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SAFETY ASSESSMENTS AND SEVERE ACCIDENTS, IMPACT OF EXTERNAL EVENTS ON NUCLEAR POWER PLANTS AND ON MITIGATION STRATEGIES

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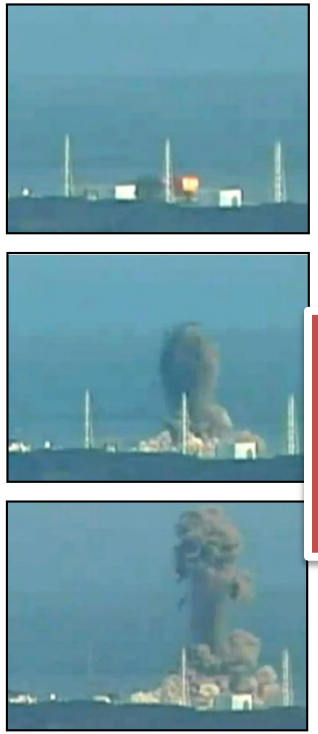
MOTIVATION



Need of further investigation to improve the Severe Accident Management strategies including external hazards

filling the gap of knowledge and reduce the uncertainties on phenomena participating in severe accidents

ALISA, SAFEST and IVMR projects

developing new mitigation systems and strategies to reduce the source term release and ensure heat removal

PASSAM, sCO2-HeRo projects

improving code suitability to address severe accident phenomena and severe accident management for a large number of reactor design including PWR, BWR, VVER and CANDU.

CESAM project

SAFEST Project : Severe Accident Facilities for European Safety Targets

Budget : M€ 5.8
EC funding: 50%
Program coordinated by KIT
Number of Partners: 9
Period: 1 July 2014 - 31 December 2018

- **Creation of an integrated pan-European laboratory for severe accident research** able to address and successfully resolve the wide
- **Development of research roadmaps** to focus future European R&D on the stabilisation and termination of severe accidents in PWRs and BWRs
- **Establishing the access to the SAFEST research infrastructure** to investigate all important phenomena from the early core degradation to corium pool formation in the lower head, and ex-vessel melt situations

- **Continuous improvement and upgrading of the SAFEST infrastructure** to increase the experimental capabilities and overall quality of R&D to meet current and future challenges

Karlsruhe Institute of Technology (**KIT**, Germany)

UJV Řež, a.s. (**UJV**, Czech Republic)

Commissariat à l'Energie Atomique et aux Energies Alternatives (**CEA**, France)

Framatome GmbH (Germany)

Royal Institute of Technology (**KTH**, Sweden)

Belgian Nuclear Research Centre (**SCK CEN**, Belgium)

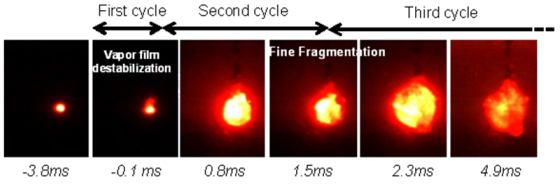
Centre for Energy Research, Hungarian Academy of Sciences (**MTA-EK**, Hungary)

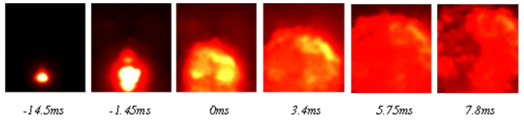
Joint Research Centre Karlsruhe (**JRC**, Karlsruhe)

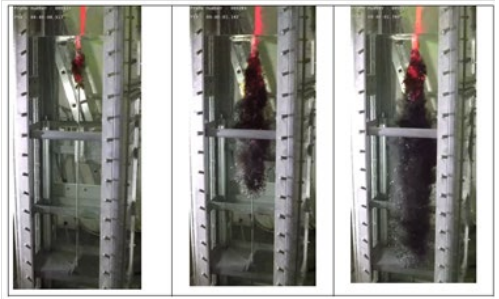
Collaborative Laboratories for Advanced Decommissioning Science (**CLADS**, Japan)

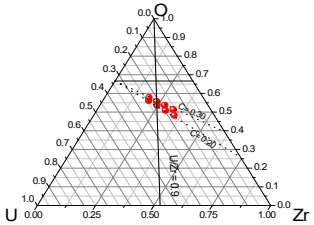
SAFEST Project : Severe Accident Facilities for European Safety Targets

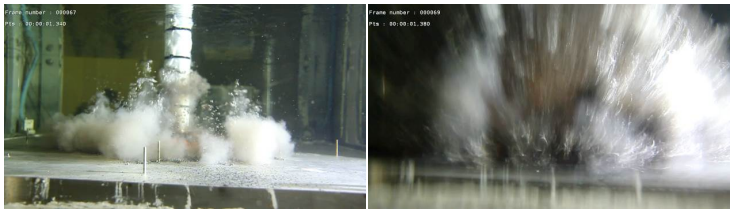
- **Two calls for proposals** for experiments in 2015 and 2016
- Altogether **16 experiments or experimental series** have been performed in the SAFEST project with participation of users from 15 organisations from 8 countries
- **Four research roadmaps** were published on corium and severe accident research
- Upgrading of the SAFEST facilities towards **BWR-specific phenomena**
- Joint research to improve the quality, precision and durability of **high temperature instrumentation**
- 3 workshops on information exchange on **engineering issues related to corium experiments**





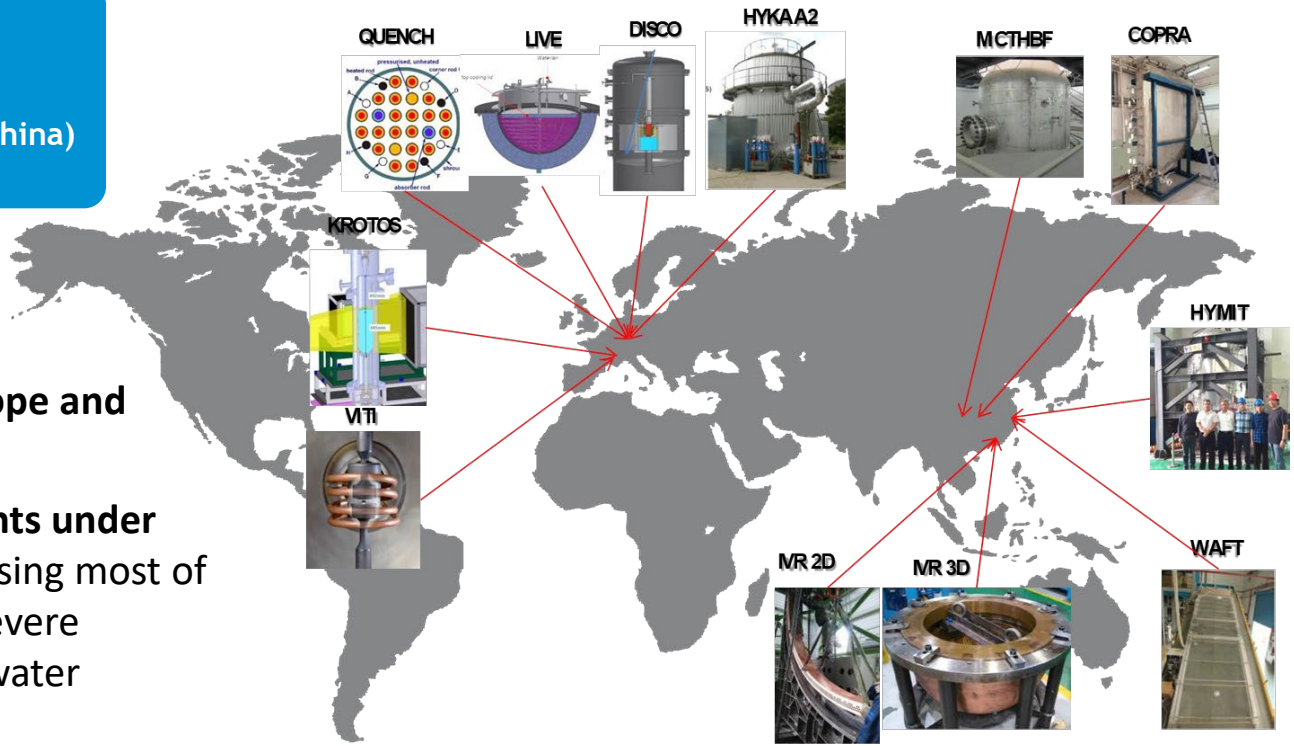






ALISA Project : Access to Large Infrastructure for Severe Accidents

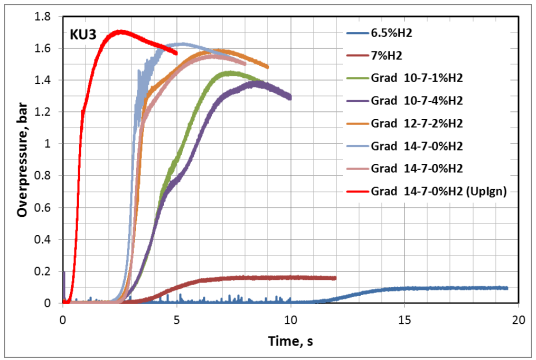
Budget : 1.7 M€
EC funding: 60%
Program coordinated by KIT
Number of Partners: 2 (EU) and 6 (China)
Period: July 2014 - June 2018

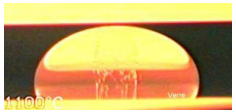


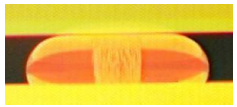
- Transnational access to large research infrastructures **in Europe and China**
- Focus **on large-scale experiments under prototypical conditions** addressing most of the remaining R&D issues on severe accident management in light water reactors

ALISA Project : Access to Large Infrastructure for Severe Accidents

- Unique opportunity for researchers to get involved in **networks and activities supporting safety** of existing and advanced reactors
- **Two calls for proposals** for experiments announced during the project
- Experimental programs provided **new data** on
  - Core degradation
  - In-vessel melt behavior and retention
  - Fuel coolant interaction
  - Containment and hydrogen behavior
  - Passive containment cooling systems
  - Corium properties





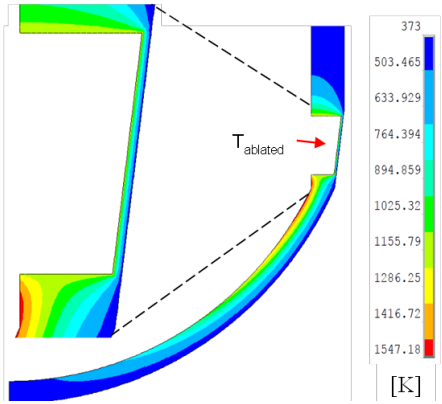


IVMR project: Assessing IVR strategy for high power reactors

Budget : 8.6 M€
EC funding: 58%
Program coordinated by IRSN
Number of Partners: 23 from Europe, 4 from Korea, 1 from Japan, 2 from Russia, 1 from Ukraine, 1 from China
Period: 2015-2019

- International Seminar about IVMR main results and other IVR activities in the world
- Venue: Juan les Pins (France)
- Dates: **21-23 January 2020**

- **Review the possibility of In-Vessel Retention (IVR) for existing and future NPPs with the standard methodology used for VVER-440 (Loviisa, Paks) and for new concepts (AP-600, AP-1000 and APR-14000)**
- **Provide new experimental results to assess the models used in the methodology**
- **Investigate several options to improve the methodology by reducing the degree of conservatism**
- **Provide an updated and harmonized evaluation methodology for the analysis of IVR to be implemented in codes and used for safety evaluation**

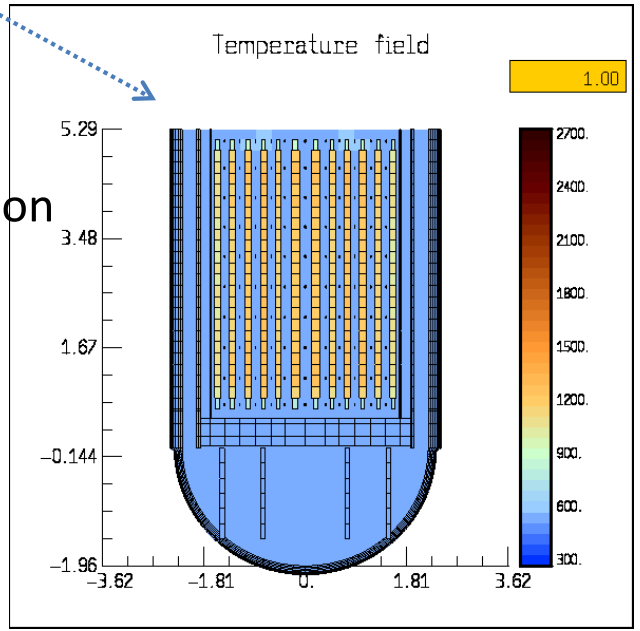


Example of mechanical calculation for an ablated vessel shape

IVMR project : Main outcomes

- A revised methodology to assess the success of IVR, based on a mechanical criterion for the residual thickness of ablated vessel, which is evaluated under transient conditions in order to integrate possible high heat fluxes before the quasi-steady state.
- Use of CFD for stratified pools: useful results for the thin metal layer and promising results for the turbulent oxide pool.
- Lack of maturity for thermo-mechanical calculations: action to be continued to reach a consensus
- Important results on stratified corium from CORDEB experiments
- Some experimental needs were identified
- Collaboration extended to international partners (China, Russia, Korea)

Example of ASTEC calculation showing the transient formation of stratified pool



PASSAM project: improving systems to limit radioactive releases

Budget : 5,1 M€
EC funding: 70,4%
Program coordinated by IRSN
Number of Partners: 9
Manpower: 33 person.years
Period : 2013-2016 (4 years)

New studies on passive and active systems towards enhanced SA source term (ST) mitigation

- **Exploring potential enhancement of existing source term mitigation devices:** aqueous ponds; sand bed filters (+ metallic pre-filters).
- **Demonstrating the ability of innovative systems to achieve larger source term attenuation:** preconditioning stage (acoustic agglomerators; high pressure sprays); filtering stage (electrostatic filters; improved zeolites; dry & wet combined filters).

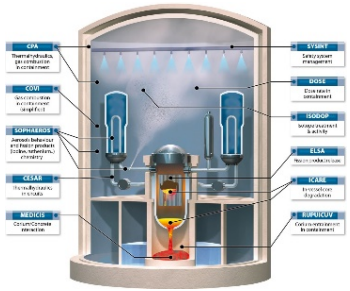
PASSAM project: improving systems to limit radioactive releases

- Main outcomes of the PASSAM Project:
  - Extension of the current database on the existing or innovative mitigation systems:
    - Gaseous iodine retention (molecular and organic iodine),
    - Hydrodynamics for scrubbers,
    - Long term stability of trapped compounds.
  - Deeper understanding of the phenomena underlying their performance.
  - Models/correlations easy to implement in accident analysis codes, like ASTEC.
  - Estimation of orders of magnitude for source term reduction for each filtration system, including on the long term, in accident conditions.

- PASSAM web site: https://gforge.irsn.fr/gf/project/passam/

CESAM Project : Code for European Severe Accident Management

Budget : 6.3 M€
EC funding: 50%
Program coordinated by GRS
Number of Partners: 19
Period: 1 April 2013 - 31 March 2017



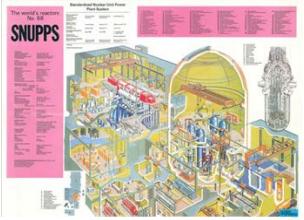
cesam
CODE FOR EUROPEAN SEVERE ACCIDENT MANAGEMENT

- **Modelling assessment, improvement and validation** of existing ASTEC models, especially those important for SAM, those dominant in Fukushima and identified in SARP
- **Integration of models in ASTEC**. Code improvements towards the new ASTEC major release version V2.1 and its subsequent updates and extension of ASTEC capabilities to diagnosis (interface of ASTEC with atmospheric dispersion tools and methodology using uncertain information provided by the plant)
- **Plant applications and SAM evaluation** by building generic reference input decks for the main types of NPPs in Europe (PWR, VVER, PHWR and BWR) as well as Spent Fuel Pools (SFP). These generic input decks have been used for plant analyses with a focus on possible improvements of ASTEC models for applications to SAM measures in various plant scenarios.
- **Dissemination of knowledge** with enhancement of the yet active ASTEC user community by organization of yearly workshops

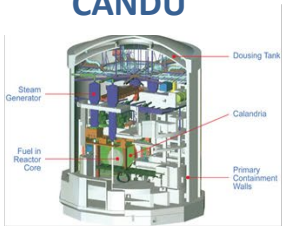
CESAM Project : Code for European Severe Accident Management

- Validation of most physical phenomena shows that **ASTEC V2.1 is at the state-of-the-art of severe accident modelling**
- **Generic NPP reference input decks** are an important contribution from CESAM partners to ASTEC code applicability
  - To serve as a basis for ASTEC new users to build their own plant deck
  - Included are first applications to BWR, PHWR and SFP (in addition to PWR & VVER)
- A large step has been made towards a **future use of ASTEC in support to decision-making** in case of emergency situations
- **ASTEC V2.1rev1 can be clearly used for SAM evaluation**, as evidenced by most partners

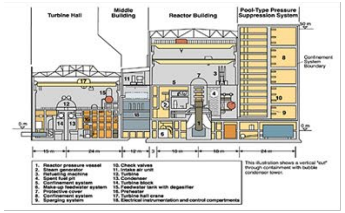
Western PWR



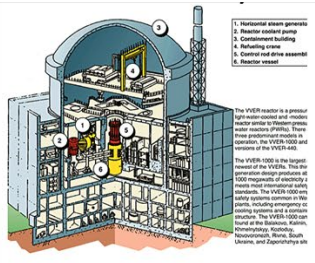
CANDU



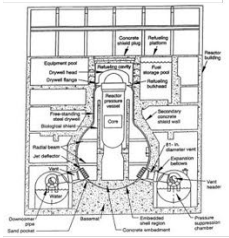
VVER-440



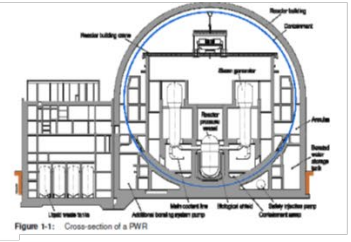
VVER-1000



BWR Mark 1



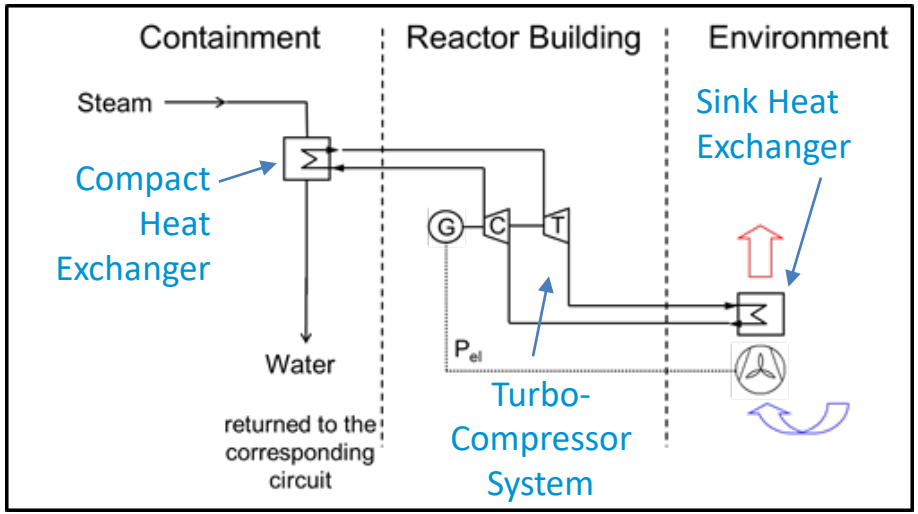
Konvoi PWR



sCO2-HeRo Project : Developing prototype for heat removal

Budget : 2.79 M€
EC funding: 100%
Program coordinated by University Duisburg-Essen, Germany
Number of Partners: 6
Period: 2015-2018 (3 years)

Objectives: To develop and show the proof-of-concept of the innovative reactor safety concept **"sCO2-HeRo"** that **safely, reliably and efficiently removes residual heat** from nuclear fuel **without the requirement of external power sources**.



sCO2 HeRo
The supercritical CO_2 heat removal system

sCO2-HeRo Project : Developing prototype for heat removal

- Main outcomes:
  - Designing a compact heat exchanger
  - Designing a turbo-machine set; self-propellant and self-launching
  - Evaluation of a sink heat exchanger
  - Ensuring quality assurance; reviews and testing components in supercritical CO2 loops (SCARLETT, SUSEN)
  - Evaluation with advanced Computational Fluid Dynamic (CFD) simulations for heat transfer
  - Proofing the concept (TRL-3) in unique PWR simulator at GfS, Essen, Germany
- www.sco2-hero.eu


Compact Heat Exchanger


Turbo-Compressor System

Main achievements

- better understanding of the severe accident phenomena, such as the core degradation, the core melt and the hydrogen deflagration, and contribute significantly to reduce the related uncertainties,
- development of novel mitigation equipment for heat removal,
- improvement of innovative strategies in support of the in vessel retention and the source term reduction,
- improvement and demonstration of the ASTEC code suitability to address severe accident phenomena and severe accident management for a large number of reactor designs including PWR, BWR, VVER and CANDU.

Knowledge dissemination and education

- involvement of PhDs student,
- demonstration prototype of sCO2-HeRO installed at PWR glass model in Essen, Germany for teaching
- numerous peer review publications,
- organization of open workshop
- participation to IAEA and OECD (SOAR, CRPs, ..)

ACKNOWLEDGMENTS

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