for sodium facilities operation.**
- **Recommendations of best practices for operation and safety of sodium experimental facilities.**

➔ **then necessity to disseminate the knowledge among partners and Universities (by Education and Training)**

Tec-Docs to be issued by 2018

Na property data :

- physical properties
-surface tension (wetting)
-saturation vapour pressure
-emissivity
-ternary oxides in sodium,
-solubility of metallic impurities
-diffusivity of metallic impurities
-….

Guidelines and good practices for Na facility design & operations:

- fill and drain, purification,
- out-gassing prior to filling,
- Na storage,
- component handling,
- drying of sodium piping / repair

Best practices for safety

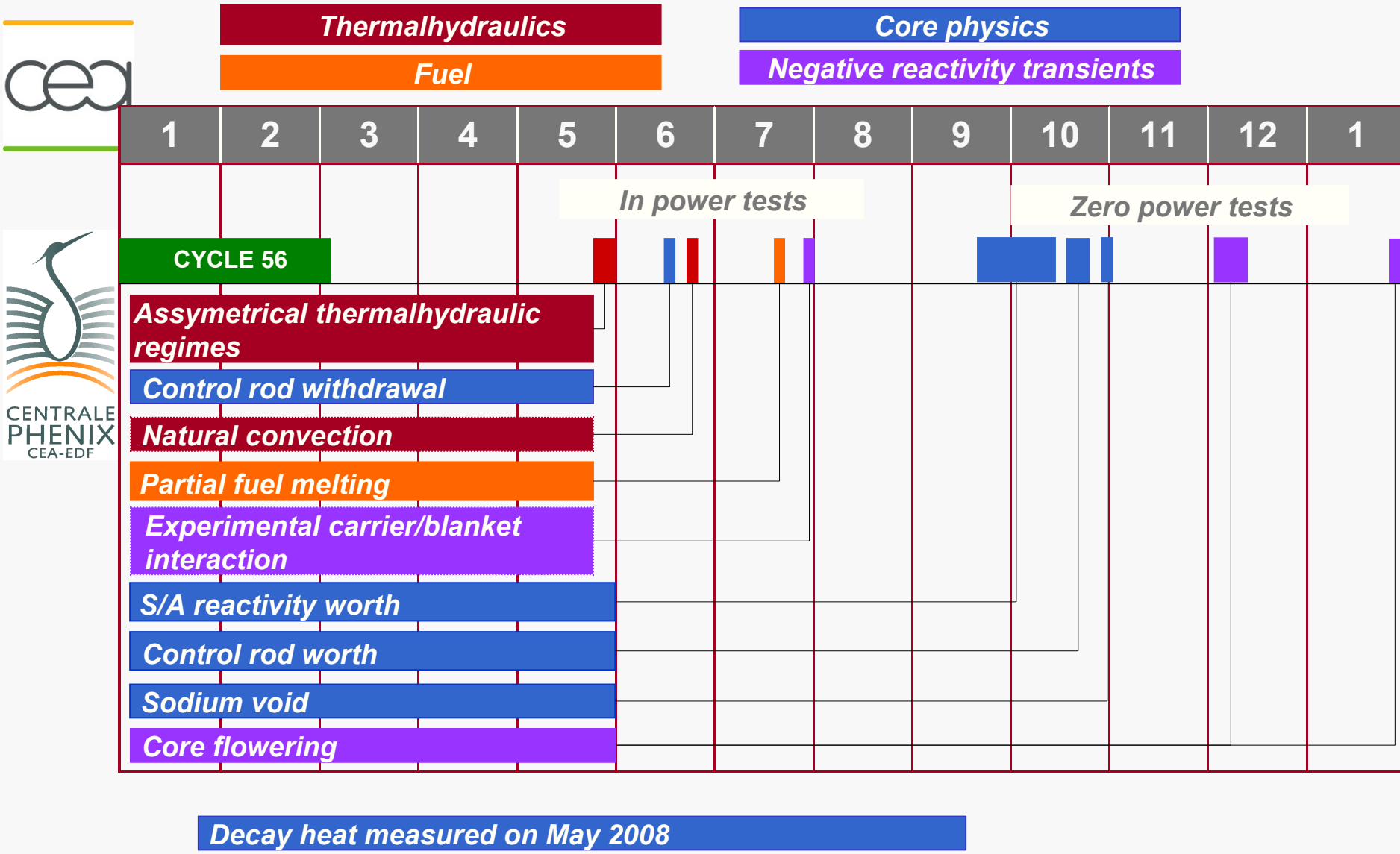
Prevention & mitigation of Na leaks, Na fires; impact studies
Assessment of:
- Na impact in the environment after accidental release,
- hydrogen hazards in cleaning facilities

Thank you for your kind attention

ACKNOWLEDGEMENTS

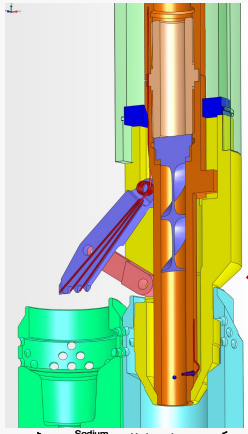
Authors would like to thank all the people involved in the Education & Training Entities and Initiatives, related to the Sodium Fast Reactors development.

Tests time schedule - 2009

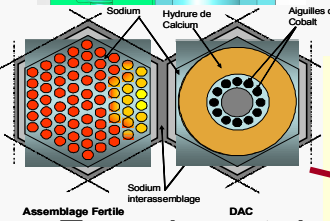


Special experimental devices

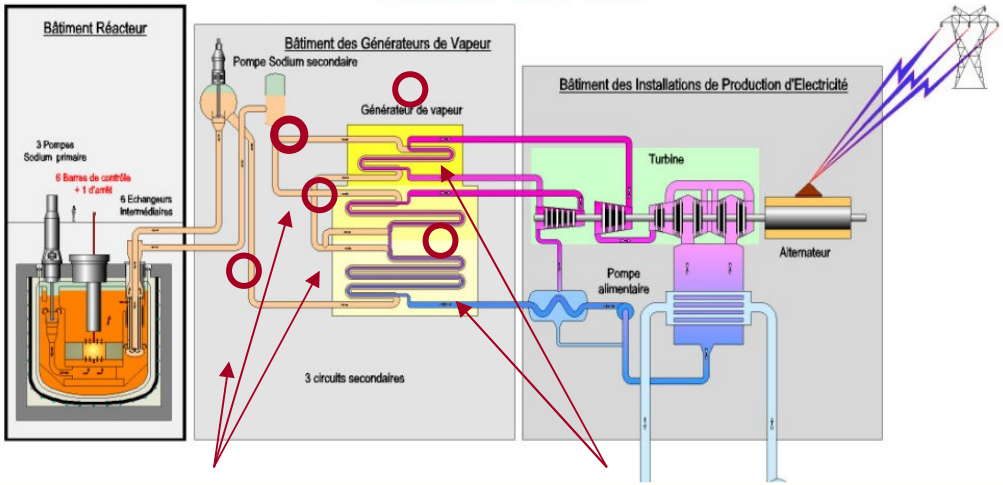
Thermocouples pole



Sensors °T,Q

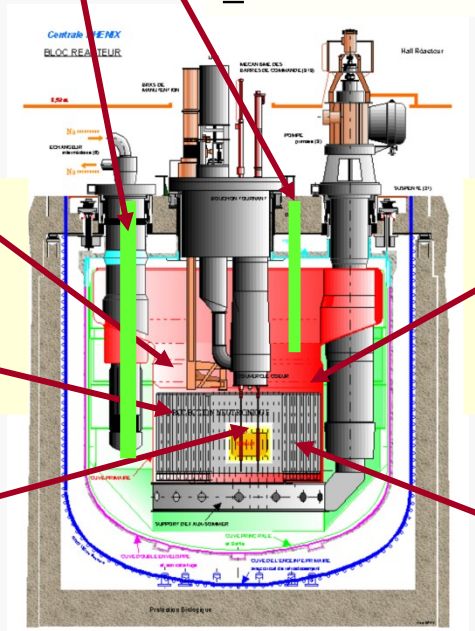


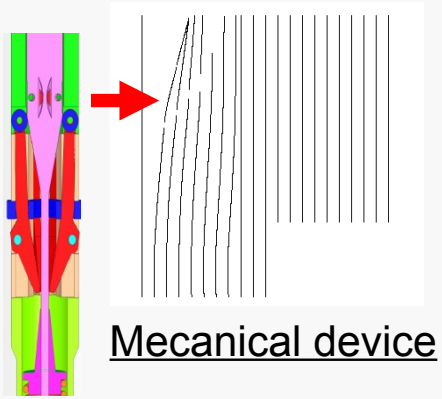
Experimental carrier



Sodium loops: Thermocouples

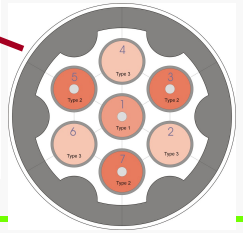
SG casing: TC + air velocity





Mecanical device

« gas » control rod



Experimental capsule (fuel melt)