DE LA RECHERCHE À L'INDUSTRIE

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A S T R I D

Advanced Sodium Technological Reactor for Industrial Demonstration

Astrid

ASTRID project

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On behalf of ASTRID Project Team

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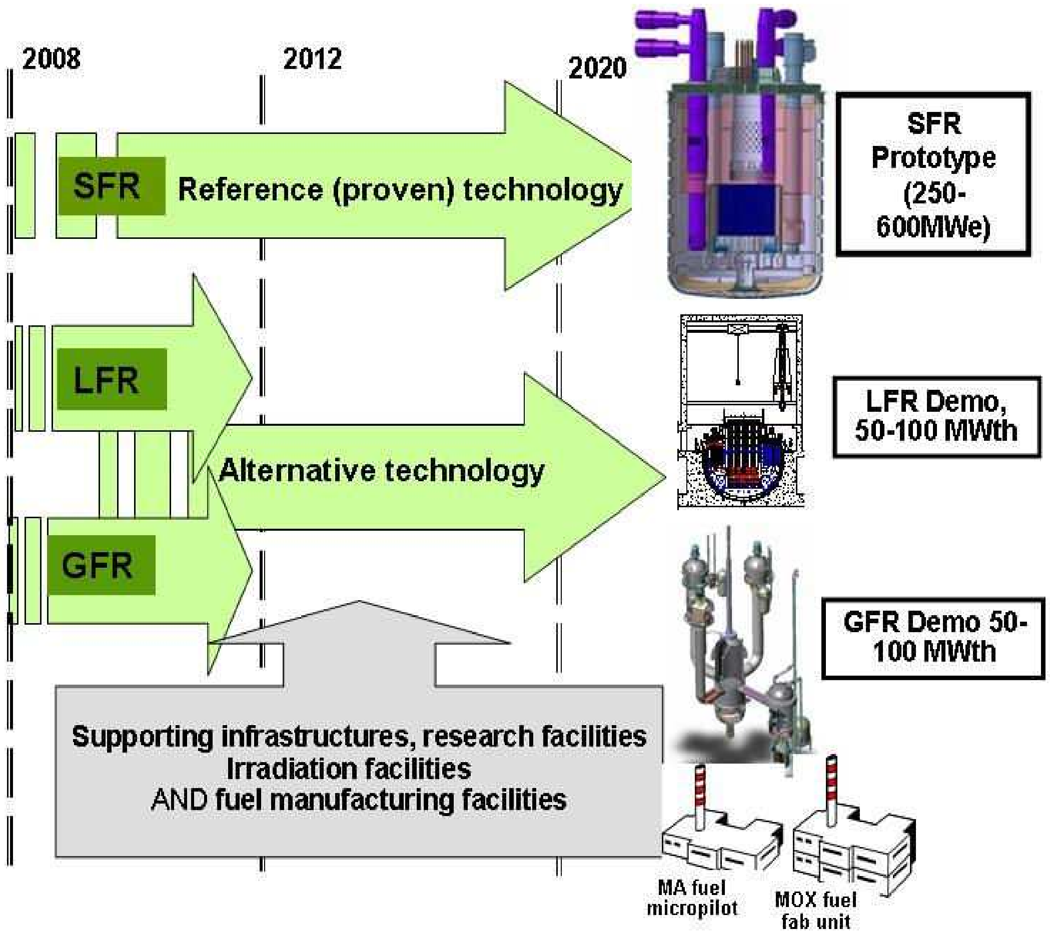
DEN/CAD/DER/CPA

Introduction

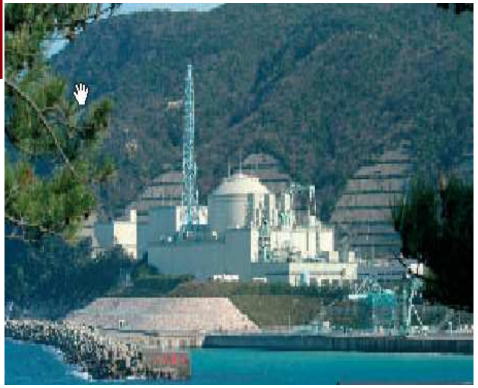


SFRs in operation

- ***Sodium Fast Reactor :*** ***world-wide developed since the 1950's : a very promising candidate for the development of fast neutron reactors, due to its very attractive sodium, nuclear, physical and even some of its chemical properties.***

➔ ***Reactors in operation in Japan, India, Russia and China,***

Monju



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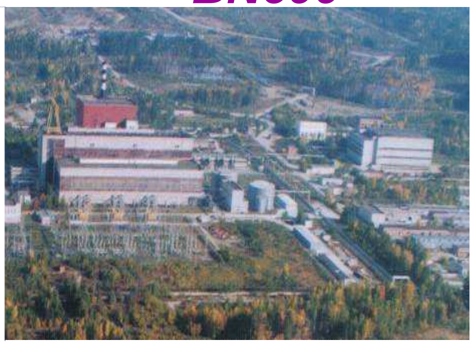

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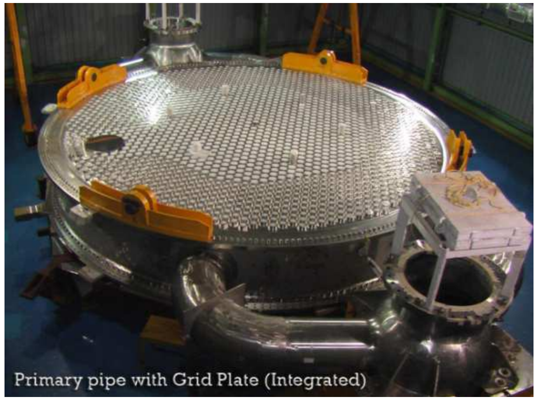
2 SFRs in commissioning phase

BN800 (Russia) 8OO Mwe (criticality last June)

PFBR (India) 5OO Mwe (criticality foreseen in spring 2015)



The ASTRID objectives

➔**Industrial prototype (***could be a step before a First Of A Kind)*

➔**Integrating French and international SFRs feedback**

➔**A GEN IV system**

***Safety* :**
- Level at least equivalent to GEN III systems (WENRA requirements)
- With significant improvements on Na reactors specificities issues
- Integrating *FUKUSHIMA* accident feedback

***Operability* :**
- Load factor of 80% or more after first "learning" years
- Significant improvements concerning In Service Inspection & Repair (ISIR)

***Ultimate wastes transmutation* :**
- Continue experimentation on minor actinides transmutation, up to large scales if decided, according to June 28, 2006 French Act on Wastes Management

A mastered investment cost

➔**Irradiation services and testing long term options**

Some details about the schedule

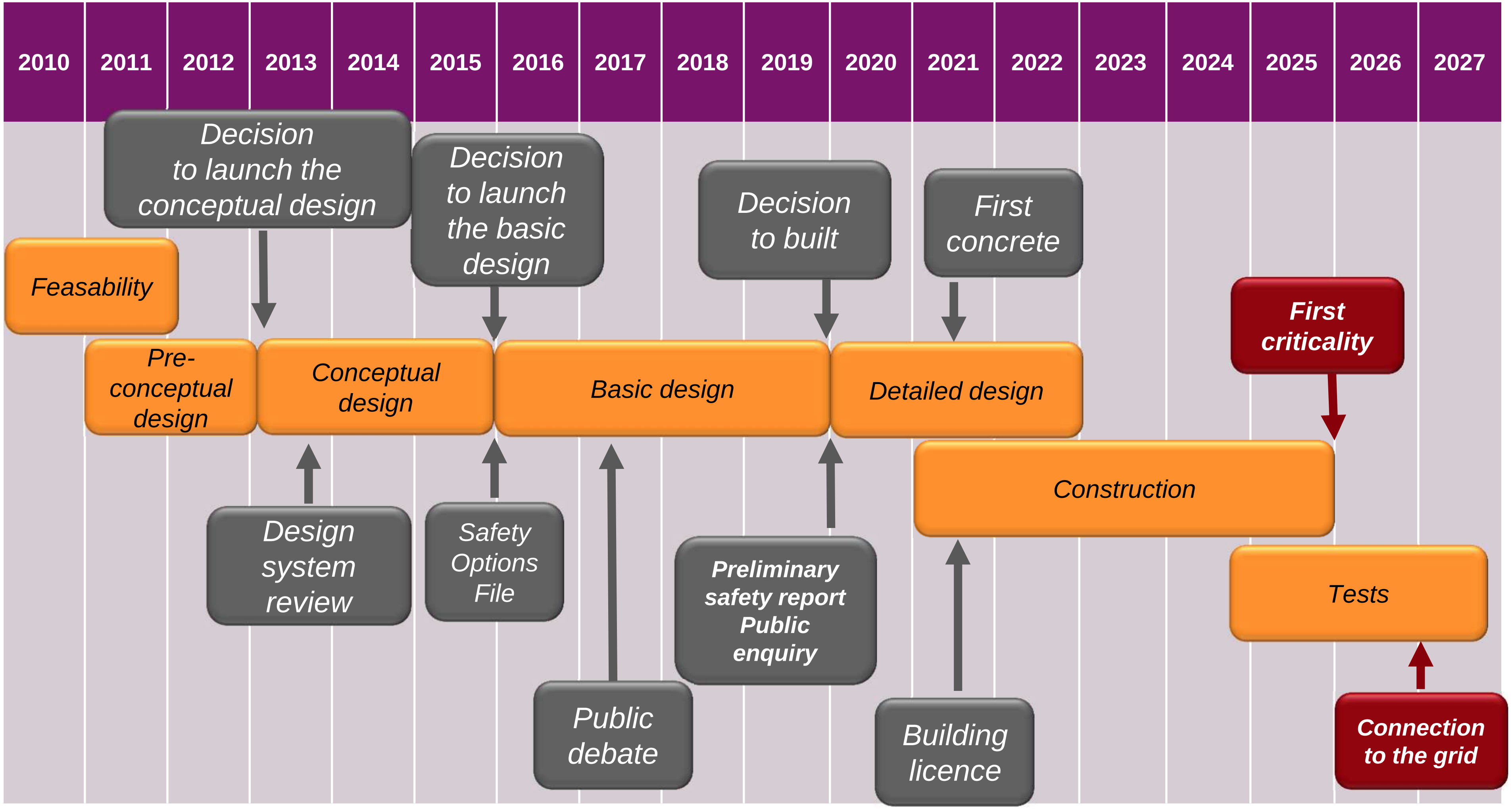
➔ 2006 to 2009: extensive R&D studies on sodium fast reactors in collaboration with AREVA and EDF

➔ Mid of 2010 : preliminary selection of ASTRID characteristics for launching the preconceptual design

➔ preconceptual design : 2010 to end of 2012 :
- The preconceptual design has considered some open options. Innovation and technological breakthroughs have been favored, while maintaining risk at an acceptable level
- During the preconceptual design phase, start of the interactions with the Safety authorities on safety objectives and orientations
- Schedule of next steps and their associated costs
- safety orientation report: report delivering and first advices of the French Safety Authorities

➔ Conceptual design : 2013 to end of 2015:
- ➔ conceptual design file
- ➔ Safety Option File
- ➔ Protection against malevolence file

SCHEDULE FOR ASTRID



OBJECTIVES OF the conceptual design

- Stabilize reference design
- Define a newly integrated operating mode with our partners on some specific topics with strong interfaces
- Optimize the costs of the reactor
- Based on the positive result of the examination by Expert Committee on Reactor Safety (June 27th, 2013), submit the Safety Options File at the end of 2015
- Complete the Conceptual design by end of 2015
- Increase the number of collaborations around ASTRID:
  - *R&D*
  - *Industry*
  - *International partners*

Partnerships around ASTRID

- Intermediate-sized companies:
  - *Our discussions are progressing well with the Pôle Nucléaire de Bourgogne (Burgundy nuclear industry cluster) to enter into new partnerships: VELAN, TECHNETICS, DAHER VANATOME, etc.*
  - *An agreement has already been signed with the VELAN company on large sodium valves development*

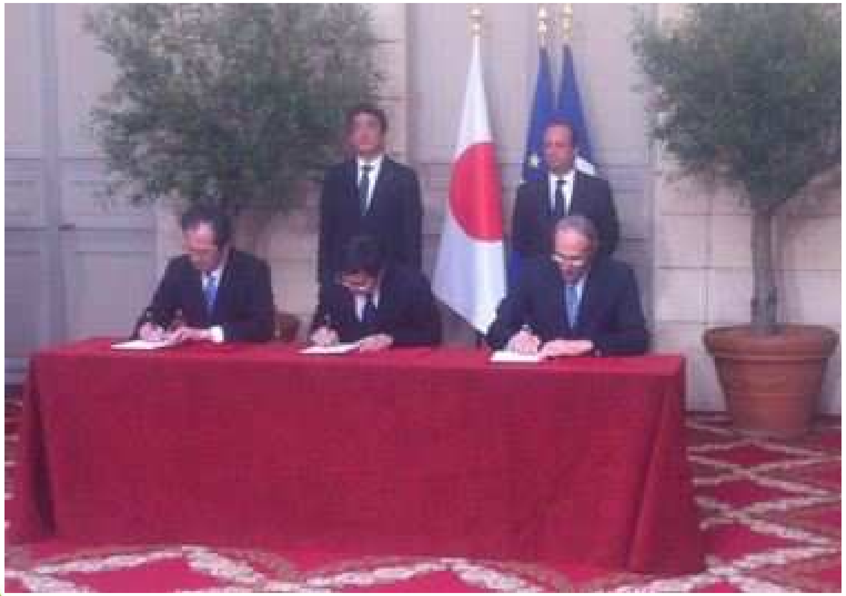
- European R&D organisations and labs: the ARDECo project
  - *Swedish universities contribute to the project*
  - *An agreement was signed with the Paul Scherrer Institute concerning studies of reactor cores in two-phase operation in severe accident conditions.*
  - *Other contacts are in progress: ENEA, HZDR, NNL, KIT, ITU.*

Current Organization of the ASTRID Project

- Industrial network made of **bilateral collaborations** between CEA and each industrial partner,
- Governmental pluriannual funding, with **industrial total or partial financing** of each industrial partner,
- Collaboration agreements signed untill **end of 2015** (AVP2 phase),
- Collaborations on specific topics which correspond to **each particular skill**, associated to **expected deliverables**
- CEA/Nuclear Energy Division is the leader of the Project. CEA is willing to develop industrial partnerships for R&D and experimental facilities in support to design and assessment on long term innovative options

Partnership with Japan

- **The "General Arrangement"**
  - ***Defining the main principles of the collaboration***
  - ***Between the Japanese Ministry of Economy, Trade and Industry (METI) and Ministry of Education, Culture, Sports, Science and Technology (MEXT) and France's CEA***
  - ***Signed on 5 May during the visit of Japan's prime minister in Paris***
  - ***The partnership agreement covers the end of the conceptual design (APS) and the basic design (APD) (until late 2019)***



JAEA MFBR Systems, Inc. MITSUBISHI HEAVY INDUSTRIES, LTD.

Signature of the collaboration agreement on Astrid by Hironori Nakanishi (METI), Satoshi Tanaka (MEXT) and Bernard Bigot (CEA General Administrator), in the presence of Shinzo Abe and François Hollande

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Partners of the Astrid project in the AVP2 phase

TOSHIBA

ROLLS ROYCE

AREVA

EDF

JACOBS

BOUYGUES CONSTRUCTION

Services Nucléaires

SEIV ALCEN

cea

Astrid

JAEA

MFBR Systems, Inc.

MITSUBISHI HEAVY INDUSTRIES, LTD.

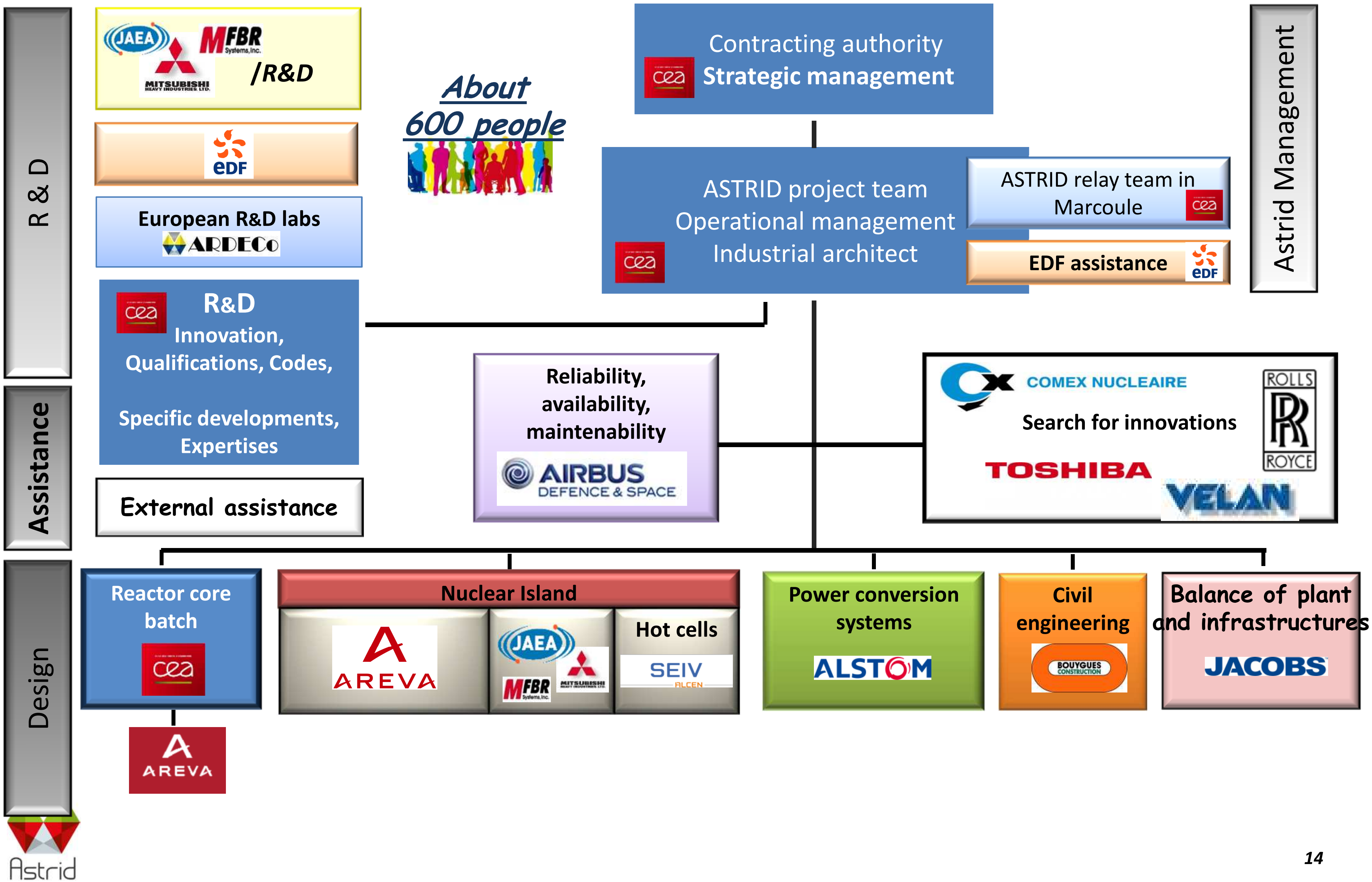
AIRBUS DEFENCE & SPACE

ALSTOM

COMEX NUCLEAIRE

Astrid

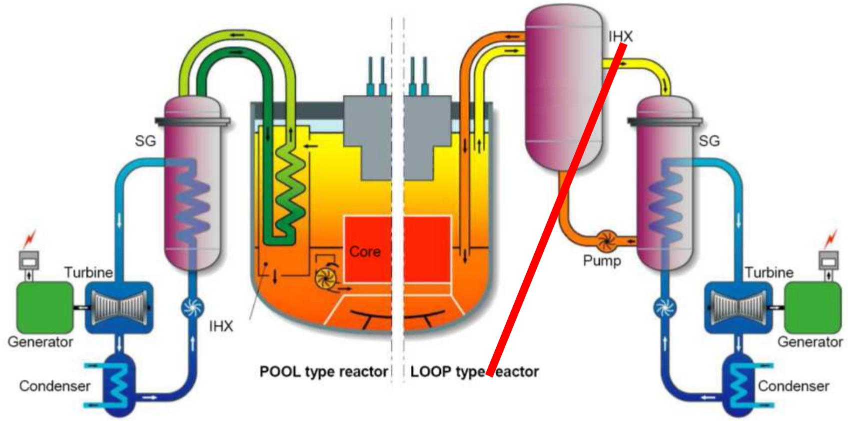
Organisation of the Astrid project in the AVP2 phase



ASTRID - Preliminary design choices

Main features at the beginning of preconceptual design - mid 2010

- 1500 thMW - ~600 eMW
- pool type reactor
- With an intermediate sodium circuit
- High level expectations in terms of safety demonstration
- Preliminary strategy for severe accidents (core catcher…)
- Diversified decay heat removal systems
- Oxide fuel UO_2-PuO_2 for starting cores
- Transmutation capability
- ….

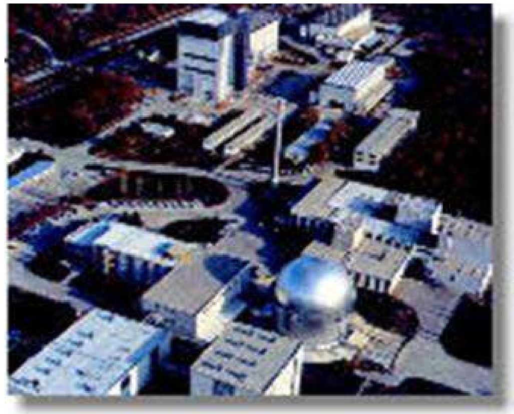


Favourable characteristics of pool type SFR

Phénix (1973-2010)

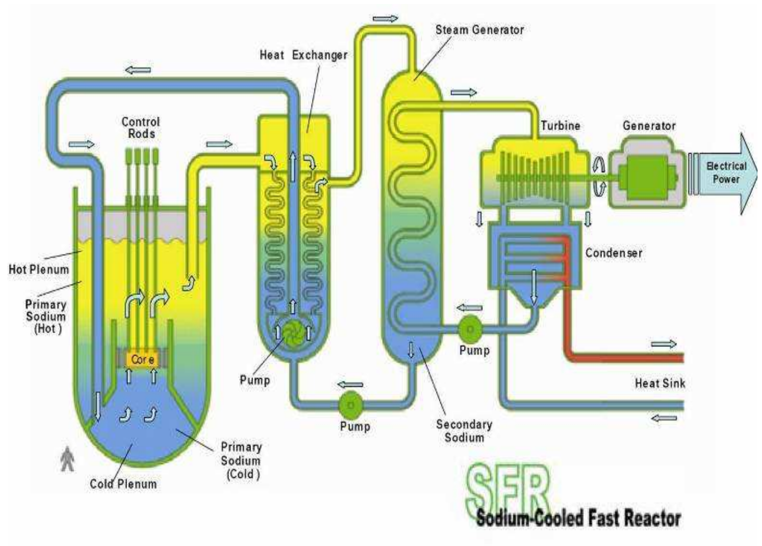
Super-Phénix (1985-1998)

Rapsodie (1967-1983)



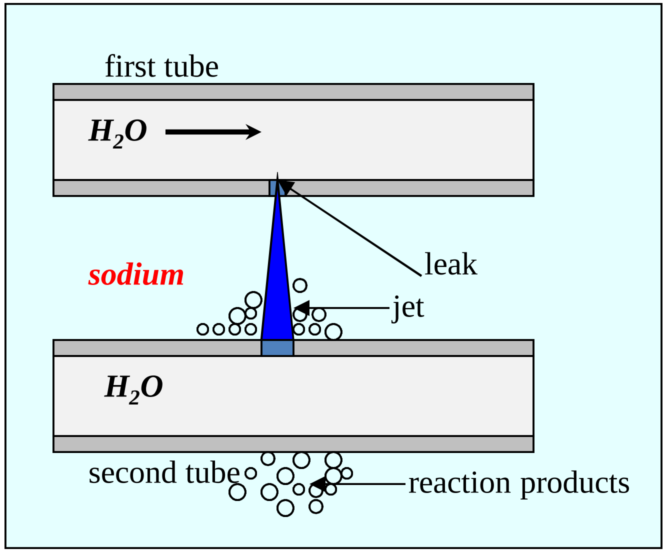
- Easy to operate: no pressurization of the primary coolant, high thermal inertia, control by single rod position, no xenon effect, no need of soluble neutron poison
- Radiation protection : higher level of protection than LWR
- Few effluents and little radioactive waste
- High thermal efficiency
- Large sodium boiling margin
- Natural convection
- Diversification of heat sink by using air

- **Coolant system for current SFR:**
  Sodium-water heat exchangers
  (Steam Generator Unit – SGU)
- **In the case of a loss of tightness:**
  Almost instantaneous reaction:

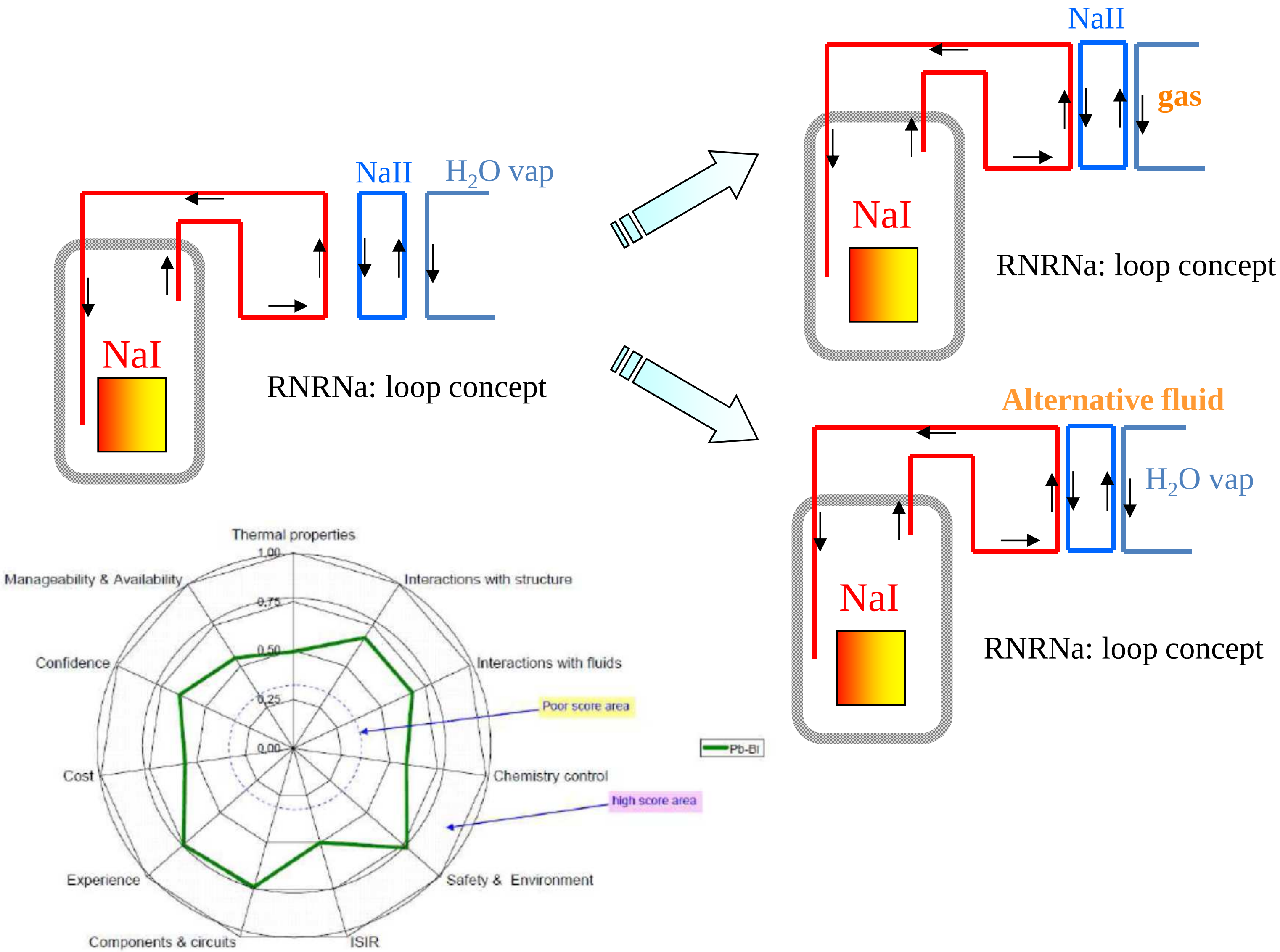


$Na + H_2O \rightarrow NaOH + ½\ H_2$ – 141 kJ/mol$_{Na}$

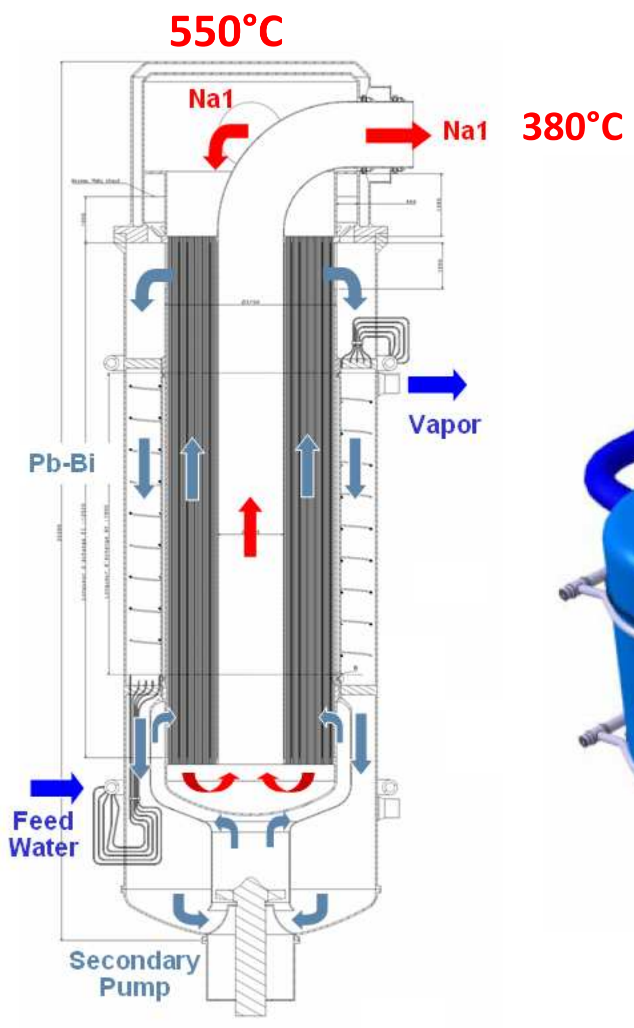
Possibility of « wastage » occurrence (propagation of holes in the steam generator from one pipe to the neighbouring ones**) even if the reaction is quickly detected**

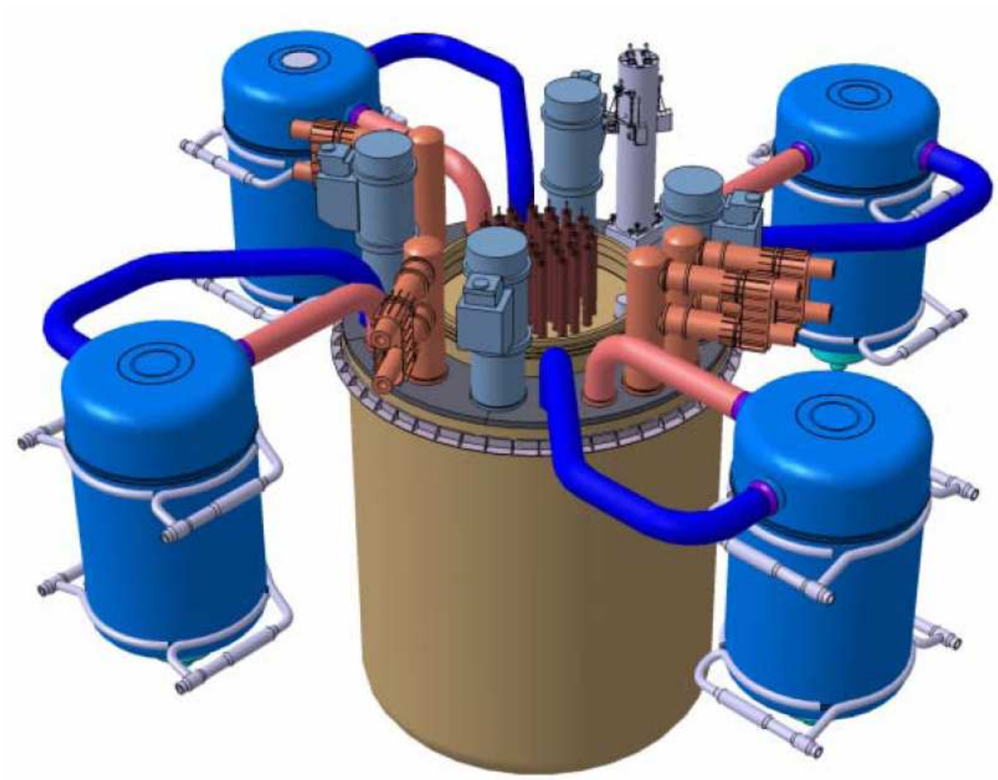


Three main tracks to mitigate Na Water interaction



SFR hybrid concept with IHX/SGU option





Feedback from basic studies in support to the design

The reasons for the choice of T91, compared to austenitic steel 316L, were the following ones:
- higher strength
- much better resistance to heat deposit (due to a lower thermal expansion coefficient and a higher thermal conductivity).
- better corrosion resistance in Pb-Bi due to a low nickel content

➔**Many studies related to :**
O control,
O measurement with ECOM
corrosion,
lead-bismuth freezing & consequences,
mechanical properties
lead-bismuth water interaction,…

Fundamental role of the natural surface oxides on the evolution of the corrosion of the two steels demonstrated,

➔The oxide layer expected at the window surface delays the steel dissolution of the steel:

With 1m.s^{-1} flow rate, 400℃
0.05m hydraulic diameter (without any specific turbulence) and
10^{-10} <[O]< 10^{-11} wt%,

→expected mean T91 steel corrosion rate: between 45 and 130 µm yr-1 for a few thousand hours period.

➔ ➔**Key point for SFR:**
- to confirm oxidation rates during longer period of operation, up to 550℃,
- to demonstrate that the surfaces are protected whatever the temperature of the loop is: from T range of 340℃ to 550℃ in steady s tate operation, down to 180℃ or 250℃ during shutdown periods.
- to demonstrate the self-healing properties of the selected materials
- to demonstrate the presence of an oxide layer, protecting the structural material, by ultra-sonic transmission and analysis of the signal.

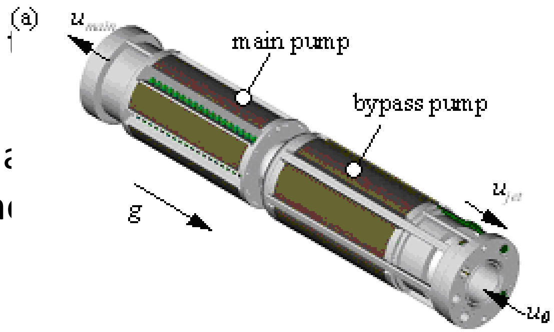
➔Aluminized coating technologies are also investigated but the feasibility of integral protection (including internal welding) has to be still demonstrated.

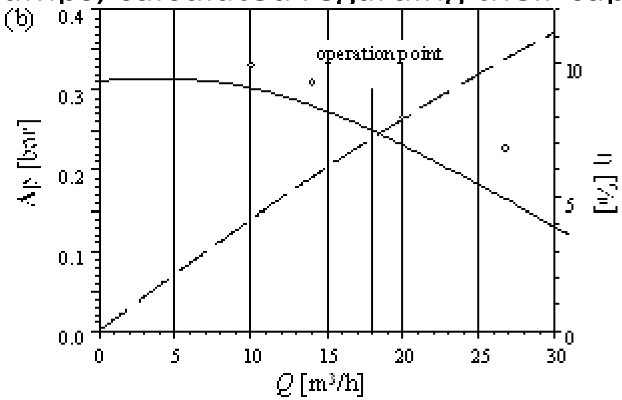
Feedback from Electro-magnetic Pump System (IPUL Latvia)

- Circulation of the lead-bismuth alloy within the target:

- generated by two independently controllable annular linear induction pumps (ALIPs), immersed in the upwards directed riser flow (pumps
- delivered by Institute of Physics of Latvia (IPUL)).
- both pumps, calculated regarding their capabilities, t their (

➔ Design ... nd attaina ... he pump ... experim

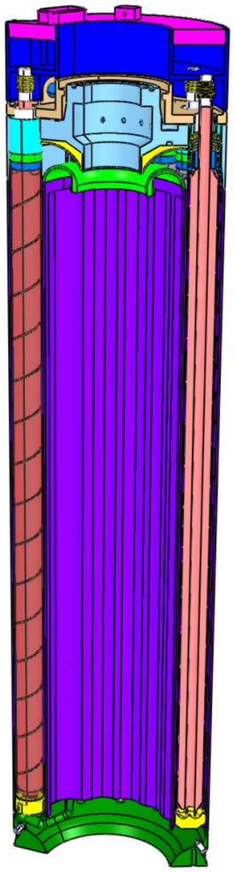




(b) Pressure head – flow-rate characteristics of the main flow electromagnetic pump for currents: 1 – 33A, 2 –30A, 3 – 25A, 4 – 20A, 5 – 15A, 6 – 10A, 7 – 5A; 8 – hydraulic characteristic of the target main channel.

➔ **For SFR application (for LBE immersed EMPs in the intermediate IHX-SGu combined component), Possibility to immerse pump. Necessity, first to reduce the uncertainty on efficiency, and secondly to analyze the extrapolation to much larger flow-rates**

Integral tests : THX design validation (CEA)



Sufficient capacity of the Heat Removal System to cope with about 600 kW of heating in the target and flexible to the changes, though the operating conditions might be differed from the predictions.

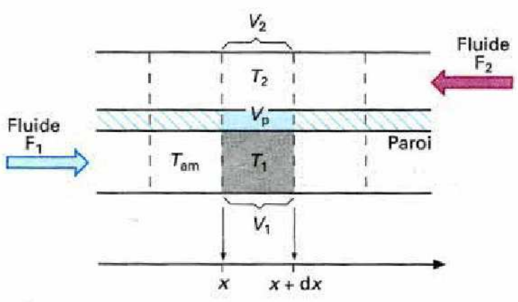
But : after the integral tests, bypass flow conditions still to be determined

Analysis of the experimental data of the LBE-oil thermal exchanger of the target (with analytical heat exchanger calculations (Global model, ε-NUT, and numerical model (1D), finite volumes) :

→For each of the 4 campaigns, computed values in agreement with the corresponding experimental results.(maximum variance between calculations and experiments very low, and below the accuracy of the model is about 20%).

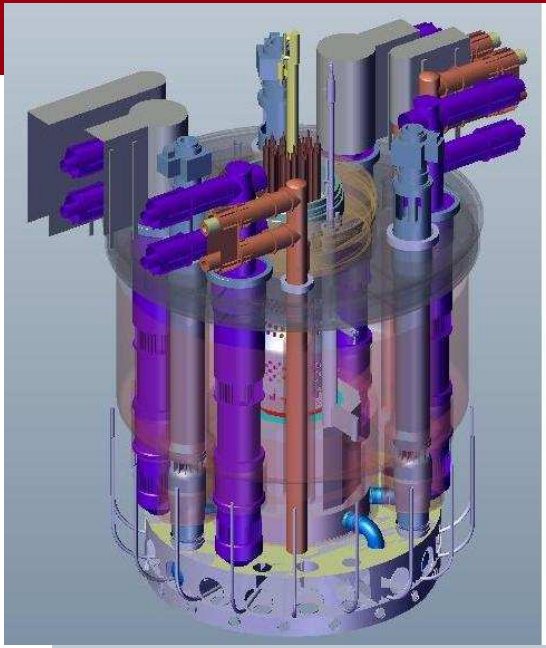
→Thus, **THX heat transfer model (and correlations) used to its design, validated,** even if some uncertainties hang over flow rates assessments.

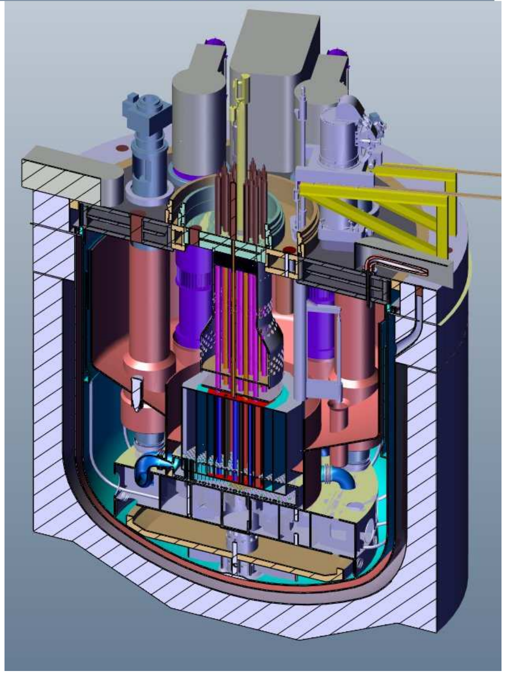
→Parametric study of sensitivity : large margins on the THX thermal exchange capacity.



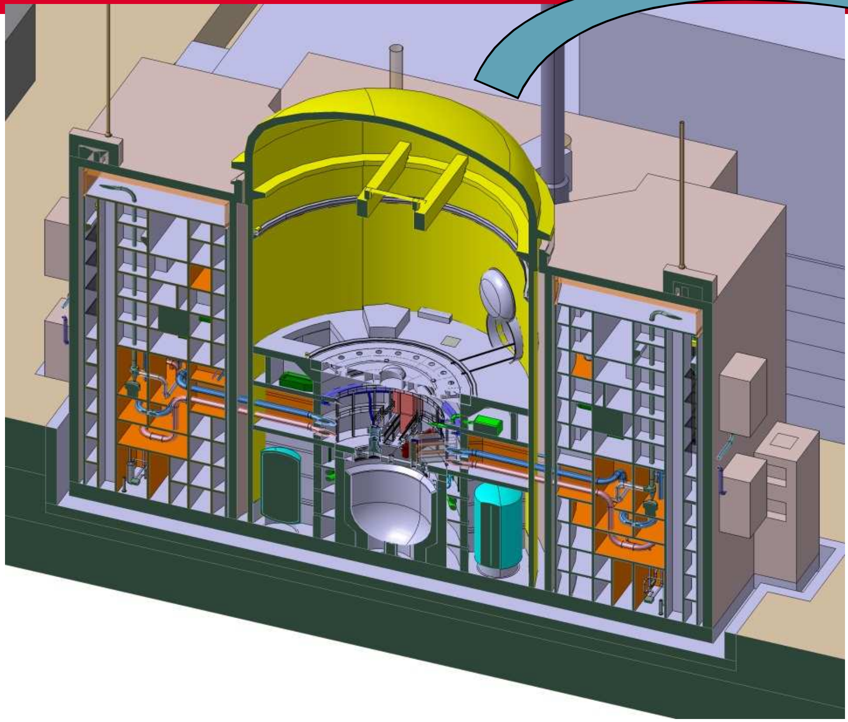
Technical choices during the preconceptual design

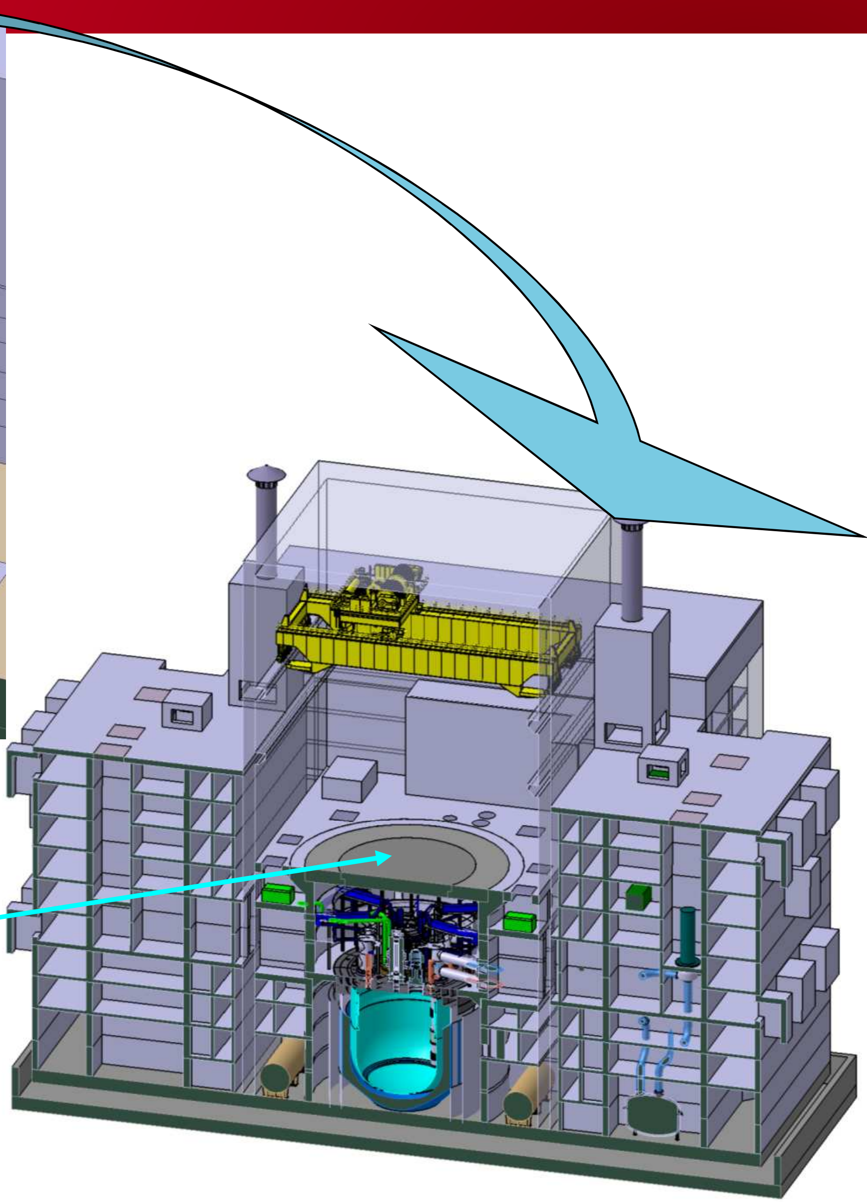
- **Integration of the electromagnetic pumps in the design of secondary circuits**
- **Preferred lay-out :**
  - *3 primary pumps*
  - *4 intermediate heat exchangers*
  - *4 secondary circuits*
  - *5 decay heat removal circuits*
- **Conical "redan" inner vessel adopted**
- **Search for complementary and diversified decay heat removal systems (no common mode failure through the roof slab)**
- **Consider the possibility to prevent the sodium fires by filling some zones with inert gases**
- **Study of new concepts to decrease the fuel loading-unloading duration**





Reactor block on paraseismic systems : configuration difference : start of AVP2 vs AVP1





Séparation of the functions resistance et tightness

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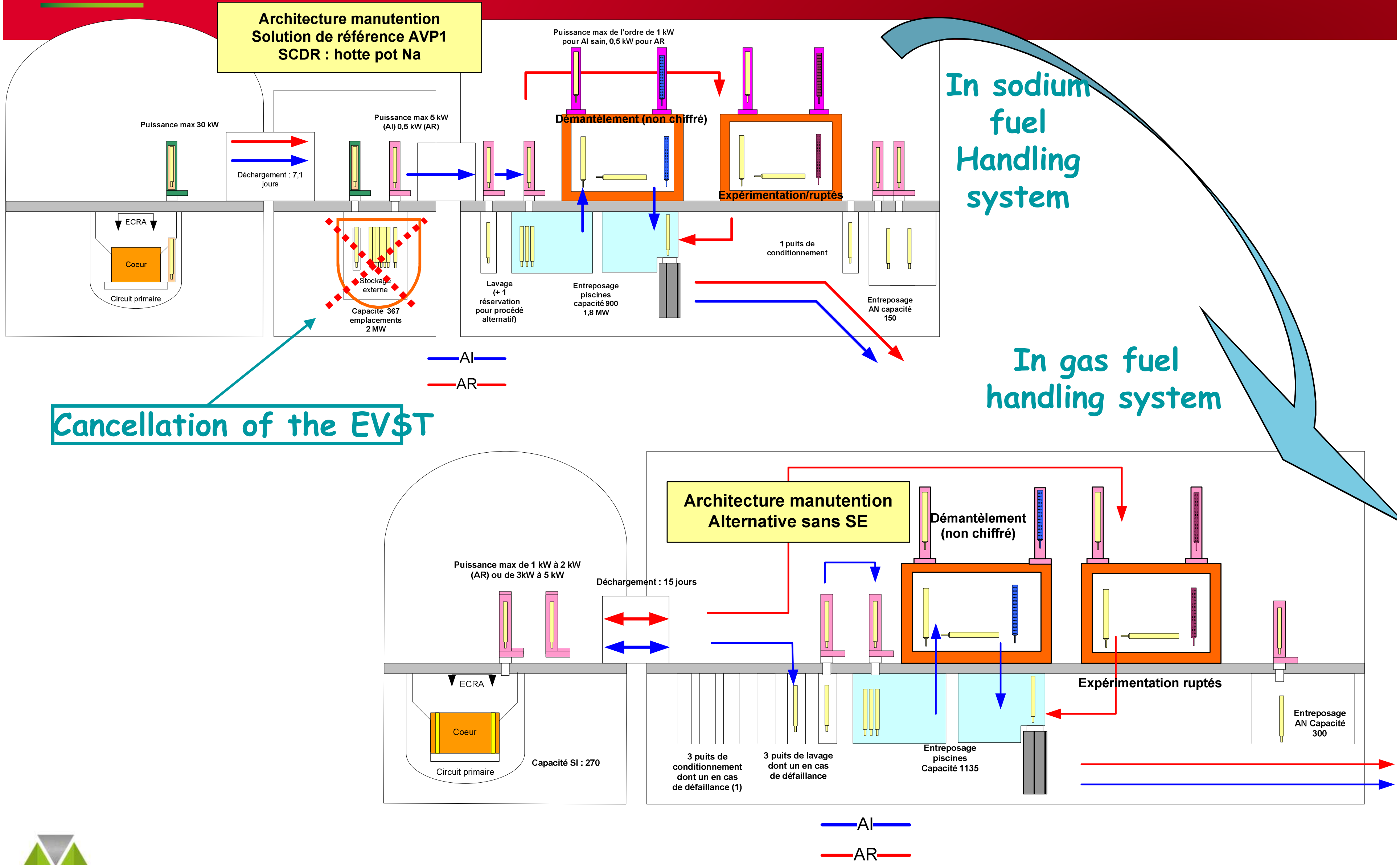
rectangular building in concrete

OPTION CHOICE REVIEW 1ST SEMESTER 2013 :
SUPPRESSION OF THE EX VESSEL STORAGE TANK



Option choices

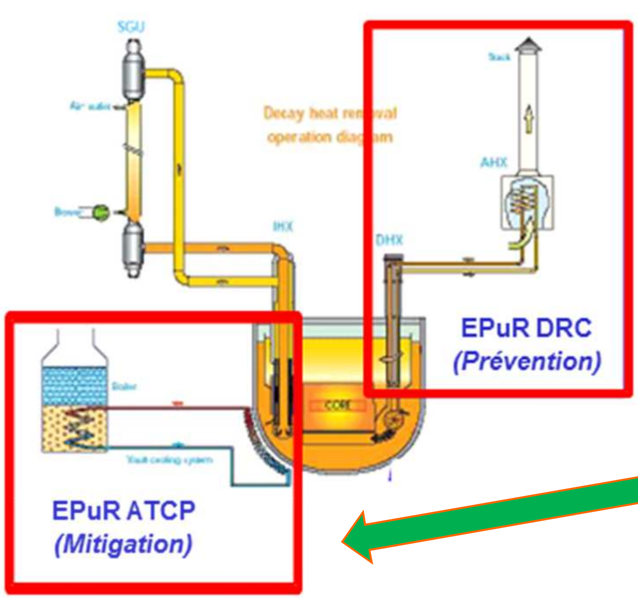
- **Fuel handling**
  - ***Fuel handling is based on transfers in gas cask.***
  - *The experimental fuel subassemblies are transferred in hot cell and operated outside the handling phase.*
  - *Washing of gas failed fuel subassemblies is taken as a reference for ASTRID (R&D to be provided for, for **c**onfirmation purposes).*

- **Internal storage**
  - *Number of positions: 144 **for sound fuel subassemblies and** 28 for fuel subassemblies with cladding failure in debugging.*
  - *An R&D programme needs to be defined so as to identify means for occasional monitoring of some positions of the **internal storage facility**.*
  - *The envelope accident scenarios are to be specified.*
  - *The cost of 200 additional fuel assemblies with internal **storage needs to be assessed.***

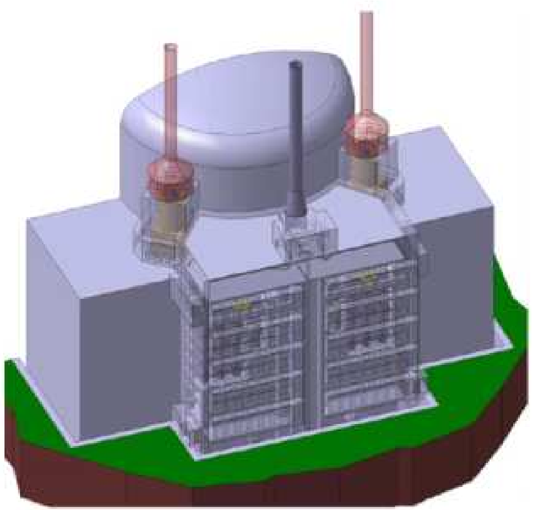
- **ISIR**
  - *Monitoring and inspection strategies are beginning **to emerge for important components:** above core structure (BCC), strongback, steam generator, etc.*
  - *The inspection techniques **still remain to be specified.***

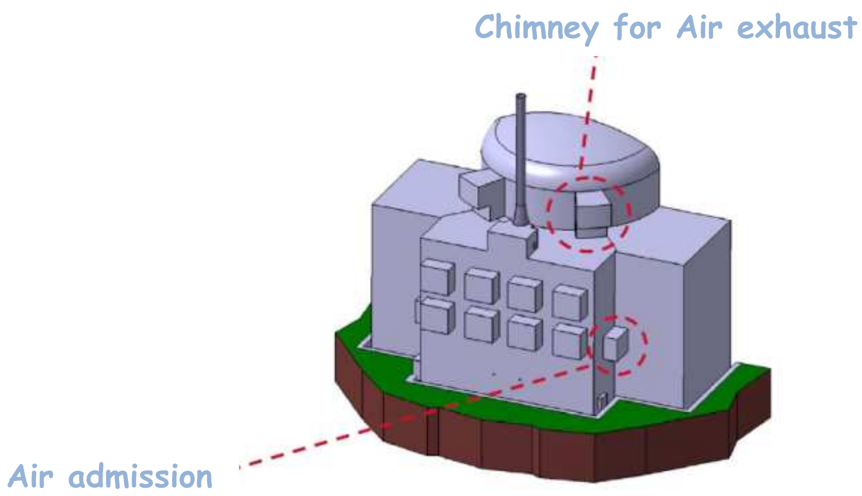
Decay heat removal

2 diversified cold sources : water & air



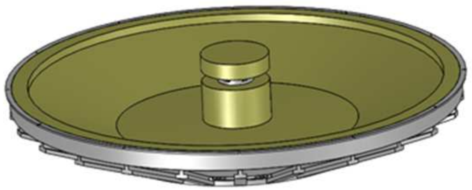
- **2 main systems (prevention):**
  - **Na/Na HX in the Primary Vessel,**
  - **air as cold source,**
  - **Redundancy :**
    - **System n°1 : 3*50% (ou 66%) in natural convection**
    - **Système n°2 : 2*100% in forced convection**
- **1 complementary system (mitigation):**
  - **RVACS (Reactor Vessel Auxiliary Cooling System)**
  - **Cold Source (water/oil)**



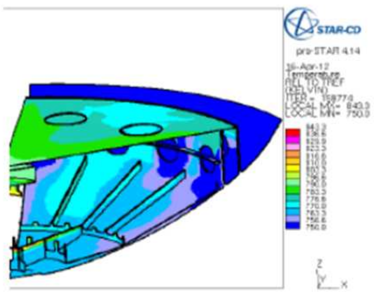


implantation of the ASTRID core catcher

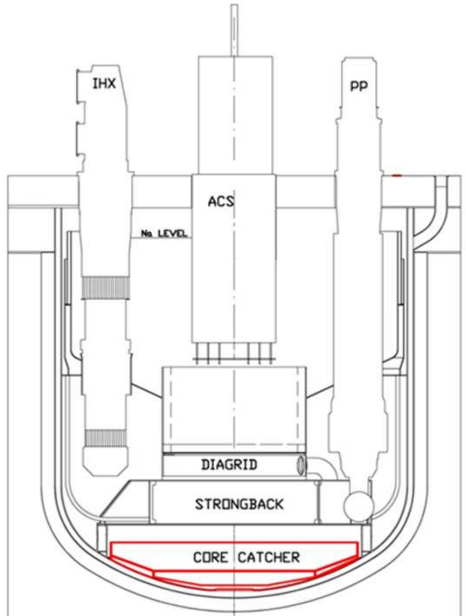
- **Selection of a core catcher inside the reactor vessel**
  - **Located inside the primary vessel**
  - **Designed to catch a whole core melting**
  - **Allow to prevent the integrity of the Reactor Vessel**
  - **Provide constrainst on material selection & inspection during the whole life of the reactor**



In-vessel core catcher design



In-vessel core catcher cooling studies



Example of in-vessel core catcher

Core design approach

ASTRID core design is mainly guided by safety objectives :

1. Prevention of the core meltdown accident

-by a natural behavior of the core and the reactor (no actuation of the two shutdown systems)

-with adding passive complementary systems if natural behavior is not sufficient for some transient cases

2. Mitigation of the fusion accident

To guarantee that core fusion accidents don't lead to significant mechanical energy release, whatever initiator event

-by a natural core behavior

-with adding specific mitigation dispositions in case of natural behavior is not suffficient

Core design objectives

● ***Natural behavior favorable for transients of unprotected loss of flow, loss of heat sink and loss of supply system power***
Target criteria : no sodium boiling for a ULOSSP transient

● ***Sodium void effect minimized***
Target criteria : Na void effect < 0

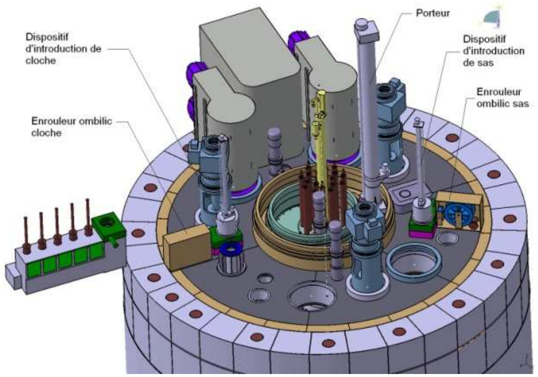
● ***Natural behavior favorable for a complete control rod withdrawal (with no detection)***
Target criteria : no fuel fusion

● ***Improved performances***
Target criteria : Cycle length ≈480 efpd, High fuel burnup, and breeding gain ≈0

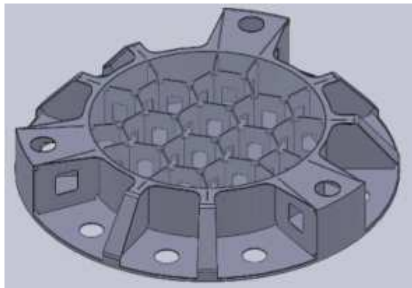
+ Core design is extrapolable to higher power

IN SERVICE INSPECTION AND REPAIR

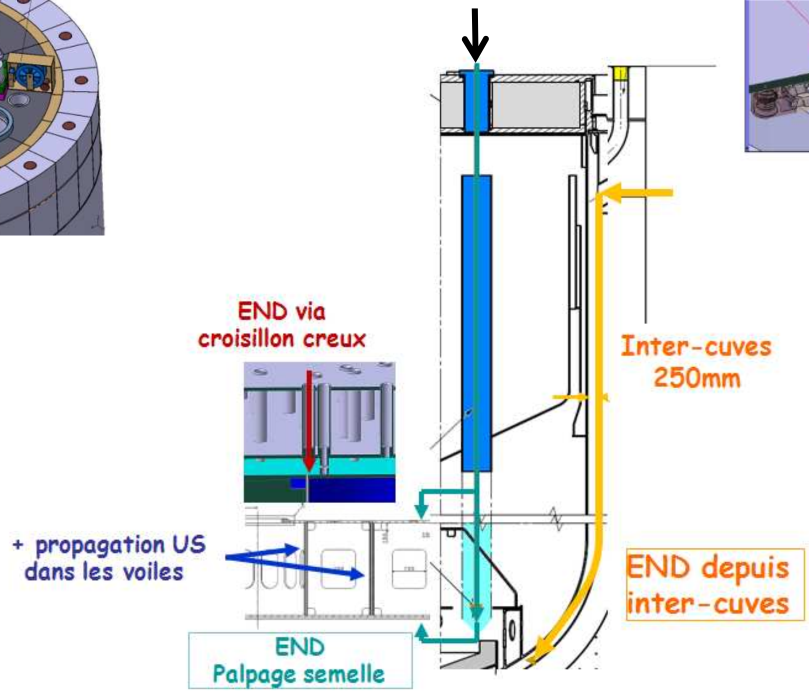
ACCESS taken into account from the early stage of the project



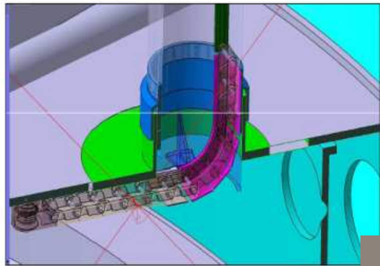
Access to the strongback

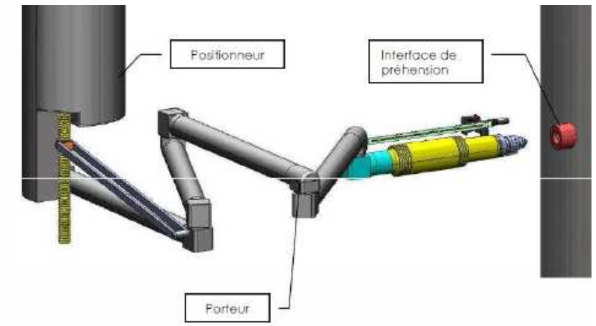


Slab penetrations dedicated to ISIR

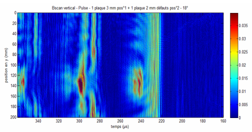


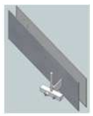
CARRIERS DEVELOPMENT
In sodium and out of sodium

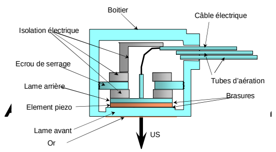




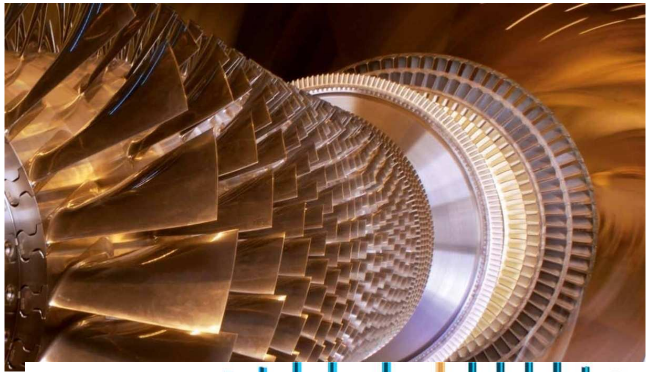
SENSORS DEVELOPMENT
In sodium and out of sodium





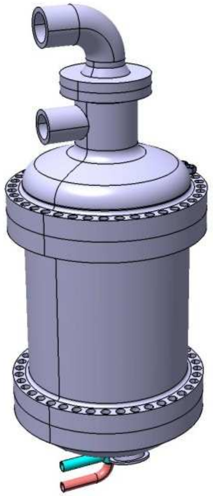


POWER CONVERSION SYSTEM



- Two power conversion systems have been investigated during the preconceptual design
- Steam PCS
  - *Most mature system based on a well-developed turbomachinery technology.*
  - *High plant efficiency.*
  - *Studies on steam generators designs and leak detection systems in progress with the aim of reducing the risk of large SWRs and of limiting its consequences.*
  - *Design and general lay-out will be done with steam PCS during the conceptual design*
  - *licensing safety assessment of a SFR must deal with the Sodium Water Air reaction (SWAR): trend to demonstrate a situation practically eliminated.*

- Gas PCS
  - *Strong advantage as it inherently eliminates the SWR and SWAR risks.*
  - *Very innovative option : major breakthroughs but feasibility and viability not yet demonstrated.*
  - *Remaining technological challenges but no show-stopper indentified.*
  - *Studies continue during the conceptual design to improve performances, operability, maintainability and technology readiness level*



STRATEGY BASED ON DIFFERENT PLATFORMS

PAPIRUS:
Mainly medium scale sodium facilities (loops and gloves boxes) (few liters to 3 m³)
90 % achieved

CHEOPS:
Large scale sodium facilities (loops for thermal-hydraulics, components development…)
Preliminary studies completed

GISEH:
Medium scale to large scale water facilities (loops for hydraulics and thermal-hydraulics)
Under construction

PLINIUS-2:
Large scale severe accidents studies (corium/sodium interaction)
Feasibility studies completed

PAPIRUS PLATFORM DETAILS

Sodium loops:

DOLMEN, FUTUNA2, IRINA, VKS PEMDYN, ARTOIS, PENELOPE, SUPERFENNEC, *FAENA, FRUCTIDOR*, **LIQUIDUS, CORONNA 1 & 2, CATANA, DISCO2**

Sodium cleaning or sodium/water reaction:

VAUTOUR, KALINA, MININANET2, CARNAC, SCORPION-ENCRINE

Water benches (prior to sodium tests):

VISIO, MUST, Strioscopy bench, NAQUALIGHT, MESANGE2, ACWABUL, IKHAR

DIADEMO

(Na, PbLi, gas)

Gas facilities in support of SFR:

HEDYT

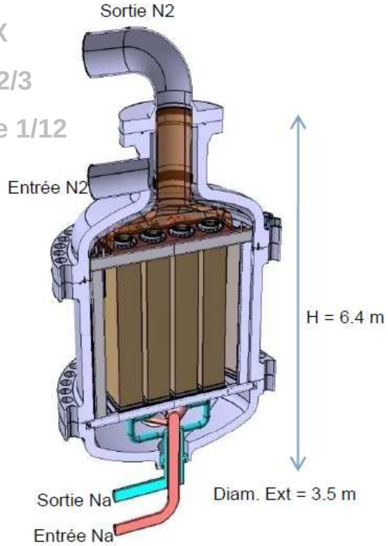
Other facilities:

SQUAT (SG tubes rupture), Ovens (850°C & 1200°C)

CHEOPS

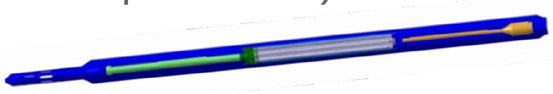
Objective: insure innovation development (requiring large scale), e.g.:

- Technology :
  - Compact heat exchanger (sodium/gas)
  - Tightness of compression ring for IHX
  - Fuel assemblies tests

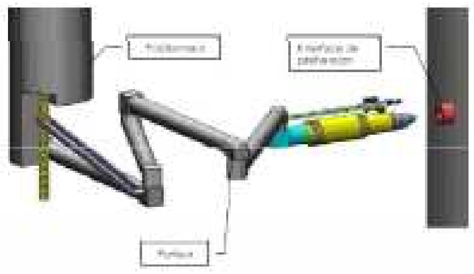


- In sodium inspection (ISI&R)
  - In sodium telemetry
  - Inspection and repair processes

- Safety
  - DCS P (Complementary safety systems – prevention)



- Instrumentation
  - Thermal hydraulic instrumentation (testing)(full scale with representative flow, temperature…)
  - High Temperature Fission Chambers (long term resistance)
  - Acoustic detection techniques validation



- Codes qualification
  - Thermal-hydraulic in gas phase (Aerosols deposit on the roof slab)

FUTURE FACILITIES
(OPERATIONS PLANNED BY 2018)

CHEOPS

Main characteristics

- Facility composed of:
  - 2 sodium loop: NAIMMO, NADYNE,
  - 1 sodium/gas loop: NSET,
  - and a cleaning facility for large components (STALACMITES).
- Sodium inventory < 100 t in a large building (30 x 22 x 28m)
- Commissionning planned for 2018

NSET GAS (10MW)

1 mock-up of compact heat exchanger

- « module » mock-up (scale 2/3)
- « Component » mock-up (scale 1/12)
- Instrumentation

NAIMMO

1 large vessel used in dynamic and static conditions

- Technology : tightness of compression ring for IHX
- Thermal-hydraulic in gas phase (incl. Aerosols transfer)
- ISI&R (telemetry)

NADYNE

1 test section for fuel assemblies

- Fuel assemblies – reactor conditions (47 kg/s – 5 bars ΔP – 580°C)
- DCS P (Complementary safety device – prevention) (700°C)

STALACMITES

1 cleaning facility

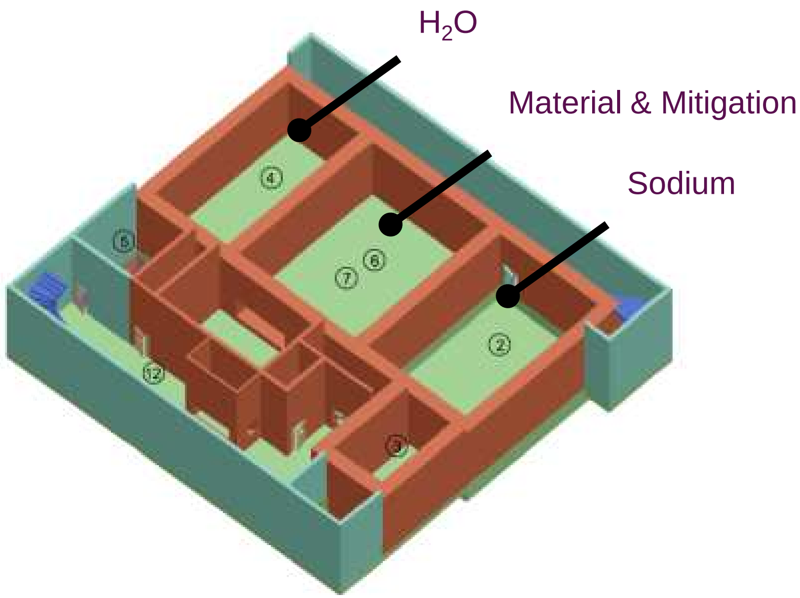
- Different cleaning processes based on water reaction (steam + carbonation)

General Specifications of PLINIUS 2

Corium-Sodium Facility

GEN4

- FCI up to vapor explosion
- Sodium temp.: 400 to 850℃
- Corium mass : 50 to 500kg
- Na test section + circuit ~2 tonnes
- X-ray imaging



Material interaction facility

GEN4
GEN2&3

- Ablation (core catcher material, ceramics, cor
- Corium mass : 50 to 500kg
- With/without cooling
- Size upto 3m x 3m x 1m
- Potentially X-ray imaging

- ✓ **Corium temperature > 2850℃**
- ✓ **Separtaion Water/Sodium rooms**
- ✓ **Handling of large masses**
- ✓ **One furnace – 3 test facilities**
- ✓ **Electric power ~ 1 000 kVA**

Corium-Water Facility

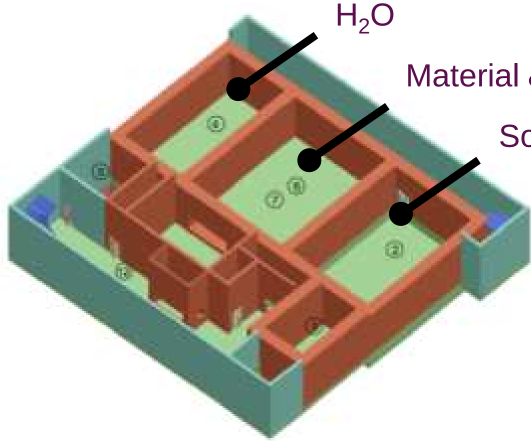
GEN2&3

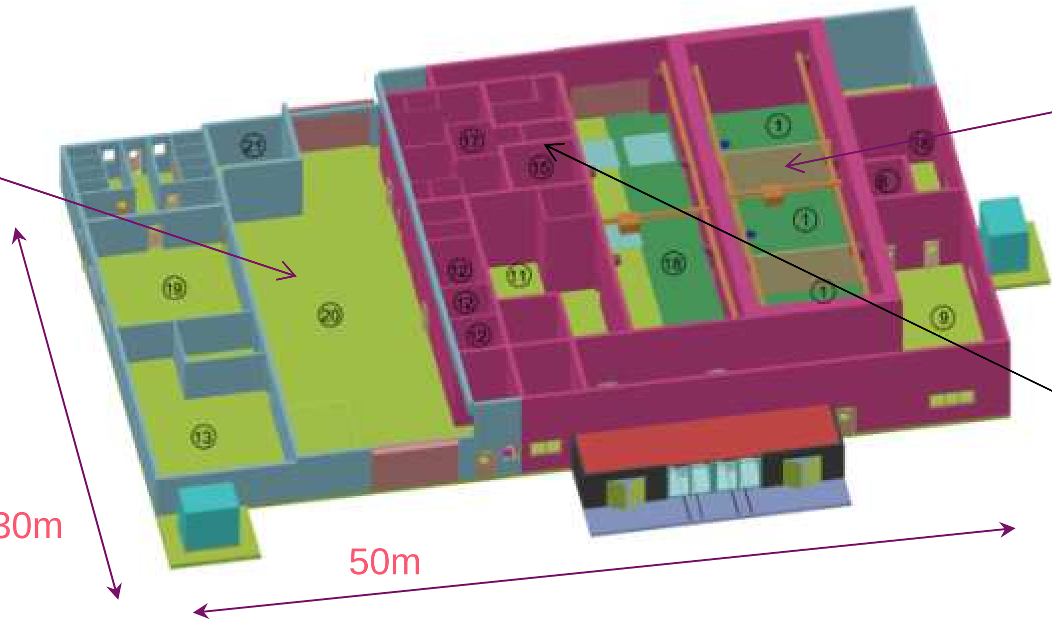
- FCI up to Steam explosion
- Temp : ~80℃
- Mass: 50 à 500kg
- Steam quenching system
- X-ray imaging

+ Phenomenological tests (VITI)

+ Analytical tests (Low Temperature)

Sketches of PLINIUS 2 Building





Thank you for your attention