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R&D and Design Studies for the ASTRID Core-Catcher

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OUTLINES

- INTRODUCTION AND CONTEXT
- EXISTING DESIGNS of CORE CATCHERS
- The ASTRID CORE CATCHER SPECIFICATIONS
- CORE-CATCHER DESIGN OPTIONS
- EXPERIMENTAL PROGRAMS for the CORE CATCHER DEVELOPMENT and QUALIFICATION
- CODE DEVELOPMENT for the CORE CATCHER DESIGN
- CONCLUSIONS

INTRODUCTION AND CONTEXT

- **Some ASTRID objectives**
  - **Improvement of the safety and the reliability**
  - **Lower the likelihood and degree of reactor core damage**
- **WENRA (Western European Nuclear Regulators Association) Recommendations**
  - **Extend, at the design stage of new reactor, 'the design beyond traditional design basis, in the area of core melt prevention and mitigation'**
  - **SA sequences have to be considered as a 4th level of defense in depth**
- **ASTRID safety strategy**
  - **Prevention of core melting sequences**
  - **Favor natural behaviors of the reactor under SA conditions**
  - **Addition of mitigation dispositions if necessary to meet acceptable consequences**

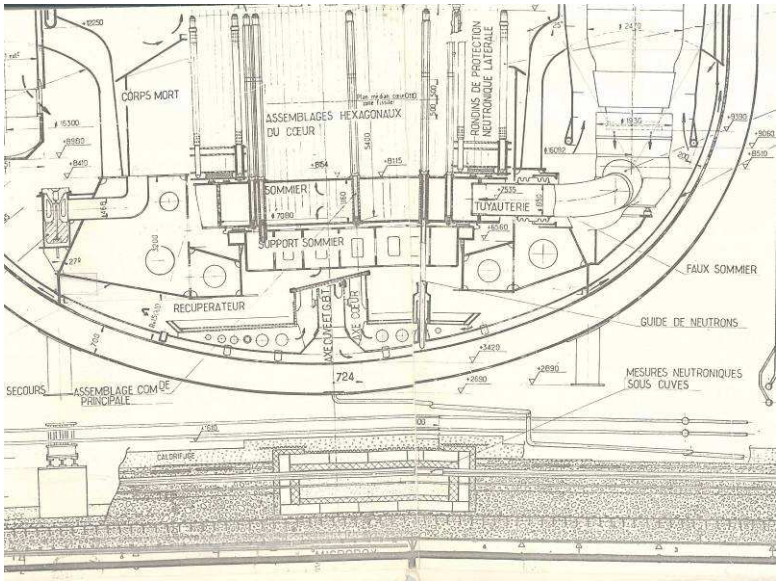
⇒ Implementation of a core-catcher for mitigation of SA

(ensure the confinement of the radionuclides by the protection of the containment structures)

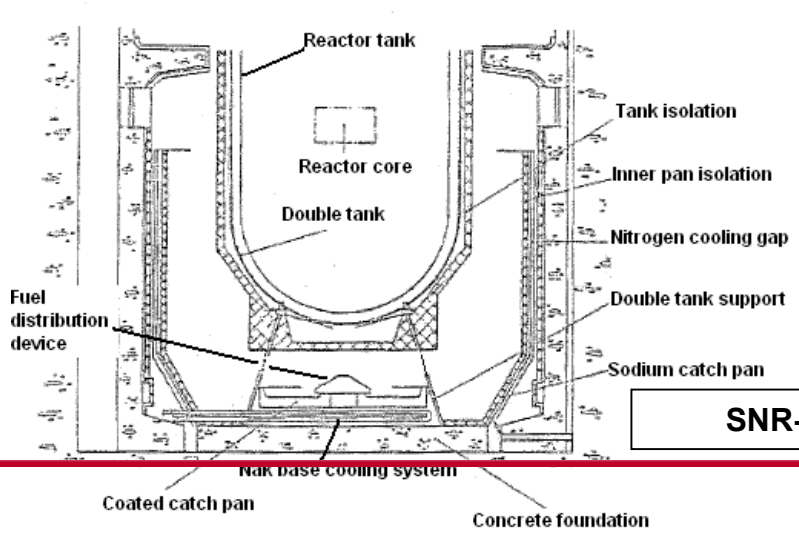
EXISTING DESIGNS of CORE CATCHERS

Review of Design of Core Catcher (existing reactors or reactor projects)

- **Two type of core catchers**
  - **In-Vessel core catchers**
    - ✓ Superphénix
    - ✓ EFR
    - ✓ BN-800
    - ✓ PFBR
    - ✓ DFR
    - ✓ JSFR
    - ✓ CFBR



SuperPhénix Core Catcher



SNR-300 Core Catcher

- **Ex-Vessel core catchers**
  - ✓ SNR-300

Functional Specifications

- **Main specifications**
  - To collect the whole core inventory during core melting sequences
  - To maintain the corium in a sub-critical state,
  - To evacuate the corium residual power and guaranty its coolability on the long term

- **Additional constraints**
  - Periodic controls
  - Dismantling
  - Sustain the mechanical energy potentially released during SA
  - Resist to any operating conditions and hazards (e.g., earthquake)
  - Be chemically compatible with its environment (Na)
  - No interference with normal operation of the reactor

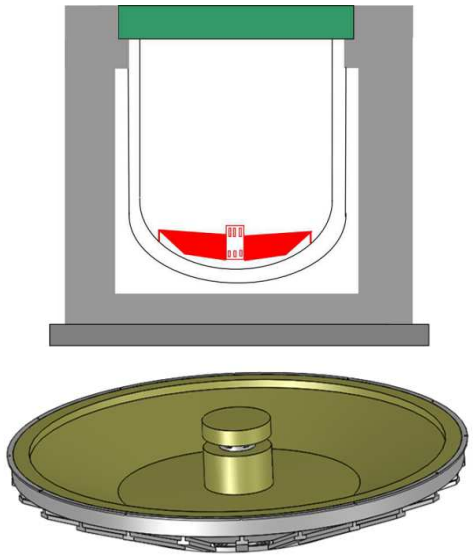
Work Hypothesis for the pre-conceptual design of the ASTRID core catcher

- **Basis of the hypotheses**
  - Simplified calculations of the corium characteristics
  - Feedback of existing experimental data base
  - Expert judgment
  - ASTRID design options
- **First set of Main Hypothesis**
  - Molten pool formation in the core region in the secondary phase
  - One or more decay heat removal systems available
  - Core subcritical
    ⇒Corium temperature arriving on the core catcher: 2850°C
  - Axial melt propagation toward the core catcher through ducts or radial propagation
    ⇒Possible impingement of the core catcher by corium jet
  - Mass of corium: about 350-370t = 60m^3 of debris
  - Decay heat removal in steady state conditions 1h after SCRAM (20MW) -> Long term decay heat removal

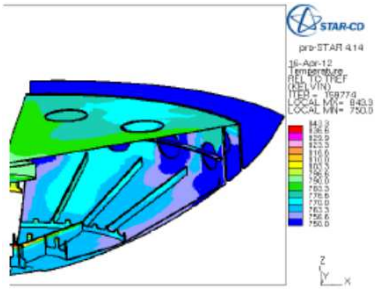
CORE-CATCHER DESIGN OPTIONS (1/3)

Option 1: In-vessel core catcher

- **Design:**
  - Located inside the main vessel below the core support structure
  - ZrO_2 covered for corium jet impingement protection (preliminary design)
  - Cooled by sodium natural convection
- **Advantages**
  - Protection of the main vessel (Integrity)
  - Well adapted to pool type reactor (large tray)
  - Could use Main Vessel DHR if available
- **Disadvantages**
  - **Need of sacrificial materials** (corium jet)
  - **Long term Na compatibility of sacrificial materials**
- **Studies carried out**
  - **Thermo-hydraulics: Core-catcher cooling, DHR**
  - **Mechanics: supporting structure, seismic resistance…**



In-vessel core catcher design

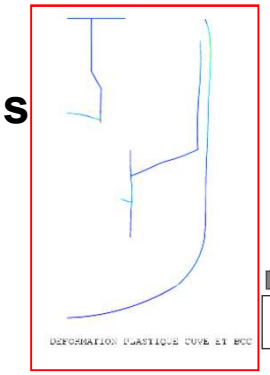


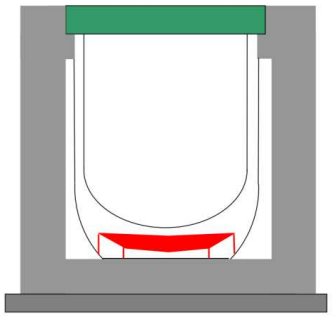
In-vessel core catcher cooling studies

CORE-CATCHER DESIGN OPTIONS (2/3)

Option 2: Ex-vessel core catcher

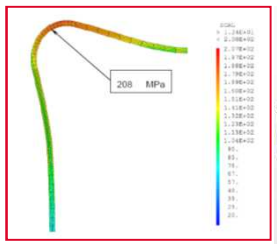
- **Design (CEA Patent):**
  - Located in-between Main and Safety vessels
  - Laying-type Safety Vessel
  - Cooling by natural convection
    - ✓ DHR in Safety Vessel (Na)
    - ✓ Additional DHR outside SV (air)
- **Advantages**
  - Large tray, space for sacrificial material
  - Under gas phase in normal operation
  - Easier inspection
- **Disadvantages**
  - Increase of inter-vessel volume:
    Na level decrease in MV in case of MV leakage
  - Na discharge with the corium from MV?
  - Main and Safety vessels Inspection
- **Studies carried out**
  - Mechanics: FCI, supporting structures…
  - Thermo-hydraulics: Na leakage, corium cooling



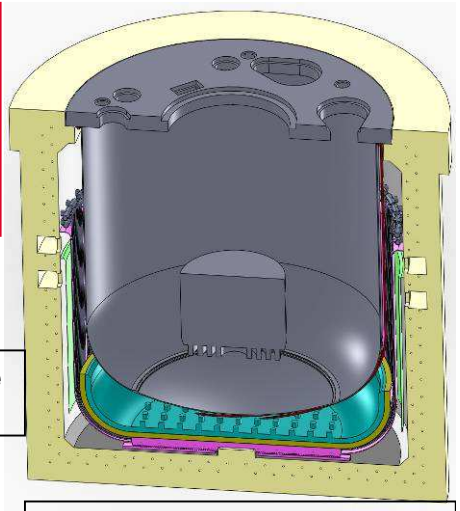


Ex-vessel core-catcher
(Sodium natural convection cooled type)

FCI study: Main Vessel Deformation



SV upper structure
Constraints

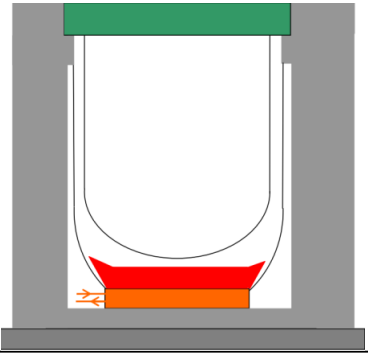


Option 2: Core Catcher Design

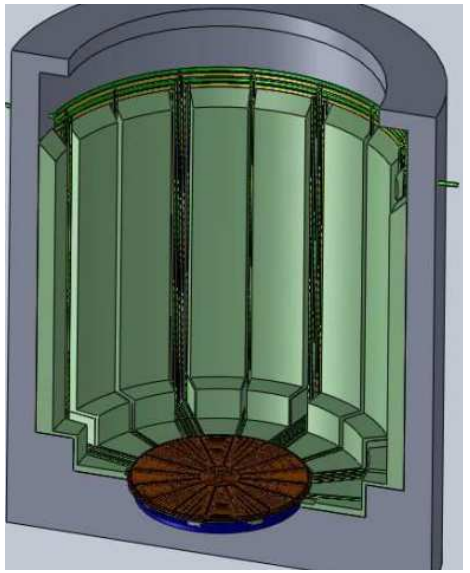
CORE-CATCHER DESIGN OPTIONS (3/3)

Option 3: Ex-vessel core catcher

- Design forced-cooled type
  - Located in-between main and safety vessel
  - Laying-type Safety Vessel
  - Cooled by forced and natural convections
    - ✓ Dedicated bottom tray cooling system
    - ✓ Additional DHR (inside or outside SV)
- Advantages
  - Same as option 2
  - Core-catcher tray cooled at corium arrival
- Disadvantages
  - Same as option 2
  - Na leak-tightness of piping penetrations (tray cooling system)
- Studies carried out
  - Thermo-hydraulics: core-catcher cooling, DHR
  - Mechanics: supporting structure, seismic resistance…



Forced-cooled Core Catcher



Core-catcher cooling system and pipes in the reactor pit

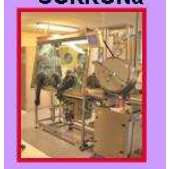
EXPERIMENTAL PROGRAMS for the CORE CATCHER DEVELOPMENT and QUALIFICATION

Large experimental programs to support the core catcher development

- **On going-programs**
  - **Properties of Corium-Sacrificial Material Mixture as UO_2 + B_4C, Al_2O_3, HfO_2, Hf, Eu_2O_3, Al_2O_3-HfO_2, Al_2O_3- Eu_2O_3 (Sacrificial Materials for jet protection, corium dilution, neutron absorbent)**
    - ✓ **Thermophysical properties (density, viscosity) and phase diagram (VITI)**
    - ✓ **Thermochemistry using high temperature mass spectrometry**
    - ✓ **Post-test characterization: XRD, SEM and microprobe analyses**
  - **Compatibility of Candidate material in Na (CORRONa)**
  - **Corium characteristics (EAGLE1&2 in IGR, SOFI at IGCAR)**

VITI

CORRONa



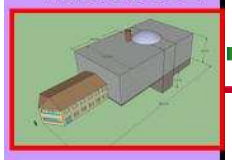
VULCANO

- **Planned programs in existing facilities (with simulant or UO_2)**
  - **Convective heat transfers in corium molten pool (CLARA)**
  - **Sacrificial material dissolution by the corium (VULCANO)**
  - **Aerosol releases from a mixture UO_2-Sacrifical Materials (COLIMA)**
  - **Core catcher cooling in PATH? (IGCAR)**

COLIMA

- **New Facilities Under Development for additional programs**
  - **Analytical facilities with simulant: material dissolution, jet impingement**
  - **Integral tests in Na: FOURNAISE**

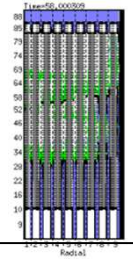
FOURNAISE



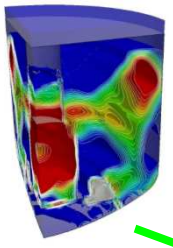
CODES for the CORE CATCHER DEVELOPMENT

Large programs of code development, adaptation, and assessment

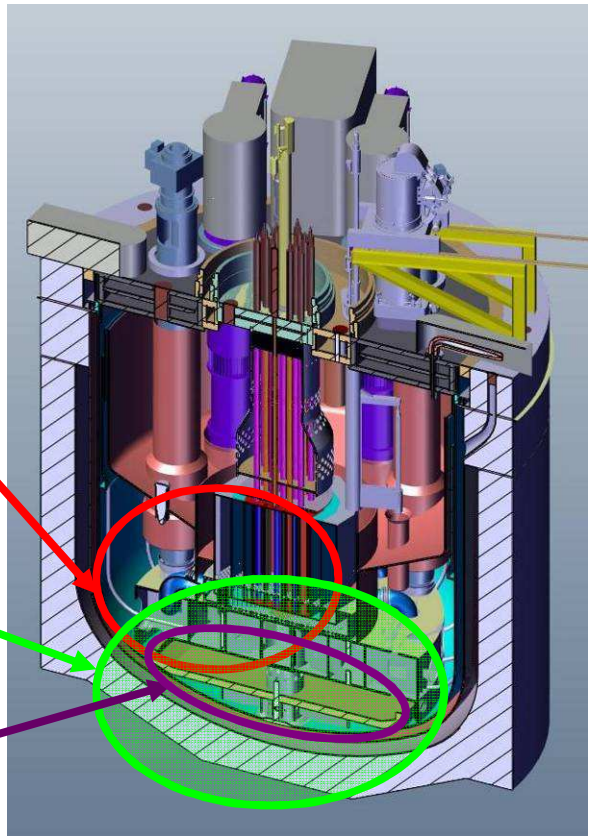
- **Corium characteristics on the core catcher**
  - SAS-SFR, SIMMER
    - ✓ Core degradation
    - ✓ Corium melt-down
  - MC3D or equivalent
    - ✓ Fuel Coolant Interactions
- **Core Catcher behavior**
  - TRIO-U, CFD codes, CATHARE
    - ✓ Core catcher Cooling
  - SYSTUS, ANSYS, CAST3M, EUROPLEXUS
    - ✓ Mechanical Behavior
  - TRIPOLI, ERANOS, APOLLO3
    - ✓ Corium reactivity
- **Corium and Sacrificial Material behavior**
  - LIDEB?
    - ✓ Debris Bed Cooling
  - CFD codes, TOLBIAC-SFR coupled to GEMINI2 or FUELBASE
    - ✓ Jet behavior and Corium-Sacrificial Material Interactions



SIMMER Calculation



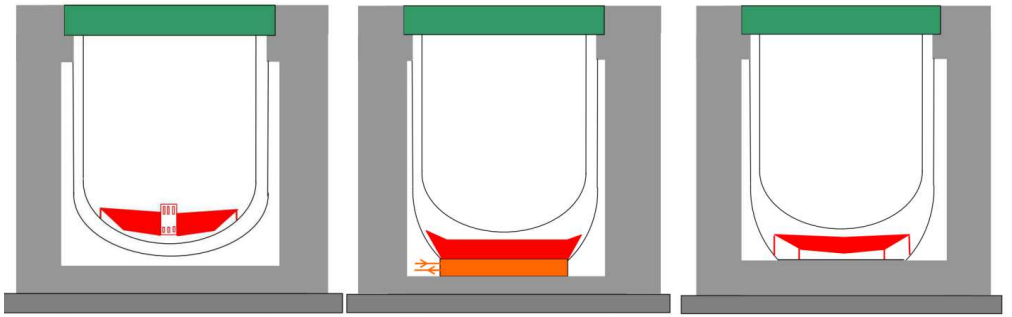
EUROPLEXUS Calculation



CONCLUSIONS on the CORE CATCHER STUDIES

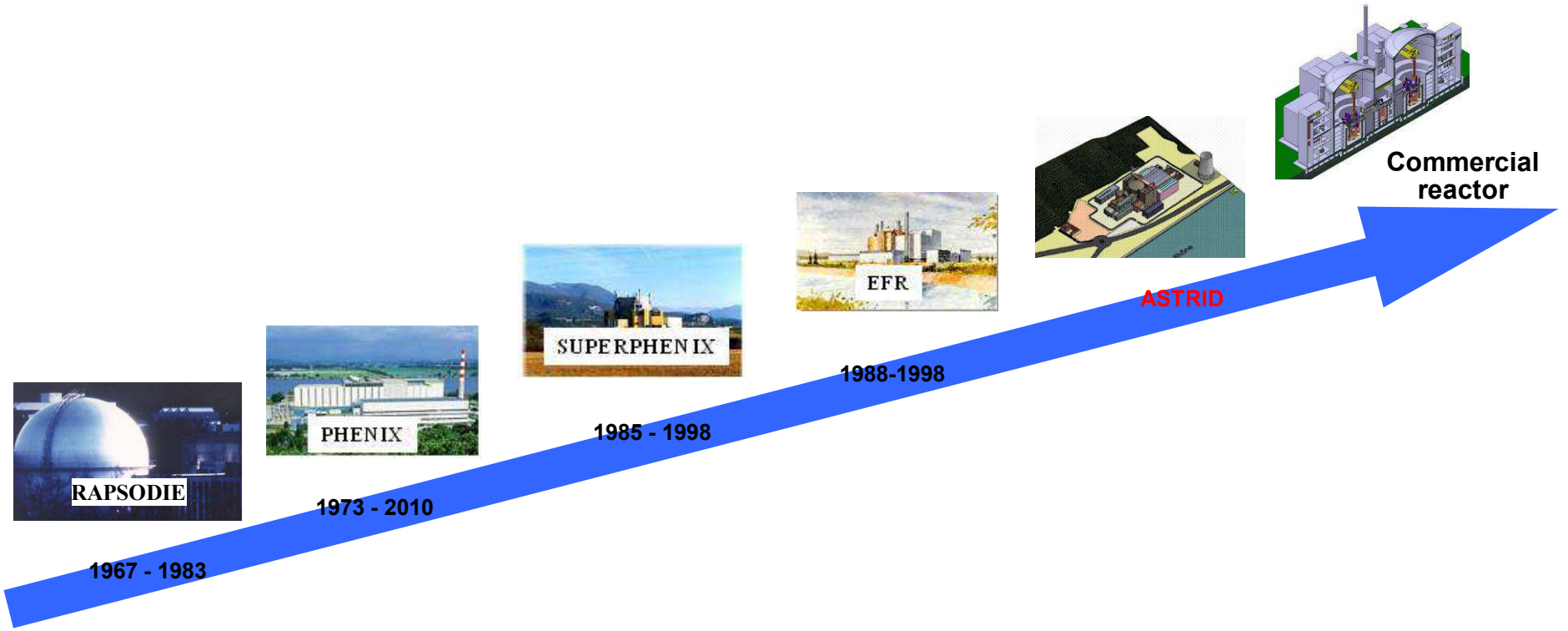
ASTRID Core Catcher development started since the ASTRID pre-conceptual design phase

- SA sequences considered as a 4th level of defense in depth
  - ⇒ Implementation of a core-catcher for mitigation of SA
- Large amount of work done during the pre-conceptual first phase
  - Review of existing or under project SFR core catchers design
  - Specifications of the ASTRID core catcher
  - Study of 3 options:



  - Associated Experimental programs
    - ✓ In particular for Sacrificial Material selection
  - Associated Code development and assessment programs
- Selection of the option in coming months

Thank you for your attention



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