DE LA RECHERCHE À L'INDUSTRIE

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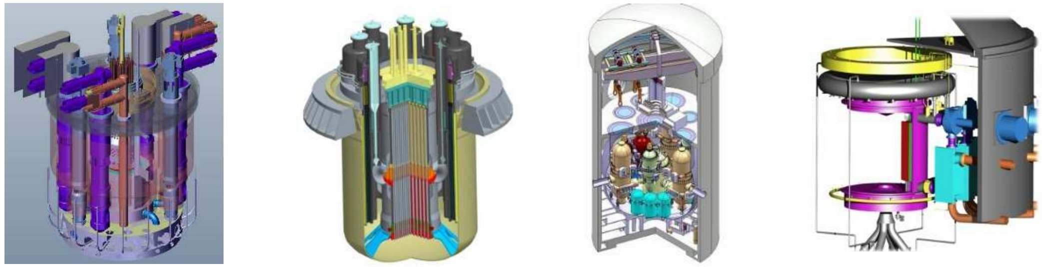
Joint ICTP-IAEA Workshop on
"Physics and Technology of Innovative Nuclear Energy Systems for Sustainable Development"
Trieste Italy
2018 August 20th-24th



Interaction coolant-material

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TOPICAL AREAS AND OBJECTIVES OF THE OECD EXPERT GROUP

➔ **Environmental conditions and factors that affect materials behaviour relevant for the structural integrity of confinement barriers and components.** These include the impact on mechanical properties from the environment such as irradiation effects and liquid metal embrittlement as well as environmental assisted property effects like corrosion.

The objective is to address the ***environmental effects relevant for construction standards via a fundamental understanding of materials behaviour (corrosion and mechanical properties in the liquid metals and under irradiation****).*

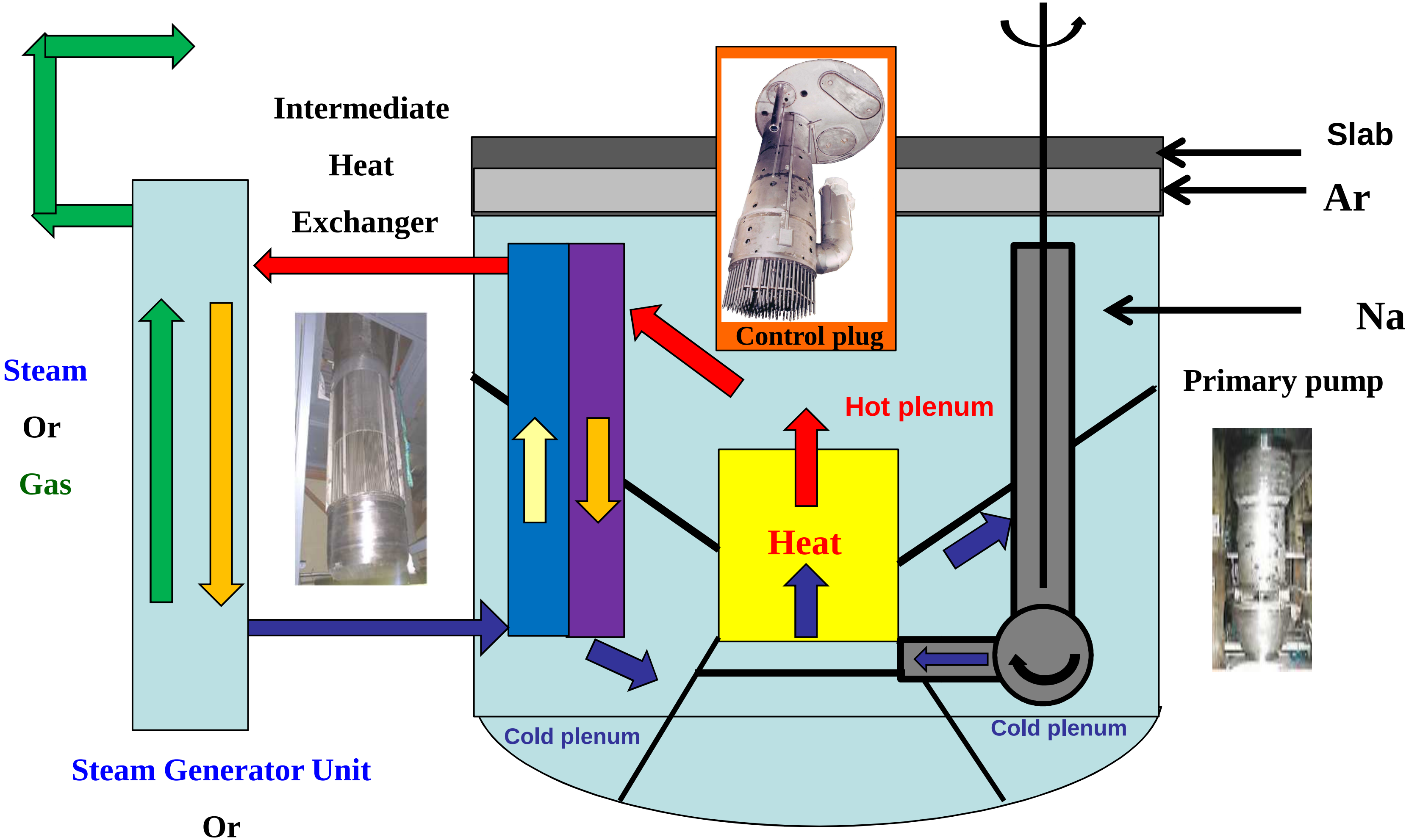
➔ **Coolant and cover gas issues. Here the focus is placed on issues relevant for radiological impact assessment, operation and handling.** Topics to be addressed are the chemistry, radio-chemistry and physics of the coolant, its interaction with the cover gas, the impact of irradiation, the influence of corrosion, etc.

The objective is to answer ***key technical issues to address radiological impact, operation, handling and inspection as relevant for licensing (reactor operation, dismantling).***

➔**Thermal-hydraulics for Heavy Liquid metals.** Thermal hydraulic behaviour of the coolant is a crucial factor in the sense that it essentially determines a large part of the environmental conditions for materials and the cooling such as the flow distribution and mixing, temperatures, erosion rates, operation of components, etc

The objective is to collect experimental data for ***correlations relevant for heat exchange, pressure drops, vibrations, mass transfer, etc. in order to assess and improve knowledge of the environmental conditions for materials and the coolant*** **behaviour.** (some points ie heat exchange and pressure drops in the frame of NAPRO for SFR; out of scope of OECD mandate)

PRIMARY CIRCUIT OF SFR (POOL CONCEPT)



Intermediate
Heat
Exchanger

Control plug

Slab

Ar

Na

Primary pump

Hot plenum

Heat

Steam
Or
Gas

Cold plenum

Cold plenum

Steam Generator Unit
Or
Heat Exchanger

MAIN ENVIRONMENTAL EFFECTS

Main parameters:

- neutron flux
- temperature T, T gradients, T cycling, T instabilities & drifts
- Na chemistry (O, N, C, H, ...)
- life duration (requirement: up to 60 years)
- local Na velocities and pressures

Involved phenomena:

➔ **On structural materials:**

- generalized corrosion and mass transfer (dissolved & particles)
- deposition
- embrittlement
- desquamation
- Activation....

➔ **On coolant:**

- activation of coolant (^{22}Na, ^{24}Na)
- Na contamination : activated corrosion products, fission products (cesium, tritium…), fuel (open pin rupture)
- introduction of particles ($NaCrO_2$) in Na,….

➔ **On cover gas:**

- contamination

MAIN ENVIRONMENTAL EFFECTS

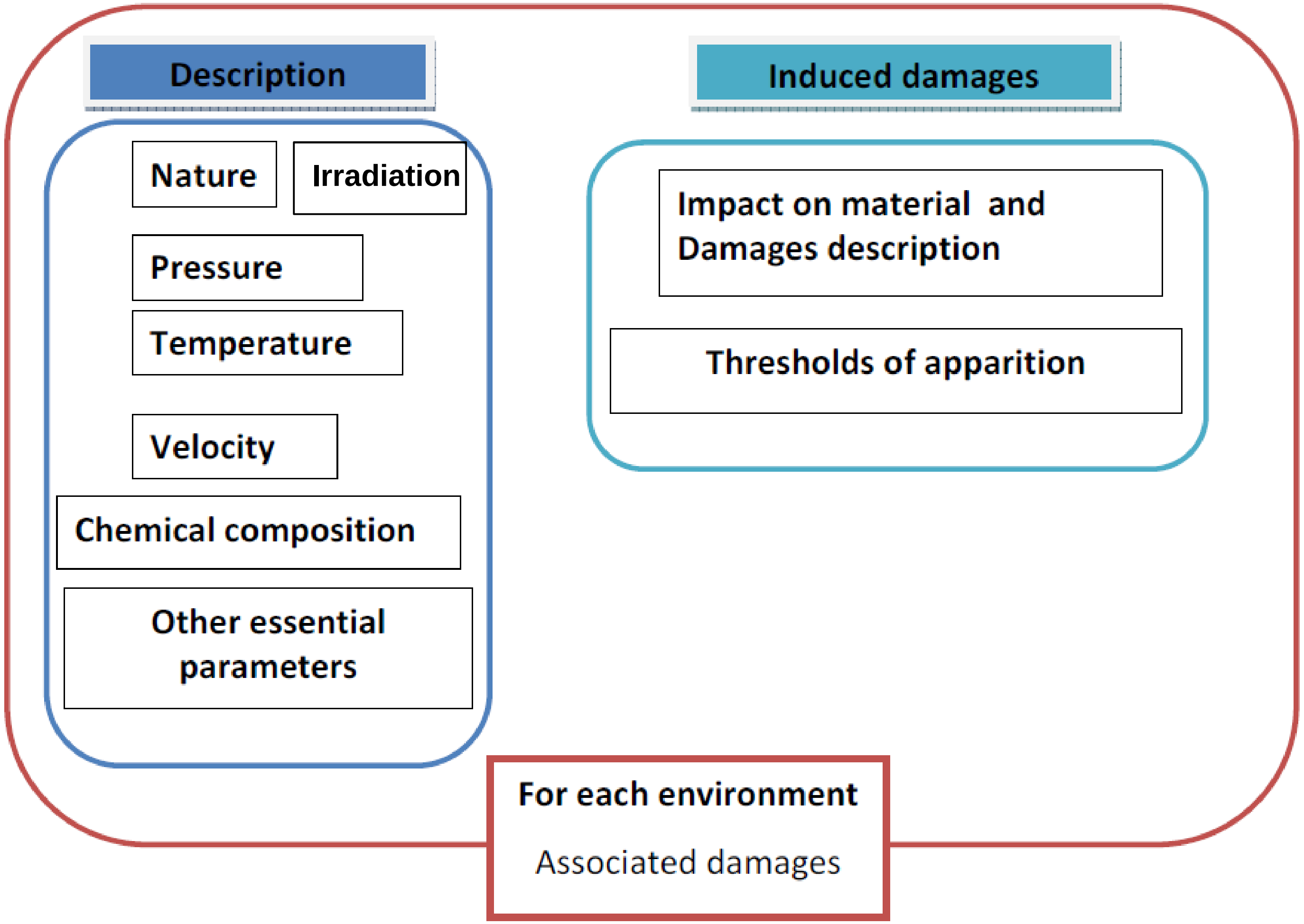
➔ Potential consequences on reactor operation

- reduction of life duration (ageing)
- plugging in narrow gaps and consequences on safety,
- deposits on Heat Exchangers and potential limited loss of efficiency,
- cleaning & decontamination of components, induced by dosimetry processes prior to inspection, removal, repair,
- increased duties for coolant purification systems (cold traps...)
- cover gas issues: gas purification and control, aerosols issues…and their consequences on handling, maintenance, personnel exposure…

➔ Potential consequences on reactor dismantling

- cleaning & decontamination of components, pipes… induced by dosimetry
- coolant decontamination systems (cold traps, carbon traps, Ni traps...)
- coolant treatment (ie NOAH process: plugging risk to adress)

Considerations for an integration of other environment effects in RCC-MRx



Description

- Nature
- Irradiation
- Pressure
- Temperature
- Velocity
- Chemical composition
- Other essential parameters

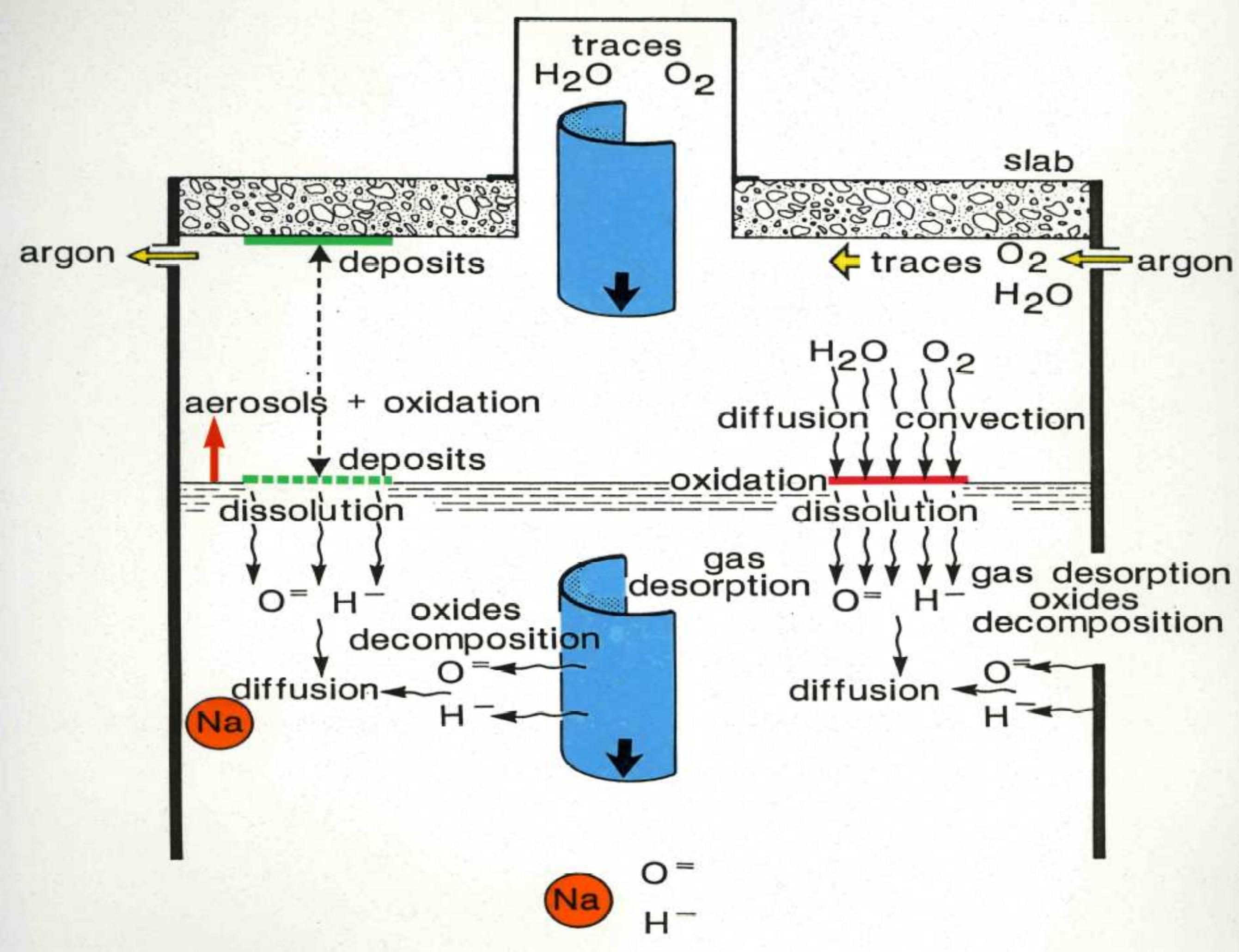
Induced damages

- Impact on material and Damages description
- Thresholds of apparition

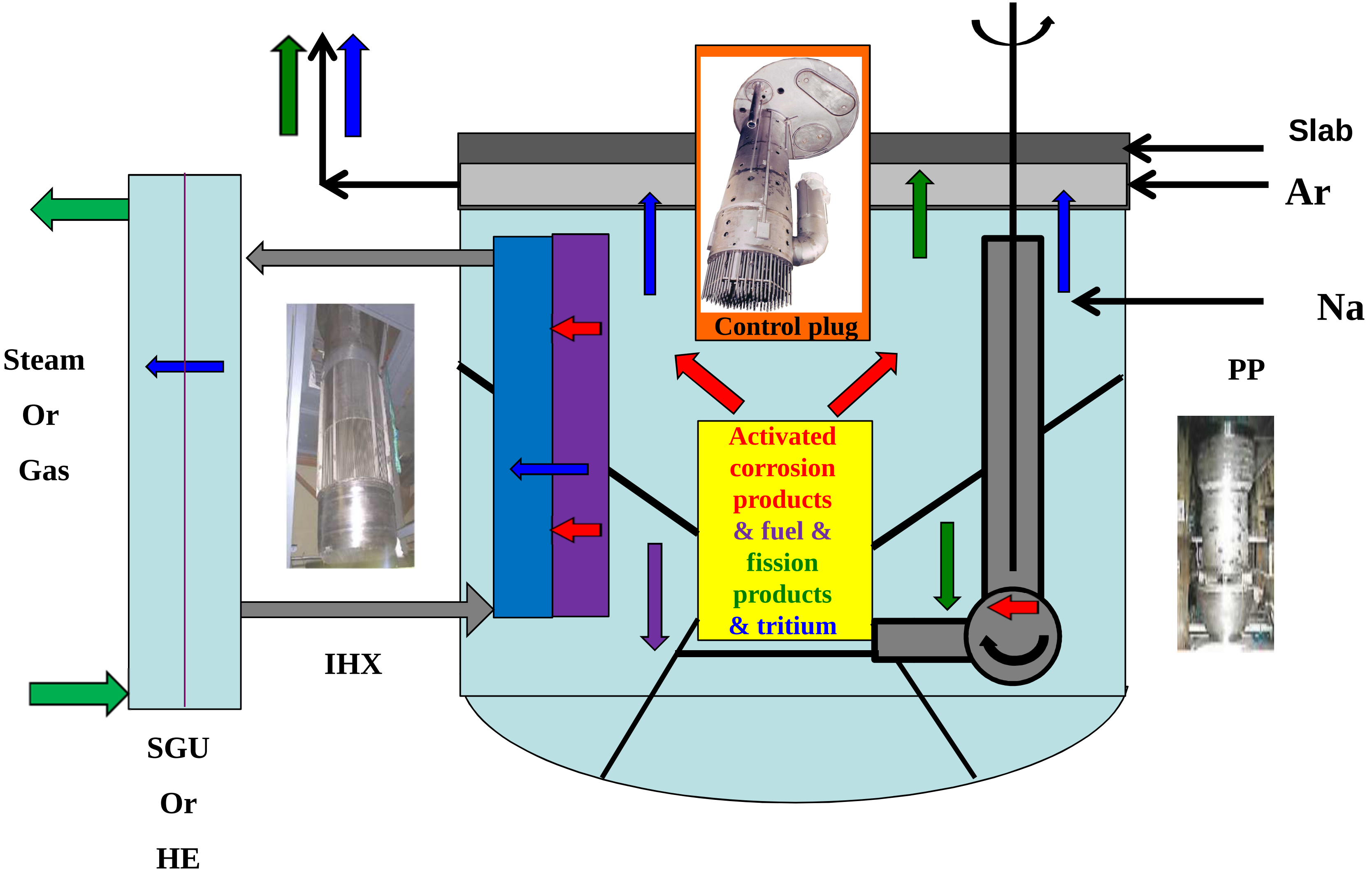
For each environment

Associated damages

POTENTIAL POLLUTION IN PRIMARY VESSEL



PRIMARY CIRCUIT : CONTAMINATION SOURCES



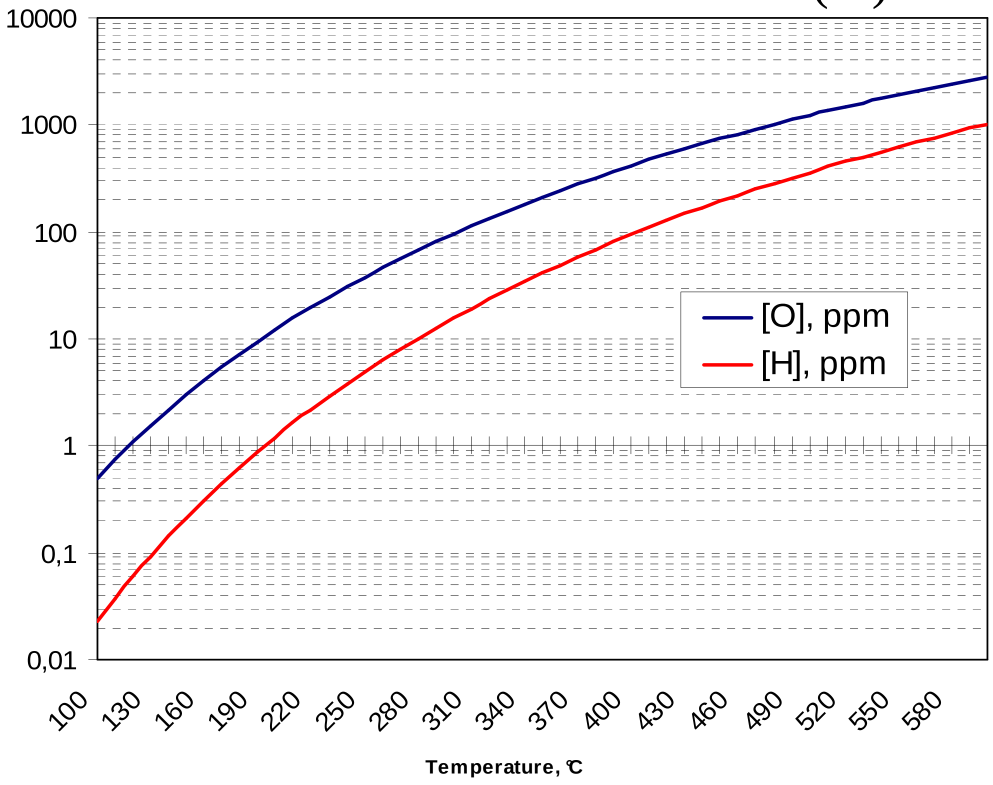
SOLUBILITIES OF O AND H IN SODIUM

Wittingham solubility law

$$\log_{10}[H(ppm)] = 6.467 - \frac{3023}{T(K)}$$

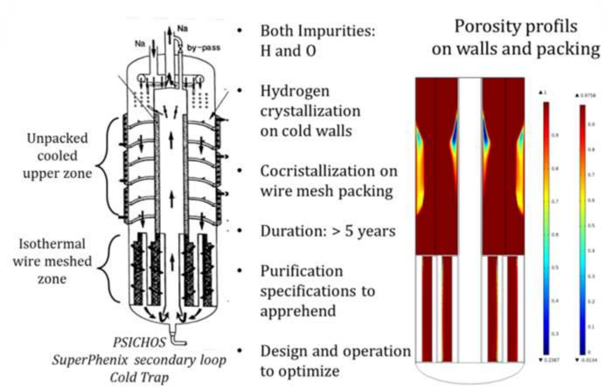
Noden solubility law

$$\log_{10}[O(ppm)] = 6.250 - \frac{2444.5}{T(K)}$$



O and H solubilities are negligible close to 97.8° C

Consequences: Na can be purified by Na cooling, leading to crystallization of O and H as Na_2O and NaH in a "cold trap"

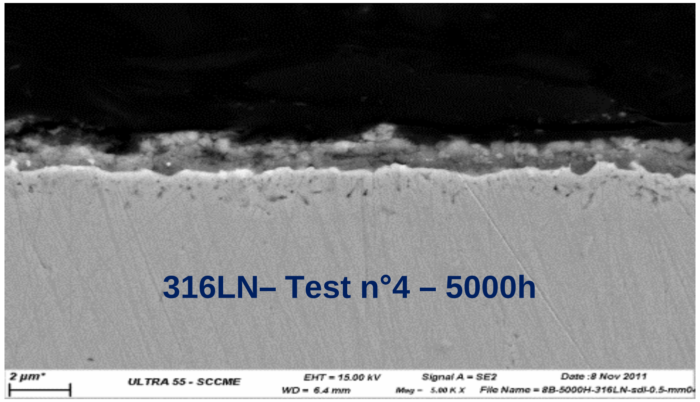


- Both Impurities: H and O
- Hydrogen crystallization on cold walls
- Cocristallization on wire mesh packing
- Duration: > 5 years
- Purification specifications to apprehend
- Design and operation to optimize

C. LATGE, *"Sodium quality control, In International Conference on Fast reactors",* Kyoto, Japan, (December 2009).

Quality of Na has been always well mastered with cold traps, in normal ([O]<3ppm) or transient situations (start-up purification, large air pollution, repair…)

CORROSION IN NA



316LN– Test n°4 – 5000h

CEA-Saclay-CORRONa

- Kinetics available up to 5000 h at 550℃ for [O] < 10 µg/g

  (now up to 200 µg/g investigated see ICAPP 2015 JL Courouau)
- Ferritic steels more sensitive to oxidation and carburization than austenitic steels
- 9Cr steels have a similar behaviour

CEA-Saclay Installation 146
CORRONa

CORRONa facility (CEA-DPC)

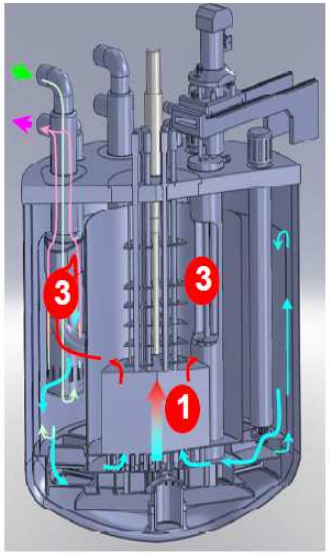
ACTIVATED CORROSION PRODUCTS IN NA

Mass transfer (Fe, Ni, Cr, …)

Is due to solubility difference between hot parts and cold parts of species in the sodium

- ➔ Steel solution in hot regions (bulk corrosion)
- ➔ Precipitation in cold regions (bulk deposition)

Radioactive corrosion product transfer (^{54}Mn, ^{60}Co, ^{58}Co, …)



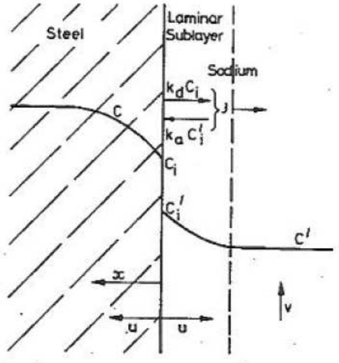
1) Release from the activated cladding
- Bulk corrosion of cladding steel
- Preferential release of highly soluble elements

2) Transfer in the flowing sodium
(parameters : T, velocity, [O])

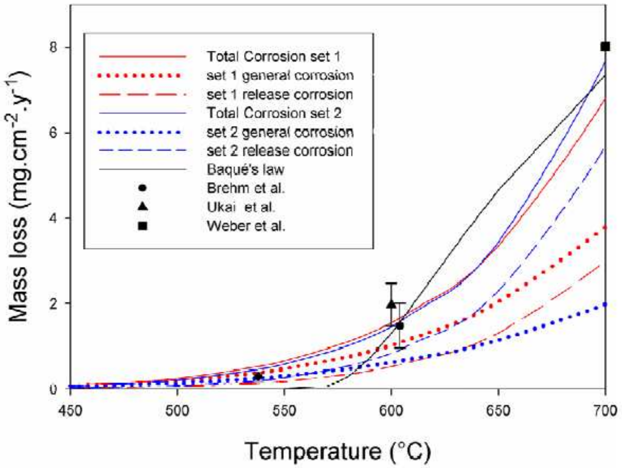
3) Contamination of out-of-flux surfaces (IHX, primary pumps, …)
- Diffusion in the steel
- Precipitation on cold surfaces

Industrial issues of contamination

- •Personnel exposure to radiation
- •Plant design
- •Waste management
- •Decomissionning



(a) Release

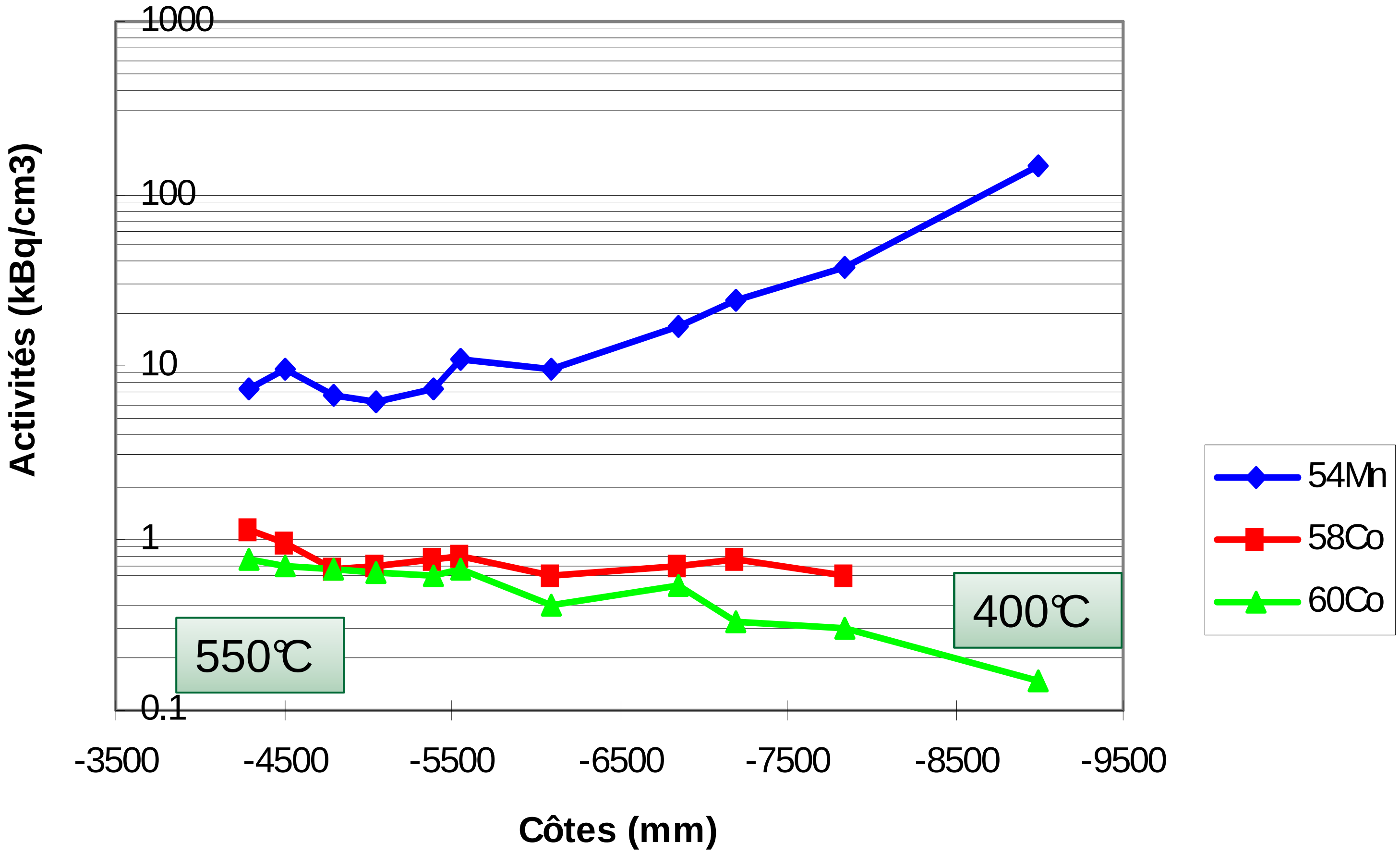


L. Brissonneau, "New considerations on the kinetics of mass transfer in sodium fast reactors: an attempt to consider irradiation effects and low temperature corrosion", Journal of Nuclear Materials 423 (2012) 67-78

Contamination and dosimetry in SFR are low in comparison with PWRs

CONTAMINATION OF IHX

Activity for main radionuclides along PHENIX IHX B



Higher contamination at low temperature but less in depth

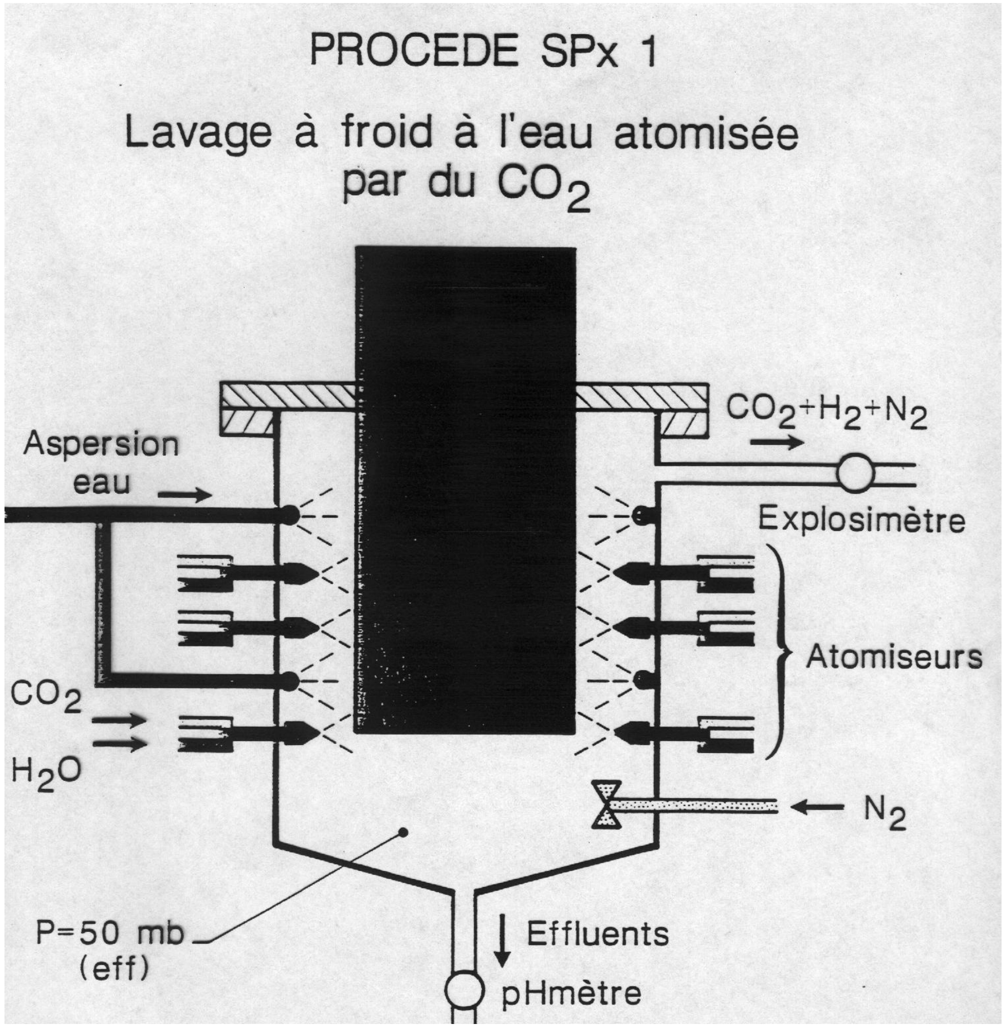
Exemple of cleaning process: SPX process (cold cleaning by CO2 and sprayed water)

Advantages

- Safe process
- Well controlled process
- No caustic corrosion

Drawbacks

- Long process
- Process requiring a lot of gas
- Low efficiency in the baffles and gaps



Decontamination process (residual contamination after cleaning) before repairing

SPm : Sulfo Phosphoric modified

$H_2SO_4 + H_3PO_4$

Duration : 6 hours

Temperature : 60°C

Criteria for decontamination process selection :

– Good efficiency

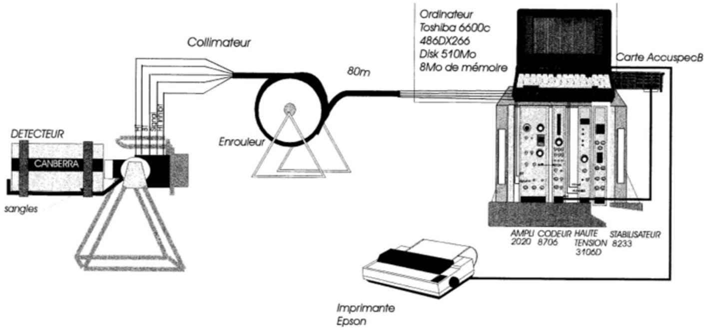
- low residual dosimetry

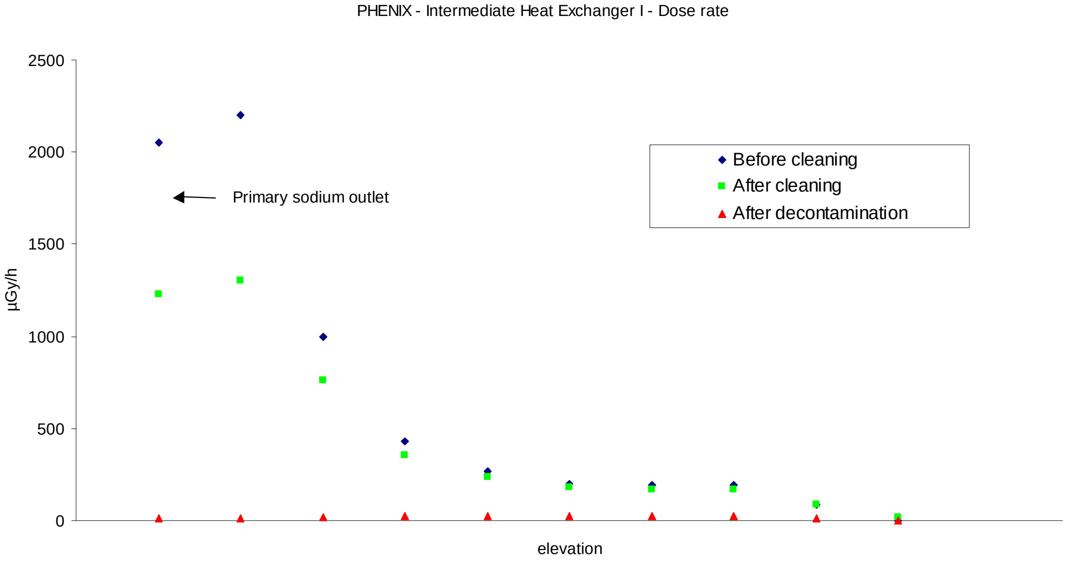
– Process easy to implement and flexibility for various components

– low cost for effluent treatment, chemical products

- Easy component requalification prior to re-use

IHX contamination mainly due to ^{137}Cs, ^{54}Mn, ^{60}Co

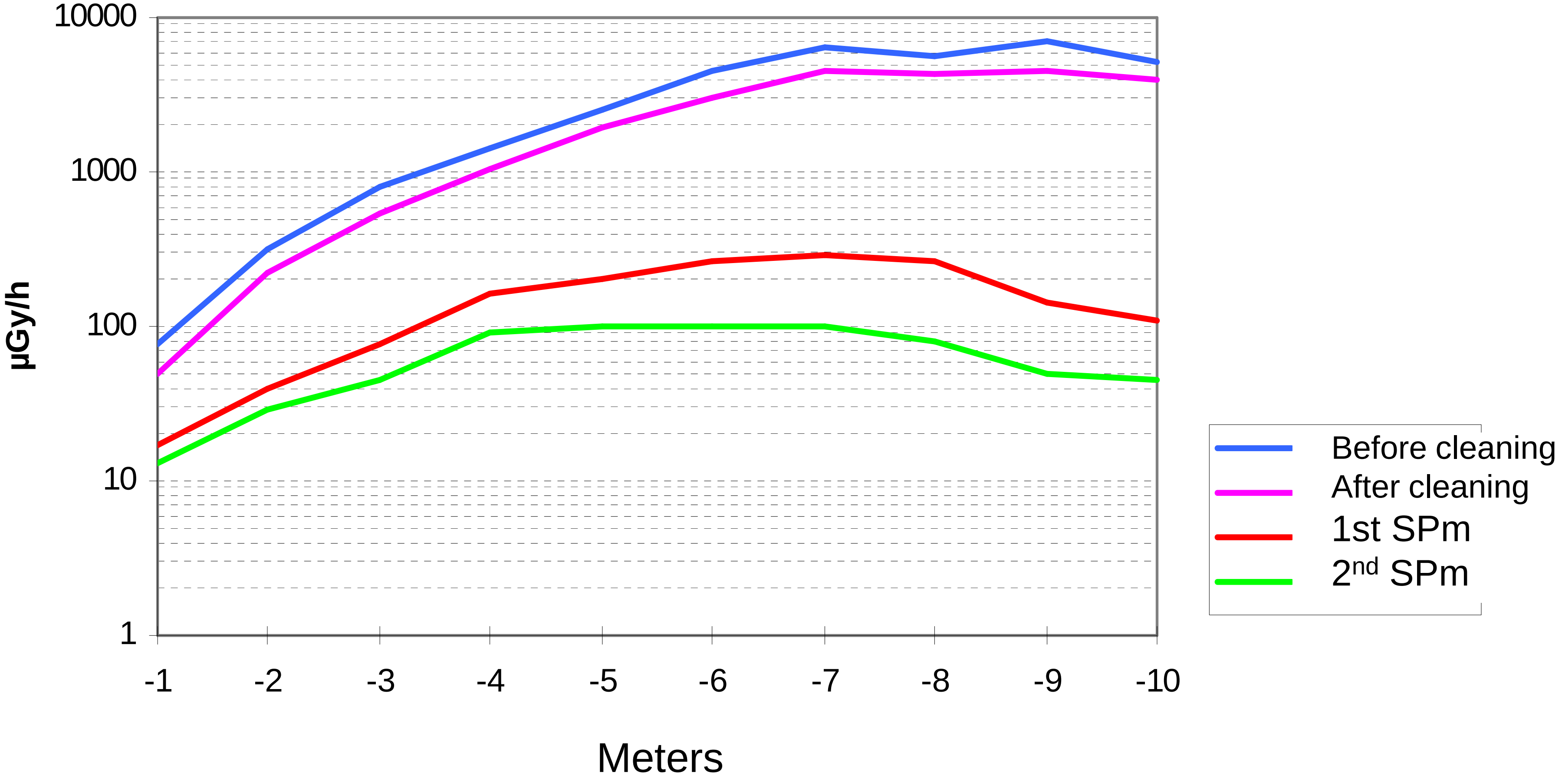




PHENIX IHX activity (exemple)

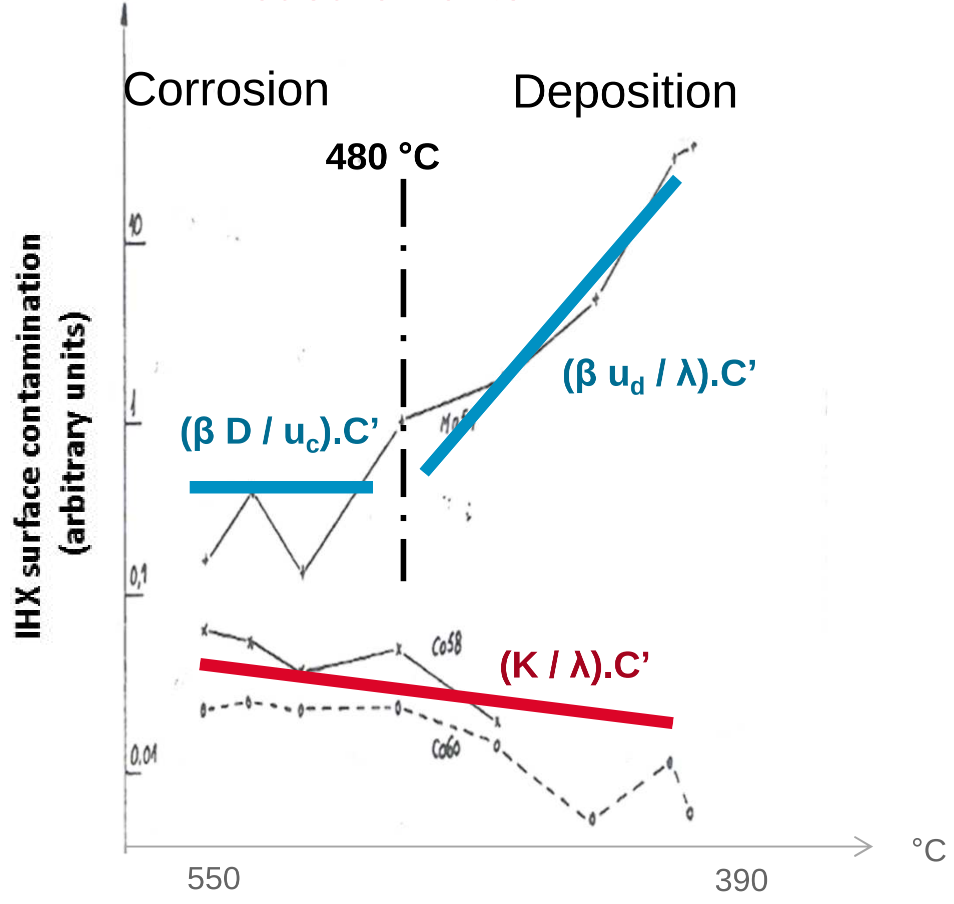
CONTAMINATION AFTER CLEANING AND DECONTAMINATION

Total Activity along PHENIX IHX B after cleaning and two decontamination runs

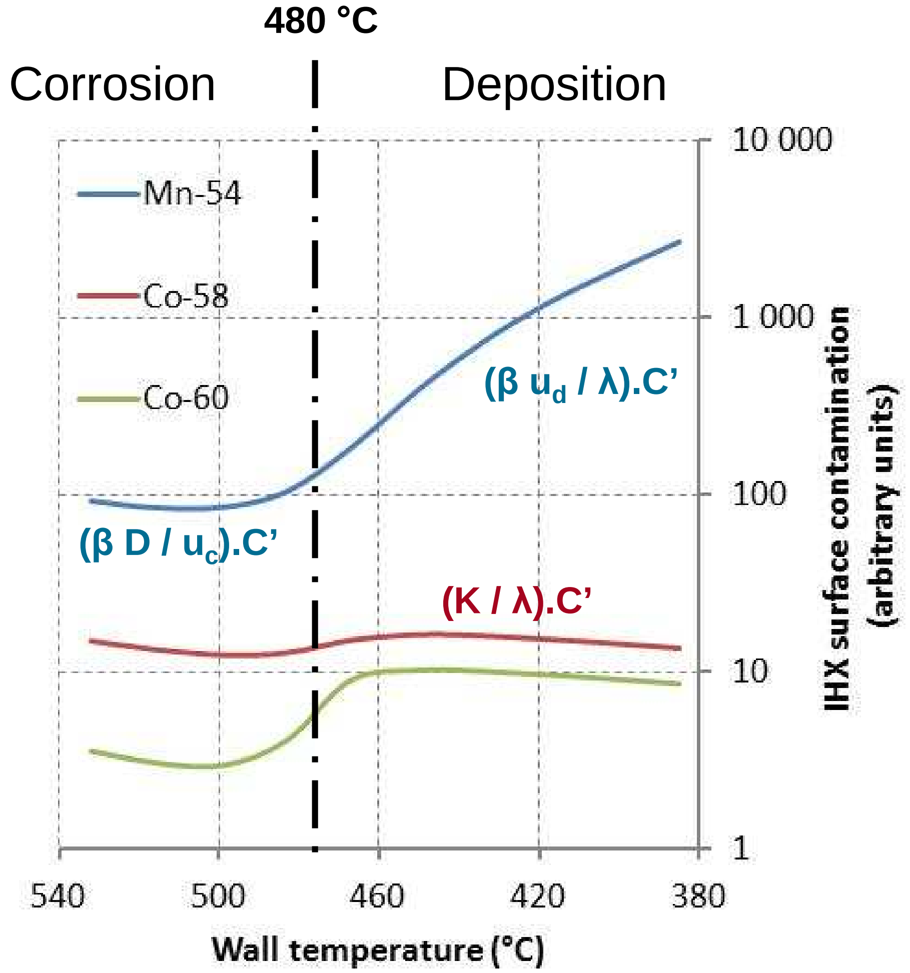


Contamination profiles on PHENIX IHX (1st OSCAR-Na validation)

Measurements



OSCAR-Na calculation



Global contamination as well as contamination profiles on PHENIX IHX are correctly simulated

J.-B. Génin et all *“OSCAR-Na V1.3: a new code for simulating corrosion product contamination in SFR reactors”* Conf. IAEA FR13, Paris March 2013

Hydrogen & tritium transfer from SGU

Kutim code - Distribution of hydrogen and tritium in the different media of the reactor :

governs tritium activities in liquid and gaseous releases, as well as tritium activities build-up in units such as the purification units.

Main objectives of the code :

Assess tritium releases to the environment (gaseous and aqueous)

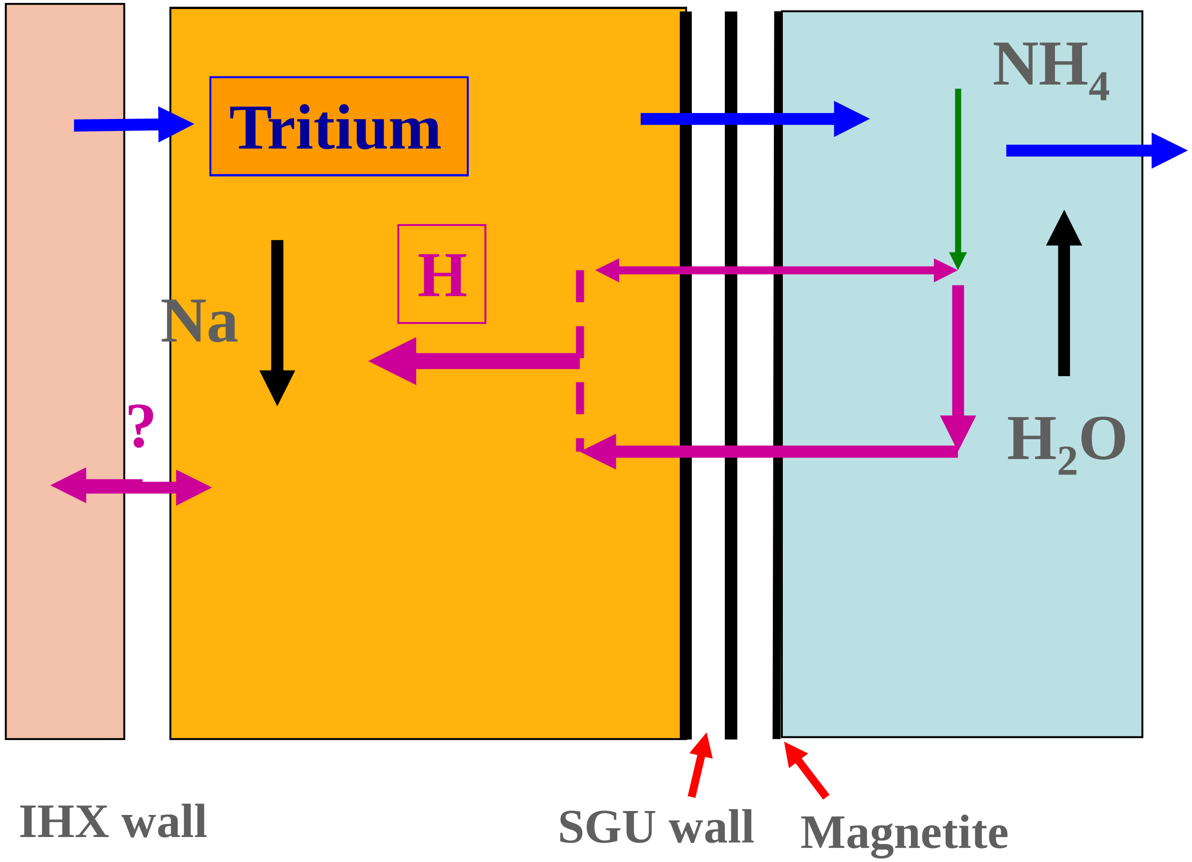
- at the design stage

- at the operating stage

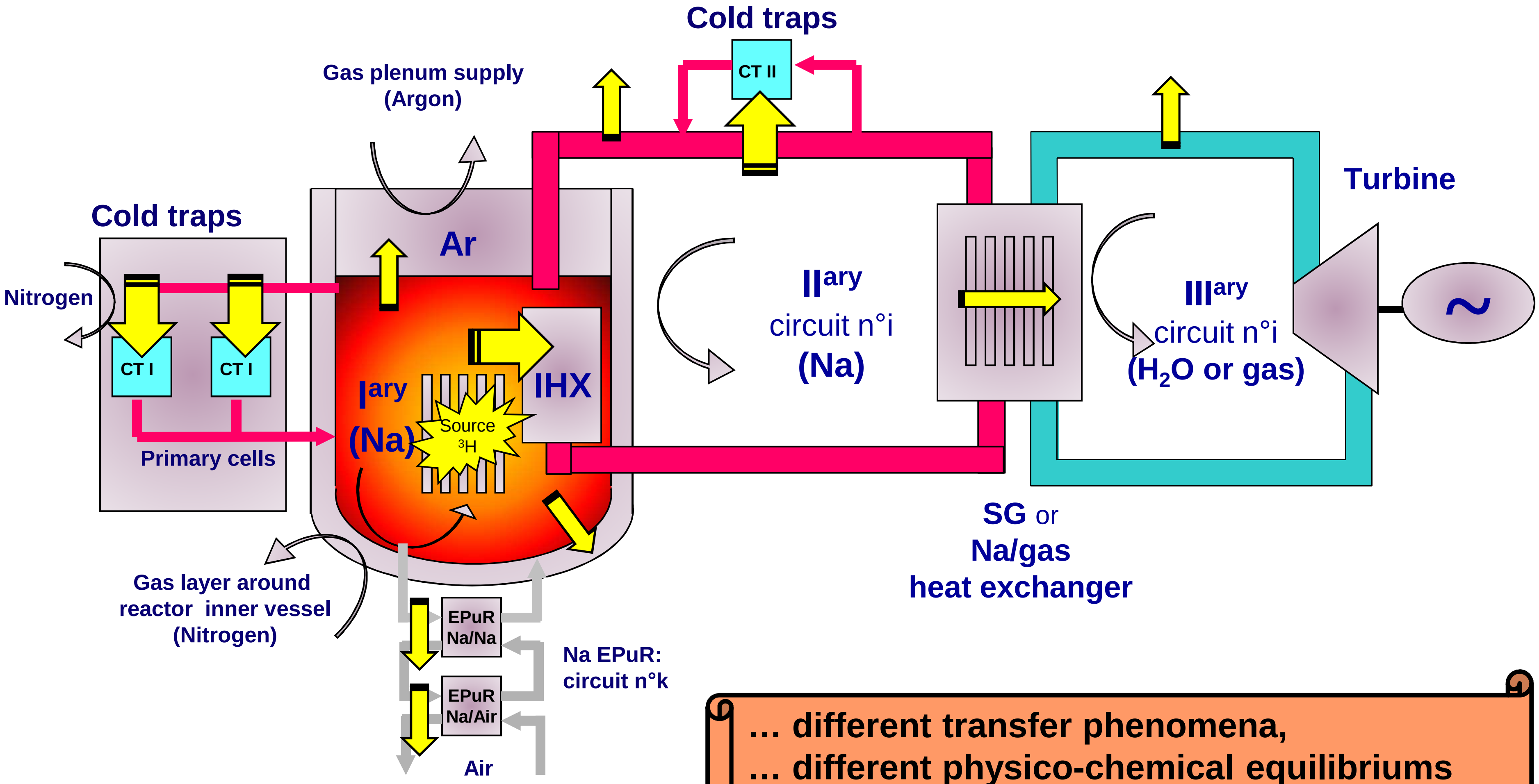
guarantee that they are below the authorised thresholds

Assess tritium activities in the different media (Na, steel,…)

Tritium build-up in purification units



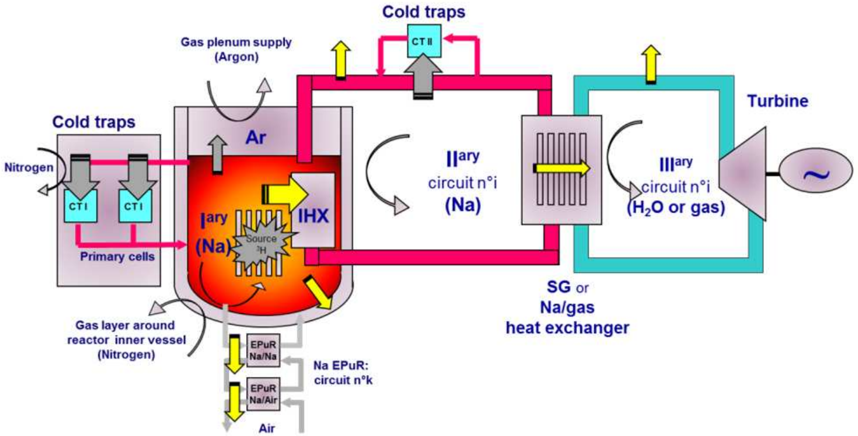
MAIN TRITIUM TRANSFERS TO BE CONSIDERED IN A SFR REACTOR



… different transfer phenomena,
… different physico-chemical equilibriums
to be considered

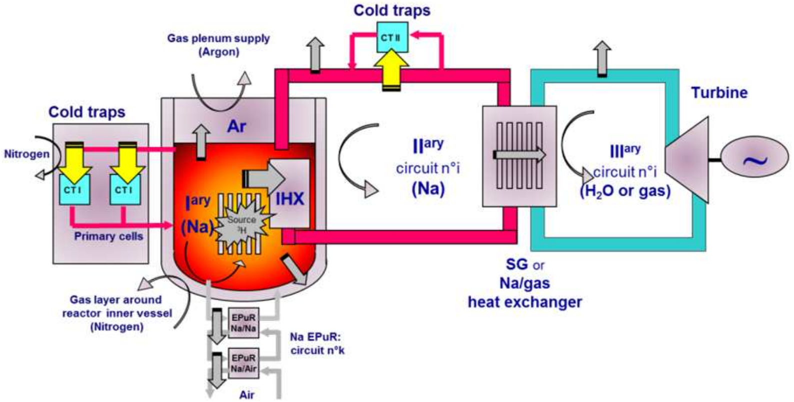
MAIN TRITIUM TRANSFERS TO BE CONSIDERED IN A SFR REACTOR

Permeation through metallic walls



- Major part of tritium transfers between circuits
- Main contributions for permeation through:
  - IHX tubes (Na I^{ary} ➔ Na II^{ary}) , sodium circuits pipings (Na ➔ air atmosphere)
  - Complementary cooling down circuits

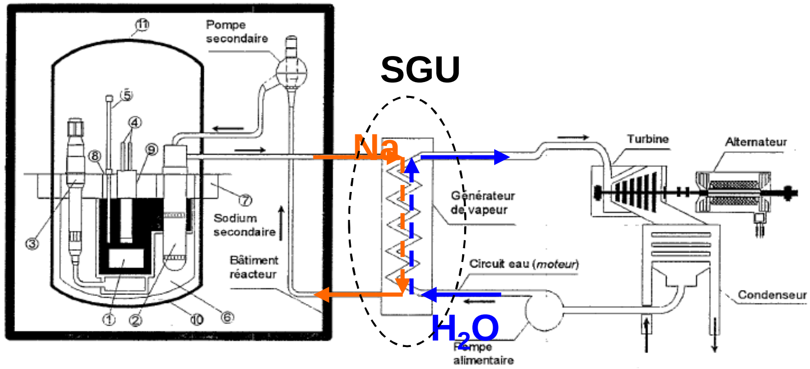
Cristallization of tritium in cold traps

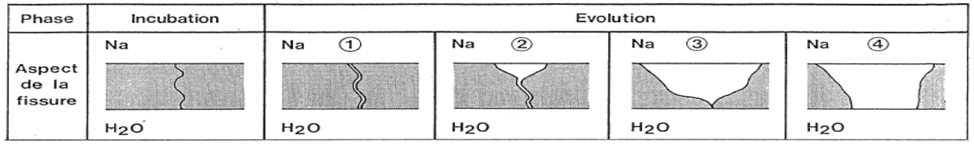


- Co-precipitation of NaT compound with higher amounts of sodium hydride NaH due to hydrogen production in tertiary circuits (water corrosion) and permeation through steam generators towards secondary sodium

- Major contribution of tritium trapping in secondary cold traps due to hydrogen higher concentrations in favour of co-precipitation
- Modeling with KUTIM code (TTT code in Japan,....)

Sodium-water reaction





No leak *Micro leak* *small leak* *evolution*

ORIGINS : **Normal operation of steam generator induces damage of heat exchange tubes**

tube corrosion : **mainly in welding zones, inducing leaks due to cracking**

thermal chocks : **when under-saturated water is injected at super heater inlet (Phenix), inducing thermal fatigue,when fluctuation of heat exchange conditions**

- ✓ ***impossible tube expansion:*** **buckling, inducing differential expansion with envelope**
- ✓ ***tube bundle vibrations :*** **hydraulic effect of sodium flow, inducing tube wear**

Na-H2O : a violent and exothermal chemical reaction

Main reaction

$Na + H_2O \rightarrow NaOH + \frac{1}{2} H_2$ + 162 kJ/water mole *(at 500 ° C)*

Complete, quasi-instantaneous and non-reversible reaction

Many secondary reactions

$2Na + NaOH \xleftarrow{2}\ \xrightarrow{1} [O^{2-}]Na + [H^{-}]Na \leftrightarrow Na_2O + NaH$

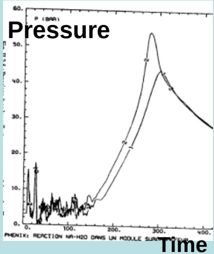
Equilibrium reaction depending on sodium temperature and hydrogen dissolved and hydrogen partial pressure equilibrium

Above about 300 ° C, and with sodium in excess,

hydroxide is decomposed in sodium oxide and hydride (reaction → 1)

Above 410 ° C, reaction (→2) occurs only if PH2 reach Pequilibrium in cover gas; The experimental conditions doesn't satisfy this condition; Thus the decomposition of NaOH is total.

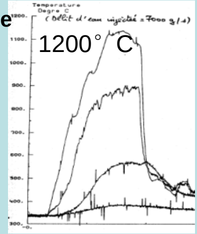
Reaction rates depend on temperature



Effects: chemical,

mechanical,

thermal



MAIN ENVIRONMENTAL EFFECTS

➔ Potential consequences on reactor operation

- reduction of life duration (ageing)
- plugging in narrow gaps and consequences on safety,
- deposits on Heat Exchangers and loss of efficiency,
- cleaning & decontamination of components, induced by dosimetry processes prior to inspection, removal, repair,
- increased duties for coolant purification systems (cold traps...)
- cover gas issues: gas purification and control, aerosols issues…and their consequences on handling, maintenance, personnel exposure…

➔ Potential consequences on reactor dismantling

- cleaning & decontamination of components, pipes… induced by dosimetry
- coolant decontamination systems (cold traps, carbon traps, Ni traps...)
- coolant treatment (ie NOAH process: plugging risk to adress)

SODIUM DECONTAMINATION / CAESIUM

→ Reticulated vitreous carbonaceous (RVC) traps : adsorption on RVC

Efficient process ; operation at T around 200℃

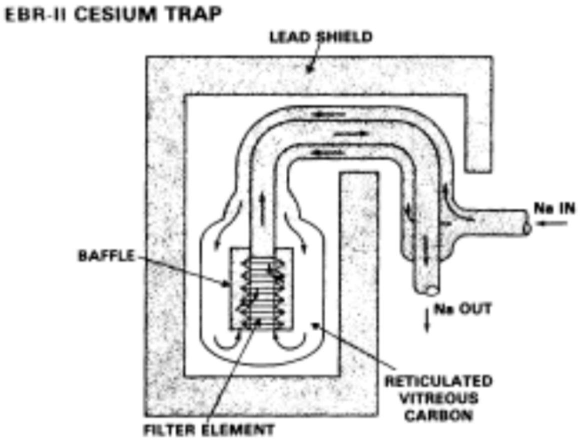
(possibility to reduce contamination by a factor 10 for each transfer through the trap)

Applied to EBR2, BOR60, RAPSODIE, …

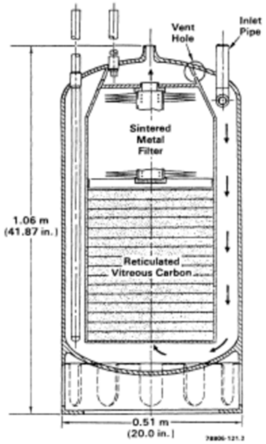
Nota : necessity to take into account delay before Na treatment and decay ^{137}Cs/ ^{22}Na (Feedback from RAPSODIE)

3 cartridges adsorbed about 0.49 TBq ^{137}Cs

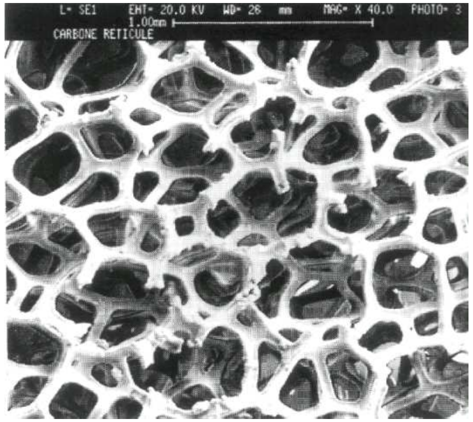
➔ Will be applied soon for primary sodium of PHENIX, prior its treatment (conversion into NaOH)



EBR2 : piège RVC



FFTF : piège RVC



RVC

POTENTIAL CONSEQUENCES OF AEROSOLS:

- **Impact on heat transfer:**

Heat transfer, that occurs according to different mechanisms, mainly:
-convection in gas,
-radiation from the sodium surface towards emerged structures,

- **Evaporation / condensation of sodium vapours.** **Sodium deposits but very limited amounts**

➔ Potential mechanical consequences on handling or rotating systems,…due to Na deposits (condensates):
Difficulties with control rods of PHENIX (one event),
➔ *Gradual decrease of magnetic lifting surface; lifting force<rod weight (lifting of the rod impossible)*
➔ *local cleaning solved the problem*

➔ Impact on viewing technologies in cover gas,…

➔ Impact on thermal insulation performances

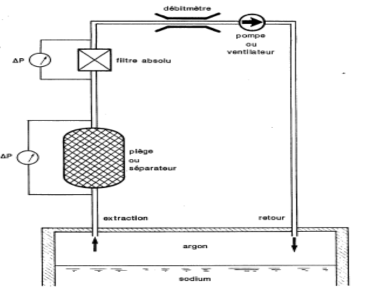
➔ Impact on contamination and dosimetry (Cs,…)

➔ Impacts on decommissioning …

➔Evaporation kinetics:

Based on Sh = 0,643.(Gr.Sc)$^{0.25}$ (Boolter relation)
R_{evap} = 0.643 D.ρ_s/Φ . (Gr.Sc)$^{0.25}$ kg/s.m^2

With Gr = g. $\Phi^3/\nu^2.(1-\gamma s/\gamma\alpha)$
And Sc = ν/D
With :
D = diffusion coefficient (m^2/s)
ρ_s = Na density at Na-gas interface (kg/m^3)
Φ = diameter of the free surface (m)
ν = viscosity (m^2/s)
g = 9.81 m/s
γs = gas density at Na-gas interface (kg/m^3)
$\gamma\alpha$ = gas density at infinite (kg/m^3)



SCHEMA DE PRINCIPE
DU CIRCUIT D'EPURATION DE GAZ DE COUVERTURE

Gas circuits are equipped with condensers and aerosol traps

Na mass transfer in cover gas; impact on safety

- The concerns attached to these phenomena are:

- A correct knowledge of the temperature of structures, thermal stresses induced, and justification of the mechanical design,

- A correct assessment of the risk of sodium aerosols deposits that could induce perturbations in the correct operation of all the mechanisms quoted above. The facility could contribute to tests of such mechanisms

- A correct prevision of the location of those deposits, with the view at dosimetry concerns at the dismantling stage of the reactor, and even if experiments will be made only with stable isotopes.

- Finally the validation of the design of the so-called upper closure of the main vessel (temperature of the reactor upper slab and cooling circuits dedicated, design of penetrations)

➔ Main influent parameters :

Vessel diameter (if increase, R decrease)

Saturation vapour pressure (related to latent heat of evaporation)

T_{argon} (ex: PHENIX (1974) (fresh argon inlet position),

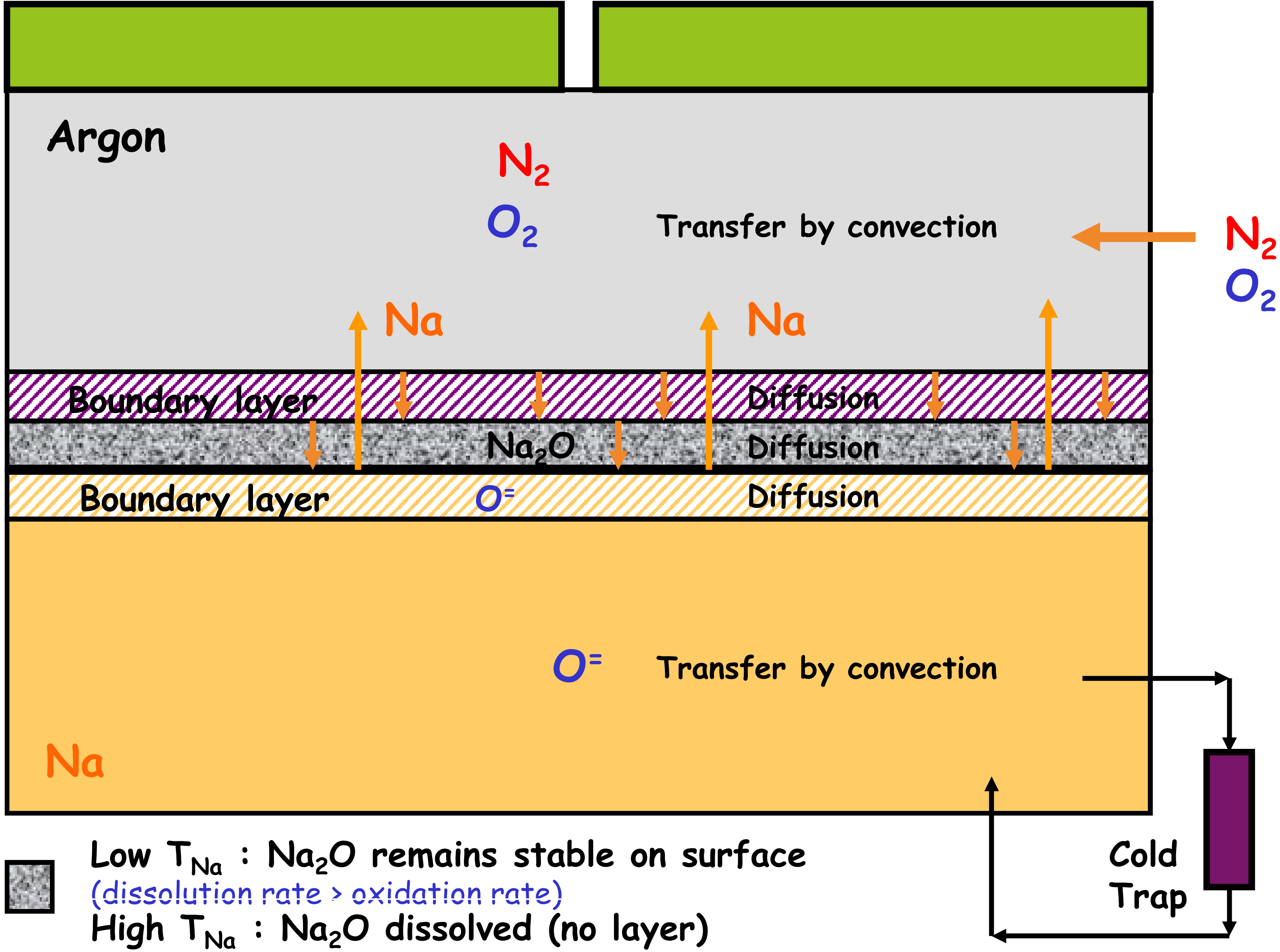
Gas velocity and local thermal-hydraulics (over the Na)

ΔT Na/roof

-Na aerosol concentration increases when the Na temperature increases (From 10g/m3 with TNa =250° C to 50 g/m3 at 545° C (in a given geometry of Cadarache Na loop : Gulliver)

O BEHAVIOR IN COVER GAS

Low PO_2:no combustion



Argon

N_2

O_2

Transfer by convection

N_2

O_2

Na

Na

Boundary layer

Diffusion

Na_2O

Diffusion

Boundary layer

$O^=$

Diffusion

$O^=$

Transfer by convection

Na

Cold Trap

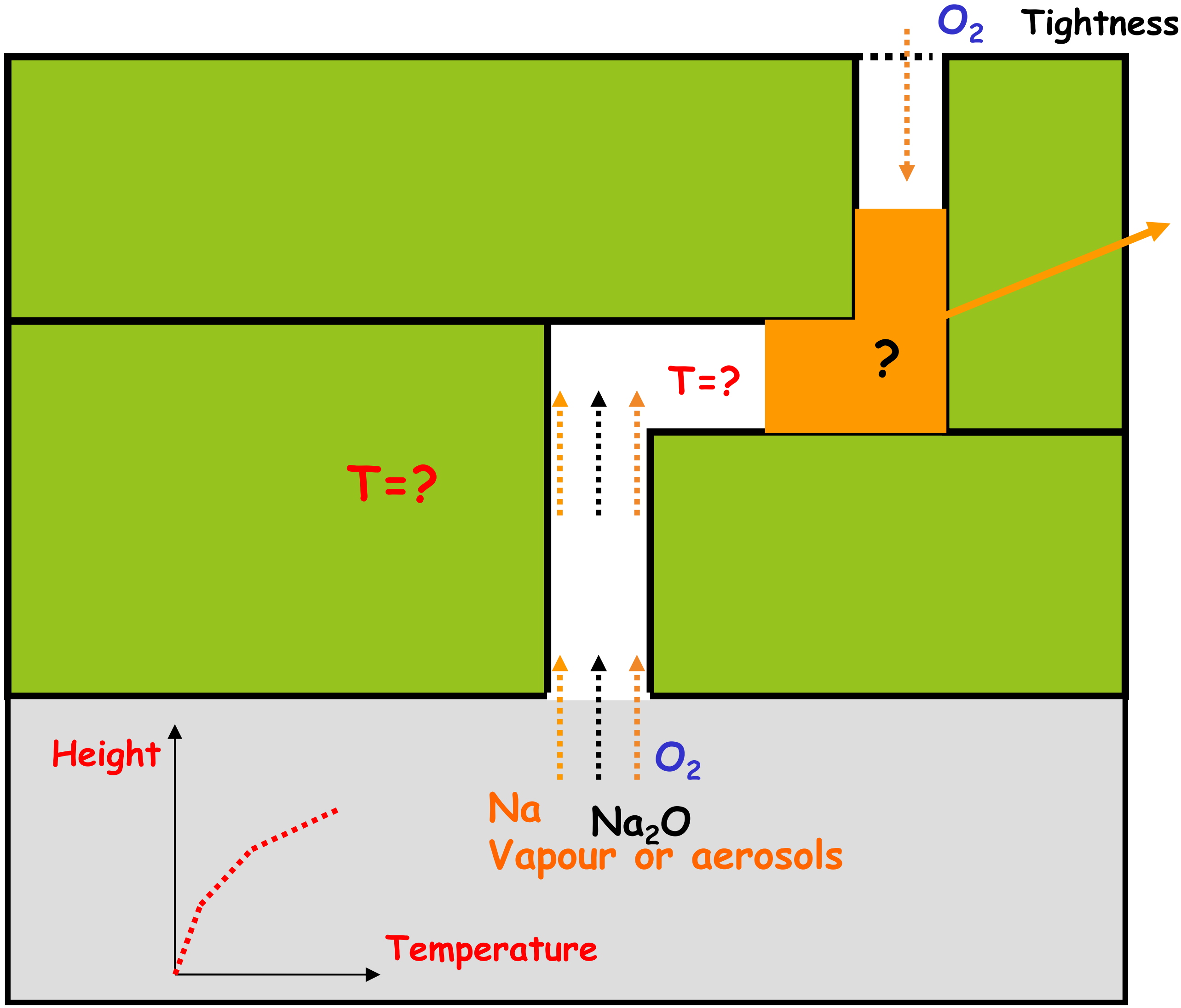
▨ Low T_{Na} : Na_2O remains stable on surface

(dissolution rate > oxidation rate)

High T_{Na} : Na_2O dissolved (no layer)

(dissolution rate > oxidation rate)

MASS TRANSFER IN COVER GAS

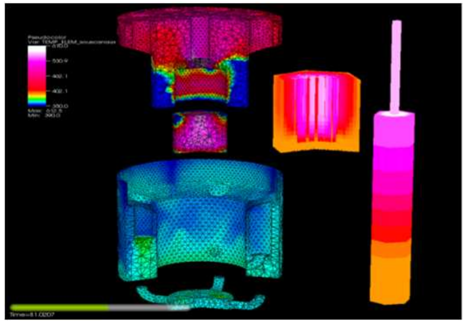


Tightness? (Handling operations)

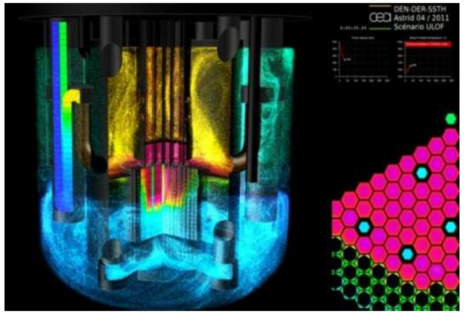
Na condensates?
Na_2O deposits ?
→ Mixture *

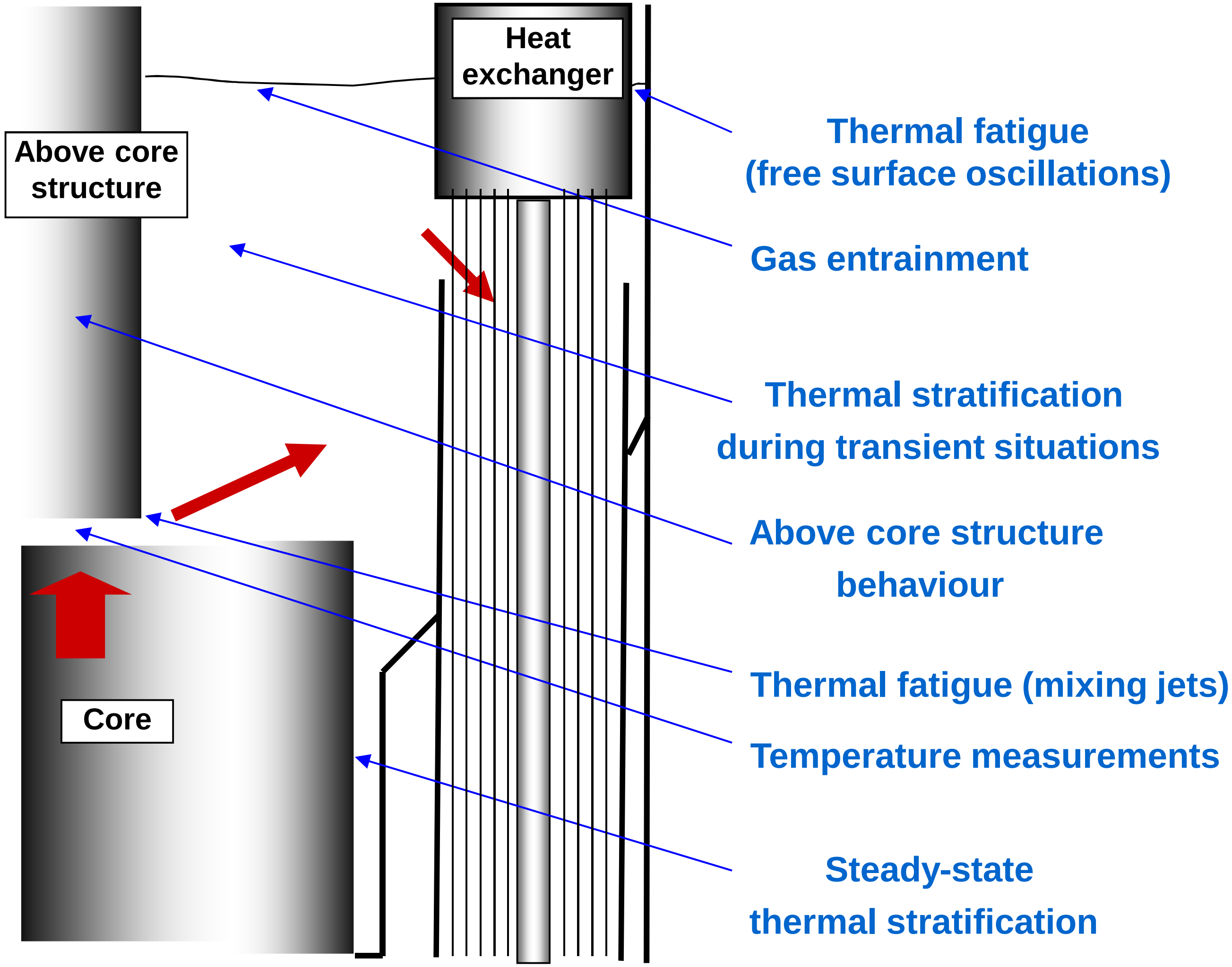
Nota Na2O deposits: density around 0.5? (less mechanical resistance)

Hydraulic and Thermal Hydraulic challenges in hot pool



Asessment of thermal stresses on the structures in:
- steady-state
- transient situations
by computation thanks to optimized system code coupled with CFD and, if required with mockups.





Heat exchanger

Above core structure

Core

Thermal fatigue (free surface oscillations)

Gas entrainment

Thermal stratification during transient situations

Above core structure behaviour

Thermal fatigue (mixing jets)

Temperature measurements

Steady-state thermal stratification

D. Tenchine, « Some thermal hydraulic challenges in sodium cooled fast reactors. », NED 240 (2010) 1195–1217.

Thermal-hydraulic ; impacts on material

Thermal-hydraulic studies relevant for material analysis

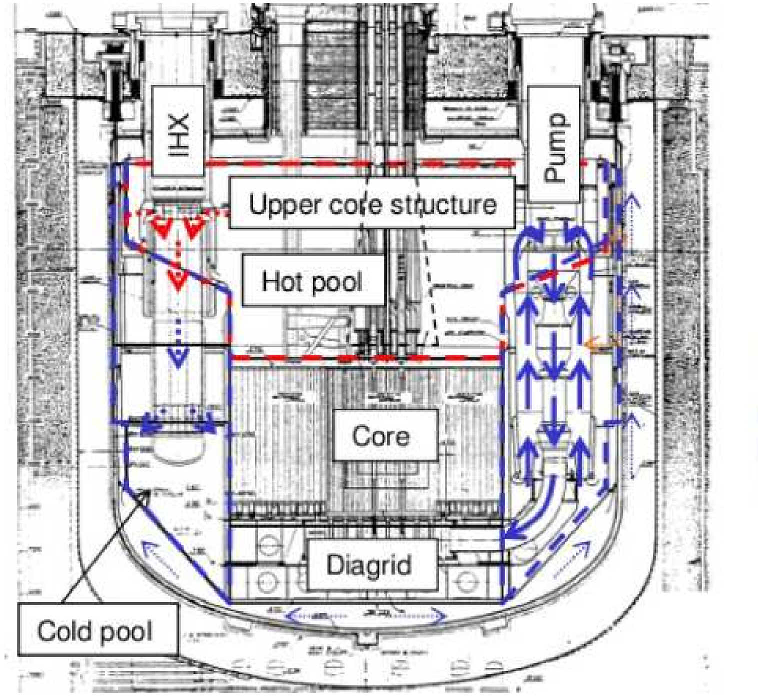
- reactor steady-state :
  justify thermo-mechanical criteria for
  - 4-year design-life : subassemblies
  - 60-year design life : most primary internals
    (inner vessel, diagrid, strongback, core catcher...)
  - somewhere in between : large components
    → IHXes, pumps(, UCS)
- planned transients :
  - reactor maintenance, shutdown, scram
  - load following (new!)

  ⇒ same design life goals as above
- accidental transients → short-term behavior of the cladding, hexcans...

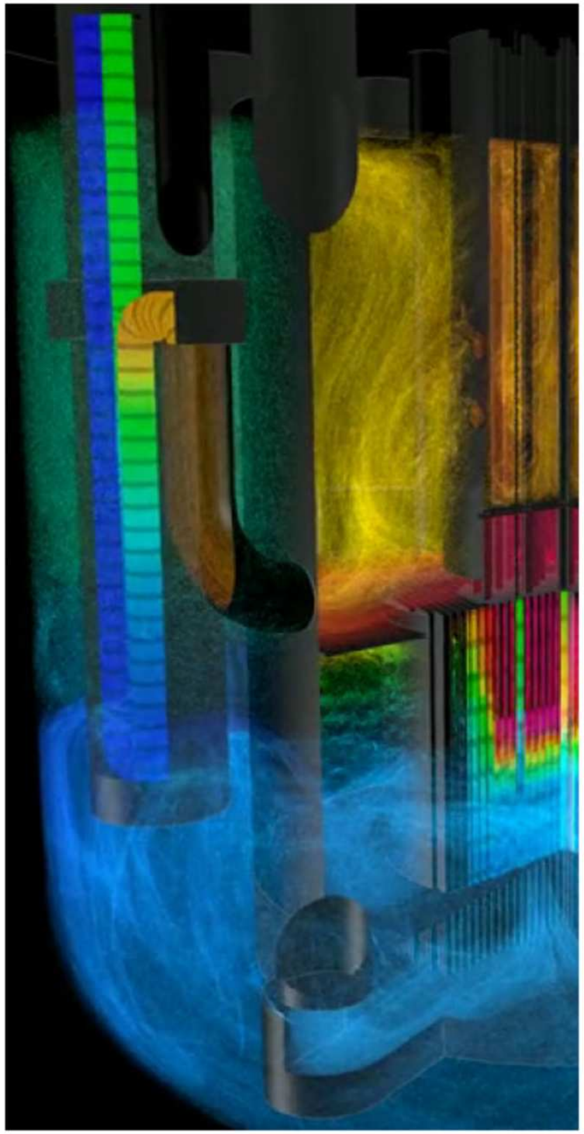
TH modeling approach

Reference tool for primary natural circulation situations**:**
CATHARE +coupling with TRIO_U-MC2 / TRIO_U

The **validation of the coupled model** against available experimental data is in progress ; first results show a reasonable agreement ;
Extra developments are foreseen to further improve the model (ex: refined model with recirculation within the core, …)



TH modeling approach



Multi-scale phenomena

- validated way to perform safety transient analysis : system scale →CATHARE, RELAP, SAS...
- however, multi-scale phenomena often affect these transients :
  - in large pools (→ LMFR) : jet behavior, stratification
  - in the core : radial heterogeneity in S/As, inter-wrapper flow

⇒ these are difficult to model in system codes

Simple approaches

- if there is no local → global feedback: system result → local post-processing
- conservative hypotheses, if possible

Thermal-hydraulic ; impacts on material

Phenomena of interest

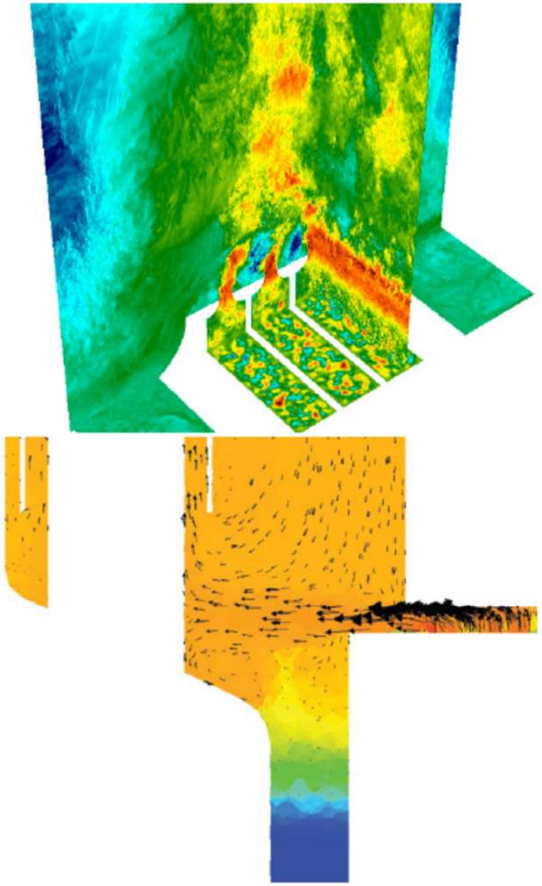
Core

- hydraulic effects : pressure losses
- thermal effects : mixing, hot spots...
- boiling behavior : stability, dryout
  → for low void-effect cores :
  boiling without dryout for ∼ 5′

⇒ cladding at high temperatures (∼ 900°)
swelling or rupture?

Thermal-hydraulic ; impacts on material

Phenomena of interest



Hot pool

- jet mixing at the core outlet :
  fuel S/A (570°) vs CR S/A (450°)
  → thermal striping on UCS
- core outlet jet behavior :
  flat (high flow) vs bent (low flow)
  → affects hot pool stratification
  → thermal load on inner vessel
- thermal shocks during transients
  (-150° in 40s during scram)
- free level fluctuations :
  at steady-state → thermal striping
  during transients → thermal shocks

Considerations for an integration of other environment effects in RCC-MRx

- Caracterise the impact of the environment on design rules
  - Examine all the possible damage modes and define adequate design rules
    - Excessive defomation/plastic instability
    - Buckling
    - Progressive deformation
    - Fatigue
    - Creep rupture, creep-fatigue…
    - Crack propagation …

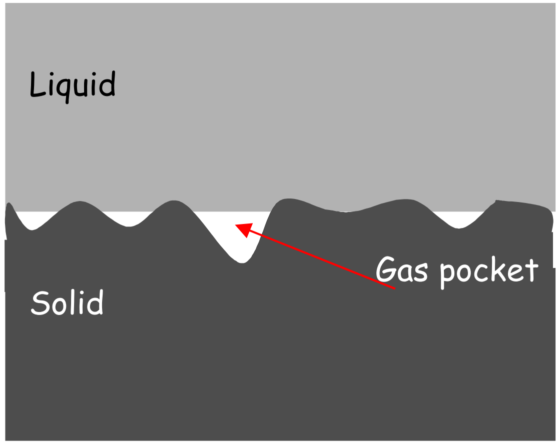
    -> **Only <u>mechanical</u> damages have to be taken into account** (avoidance of stress corrosion cracking by design in RCC-MRx, what about Liquid Metal embrittlement ?)
  - Confirme the way stress/strain have to be calculated
    - Elastic/inelastic
    - Treatment of primary/secondary stress
    - …

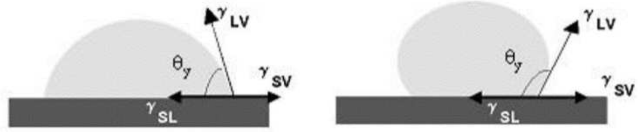
- **This work is to be done prior to an introduction in the Code – This will constitute a basis**

WETTING PHENOMENA

Wetting phenomena, which depend of gas adsorption, structural material oxidation,… are key interface phenomena between the coolant and the structural material. Therefore it is considered as a key factor with regards the following items:

- accuracy of measurements for some instrumentation devices such as ultra-sonic based traducers, electro-magnetic flow-meters, electro-chemical cells,…
- interactions between structural material and liquid metal: corrosion, embrittlement, stress corrosion cracking….
- mass transfer such as activated corrosion products, tritium,…
- thermal exchanges in Heat Exchangers, liquid metal targets,…
- Technology developments, cleaning of residual layer,…





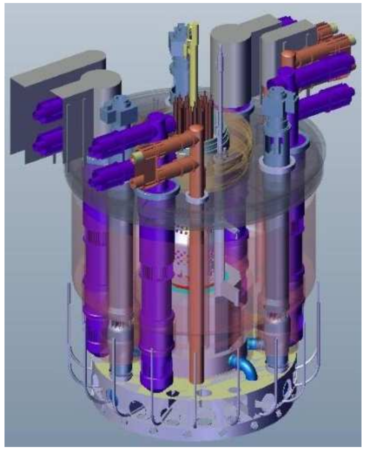
➔ Due to non-significant material embrittlement in Na, there is no necessity to foresee coatings to prevent wetting and its deleterious consequences.

(except to prevent from wearing & fretting effects)

➔ Na: a strong reducer: a very good wetting is obtained, even at low temperature *(ie T=180°C)* thanks to the possibility to reduce oxygen content down to a very low value (< 3ppm)

ISI REQUIREMENTS

- ➔ To satisfy the requirements of this 4th generation in terms of safety, reliability, availability and energy savings, **SFRs will need to achieve a higher level of performance than that of previous fast reactors.**



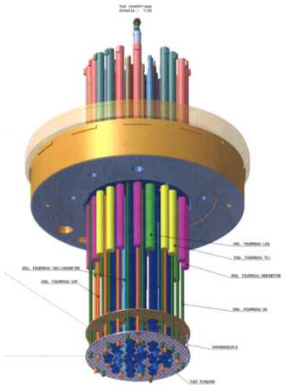
- ➔ **In-Service Inspection and Repair** must contribute to this increase of the safety and availability levels:

  - continuous monitoring of the operating parameters during reactor operation (including core monitoring and protection against abnormal events)

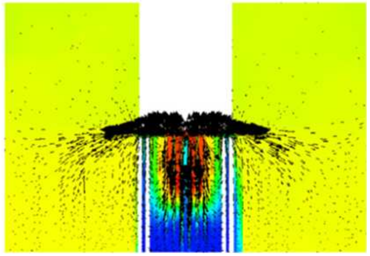
  - periodical inspection of structures, welds

- ➔ **Limitation by design of the areas to be inspected:** few and shorter welds, design margins, structures redundancy, slow evolution of defects, possible access in the reactor block for inspection...

- ➔ **Requirements for implementation of instrumentation and related systems taking into account "environmental" conditions** (temperature, Na velocity, radiation, presence of Na aerosols…)



➔ ACS*, a key component/system, with hard "environmental" conditions, inducing permanent demonstration of its reliability and availability (core reactivity control,…)



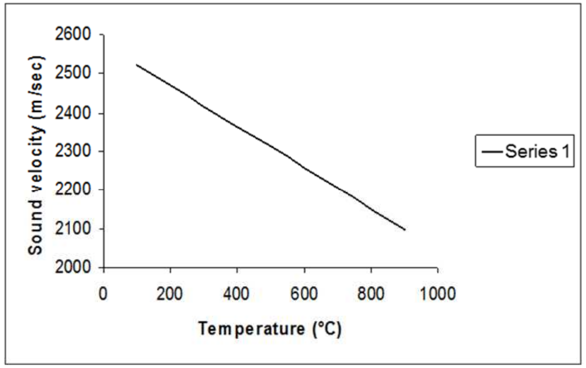
* Above Core Structure (ACS)

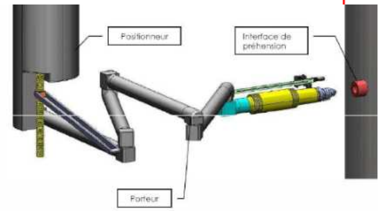
SODIUM OPACITY: ULTRA-SOUND TECHNOLOGIES

➔ As all liquid metals, sodium is opaque;
➔ necessity to develop adapted technologies for telemetry and visualization

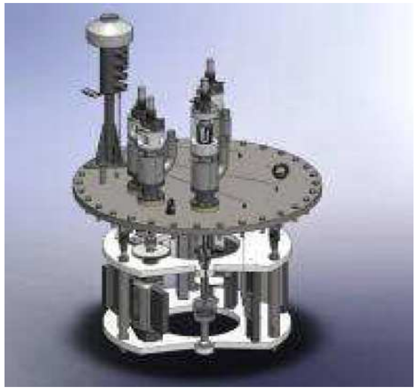
Sound velocity in sodium varies little with temperature and is given by the following relationship:

$$C\ (\text{m/sec}) = 2577.2 - 0.5234\ \theta \qquad 100 < \theta < 370°\text{C}$$

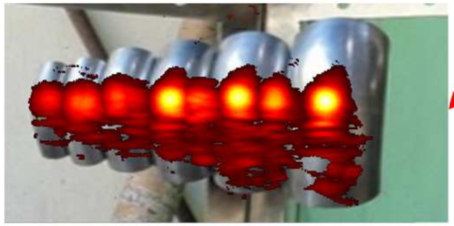




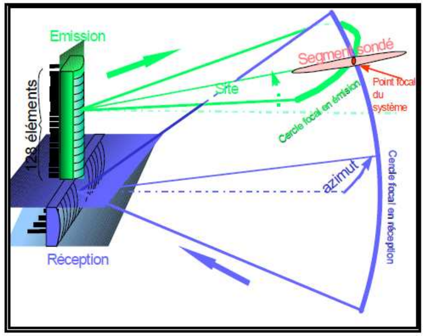
Consequences: Property used for telemetry and visualisation in sodium facilities, and for acoustic detection of events in Na



Multireflector mock-up



F. Baqué et all: *"Sodium Fast Cooled Fast Reactor: R&D Program for improving periodic examination and repair"* . Science and technology of nuclear installations Journal, July 2012



- Surface mapping (imaging) of submerged structures/components,
- Integrity inspection of structure/component surfaces (including the detection and sizing of opened cracks),
- Determination/confirmation of robotic system positioning,
- Fuel assembly identification,
- Detection, localization and sizing of immersed objects (including migrating bodies).

RECOMMENDATIONS FOR SFR DESIGN AS REGARDS NDE (NON DESTRUCTIVE EXAMINATION)

- **Observation:** **all Non Destructive Examination rules/codes** (RCC-M … MR….MX… MRx)
  are devoted to NDE during manufacturing,
  but not for periodic inspection.

- **unless** inspection and repair (ISI&R) = important aspect for SFRs
  guarantee / need for safety assessment,
  preservation of the investment.

- **thus** specification for the designer = guide / choice for design activity,
  taking into account all NDE operations
  which are undertaken during plant life.

➔ **It means also to take into account local environment during inspection**

- **accessibility (ie** the choice of welding join location for pipes should allow enough access for NDE operations (X-Rays, ultrasonics, Eddy current…)
- **in Na, with residual Na, or without Na,**
- **In Na, with different T**
- **With potential deposits**
- **with various local dosimetry...**

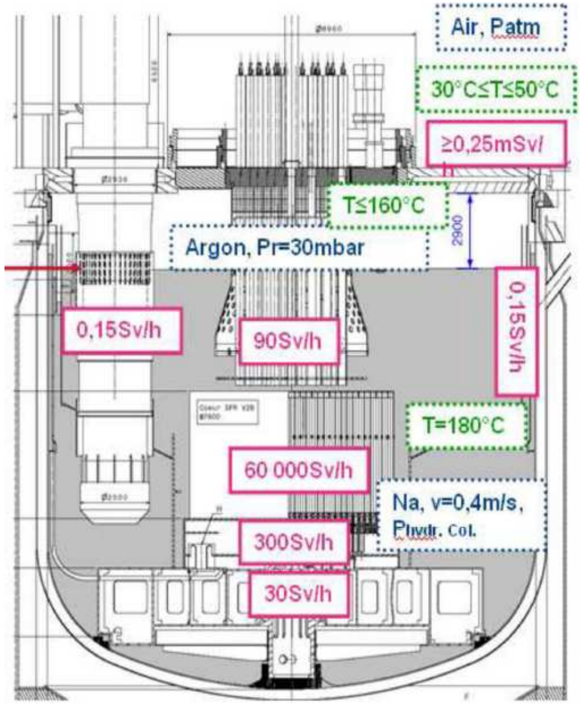
➔ **The notion of « controlability of materials » has to be developped**

Two main constraints:

→ identification of each case which could generate a conflict between the choice of the designers and the NDE requirements.

→ analysis and recommendations for NDE rules, which could be understandable by a designer (= not a NDE expert).

UNDER-SODIUM REPAIR



For non-removable components, repair operations will be performed in a gas environment.

➔ **If the faulty area is located under the sodium free level, the gas-tight system will have to contain the inspection and repair tools, to protect them from the surrounding Na.**

Repair scenario for in-sodium structures:

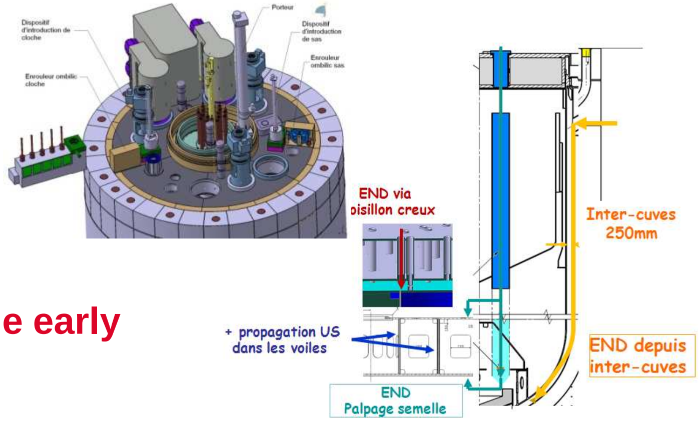
- **removing the sodium (after bulk draining),**
- **machining and welding.**

Nota: for components removed: cleaning & decontamination

Tools:

- laser and as back-up solution conventional tools brush or gas blower for sodium removal, milling machine for machining and TIG* for welding (feasibility demonstrated in the 1990s)

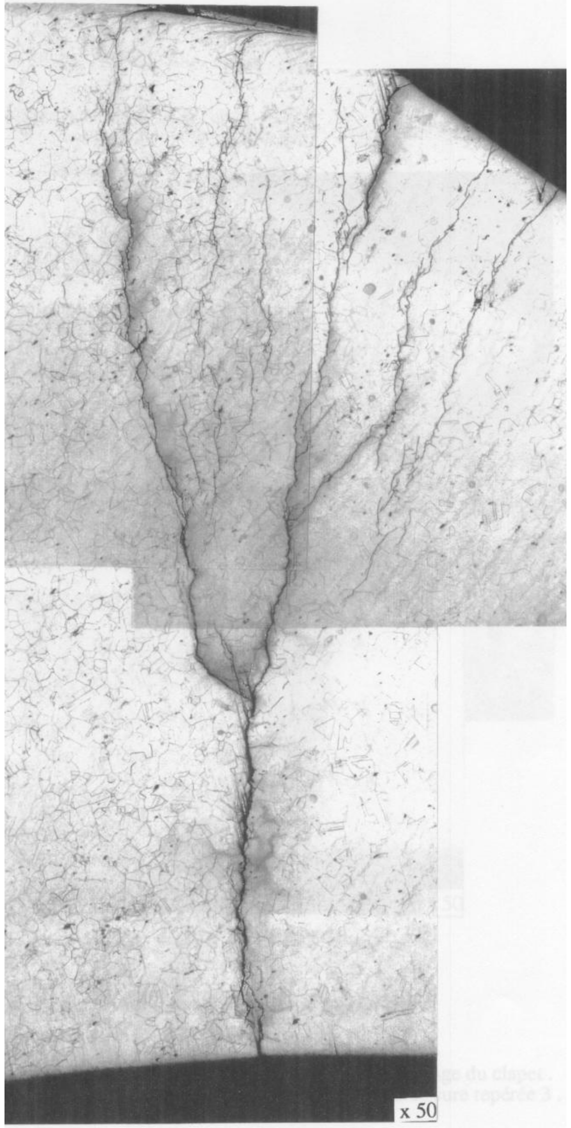
➔ **In-pile examination or repair requires robotic carriers. These carriers have to be compatible with the Na environment, either in the cover-gas plenum or in gas after sodium draining, or even under Na.**



For repair (as for ISI) : key point: access taken into account from the early stage of the project

* TIG (Tungsten Inert gas): Arc welding with or without addition of metal)

Phenomenology of Stress Corrosion Cracking



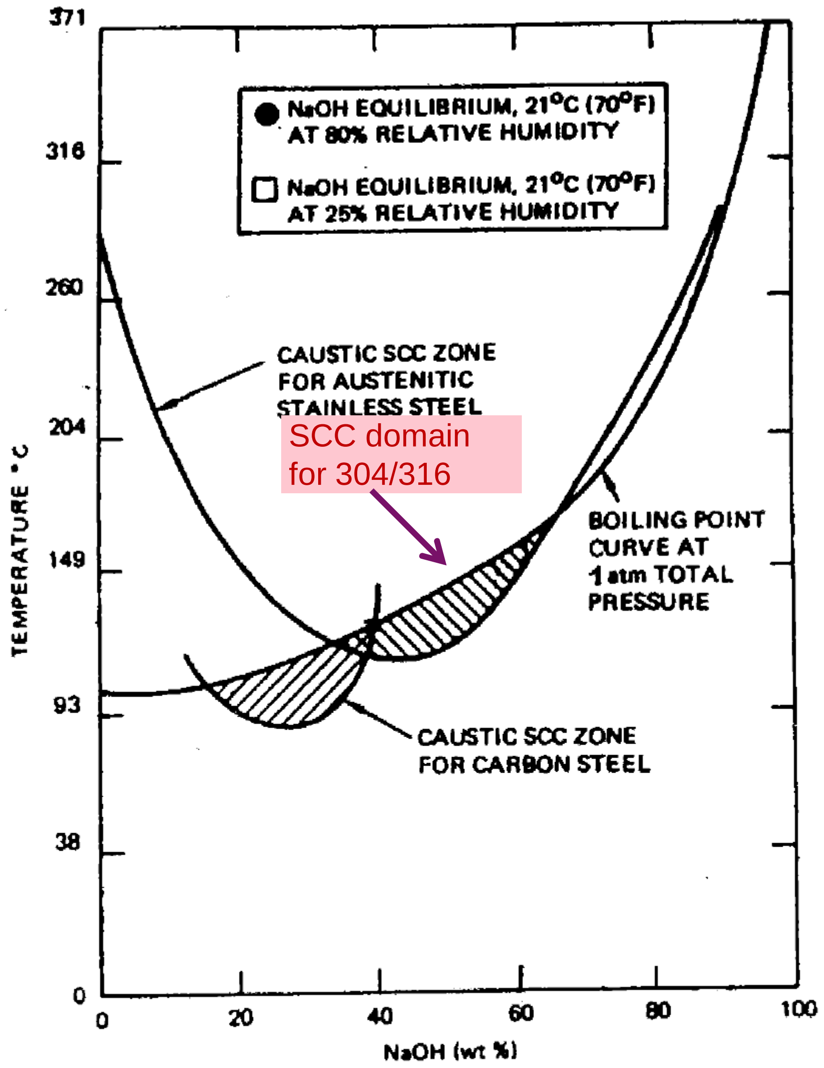
Phénix : support de palier de
guidage du clapet

- **Very localized corrosion with small amount of aqueous NaOH**
- **Corrosion Process characterized by transgranular cracks (austenitic steels)**

(Can be intergranular under low stresses)

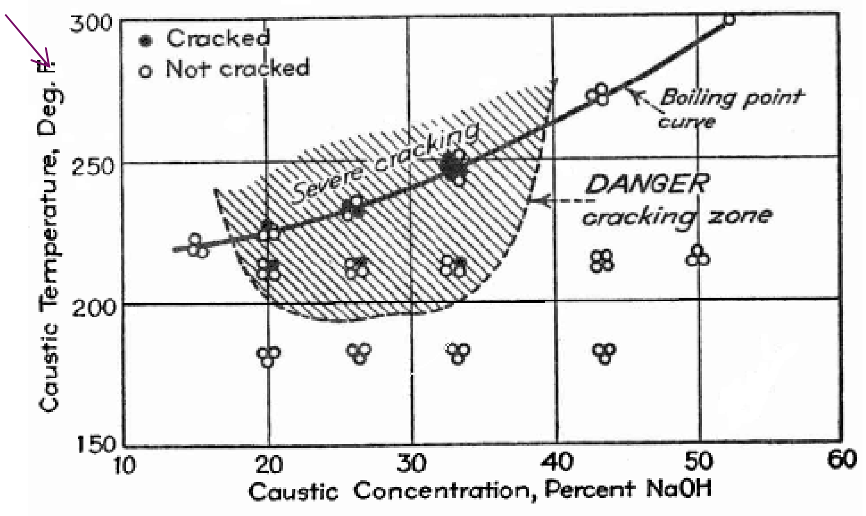
- **Very fast phenomena**

Domain of SCC



SCC domain for 304/316

°F



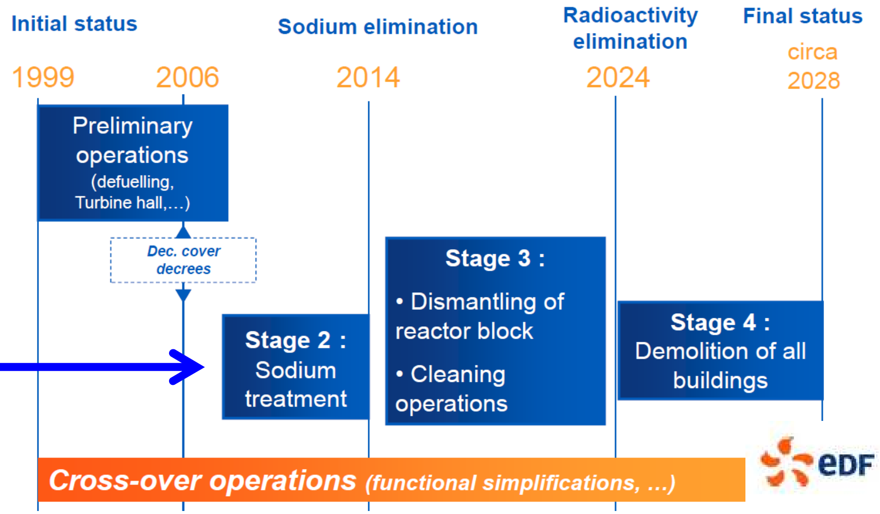
Caustic users will do well to keep out of the zone above 180 deg. F. and between the concentrations, 15 and 43 percent.

DOMAIN OF SCC for SAE 1020 steel
(Immersion during 30 days of U-Bend)
0,2%C 0,3-0,6% Mn

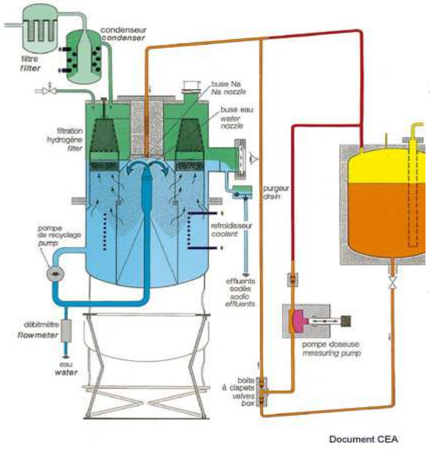
SFR DISMANTLING

- **Na bulk treatment (ie NOAH Process) (Na-H2O process)**
- **Na residual retentions treatment after draining (carbonation)**
- **Cold trap treatment**
- **Components cleaning in cleaning pits,...**

Environment to take into account: Na reactivity (air, water), NaOH, H_2, dosimetry, ...

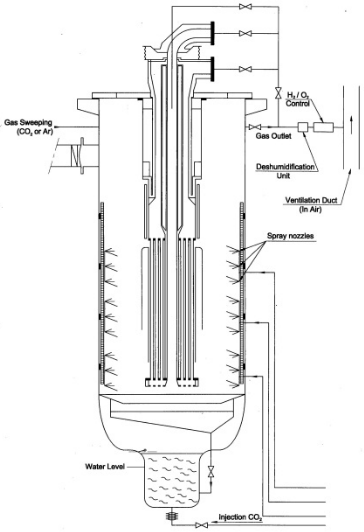


Decommissioning schedule in 4 stages



Document CEA

NOAH Process



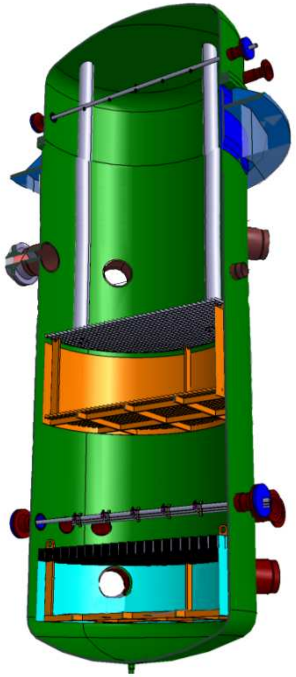
Cleaning pit

NaK treatment

Carbonation process

SFR DISMANTLING: R&D IE COLD TRAP TREATMENT

ELA



- ELA = Enceinte de Lavage en Actif (radioactive sodium waste treatment process).
- Under development for the hydrolysis of residual sodium containing impurities such as **NaH**, **Na_2O** and **NaT** (tritiated sodium hydride).
- Implementation of the **sodium-water reaction** in a controlled and progressive way.
- Water sprayed on sodium wastes packed in a basket.
- High flow rate of inert gas.
- Main reactions involved:

$Na_{(s)} + H_2O_{(l)} \rightarrow NaOH_{(s)} + ½ H_{2,(g)}$ ($\Delta_rH^0 = -141\ kJ\cdot mol^{-1}{}_{Na}$)

$NaH_{(s)} + H_2O_{(l)} \rightarrow NaOH_{(s)} + H_{2,(g)}$ ($\Delta_rH^0 = -82\ kJ\cdot mol^{-1}{}_{Na}$)

$Na_2O_{(s)} + H_2O_{(l)} \rightarrow 2\ NaOH_{(s)}$ ($\Delta_rH^0 = -76\ kJ\cdot mol^{-1}{}_{Na}$)

$NaOX_{(s)} \rightarrow Na^+_{(aq)} + OX^-_{(aq)}$ avec X=H ou T ($\Delta_rH^0 = -45\ kJ\cdot mol^{-1}{}_{Na}$)

Thank you for your attention