



**SAR**<sub>net</sub>



SIXTH FRAMEWORK  
PROGRAMME

# **Overview of progress in the Corium Area**

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# Overview of progress in the Corium Area

- Recall of corium topic organization
  
- Overview of progress
  - in Early phase of core degradation WP
  - in Late phase of core degradation WP
  - in Ex-vessel corium recovery WP
  - in thermodynamic and material properties databases
  
- Conclusion in term of networking activity

## Corium topic organization

- **Corium topic focuses around the corium behavior**
  - From early phase core degradation to in or ex vessel corium recovery
- **Organization based on EURSAFE concerted action conclusion**
  - Regroups in an ex-vessel domains
    - **311 phenomena** have been selected
    - 92 of them are important for safety
    - **52** of them are **important for safety** and present an **important lack of knowledge**
  - Those 52 phenomena have been merged according to their similarity or their interactions in **10 items** for a better readability
- **To progress jointly, by sharing effort, resources and costs**
  - in the **corium behavior understanding**,
  - in **phenomena modeling** and assessment
  - with the final goal to implement models in **ASTEC code to capitalize the knowledge**
  - Keeping in mind EURSAFE spirit, i.e. feedback from regulatory bodies and utilities to progress in a **consistent way and as far as it is necessary**

## Corium topic subdivision

- **Early phase of core degradation (WP9 EARLY)**
  - WP9-1: Hydrogen generation during Core reflooding (FzK)
  - WP9-2: Early core degradation and B4C effects (IRSN)
  - WP9-3: Zircaloy oxidation by air and steam-air mixture (IRSN)
  
- **Late phase core degradation (WP10 LATVES)**
  - WP10-1: Late-phase core degradation and corium behavior in lower head (KTH)
  - WP10-2: Vessel failure and corium release into cavity (IRSN)
  
- **Ex-vessel corium recovery (WP11 EXCORE)**
  - WP11-1: Core and debris coolability during reflooding (IKE)
  - WP11-2: Molten corium concrete or ceramic interaction (CEA)
  - WP11-3: Ex-vessel corium coolability (CEA)
  
- **Thermodynamic and material properties databases**
  - a last subtopic distributed within others WP to promote exchanges among partners (IRSN)

# Task identification and link with other WPs

WP9 Tasks	WP 9	Lead.	Months 13 - 18	Months 19- 24	Months 25-30
<b>MEETINGS</b>			M	M	
		<b>Part. Id.</b>	↓		
1	Joint review of experiments	<i>All</i>	-----↓-----	-----D12	-----
2	Joint interpretation	<i>All</i>	-----	-----↓----- D13	----- →WP7 SARP
3	Proposals of models for ASTEC	<i>All</i>	-----	-----D14	----- →WP2 ASTEC
4 (Depends on WP)	Synthesis of plant applications	<i>All</i>	-----	-----D15	----- →WP7 SARP

}

**D11**

## Overview of progress in Early phase ... WP

- **Early phase of core degradation objectives**
  - Hydrogen generation during reflood or melt relocation into water EURSAFE item N°1.1 ⇒ **improve knowledge about the magnitude of hydrogen generation**, risk associated with hydrogen rapid generation
  - COLOSS conclusion and preparation of FPT3 needs of improvements of understandings and modeling of **B<sub>4</sub>C or fuel burn-up impact on core degradation**
  - **Oxidation by air or air /steam mixture** ranked at low level for core degradation but strong impact for FP release ⇒ issue identified as separate subtopic WP9.3
- **Resources**
  - **10 partners** : EDF, ENEA, FzK, GRS, INR, IRSN, JRC-ITU, PSI, THERMODATA, UJV
  - **Separate effect test and bundle tests** : QUENCH, SETs, MAESTRO plat-form, PHEBUS, INR experiment
  - **International collaboration** in the frame of ISTC projects : #1648, PARAMETER
  - **Modeling and interpretation capabilities** : ICARE/CATHARE, SCDAP/RELAP5, ATHLED-CD, MELCOR, ASTEC

## Overview of progress in Early phase ... WP

- Overview of progress

- Experimental activities

- IRSN/FzK share **jointly test matrixes** to improve knowledge on oxidation by air/steam mixture and on  $B_4C$  degradation to support modeling activity and PHEBUS FPT3 (IRSN Nov. 04) interpretation
- **QUENCH 10** experiment (FzK July 04) to study the **impact of air ingress** on core degradation  $\Rightarrow$  results open to all partners for interpretation needs for a new oxidation model
- **QUENCH 11** (FzK Nov. 05), **boil-off bundle test** will be the second test performed in the frame of EC LACOMERA transnational access
- **SETs tests** (FzK 05) steam/air mixture – Zry oxidation up to 1500°C
- Air-Zry oxidation experiments (600/1000°C) on the **MOZART facility** (IRSN 05)
- **VERDI experiments** (IRSN May-July 05) on  $B_4C$  degradation, effect of oxidation kinetic, and  $B_4C$ -steel tests are on going
- **JRC-ITU** (04-05) extend the COLOSS test matrix with additional irradiated fuel dissolution experiments

## Overview of progress in Early phase ... WP

- **Overview of progress**
  - **Interpretation activities**
    - PSI performed **pre and post Quench 10 test calculations** with MELCOR and SCDAP/RELAP5 ⇒ needs to improve oxidation models
    - **Interpretation of PHEBUS FPT3**, ICARE2 post test calculation focused on the  $B_4C$  compartment under oxidizing conditions in bundle geometry have been performed by IRSN

## Overview of progress in Early phase ... WP

- Overview of progress

- Modeling activities

- Edf develop a **top flooding model** that will be qualified by PARAMETER tests in the frame of ISTC project
    - Diploma thesis has been started at FzK on **sequential oxidation by steam and after by air/nitrogen**
    - PSI has developed an **air oxidation model** based on SET's test results
    - IRSN, **ICARE/CATHARE development** :
      - **Zry/air-steam oxidation model** has been developed by IRSN
      - **UZrO mixture oxidation model** has been developed and tested on reactor application
      - For B<sub>4</sub>C degradation calculation, **ICARE/CATHARE and GEMINI2 have been coupled** but additional work is requested to take into account chemical kinetic reaction
      - The **fuel dissolution model** has been improved.

## Overview of progress in Late phase ... WP

- **Late phase of core degradation objectives**

- Item N°1,3 “Corium coolability in lower head...” : to improve predictability of **the thermal loadings on RPV lower head** (or corium catcher devices) to maintain their integrity.
- Item N°3.1 “Melt relocation into water and particulate formation”: to improve **debris bed formation** (partially). Item N°1.2 on debris coolability addressed with ex-vessel
- Item N°1.4 “External vessel cooling and RPV integrity” for in-vessel melt retention strategies : to **improve CHF data base to evaluate and design AM strategies.**
- Item N°1,6 “Corium release following vessel failure” : to improve predictability of **mode and location of RPV failure**

- **Resources**

- **11 partners** : CEA, EDF, FzK, FzR, GRS, IKE, IRSN, IVS, KTH, RUB,TECHNICATOME, THERMODATA
- **Separate effect test and integral tests** : SIMECO, FOREVER, LIVE
- **International collaboration** in the frame of OECD or ISTC projects : OLHF, MASCA, METCOR
- **Modeling and interpretation capabilities** : ICARE/CATHARE, ATHLED-CD, AIDA-3D, IKEMIX, MEWA, ANSYS, ASTER, ASTEC

## Overview of progress in Late phase ... WP

- **Overview of progress**
  - **Experimental activities**
    - **COLIMA facility** (CEA, 03) **corium pool fission product release** experiment for VVER composition in the frame of **EC PLINIUS** transnational access plat-form (Bulgarian team). Post-test analysis has been completed and documented.
    - **LIVE facility** (FzK,05) , first experiment with Bulgarian team in the frame of **EC LACOMERA** to study **corium pool behavior in 3D geometry** by the end of 2005. Second experiments under definition, following IRSN proposal, to study **melt relocation process**
    - **Metallurgical tests** at CEA and INSA(Lyon) with IRSN to study the **variability of 16MND5 properties at high temperature** in relation with different chemical compositions
    - **CNU facility** : definition of a scale 1:1 facility (1:10 angular sector) to **validate the cooling device concept** retained by CEA and TECHNICATOME for low power reactor.

## Overview of progress in Late phase ... WP

- Overview of progress

- Interpretation activities

- RUB and IKE performed **TMI-2 and FPT4 calculations**. Improvement with the use of MESOCO degradation module (ATLET-CD). Use of IKEMIX and MEWA by IKE to simulate **corium relocation, debris formation, coolability or re-melting**.
    - In relation with **MASCA issues**, interpretation of **3 layers SIMECO experiments** by KTH
    - Interpretation of **FOREVER** (KTH) experiments by FzR through **coupled pool convection and thermo-mechanical vessel failure calculations**. Feedback of ISTC METCOR (NITI) for reactor application
    - EDF joins the thermo-mechanical thematic circle to **take part to FOREVER interpretation** with ASTER and to **validate the existing models** and behavior laws.

## Overview of progress in Late phase ... WP

- **Overview of progress**

- **Modeling activities**

- GRS has improved the AIDA-3D code by **adding simulation rules** to describe in simplified way **the upper unstable layer** in a convective corium pool.
    - Development of **more realistic lower head configurations** by CEA taking into account the feed back of MASCA miscibility gap knowledge improvement.
    - Development of **external cooling models** by CEA and IVS to perform **coupled simulations** and validate AM strategy based on reactor vessel external flooding
    - Joint analysis and experimental program between IRSN, CEA and INSA (Lyon) to develop a **new failure criterion** taking into account **effect of steel chemical composition** on failure characteristics
    - Additional **mechanical sub model** developed by FzR during FOREVER interpretation

## Overview of progress in Ex-vessel ... WP

- **Ex-Vessel corium recovery objectives**

- Items N°2.1 “MCCI: molten pool configuration and concrete ablation” and N°2.3 “Ex-vessel corium catcher: corium ceramics interaction and properties” : to improve **predictability of axial versus radial ablation up to late phase MCCI** to determine basemat failure time and loss of containment integrity; demonstrate the **efficiency of specific corium catcher designs** by improving the predictability of the corium interaction with corium catcher materials.
- Items N°2.2 and 2.4 “Ex vessel corium coolability...” : to increase **knowledge of cooling mechanisms by top flooding** the ex-vessel corium pool to demonstrate termination of accident progression and maintenance of containment integrity; demonstrate **efficiency of water bottom injection** to cool corium pool and its impact on containment pressurization.
- Extension to Item N°1.2 “Core coolability ... **particulate debris**” : to termination of the accident by re-flooding of the core while maintaining RCS integrity. Increase predictability of **core cooling during re-flooding**.

- **Resources**

- **12 partners** : CEA, EDF, FRA-ANP GmbH, FzK, GRS, IKE, IRSN, KTH, THERMODATA, UJV, UPM, VTT
- **Separate effect test and integral tests** : DEBRIS, STYX, POMECCO, DECOBI, COMET, VULCANO, COMECO, SICOPS
- **International collaboration** in the frame of OCDE or ISTC projects : MACE, MCCI, CORPHAD, CHES
- **Modeling and interpretation capabilities** : ICARE/CATHARE, KESS and ATLET-CD, WABE, MC3D, COSACO, MEDICIS (ASTEC), TOLBIAC-ICB, WEX

## Overview of progress in Ex-vessel ... WP

- Overview of progress

- Experimental activities

- **STYX** experiments by VTT (2004) with irregular shapes and various diameter particles
- New dedicated **DEBRIS** experiments by IKE (2005) for comparison with ICARE/CATARE IRSN calculations : **2D effects** and **cooling of dry region** by the steam flow.
- **COMET L1** 2D MCCI experiment performed by FzK (July 04) in the frame of **EC LACOMERA** with IRSN. **COMET-L2** experiment in homogeneous pool configuration (Feb. 05) candidate for blind benchmarking activity. **COMET-L3** test in **stratified configuration** scheduled by the end of 2005
- **ARTEMIS 1D** experiments performed by in simulant fluid CEA (03-05) to study boundary conditions in MCCI conditions ⇒ **for reactor conditions interface close to liquidus** temperature. First **ARTEMIS 2D** test performed (Sept. 05), faster radial ablation reported
- **Three VULCANO-CCI 2D** experiments performed by CEA (04-05) for prototypic oxidic pool **faster radial ablation observed for siliceous concrete**, first test in stratified pool configuration under preparation
- **VULCANO-COMET**, validation of **COMET-PCA core catcher concept** in prototypic material at CEA (Oct. 05) with FzK in the frame of **EC PLINIUS plat-form**

## Overview of progress in Ex-vessel ... WP

- Overview of progress

- Interpretation activities

- STYX, DEBRIS, POMECA, SILPHIDE **joint interpretation** with WABE, MC3D, CATHARE/ICARE, ATHLET-CD by IKE, IRSN, EDF, CEA, KTH, VTT ⇒ **contribution to a special issue volume of NED** on Particulate and Porous Debris Coolability
    - **Interpretation of SWICCS and CCI experiments** in the frame of MCCI-OECD program
      - CCI benchmark exercise ⇒ behavior for siliceous concrete, **faster radial ablation**, still not understand. Benchmark around CCI-2 LCS test, power distribution and **ablation rate well reproduced** but large **differences appear in pool temperature** according to solidification models and heat transfer correlations.
      - Separate effect coolability experiments : **water ingress mechanism** quantified but **effect limited** for reactor application. Ejection test stumbles over technological difficulties to avoid crust anchorage.
    - Pre test and post test **VULCANO-COMET calculations** have been and will be performed by IKE with WABE **jointly** with CEA and FzK.

## Overview of progress in Ex-vessel ... WP

- Overview of progress

- Modeling activities

- Special issue of NED on debris coolability presents also an **overview of theoretical approaches on basic laws**. Extended coolability linked to 2D effects predicted.
    - IKE is developing a **unified approach** to treat both porosity formation by water injection from below or porosity formation by **effect of sparging gas** and melt ejection **in case of top flooding**
    - CEA focused its activity on **melt ejection modeling** with implementation of PERCOLA models in TOLBIAC-ICB code
    - Explanation of **different behaviors between LCS and siliceous** concrete request additional modeling activity and material analysis to **understand boundary conditions** in prototypic conditions
    - IRSN and CEA performed **analysis and reactor applications** to evaluate the sensitivity of remaining uncertainties. The most important parameters are **pool configuration** and **heat transfer between oxidic and metallic layers**.

# Overview of progress in databases development

- **SARNET thermodynamic and material properties databases objectives**
  - **Maintain and develop the thermodynamic and material properties databases** that are indispensable tools for reactor application but also for the design and the interpretation of experiments.
  - **Consolidation of the ASTEC database MDB.**
- **Resources**
  - **5 partners** : CEA, IRSN, JRC-ITU, THERMODATA, UJV
  - **Dedicated experiments** : JRC-ITU and UJV experiments
  - **International collaboration** in the frame of ISTC projects : CORPHAD (NITI)
  - **Modeling and interpretation capabilities** : NUCLEA database selected after ENTHALPY project, GEMINI or other solvers
- **Overview of progress**
  - **NUCLEA maintenance** : yearly workshop to define the priorities and the future work to take into account new data or new models obtained from dedicated experiments or after analysis of prototypic material experiments.
  - **Several coupling approaches** between thermo-hydraulic and physico-chemistry codes have been performed : COSACO, TOLBIAC-ICB, ICARE-CATHARE
  - For **physical properties** a **survey** will be organized by CEA among SARNET partners to collect properties and associates references to perform **jointly an evaluation task** and formulate additional recommendations for MDB

## Conclusion in term of networking activities

- **First objective** : initiate and make visible networking activities within a group where most of the partners use to collaborate in the frame of previous Europeans or other international projects.
  - **Promotion of networking** with several tools available through the ACT (templates, forum, meeting organization, document sharing...) : first results are encouraging but **we can do more**, keeping in mind that partners can exchange freely in ACT restricted area if it is necessary.
  - **Identification of thematic coordinators** at sub-topic level for a better efficiency and to promote exchanges at good technical level
- **Best results in term of jointly activity** are observed around data that can be available for a significant kernel : OECD, ISTC, LACOMERA, PLINIUS, STYX... ⇒ promotion of European program funded by partners on the OECD model ?
  - **Joint test matrix between** FzK and IRSN in term of rationalization of European resources
  - **Joint interpretation activity** around OECDD CCI tests
  - **Joint publication** in a special issue of NED on debris formation and coolability
- **New contributors** for the second period and specific request to access experimental data or simulations tools : INR (Zry/air oxidation tests), IVS (external cooling development), EDF (contribution to FOREVER interpretation), CEA (interest for SICOPS experiments) ...
- **Exchanges between topics** : discussion with source term topic to study aerosol release through cracks in the concrete taking the opportunity of ongoing prototypic experiments.