



THE FRENCH SFR OPERATING EXPERIENCE

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Licensing and Operating Advanced

Non-Light Reactors: International

Knowledge Gaps

OUTLINES

Phénix and Superphénix operation

Acquired scientific and technological knowledge

Challenges for the future



Superphenix nuclear power plant

SODIUM FAST REACTORS ?

□ 1945 – Enrico FERMI:

“The first country to develop a fast breeder reactor will have a commercial advantage for the exploitation of nuclear energy”

□ 1956 – Hyman RICKOVER:

“Sodium-cooled fast reactors are expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair”



PHENIX & SUPERPHENIX OPERATION

The French SFR
Operating Experience

PHÉNIX

Prototype reactor

Marcoule (Languedoc – Roussillon)

1973 – 2009

CEA (80 %) – EDF (20 %)

563 MWth – 250 MWe

Pool reactor (800 t of Na)

Three intermediate circuits

Modular steam generators

Demonstration of SFRs = operating the reactor for a long time with provisional characteristics and feedback

Closing the fuel cycle (breeder ratio = 1,16)

Irradiations of experimental fuels and materials



Marcoule

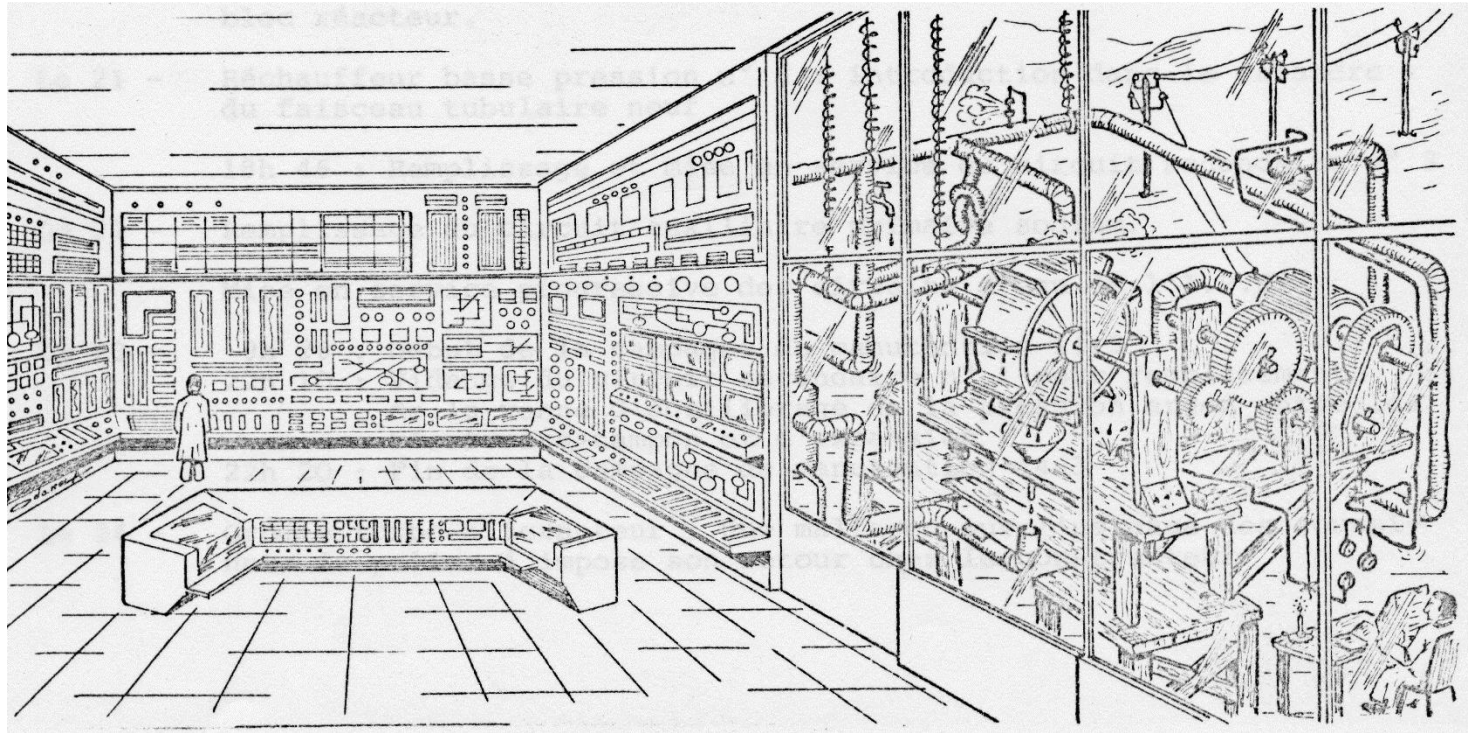


OUTCOME OF PHÉNIX OPERATION

4,580 EFPD, 128,500 hours grid connection, 28 billions of KWh

Availability rate programmed outages excluded : 75 %

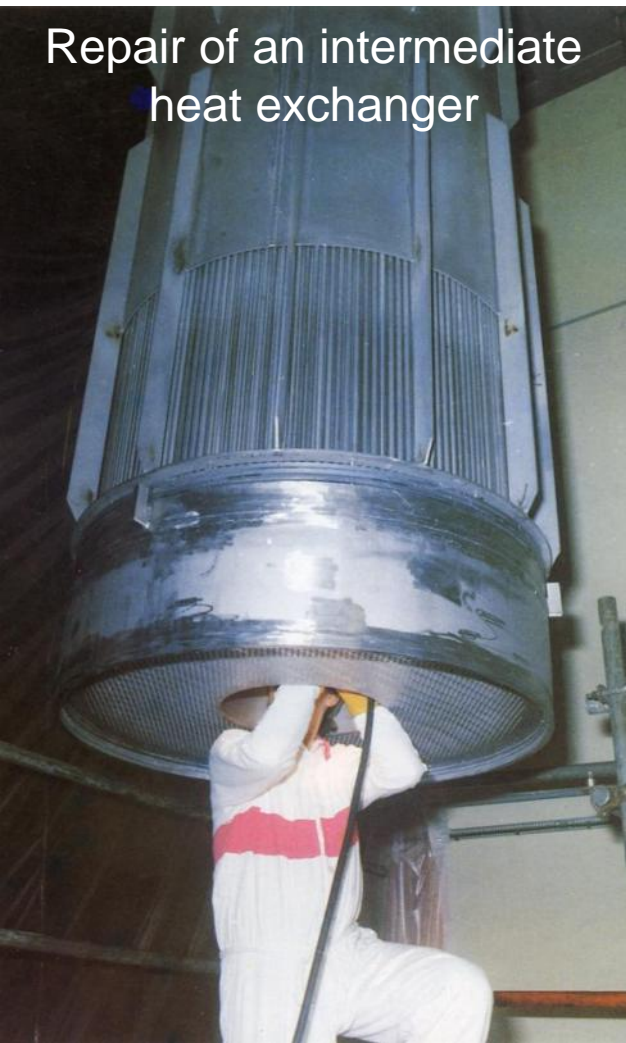
Main unavailability: intermediate heat exchangers, electricity generating facility



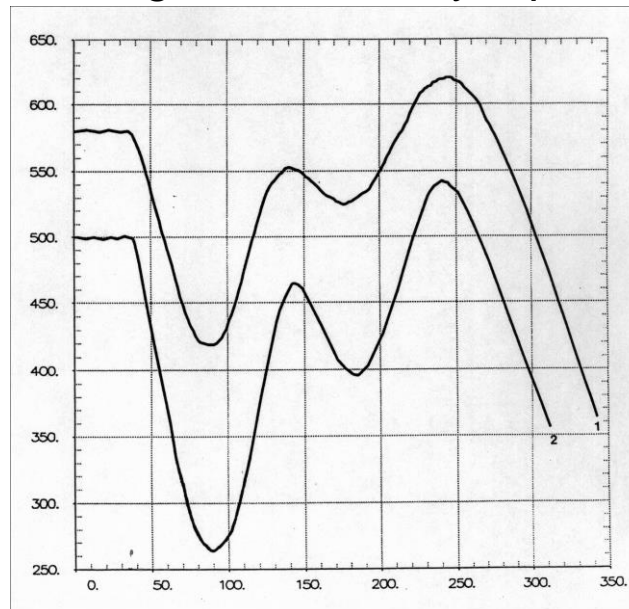
Nuclear control room and
electricity generating facility!

PHÉNIX MAIN EVENTS

Repair of an intermediate heat exchanger



Negative reactivity trips



Seismic renovation works in the reactor building



Defect on a steam generator tube

SUPERPHÉNIX (SPX)

Nuclear power plant

Creys-Malville (Rhône - Alpes)

1985 – 1997 (governmental decision)

Licence : CEA

Constructor : Framatome + Ansaldo

Utility : NERSA (European society) :

FR (51 %) – IT (33 %) – GER (16 %)

3000 MWth – 1200 MWe

Pool reactor (3300 t Na)

Four intermediate circuits

Single-blocks steam generators

Two turbo-alternator groups

Strongly anti-nuclear contestation (mass demonstrations, judicial actions, rockets):
use of plutonium, large quantities of sodium, risk of accident in the event of nuclear reaction racing or core compacting



Creys -
Malville



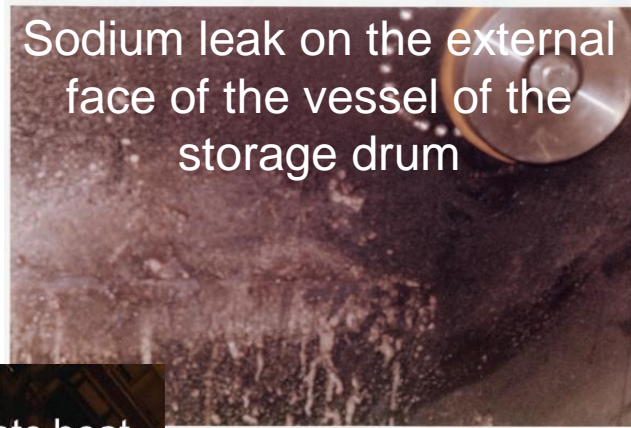
OUTCOME OF SPX OPERATION

From the beginning of 1986 (first connection to the grid) to the end of 1996 (last electricity production):

- 25 months of outages after the “main” incidents (20%)
 - crack on the external fuel storage drum: 10 months
 - air pollution of the primary sodium: 8 months
 - argon leak from the intermediate heat exchanger: 7 months
 - 54 months of administrative procedures (40 %)
 - 53 months of normal operation (40 %)
 - 8 months of start up tests without connection to the grid
 - 11 months of programmed outages (handling, inspections, maintenance)
 - 34 months of electrical production (availability : 41,5 %)
- ➔ In 1996 : 95 % availability (planned outages excluded)

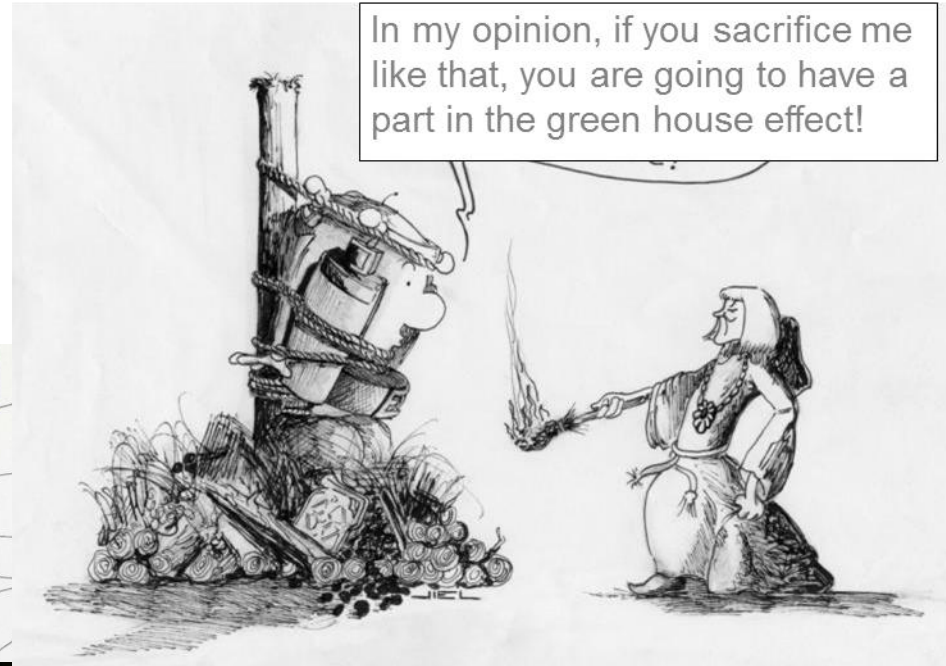
SPX MAIN EVENTS

Sodium leak on the external face of the vessel of the storage drum

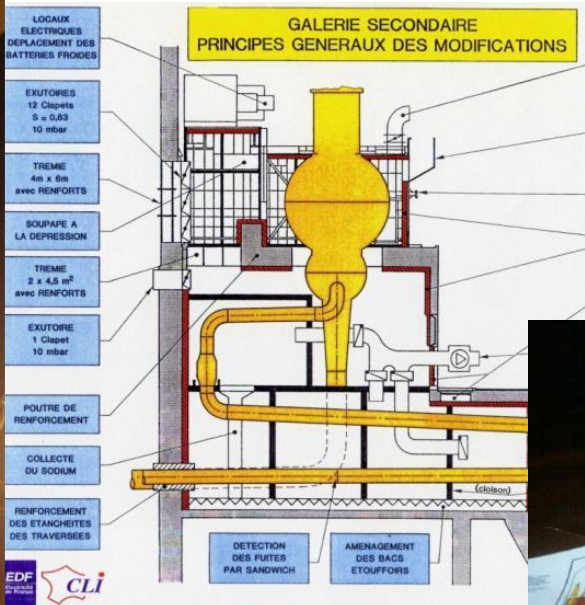


Prime Minister decision (June 1997):
“Superphénix will be abandoned”

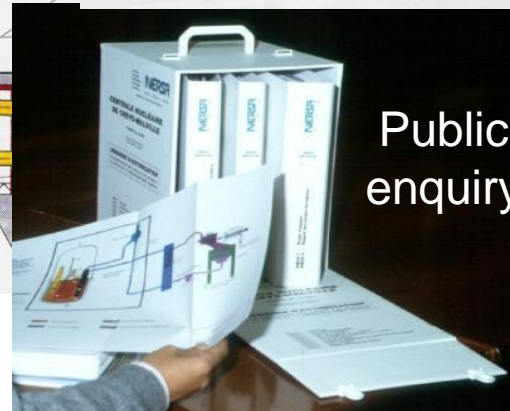
In my opinion, if you sacrifice me like that, you are going to have a part in the green house effect!



“Sodium fire” works



Public enquiry





ACQUIRED SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE

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FUEL

Excellent feedback from the mixed oxide fuel:

- 115 000 MWd/t (100 dpa) standard
- 144 100 MWd/t (155 dpa) experimental

Very few clad failures:

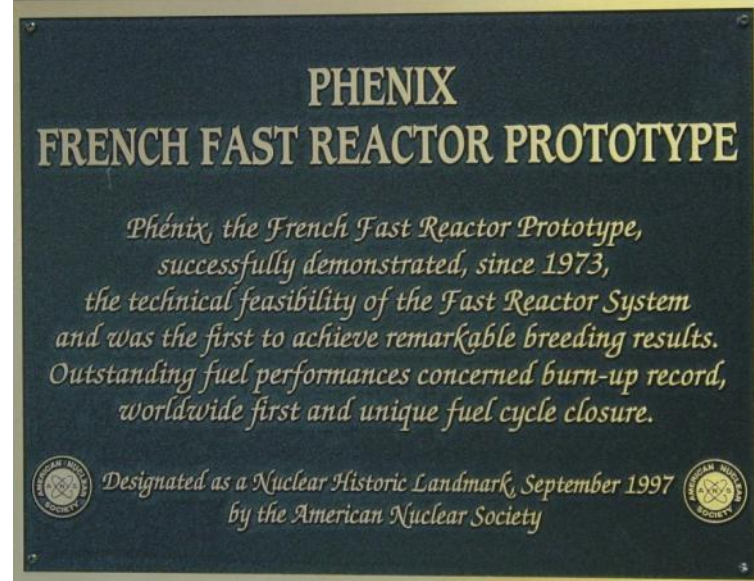
15 “open” failures in Phénix

half of which on experimental clads

Qualification of titanium-stabilised steel (316 Ti, 15-15 Ti ϵ) for cladding and ferritic steel (EM 10) for wrapper tube

Closing the fuel cycle (breeding rate: 1,16)

Irradiations (materials, fuel, transmutation)



SFR OPERATING

Easy to operate: no pressurisation of the primary coolant, high thermal inertia, control by single rod position, no xenon effect, no need of soluble neutron poison

High thermal efficiency

Few effluents and little radioactive waste

Possible operating at reduced load

Very low dosimetry for workers

- Phénix: 2.5 man.Sv in 35 years
- Superphenix: 0.25 man.Sv in 12.5 years

Decommissioning is successful, without major technical issues, and the treatment of decommissioning waste has reached the industrial stage

SPX control room



MAIN COMPONENTS

Mixed operating feedback:

- excellent operation of the pumps
- defects on intermediate heat exchangers

Steam generators:

five sodium – water reactions in Phénix SG, all mastered and source of feedback experience

The modular design of the Phénix SG enables expertise and replacement of the defective modules

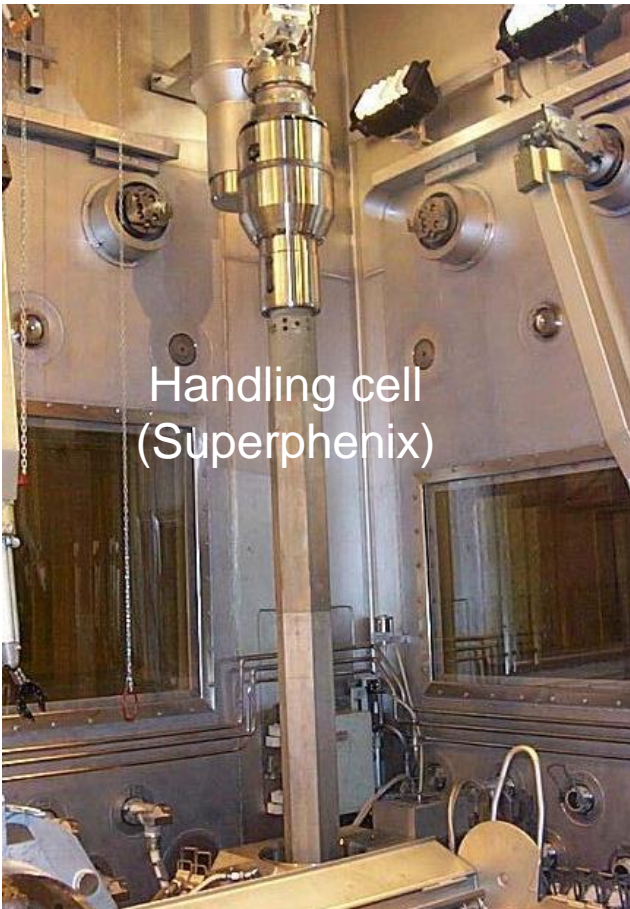
Primary pump (Phénix)



FUEL HANDLING

Sodium opacity (inside reactor or inside external storage)

→ “blind” work, methods to control movements and check obstacles (ultrasounds)



- Removing the remaining sodium on the sub-assemblies before storage under water
→ operations in cells (biological shields and tele-operation)
- Positive feedback in Phénix but lengthening of the core refueling campaigns (ageing of equipment + more stringent procedures for monitoring sub-assembly movements)

BEHAVIOUR OF MATERIALS AND EQUIPMENT

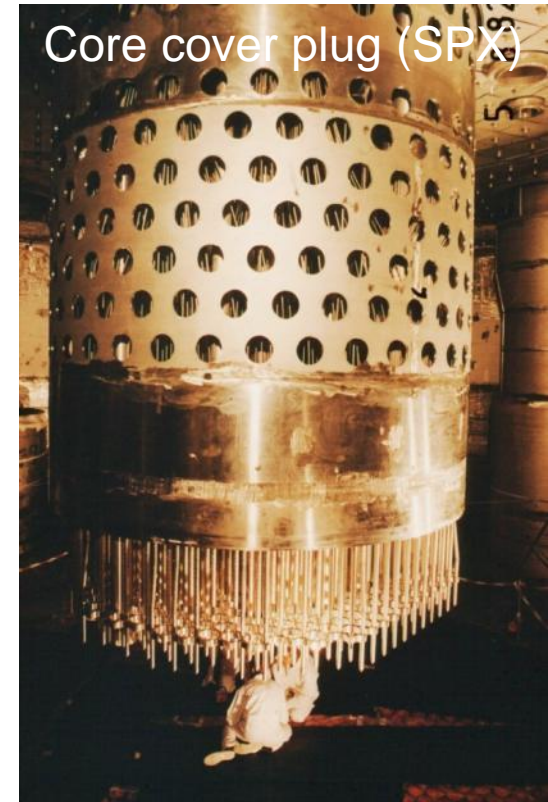
Good behaviour of materials exposed to sodium except 15D3 (Superphénix) and 321 (Phénix) steels

Good performances of SFR specific equipment:

- electromagnetic pumps,
- plugging indicators, cold traps,
- thermocouples,
- clad failure detection and location, ...

however mixed behaviour for instrumentation:
spurious alarms, dysfunctions

Under insulation corrosion during a sodium leak





CHALLENGES FOR THE FUTURE

The French SFR
Operating Experience

SAFETY AND LICENSING ACHIEVEMENTS AND GAPS

Favourable characteristics of French SFR:

- no pressurisation
- sodium boiling margin
- leak tightness of primary circuit
- high thermal inertia
- natural convection

PSA has given similar results for SPX and French 1300 MWe PWR

Future SFR safety level = contemporary 3rd generation reactors,

The sources of improvement are multiple:

- Better use of favourable core characteristics
- Reduced failure probability for decay heat removal
- Large sodium fires and violent Na-H₂O reactions
- Carryover of gas in the primary circuit
- Production of H₂ during sodium residues processing
- Core melting accidents (prevention and mitigation)
- Jamming / inadvertent withdrawal of a control rod
- Prevention and detection of a fuel handling mistake

OUTCOMES / LESSONS FOR THE FUTURE

Extremely valuable knowledge:

- fuel and core
- sodium technology and steel for clads and components
- operation of a SFR

Challenge : design futures SFR / requirements ~ PWR (availability, safety, cost, financial risk) + sustainability

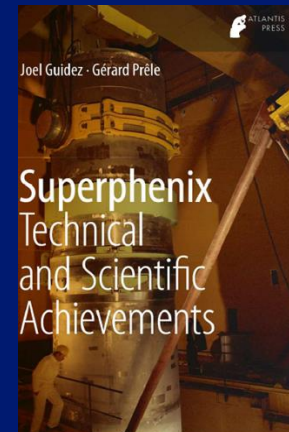
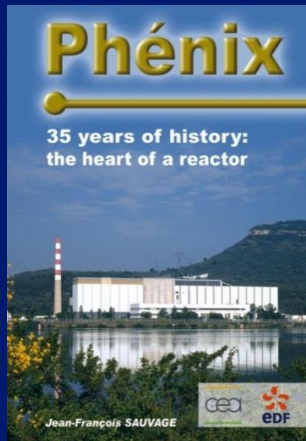
Progress can still be made:

- to raise safety level (= 3rd generation)
- performances (fuel, availability, manoeuvrability)

Passing on the knowledge and skills acquired in the past to engineers who will develop, design, construct and operate the future SFR



THANK YOU FOR YOUR ATTENTION



“A person who can’t learn lessons from the previous 3000 years only lives from day by day”
Goethe