The European PASSAM Project on severe accident source term mitigation: halfway status

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PASSAM general context and objectives

PASSAM main features and organization

State of progress of work packages

Conclusions
PASSAM general context and objectives: severe accident source term mitigation
PASSAM main features: European frame

- Four years duration: 2013 - 2016.
- Project mainly experimental on PASSIVE and ACTIVE SYSTEMS on SEVERE ACCIDENT SOURCE TERM MITIGATION → Mainly FCVS, but also pool scrubbing in suppression pools and SGTR conditions, ...
- Partnership: 9 partners, IRSN (France) Coordinator.
- Large amount of work to be performed: 395 person.months (33 person.years) for the 9 partners.
- Total budget: 5.11 millions euros, out of which 70% are funded by the European Commission.
| Month       | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
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| WP1 MANAG  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP2 THEOR  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP2.1 SOAR |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP2.2 MODEL|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP3 EXIST  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP3.1 POOL |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP3.2 SAND |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4 INNOV  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4.1 ACOU |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4.2 SPRAY|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4.3 ELEC |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4.4 ZEOL |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP4.5 COMB |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP5 DKS    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP5.1 DISK|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| WP5.2 SYNTH|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

**PASSAM organization: 5 work packages**

1. **Scientific coordination, administrative management, financial management, quality management:** all along the project duration
2. **WP2.1 SOAR**
   - State of the art report
   - Exp test matrix
3. **WP2.2 MODEL**
   - In-depth analysis of experimental results and modelling
   - Experimental results
     - Experiments on pool scrubbing systems
     - Experiments on sand bed filters plus pre-metallic filters
     - Experiments on acoustic agglomeration systems
     - Experiments on spray agglomeration systems
     - Experiments on electric filtration systems
     - Experiments on improved zeolite filtration systems
     - Experiments on combined filtration systems
4. **WP3 EXIST**
   - Experiments on combined filtration systems
5. **WP4 INNOV**
   - Experiments on combined filtration systems
6. **WP5 DKS**
   - Synthesis report of the project

**Timeline:**
- **January 1st, 2013**
- **February 16-20, 2015**
- **December 31st, 2016**
WP2: (THEOR) STATE OF THE ART AND MODELLING (leader CIEMAT)

Two scientific parts of the project in support and in conclusion to the experimental work: real shared work between the partners.

- WP2.1 (SOAR): State of the art report (leader CIEMAT)
  
  Literature review (performed in 2013) on the systems to be addressed within the project to settle the technical bases for experimentation
  
  - Existing filtration systems: pool scrubbing; sand filters plus metallic pre-filters.
  
  - Innovative systems: acoustic agglomerators; high pressure sprays; electric filters; improved zeolites; combined systems.

  The ranges of major parameters determining FCVS operation are included in the report.

  As a result of this work, tests to be performed have been clearly identified and test matrices have been defined for each type of system to be experimentally studied in WP3 and WP4.

  Note: main outcomes of this work package have been given at the NUTHOS-10 Conference at Okinawa (Japan), December 14-18, 2014. The corresponding reports are open:

  - https://gforge.irsn.fr/gf/project/passam/docman/?action=DocmanFileEdit&id=5627
  - https://gforge.irsn.fr/gf/project/passam/docman/?action=DocmanFileEdit&id=5948

- WP2.2 (MODEL): Development of simplified models/correlations (leader RSE)

  The partners will share the experimental results of the project and will proceed to a common detailed analysis of the experimental results obtained through WP3 and WP4 in order to understand the major phenomena which allow the trapping of the fission products and their longer term behavior under accident conditions.

  This analysis will allow deriving simplified models and/or correlations for each type of system studied, that will be easy to implement - but not included in the PASSAM project - in accident analysis codes, as ASTEC.
FILTRA-MVSS (circled) at Forsmark 3, Sweden
Typical Implementation: Schematics

Water conditioning
Automatic Discharge by Venting Initiation

Water conditioning for post accident phase

Scrubbing water

Clean gas line

N2

Stack

Customer defined

Rupture disk

Isolation valves

Containment

Reactor building

Drain
PASSAM WP3.1 - Pool scrubbing Systems

Application to BWR wetwell (scheme of Mark 1 BWR)
PSI: TRISTAN facility for investigation of two-phase flow characteristics
General view of the facility - Focus on a single tube test
**WP3.1 (POOL): Experimental studies of pool scrubbing systems (leader PSI).**

Number of studies on pool scrubbing efficiency already exist but the results are still largely scattered and complementary experiments remain relevant to provide understanding of the phenomena identified in the PASSAM literature survey ("SOAR"):

- Pool scrubbing of aerosols in the jet injection regime (CIEMAT).
  - *Experiments foreseen in 2016.*

- Pool scrubbing of aerosols in the presence of additives in the water, simultaneous determination of aerosol scrubbing efficiency and pool two-phase flow hydrodynamics (RSE).
  - *Preliminary experiments ongoing on bubble studies.*
  - *Experiments with aerosols foreseen from early 2015.*

- Pool hydrodynamics under churn-turbulent two-phase flow representative of the steam generator tube rupture (SGTR) conditions when the tube rupture is submerged (PSI).
  - *Experiments performed in the Tristan facility in 2013 and 2014.*
  - *Use of imaging technology and successful development of a wire mesh sensor technology for measurement of 3D flow patterns and void fractions.*
  - *Observation of clear differences between different flow regimes.*
  - *Highly three dimensional nature of the flow clearly visible.*
  - *Large gas-agglomerates are present next to small bubbles.*
  - *Big spread of bubble sizes throughout the channel.*
  - *Bubble shapes could be reconstructed.*
  - *A so-called “Gradient Methods” has been implemented for determining some specific interfacial properties and for estimating isotropy and void fractions.*
  - *New experimental data collected for bundle and large square channel.*
  - *Data to be used for the validation of 3D hydrodynamic models.*
  - *New experience gained in understanding the phenomenology of two-phase flows.*

PASSAM: state of progress of work package 3.1 as of July 1st, 2014
WP3.1 (POOL): Experimental studies of pool scrubbing systems (leader PSI) (continued)

- Mid/Long term behaviour of iodine in the water pools under irradiation (IRSN).
  - First test performed in December 2014: results being currently analyzed, but under the experimental (severe) conditions, a significant release of iodine from the “scrubber solution” was observed.
  - Other tests scheduled in 2015.

- The retention of organic iodine in the pool, including in the presence of scrubbing additives and submerged structures (AREVA).
  - Experiments at laboratory scale (VESPER34 facility) recently performed on the influence of scrubbing liquid composition, of mixing elements and of temperature.
  - The CH$_3$I retention performance in the scrubber could be moderately increased by:
    - Aliquat 336 (quaternary ammonium salt),
    - Mixing Elements (increase of residence time and of metallic surface),
    - Increased Temperature.
  - ... However, if Aliquat scrubbing liquid is used, the retention performance is not further increased by:
    - Mixing Elements,
    - Increased Temperature (reduces CH$_3$I retention above 110 °C).

- It was not possible to reach high CH$_3$I retention performance with any of the studied parameters, under the conditions used in the tests. Alternative filtration methods (e.g. dry filtration) are necessary to reach high CH$_3$I retention.

- The application of sliding pressure to AREVAs FCVS (scrubber is operated close to containment pressure) results in increased pool temperatures and thus increased CH$_3$I retention (see PASSAM WP4.5)
PASSAM WP3.2 - Sand bed filters plus metallic pre-filters

Sand bed filter (circled) at Saint Alban, France
PASSAM WP3.2 - Sand bed filters plus metallic pre-filters

Containment Pre-filter by-pass necessary

Sand bed filter

Containment Pre-filter (metal cartridge)

LEGEND:
1. Pre-filter;
   Existing penetration, 300 mm diameter for 1300MWe plants, 250 mm diameter for 900 MWe plants.
3. Pressure letdown orifice.
4. Filtered dry air supply during normal operation / Preheating for "H2 risk" in case of SA
5. Sand filter.
6. Radiation monitor
7. Plant stack, with small vent stack
8. Arrangement for twin units (900 MWe)

Schematic diagram of the containment venting system
IRSN: View of EPICUR facility

IRSN: General scheme of the PERSEE facility

PASSAM WP3.2 - Sand bed filters plus metallic pre-filters

IRSN: View of EPICUR facility

Filtered Air

I₂ and ICH₃

Humidity and heating systems

10 - 200 m³/h

Filtering Device to be tested

Spectro gamma

Sampling Charcoal filters

Additive air

Filtering before release

Fan

6 m³/h

Activated charcoal

ICH₃

ICH₂

ICH₃

I₂

Condensation vessel H₂O - I₂

Test on samples

IRSN: General scheme of the PERSEE facility

Filtered Air

I₂ and ICH₃

Humidity and heating systems

10 - 200 m³/h

Filtering Device to be tested

Spectro gamma

Sampling Charcoal filters

Additive air

Filtering before release

Fan

6 m³/h

Activated charcoal

ICH₃

ICH₂

ICH₃

I₂

Condensation vessel H₂O - I₂

Test on samples
**WP3.2 (SAND): Experimental studies of sand bed filters plus metallic pre-filters (leader IRSN).**

Implemented on all French PWRs and tested in the late eighties and early nineties for aerosol retention. Complementary tests are needed for:

- Molecular and organic iodine retention.
  - *First laboratory scale experiments recently performed showed no trapping of gaseous molecular iodine (I$_2$) in the tested conditions on pure sand.*
  - *A dedicated iodomethane Gas Chromatography analysis method was largely improved and allows now to reach extremely low detection limit for CH$_3$I (10 ppt) without pre-concentration.*
  - *Next experiments planned in 2015 and 2016 on*
    - I$_2$ retention on sand filter system in more representative conditions,
    - I$_2$ and CH$_3$I retention by metallic prefilters.

- Mid/Long term stability of filtered fission products, in particular iodine, under severe accident conditions (temperature, flow-rate, pressure, humidity, irradiation).
  - *Experiments foreseen in 2015 and 2016.*
Acoustic agglomeration: principle

Filtration efficiency typical curve

PECA facility for Acoustic Agglomerator tests
• **WP4.1 (ACOU): Acoustic agglomeration systems (leader CIEMAT, contributor CSIC)**
  
  **Objectives:** Improving the retention efficiency of FCVS by agglomerating aerosol particles upstream of the filtration device (either in the containment building or in the venting line).
  
  **Means:** Tests of acoustic agglomerator under severe accident conditions and optimization of its working conditions
  
  - *Preliminary tests have been carried out with the Acoustic Agglomerator (21 KHz, 300W/unit) implemented in the PECA facility, allowing to set up the test protocol.*
  
  - *Experimental phase in the PECA facility is foreseen from November 2014 to May 2015.*
PASSAM WP4.2 - Spray agglomeration systems

Decontamination Factor:
- Inlet aerosol concentration
- Outlet aerosol concentration

Agglomeration:
- Outlet aerosol concentration

Dry aerosol  Wet aerosol

SCRUPPOS facility for Spray Agglomerator tests
WP4.2 (SPRAY): Spray agglomeration systems (leader RSE)

Objectives: Improving the retention efficiency of FCVS by agglomerating aerosol particles upstream of the filtration device (either in the containment building or in the venting line).

Means: Tests of high pressure sprays on aerosol collection efficiency; understanding of the associated mechanisms; tests with droplets of water and ionic additives and of water with electrical charging; other tests if needed.

- SCRUPOS facility has been set-up and preliminary tests have been carried out for checking the good performance of the instrumentation.
- Experimental phase in the SCRUPOS facility is foreseen up to mid 2016.
 Electrostatic precipitator: principle and industrial application
PASSAM WP4.3 - Electric filtration systems

Wet ElectroStatic Precipitator (WESP) test facility
WP4.3 (ELEC): Electric filtration systems (leader VTT)

Objectives: Use of existing industrial systems (with potential improvements) to severe accident conditions and determination of the best strategy (location of the filters).

Means: Tests of retention of gaseous (molecular and organic) iodine, of iodine aerosols and of mixture of them for wet and dry electric filtration systems under severe accident conditions.

- Gaps in knowledge to be examined
  - Trapping of gaseous iodine
    - Oxidation of iodine to particles
    - Dissolution of iodine to water
    - Iodine chemistry in an electric field
  - WESP operation with saturated or superheated steam

The facility has been set-up and preliminary tests have started in April 2014 using Wet ElectroStatic Precipitator (WESP) at room conditions.

Experimental phase in more representative conditions has began recently using TiO₂ aerosols and showing a strong decrease of the trapping efficiency for voltages below 15 kV (negative). Preliminary retention tests for gaseous iodine have also been conducted.
Examples of targeted zeolite structures

Faujasite (3D)

Mordenite (1D)

Experimental set-up for CH$_3$I experiments

Total flow rate: 150 ml/min
Zeolite mass: 200 mg
T: 100°C
[CH$_3$I]$_0$: 1333 ppm
[H$_2$O]: 0-30000 ppm

Quantification of CH$_3$I, other organic by-products (MeOH, DME...), contaminants (NO$_x$, CO$_x$, H$_2$O...)

Zeo-lite Ag-FER before test | Zeo-lite Ag-FER after I$_2$ test | Zeo-lite Ag-FER after CH$_3$I test

White | Pink | Pale yellow
WP4.4 (ZEOL): Improved zeolite filtration systems (leader IRSN)

Objectives: Develop innovative filtration systems based on zeolites (supposed high stability to dose rate).

Means: Preliminary studies to identify the most suitable zeolites able to trap volatile iodine; Tests of retention efficiencies for molecular and organic iodine, including influence of humidity; Mid/long term stability of filtered iodine compounds under severe accident conditions (temperature, flow-rate, pressure, humidity, irradiation).

Gaps in knowledge to be examined

- Nature of zeolite (avoid poisoning effects and obtain high iodine decontamination factors).
- Definition of optimal active sites for the trapping of iodine and organic iodides (deeper understanding of the trapping mechanisms).
- Extensive and sound data on the effect of expected severe accident working conditions including influence of chemical effects (steam and gas contaminants) and potential irradiation effects on iodine trapping capacity.

Experimental programme started in 2013 and foreseen up to 2016

Main results acquired up to now:

- Up to 20 metal-exchanged zeolites were prepared and characterized
- Adsorption tests of CH$_3$I in gaseous phase under different conditions
  - Trapping efficiency:
    - silver zeolites lead to the best adsorption performances in the absence of contaminants
    - Need to better assess the effects of structure and silver incorporation method/speciation
  - Trapping stability: formation of a highly stable AgI phase as well as less stable products
1. **Venturi Scrubber**
- Most aerosols retained
- Most elemental iodine retained (mid term)
- Large quantity of organic iodine retained (mid term)

2. **Metal Fibre Filter**
- Large pre and fine filter surfaces
- Penetrated Fine Aerosols retained
- Re-suspension Aerosols captured

**Orifice plate**
- Passive speed & sliding pressure control

3. **Sorbents Section**
- Retaining of remaining and re-volatilized iodine (Elemental & Organic)

AREVA High Speed Sliding Pressure Venting Plus
(patent rights reserved)
AREVA GmbH: JAVA Facility

PASSAM WP4.5 - Combined filtration systems
**WP4.5 (COMB): Combined Filtration Systems (Leader AREVA)**

**Objectives:** Gain knowledge about Combined Filtration System (wet and dry filters as well as of adsorptive filters) both on thermohydraulic behavior as well as on CH\textsubscript{3}I retention efficiency in representative operation conditions during containment depressurization during a severe accident.

**Means:** Large scale experiments in the JAVA PLUS facility in representative severe accident conditions. **Most representative prototype test facility** *(Equivalent height to real FCVS -> Identical hydrodynamic behavior; About 1:10 scale (mass flow) of a real FCVS; Installation of full process sections and original equipment, e.g. Venturi nozzle) leads to most representative test results *(Thermal inertia; Heat transfers & heat losses; Surface-volume ratio; Flow dynamics; Residence time; Etc.).*

- **Experimental programme completed in 2013.**
- **Main results on organic iodine retention:**
  - *Extensive test campaigns were conducted resulting in a fully qualified combined filter design: FCVS PLUS. This combined filter is able to reach a target decontamination factor > 50 for organic iodine (> 98% retention).*
• **WP5.1 (DISK): Dissemination of knowledge (leader IRSN).**
  o Redaction of a paper of general presentation of the project.
  o Elaboration of the general communication action plan.
  o Creation of a web site: [https://gforge.irsn.fr/gf/project/passam/](https://gforge.irsn.fr/gf/project/passam/).
  o Education and Training programme. PhD students involved in partners’ organizations working as part of the proposed project are encouraged to participate to training courses. Secondments between partners’ organizations are envisaged.
  o Publication of several papers in scientific journals or conferences.
  o Organization of two open workshops mainly targeted to R&D organizations, National Safety Authorities and their Technical Support Organizations, to the utilities and to the vendors.
    - one workshop after writing the “state-of-the-art report” to present the outcomes of this report and the envisaged test programme: held on February 26th, 2014 in Madrid (Spain).
    - one workshop at the end of the project (December 2016 or early 2017) to present the major outcomes of the project.

• **WP5.2 (SYNTH): Project synthesis (leader IRSN).**
  o Final synthesis report of the project (open literature)
The European PASSAM project: conclusions

The PASSAM project is ongoing for a 4 year duration (2013 - 2016).

It involves 9 European partners bringing together their competencies and their various test facilities. Most of the experimental programmes are currently ongoing and are bringing interesting results.

The main technical outcomes will be documented in a final synthesis report and presented in a final workshop:

- **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.

- **Advantages and drawbacks of all the systems studied** (efficiencies, passive behavior, robustness, long term retention, etc...).

- **Estimation of orders of magnitude for source term reduction** for each filtration system, including on the long term, in accident conditions.

- **Hints for improved filtration system.**

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