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ASTRID and SFRs R&D Needs

Topic 'Safety & Instrumentation'

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CADARACHE

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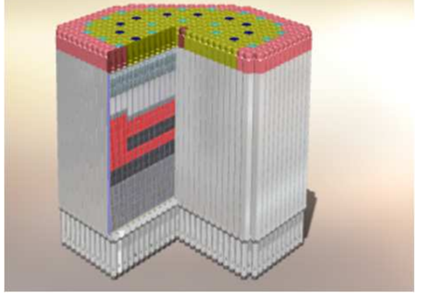
ASTRID & SFRs R&D NEEDS related to SAFETY ISSUES

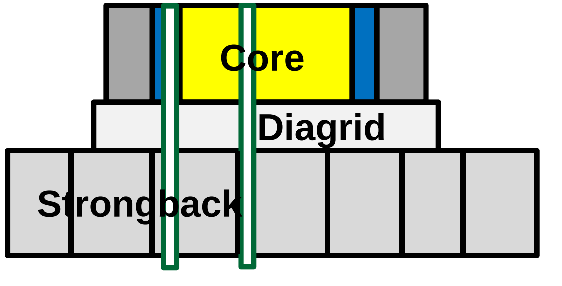
ASTRID and SFR BACKGROUND

- SAFETY OBJECTIVES:
  - Prevention of Severe Accidents (SA)
    - Good Natural Behavior in Accident Conditions when safety systems failed
    - Implementation of Complementary Safety Devices for SA Prevention (DCS-P)
  - 4th Level of Defense in Depth: Severe Accident taken into account at the design stage: in particular, do not jeopardize the second barrier
    - Minimization of Mechanical Energy Releases (Fuel Coolant Interaction)
    - Implementation of Complementary Safety Devices for SA Mitigation (DCS-M)

ASTRID MAIN DESIGN OPTIONS



- CFV CORE: Negative Na Void Worth
  - Good natural behavior: No boiling in ULOF sequence
  - Complementary Safety Devices for SA Prevention
    - Hydraulic actuated systems: (DCS-P)-H
    - Heat-actuated system based on Curie point electromagnet (DCS-P)-RBD-Curie
  - Complementary Safety Devices for SA Mitigation
    - Control Rod Guide Tube
    - Corium Transfer Tube (DCS-M)-TT



- IN-VESSEL CORE CATCHER
  - Covered with sacrificial material (ZrO2)

ASTRID & SFRs R&D NEEDS related to SAFETY ISSUES

IMPORTANT SEVERE ACCIDENT ISSUES

- Evaluation of Mechanical Energy Releases (Fuel Coolant Interaction)
- Mitigation Devices Efficiency Demonstration (Corium Transfer Tubes, Core Catcher)

MAIN PRIORITIES for ASTRID and SFRs

- 1- FCI modeling and extension of the experimental data base
  - Modeling of corium/Na heat transfer and of corium fragmentation
  - Analytical experiments and large scale experiments (with simulants or UO_2)
- 2- In-Core Corium Transfer Tube Efficiency Assessment
  - Representative Duct Geometry, Prototypic Corium and Na
- 3- IN-VESSEL CORE CATCHER DESIGN
  - Specification of the sacrificial material (Na environment)
  - Long term behavior of the sacrificial material in Na
  - Modeling of corium/sacrificial material interactions (including jet impingement)
- 4- FAST-RUNNING SFR Multi-physics & statistical CODE Development: (PROCOR-Na)
  - Simulation the whole severe accident scenario (short & long terms)
  - Study of accident progression variation

ASTRID AND SFRS NEEDS FOR OUT-OF PILE CORIUM EXPERIMENTS (1/2)

Needs for Corium Experiments with Depleted UO_2 or Simulants

- Severe Accident Transition and Secondary Phases
  - Corium-Sodium Interaction and Vapor Explosion :
    - Sodium Film Boiling
    - Jet Fragmentation
    - Corium-Sodium Interaction in Molten Pool Configuration
  - In-Core Molten Pool Progression
  - Metal-Oxides phases Separation
  - Heat Transfers between separated material phases
  - Heat Transfers between Pool & Walls
  - Local Explosions – Intact Sub-Assembly Degradation Coupling
  - Fuel/Stainless Steel Boiling Pool Behavior
- Severe Accident Mitigation Phenomenology or Devices
  - Diluants or Absorbants Neutron Materials: Material Mixture
    - Thermodynamic data (phases diagrams)
    - Material Mixture Formation Kinetics
    - Thermo-physical Properties (viscosity, surface tension, Diffusion Coefficient)
    - Corium-Na Interaction Impact
    - Impact of the diluants on the FP releases

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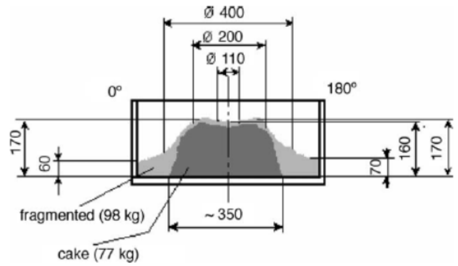
ASTRID AND SFRS NEEDS FOR OUT-OF PILE CORIUM EXPERIMENTS (2/2)

Needs for Corium experiment with UO_2 or Simulants (Cont'd)

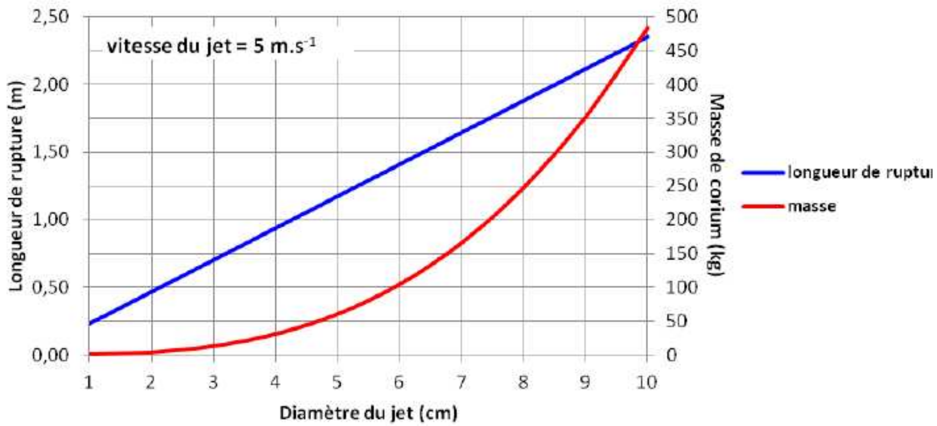
- Severe Accident Mitigation Devices (continued)
  - Corium Dispersal Devices (Transfer Tubes)
    - EAGLE1&2 complementary Test in ASTRID geometry
    - **Corium-Na Interaction**
    - **Corium Flow in Mitigation Device Tubes (Liquid or Particles Flow ,...)**
  - Core Catcher
    - **Corium Rheology**
    - **Corium Jet Impingement on the Core Catcher**
    - **Debris Bed Spreading on Core Catcher with Sacrificial Materials**
    - **Sacrificial Materials Dissolution by Corium, Kinetics, Steady State**



Needs of Prototypic Corium and large

- Corium-Na Interactions
  - Coherent Corium Jet: **300-500Kg**

- Corium-Core Catcher Interactions
  - FARO: 150kg (wall effects)
  - Expert Advice: **300-500kg**

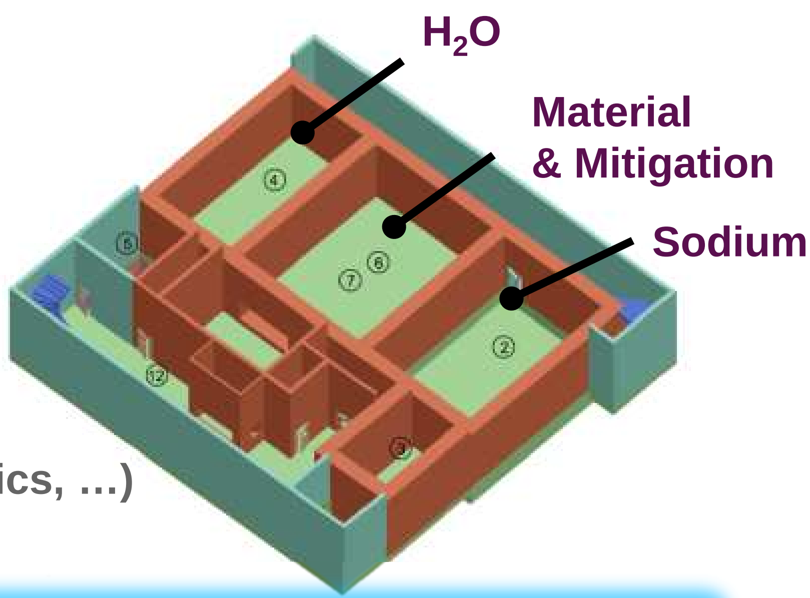


PLINIUS-2: a DEDICATED PLATEFORM FOR MATERIAL INTERACTION STUDIES

Corium-Sodium Facility

GEN4

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



Material interaction facility

GEN4
GEN2&3

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

Corium-Water Facility

GEN2&3
LWRs

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

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

+ Phenomenological tests (VITI)

+ Analytical tests (Low Temperature)

PLINIUS-2: SAFEST Research Infrastructure

PROCOR – Na : A future PROCOR application for ASTRID

PROCOR APPLICATIONS (CEA code)

- PROCOR: Simulation Platform developed for LWRs
  - Set of fast running models
  - Management of Model Coupling
  - Management of Input Data
  - Set of Material properties
- PROCOR-Na :
  - ASTRID application to be built with the PROCOR framework
  - Extension of PROCOR framework to deal with complete scenario simulation (not only corium progression)
- First step for PROCOR-Na: modelling the core degradation
- Development strategy : development of models and progressive implementation in PROCOR
- PROCOR-Na Models: under development
  - Under development
    - Models for ULOF, TIB, UTOP scenarios
    - Molten Pool behavior
    - FCI
  - To be developed
    - Debris Bed
    - Pool behavior on the Core catcher
    - Core Catcher behavior and cooling, ….

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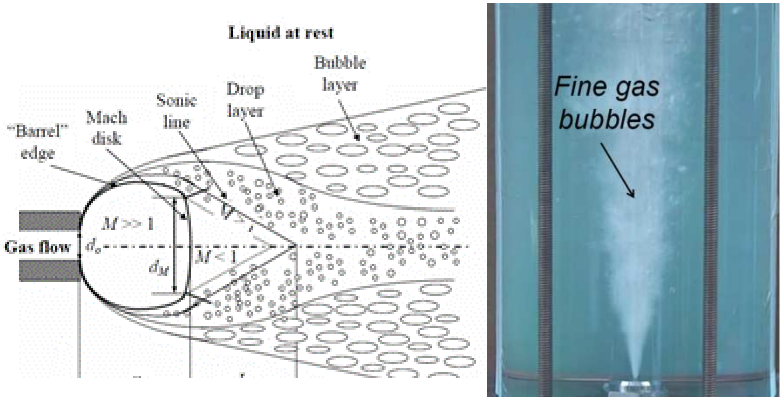
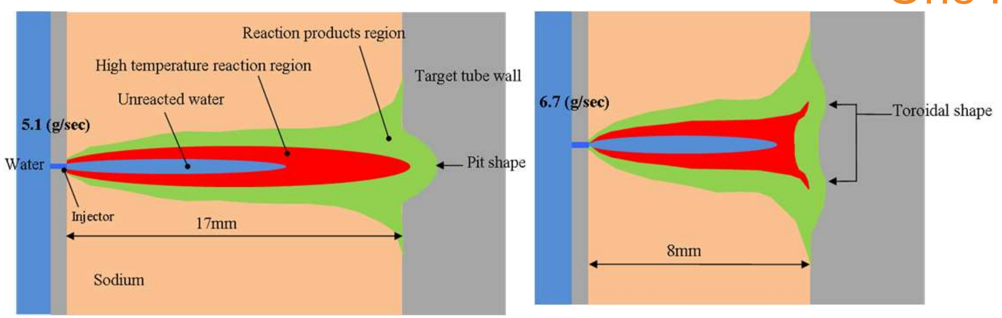
SAFETY : NA-WATER INTERACTION MODELING (PROPAGATION)



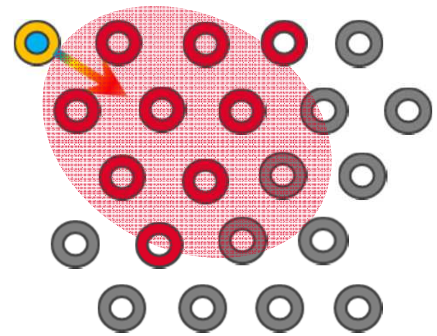
➔ **Necessity** to improve models on water leak evolution **&** develop a model for "multi-tubes" propagation

(to avoid conservative hypothesis:
all pipes have to be considered in a Na-water scenario)



Wastage profile: (a) Pitting wastage (b) Toroidal wastage

One leaking tube



Ref :IAEA FR13 Conference " Cooperation on impingement wastage experiment of Mod. 9Cr-1Mo steel using SWAT-1R sodium-water reaction test facility« F. Beauchamp, M. Nishimura› R. Umeda, A. Allou

The key questions are:
- **how many tubes will be affected?**
- **what is the chronology of tubes ruptures (dynamic to consider)?**

INSTRUMENTATION: Xe and Kr detection following clad failure

RECALL OF THE REACTOR NEEDS

- Core protection against the risk of fission products release in primary circuit

MISSION TO BE INSURED BY MONITORING SYSTEM

- Detect the failure of one or several fuel claddings
- Complementarily localized the fuel assembly with at least a failed pin fuel cladding

OBJECTIVES OF THE INSTRUMENTATION DEVOTED TO FUEL CLADDING FAILURE

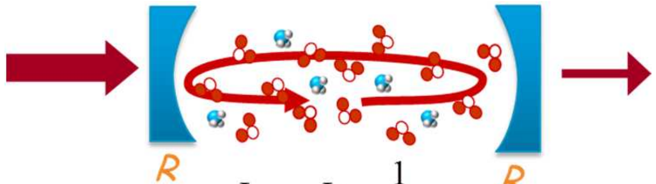
- Detect at least a cladding failure with FP release in cover gas
- Follow the evolution of the signal corresponding to this failure
- Detect at least one open fuel cladding failure with fission products release in the primary sodium
- Follow the evolution of the associated signal

INSTRUMENTATION: Xe and Kr detection following clad failure

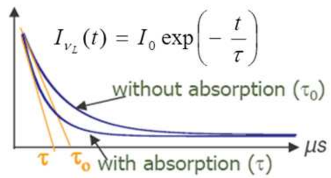
R&D CHALLENGES FOR GASEOUS FP DETECTION

- **Detect fission products at very low concentration following preliminary fuel cladding failure (value to be consolidated by establishment of release scenario)**
- **Develop and validate at least one technology among**

  - Mass spectrometry
    - Reference PX/SPX
    - Optimization by using API/MS
    - Detection threshold : few ppt (10^{-9})
    - Potential application to the ASTRID monitoring control and protection system au SSG à l'étude (AVP2)
  - Laser spectrometry
    - Innovative techniques
    - → CRDS (Cavity Ring Down Spectroscopy) for Xe and Kr
    - Detection threshold of few tens of ppt
    - Optimization needed: to limit optical saturation effect inducing signal decrease
    - Xe has already been studied,
    - **For Kr study is needed**



$$L_{eff} \approx L \times \frac{1}{1-R} = 10 \text{ km}$$



$$1/\tau = 1/\tau_0 + \alpha(\nu)\, c$$

INSTRUMENTATION: Spent fuel assemblies residual power measurements

RECALL OF THE REACTOR NEEDS

- Fuel handling route is principally driven in gas after withdrawal of fuel from the external storage
- Spent fuel could have important residual power → potential temperature increase during handling in gas

  → Residual power measurement is needed to guarantee the maximum design value is not reached (for safety and availability objectives)

MISSION TO BE INSURED BY THE SPENT FUEL RESIDUAL POWER MEASUREMENT

- Measure residual power at the beginning of the fuel handling route and compare it to a threshold

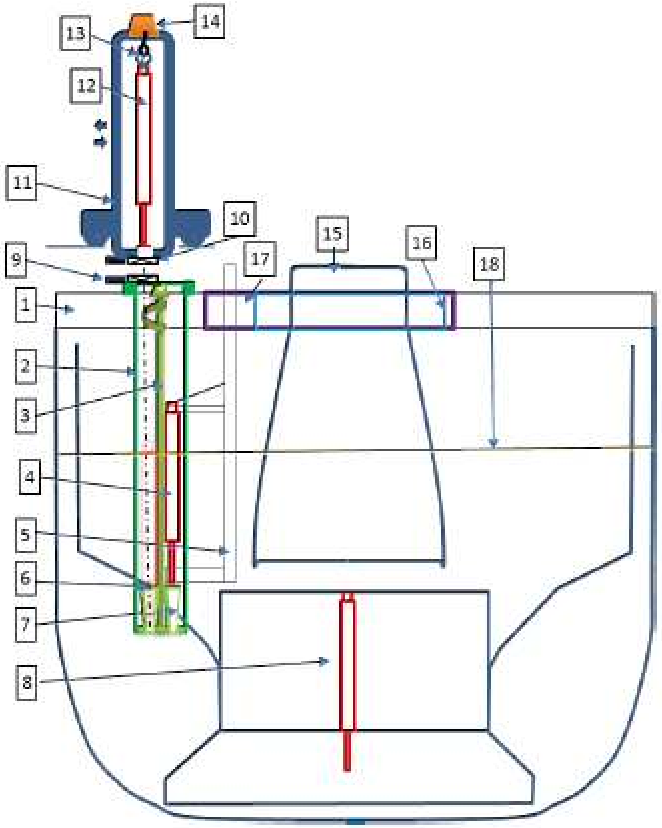
STATUS OF CURRENT R&D

- Analysis of potential technical solutions
- Selection of a promising concept based on a measurement located in the rotor used for core loading/unloading

INSTRUMENTATION: Spent fuel assemblies residual power measurements

POTENTIAL TECHNICAL SOLUTION

- Use a specific supplementary position in the rotor to insure the measurement
- Measurement techniques based on a kind of calorimetric measurement



FURTHER INVESTIGATION ARE NEEDED

- To confirm the feasibility
- To investigate alternative if needed
- To develop the selected technical solution to the required level of maturity

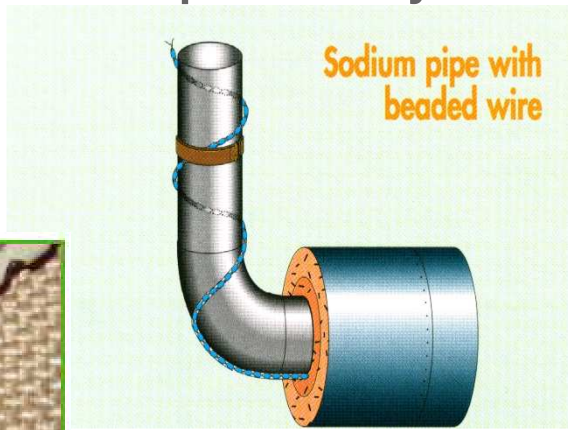
INSTRUMENTATION: Sodium leak detection

RECALL OF THE REACTOR NEEDS

- Sodium leak on reactor piping and components has to be detected within a specified time response to avoid large sodium fire

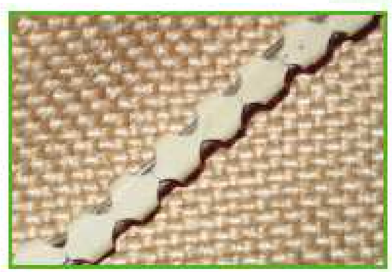
MISSION TO BE INSURED BY SODIUM LEAK DETECTION SYSTEM

- Local detection: detection of small leaks with location closer to the circuit,
- Overall detection: detection of large leaks, usually on a set of circuits or elements on which a local detection system can not be installed.
  These two types of detections are generally considered complementary but not redundant.



EXISTING DETECTORS

- Large feedback on electrical beaded wire detectors



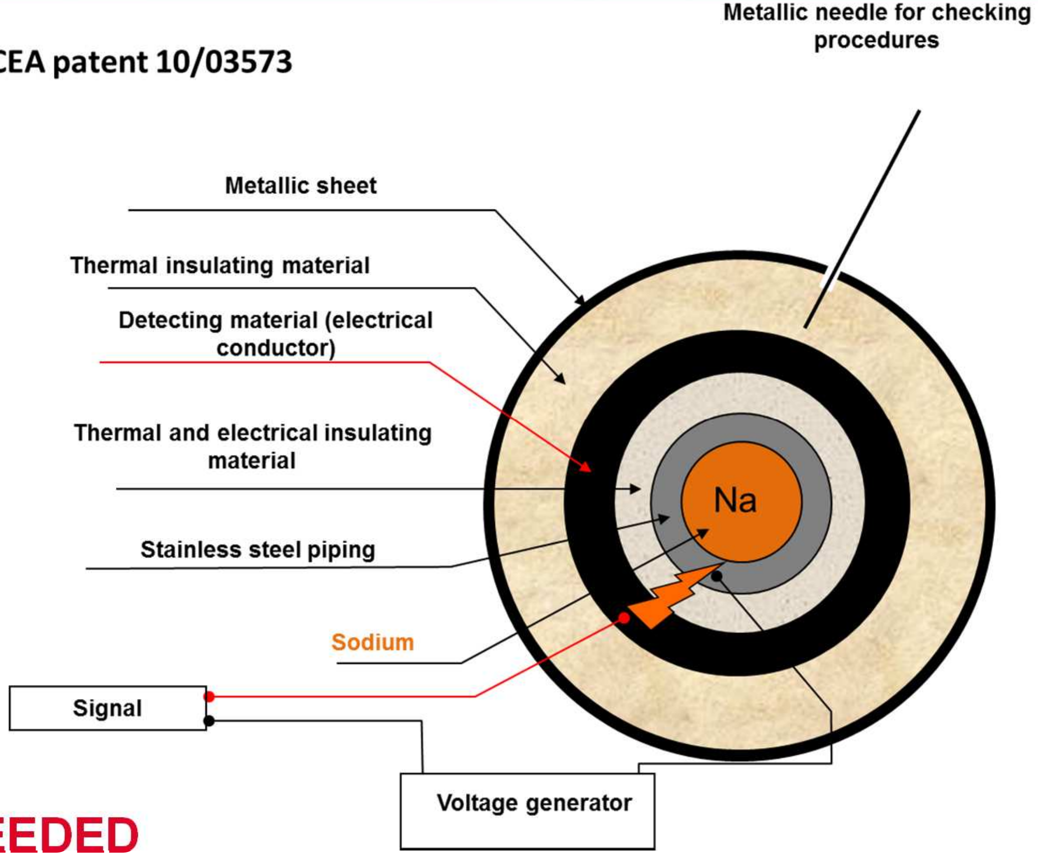
But rate of false alarms is not negligible and time response can be rather long for low leak flow rate and large pipe
→ Need of improvements

INSTRUMENTATION: Sodium leak detection

INVESTIGATION OF TECHNICAL SOLUTIONS

- Previous studies identified some alternative detectors as for example a multilayer heat insulator integrating the detection function

CEA patent 10/03573



BUT DEVELOPMENT WORK IS NEEDED

- Confirmation of materials behavior (normal and incidental conditions)
- Validation of detection efficiency
- Ageing study
- Design improvement to reduce cost and improve the way to implement it on long piping network
- …