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

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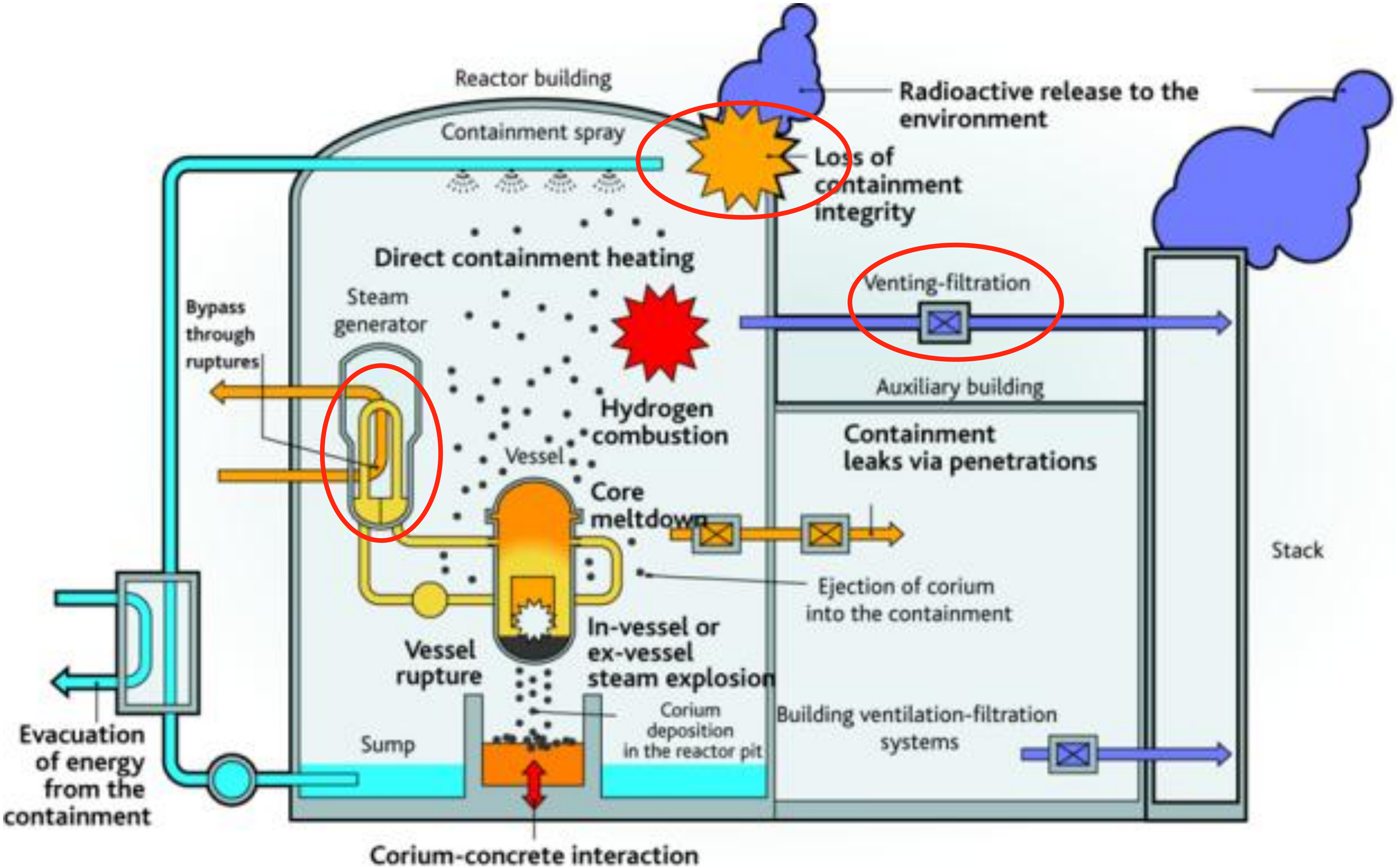
IAEA IEM8 - International Experts' Meeting on Strengthening Research and Development Effectiveness in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant

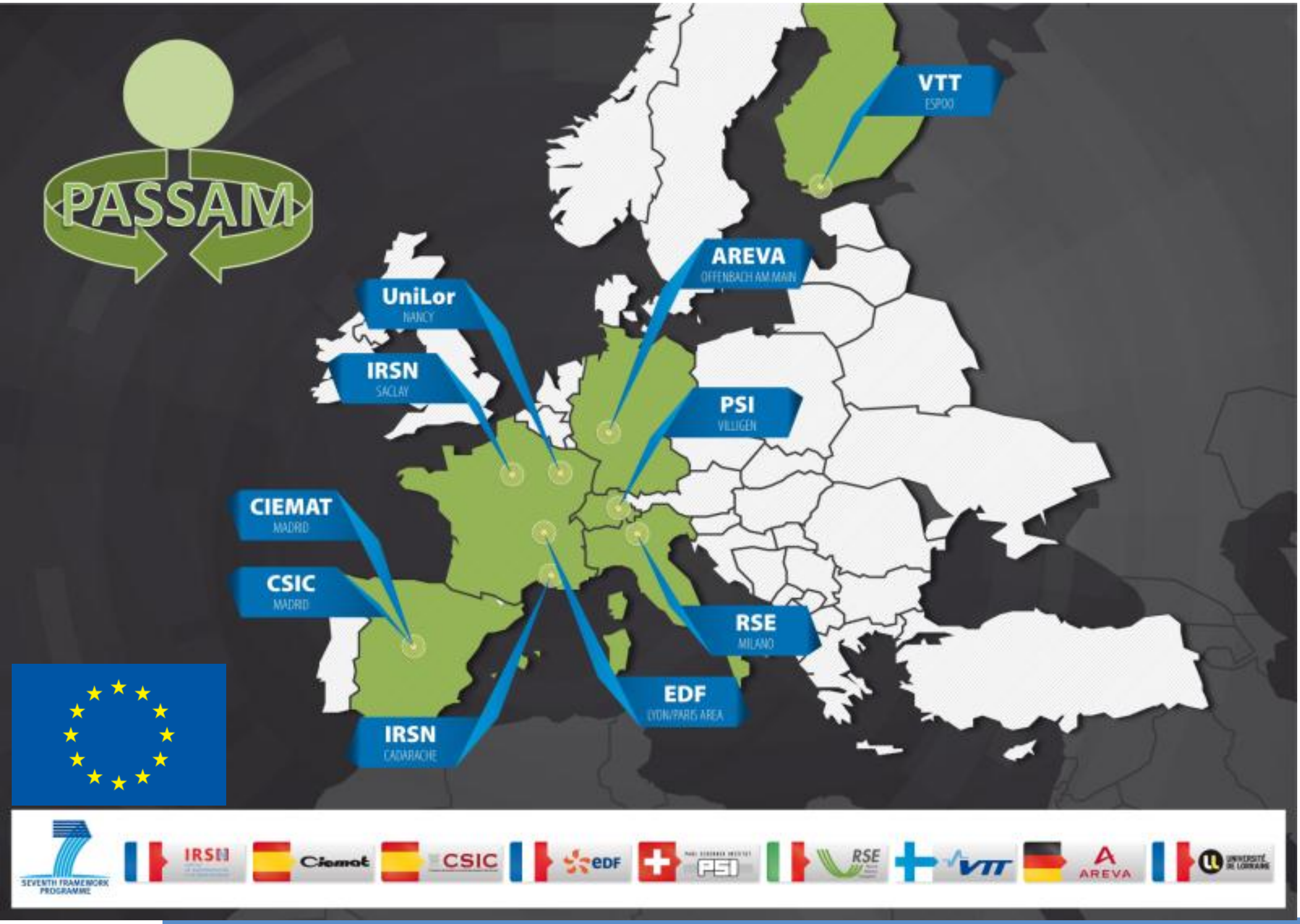
Vienna (Austria)

February 16-20, 2015

- PASSAM general context and objectives
- PASSAM main features and organization
- State of progress of work packages
- Conclusions

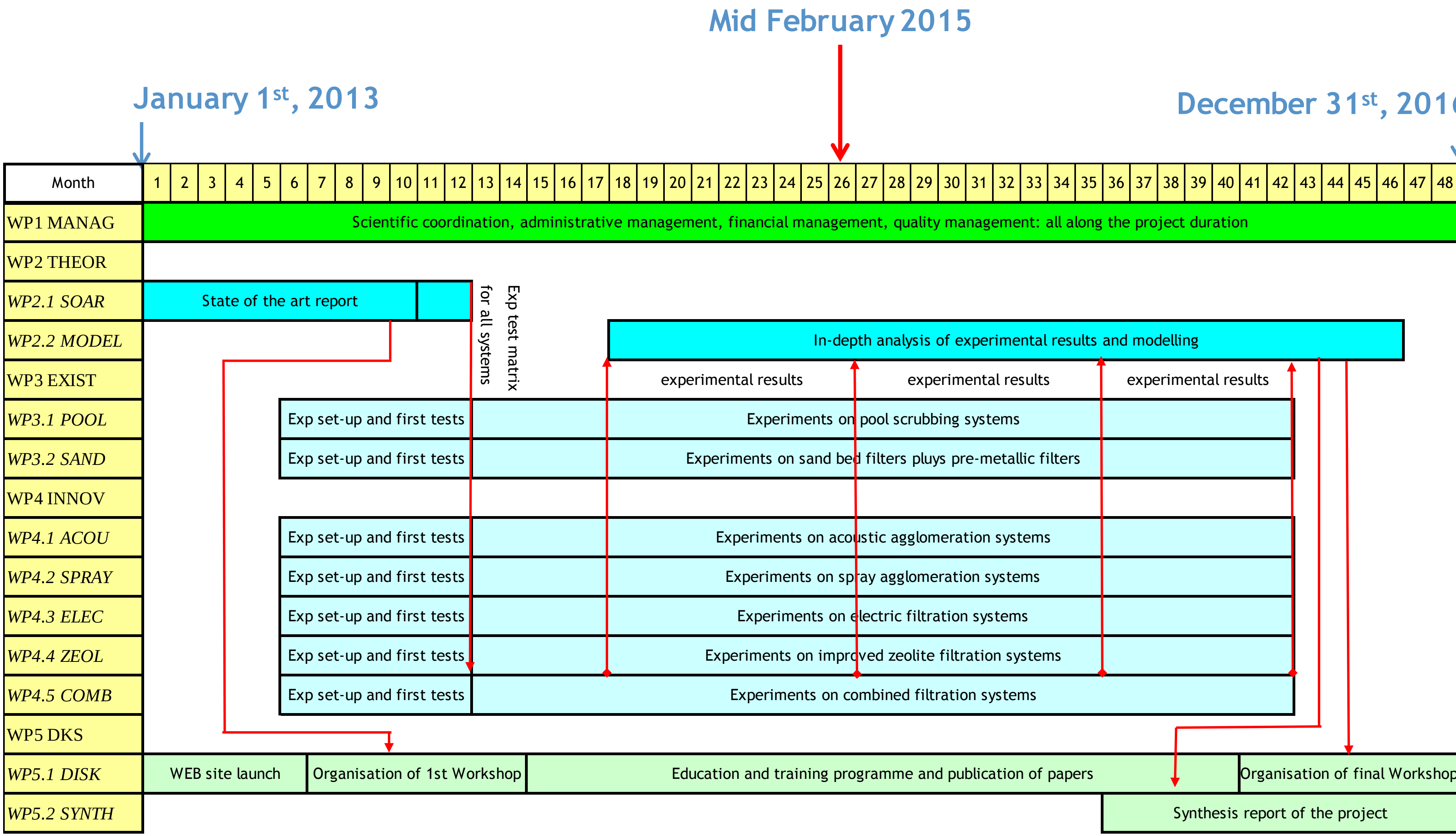

Reactor building
Containment spray
Radioactive release to the environment
Loss of containment integrity
Direct containment heating
Venting-filtration
Steam generator
Bypass through ruptures
Hydrogen combustion
Auxiliary building
Containment leaks via penetrations
Vessel
Core meltdown
Stack
Ejection of corium into the containment
In-vessel or ex-vessel steam explosion
Vessel rupture
Corium deposition in the reactor pit
Building ventilation-filtration systems
Sump
Evacuation of energy from the containment
Corium-concrete interaction

- 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.



PASSAM project partnership

PASSAM organization: 5 work packages



- ***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.

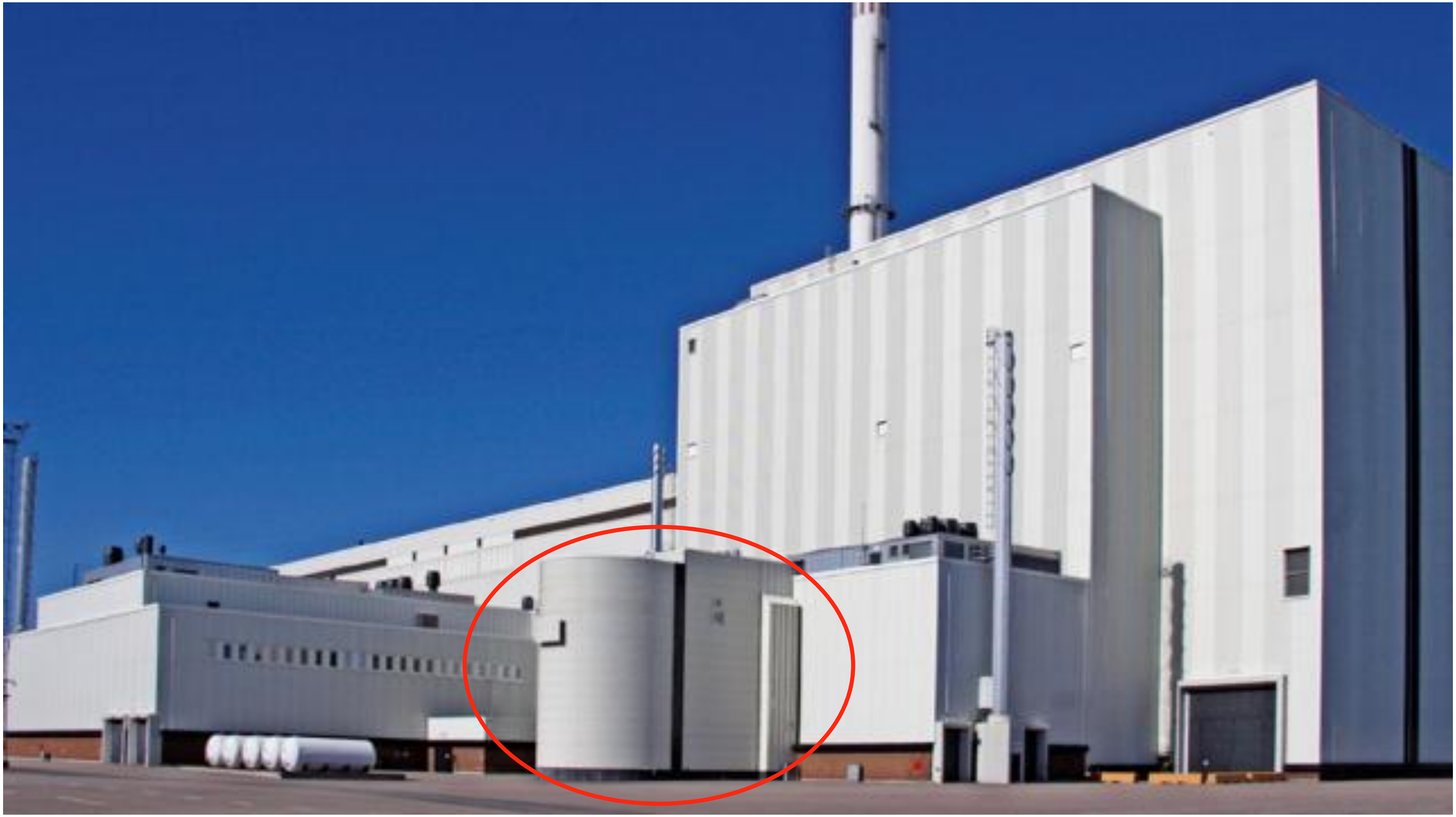
    As a result of this work, tests to be performed have been clearly identified and test matrices have been defined for each type of system to be experimentally studied in WP3 and WP4.

    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)***

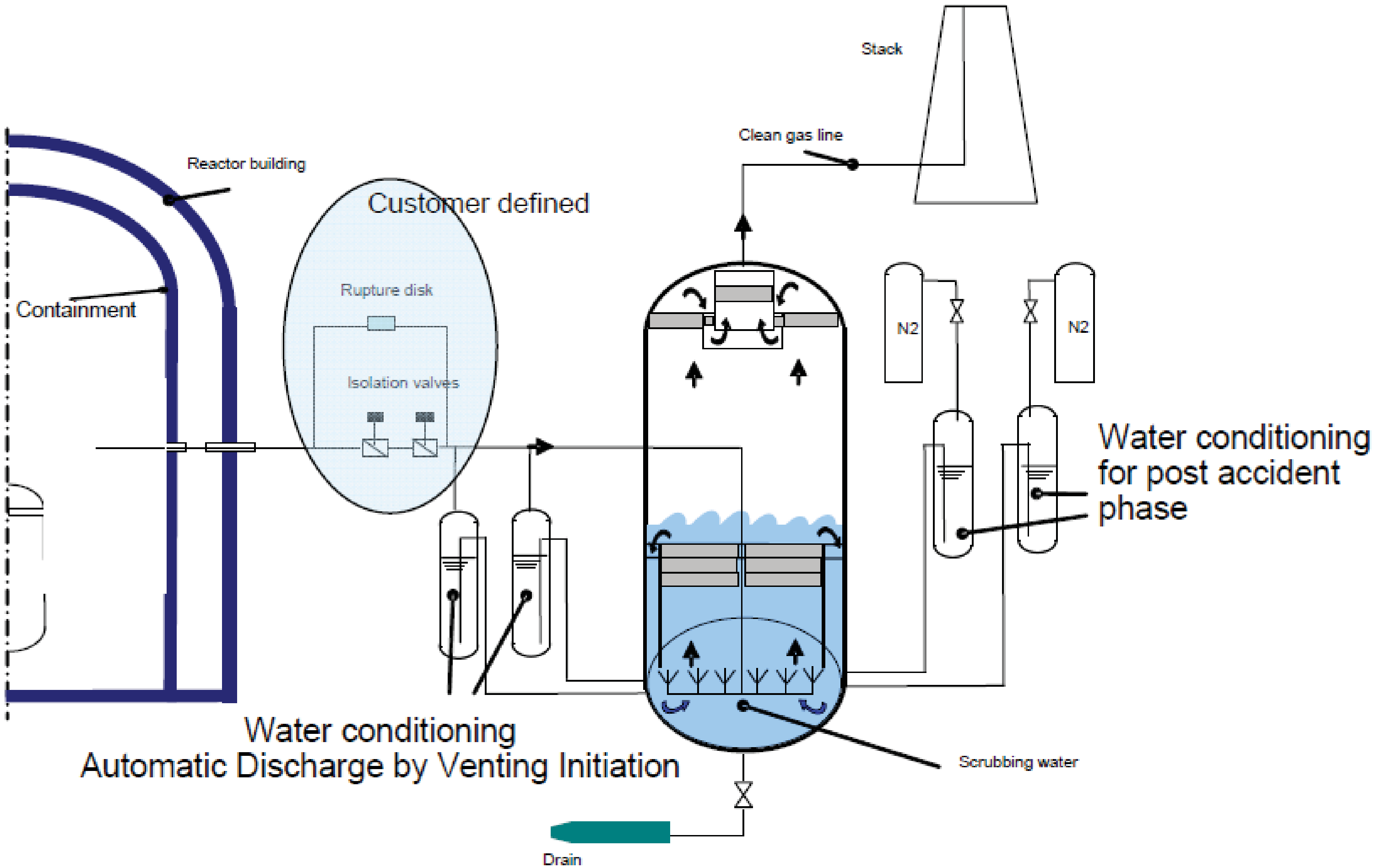
    The partners will share the experimental results of the project and will proceed to a common detailed analysis of the experimental results obtained through WP3 and WP4 in order to understand the major phenomena which allow the trapping of the fission products and their longer term behavior under accident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

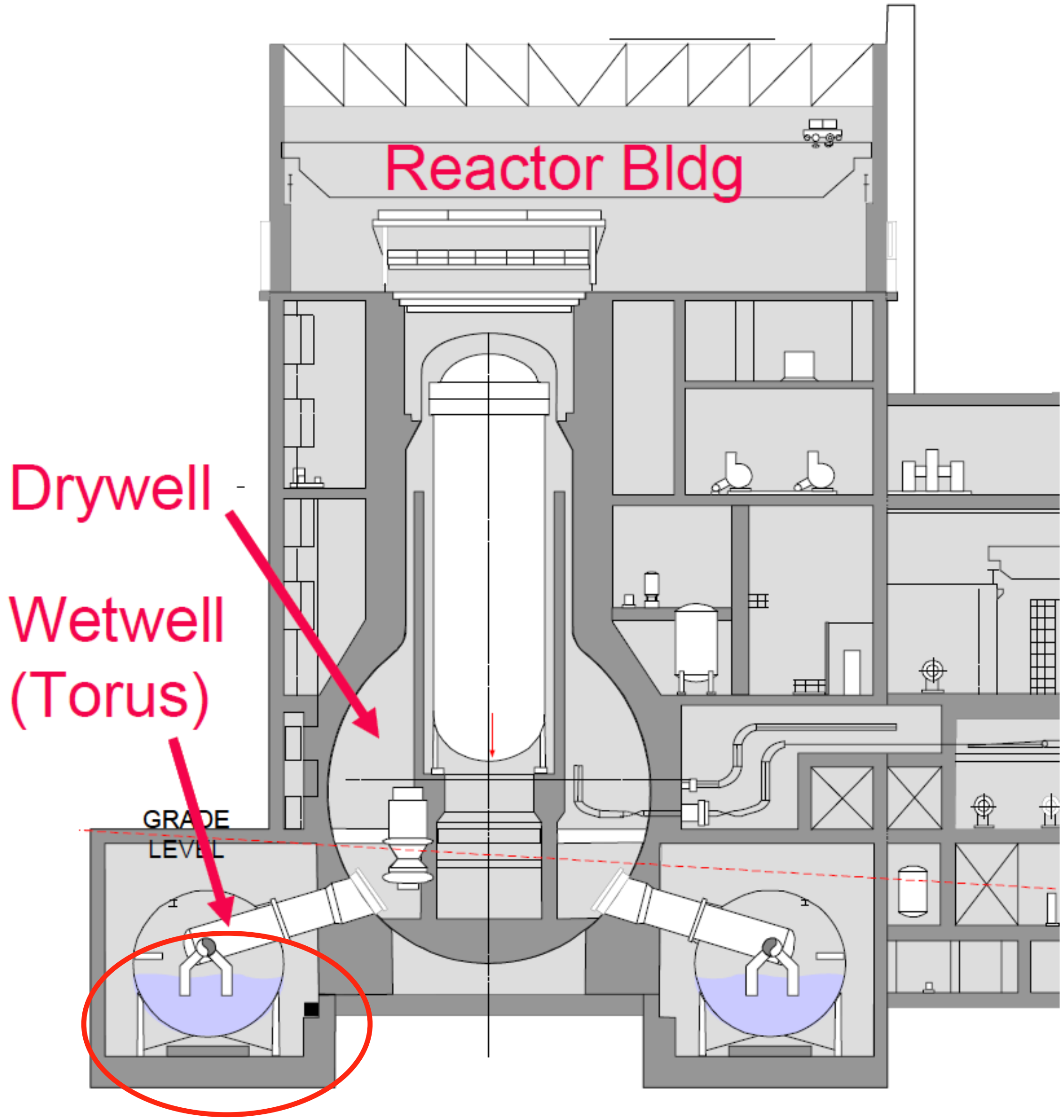
    This analysis will allow deriving simplified models and/or correlations for each type of system studied, that will be easy to implement - but not included in the PASSAM project - in accident analysis codes, as ASTEC.



FILTRA-MVSS (circled) at Forsmark 3, Sweden

Typical Implementation: Schematics





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 ar*
    - *Use of imaging technology and successful development c measurement of 3D flow patterns and void fractions.*
    - *Observation of clear differences between different flow*

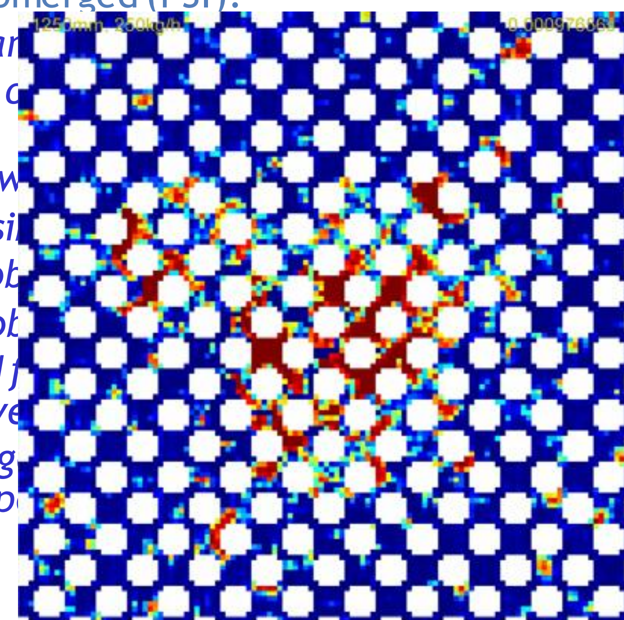
      Highly three dimensional nature of the flow clearly visi

      Large gas – agglomerates are present next to small bubb

      Big spread of bubble sizes throughout the channel. Bubb

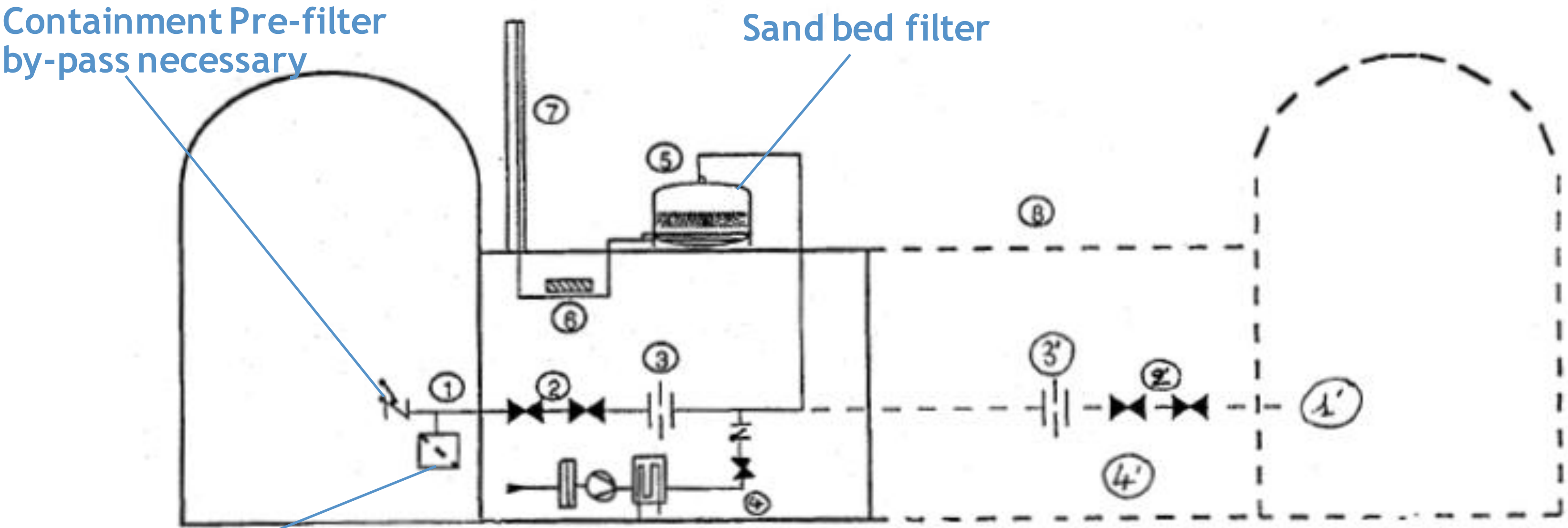
      A so-called "Gradient Methods" has been implemented f interfacial properties and for estimating isotropy and ve

New experimental data collected for bundle and larg for the validation of 3D hydrodynamic models. New exp phenomenology of two-phase flows



- ***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_3I 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_3I retention above 110 °C).*
    - *It was not possible to reach high CH_3I 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_3I 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_3I retention (see PASSAM WP4.5)*

Sand bed filter (circled) at Saint Alban, France



LEGEND:

1. Pre-filter;
Existing penetration, 300 mm diameter for 1300MWe plants, 250 mm diameter for 900 MWe plants.

2. Manual valves, operatd by reach rods from behind shelding.

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

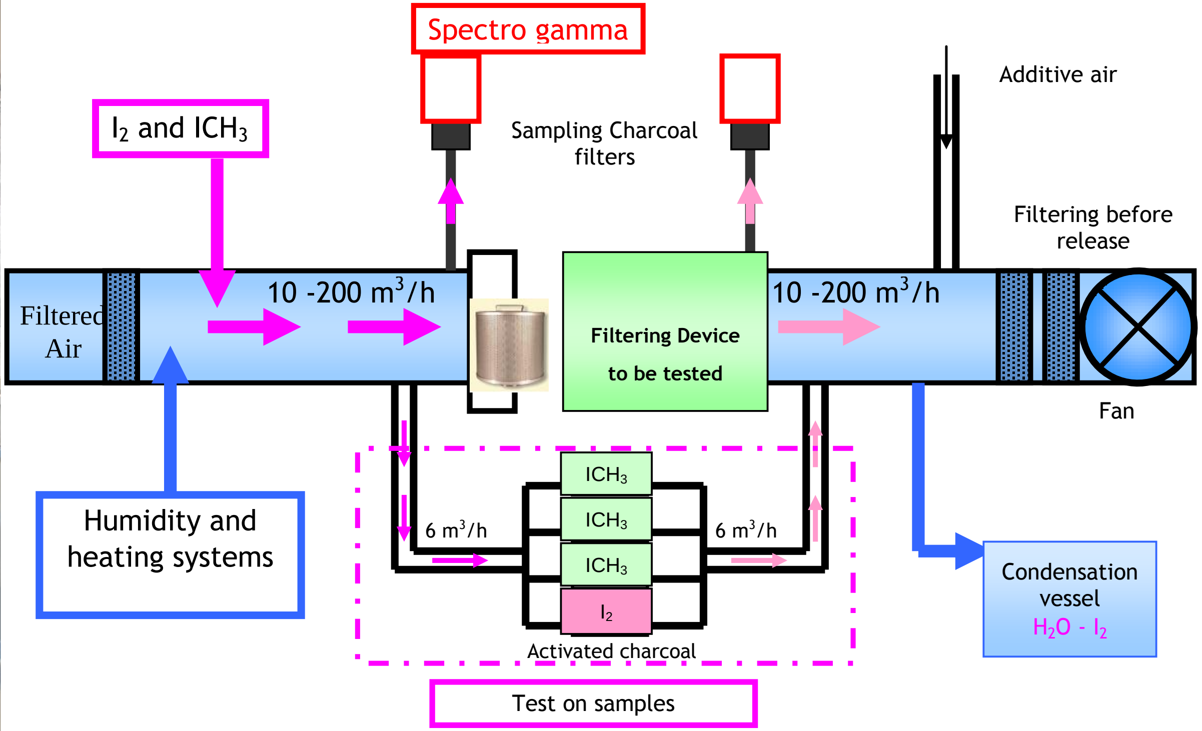
7. Plant stack, with small vent stack

8. Arrangement for twin units (900 MWe)

Schematic diagram of the containment venting system

IRSN: View of EPICUR facility

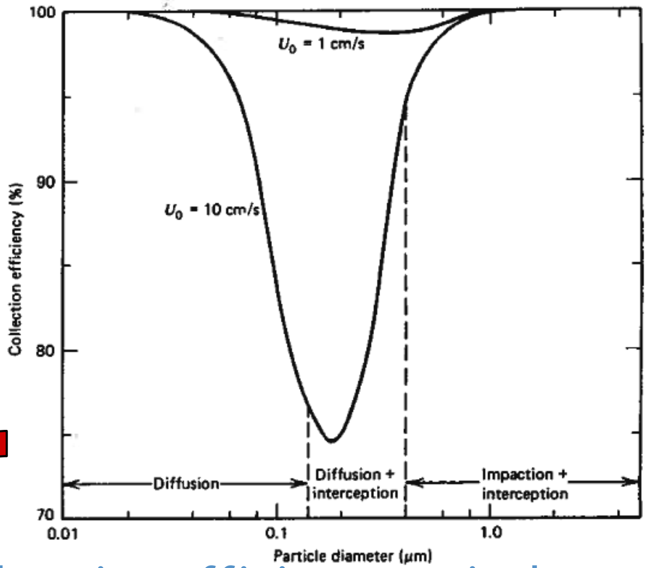
IRSN: General scheme of the PERSEE facility



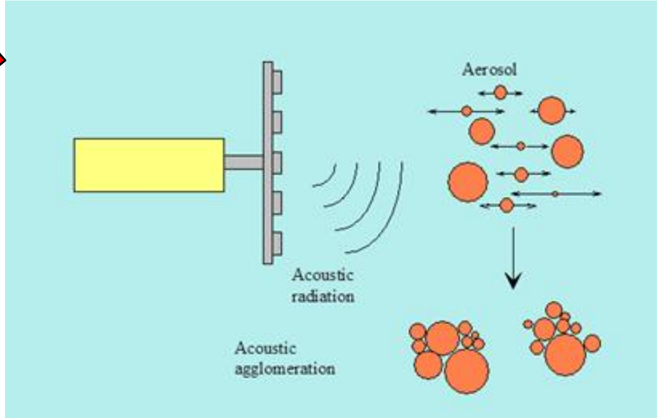
- ***WP3.2 (SAND): Experimental studies of sand bed filters plus metallic pre-filters (leader IRSN).***

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

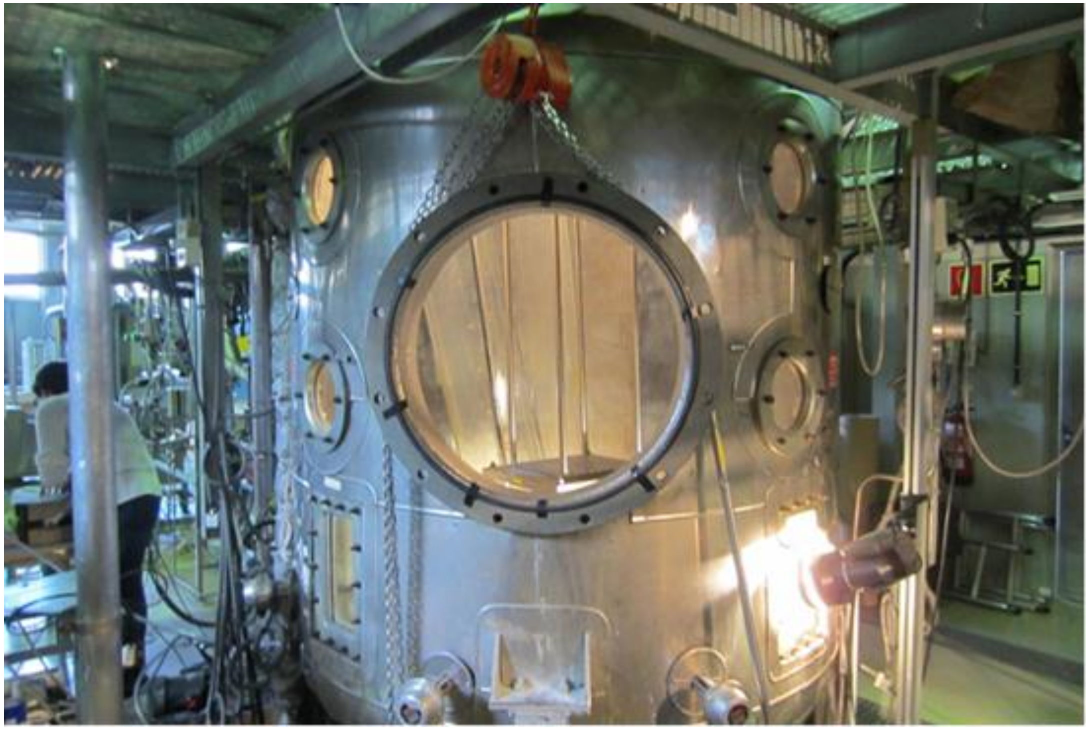
  - Molecular and organic iodine retention.
    - *First laboratory scale experiments recently performed showed no trapping of gaseous molecular iodine (I_2) in the tested conditions on pure sand.*
    - *A dedicated iodomethane Gas Chromatography analysis method was largely improved and allows now to reach extremely low detection limit for CH_3I (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_3I 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.*



Filtration efficiency typical curve



Acoustic agglomeration: principle



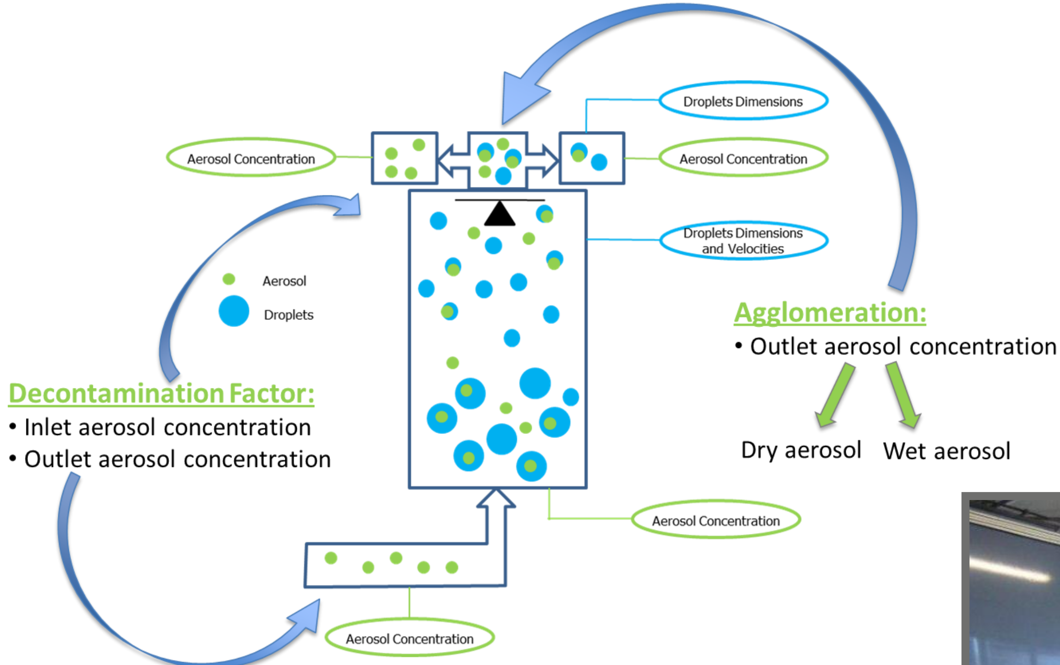
PECA facility for Acoustic Agglomerator tests

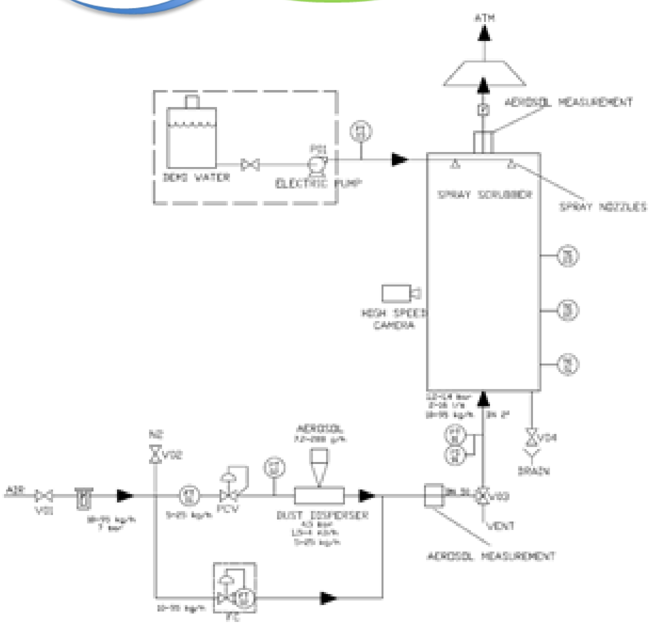
- ***WP4.1 (ACOU): Acoustic agglomeration systems (leader CIEMAT, contributor CSIC)***

  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.*





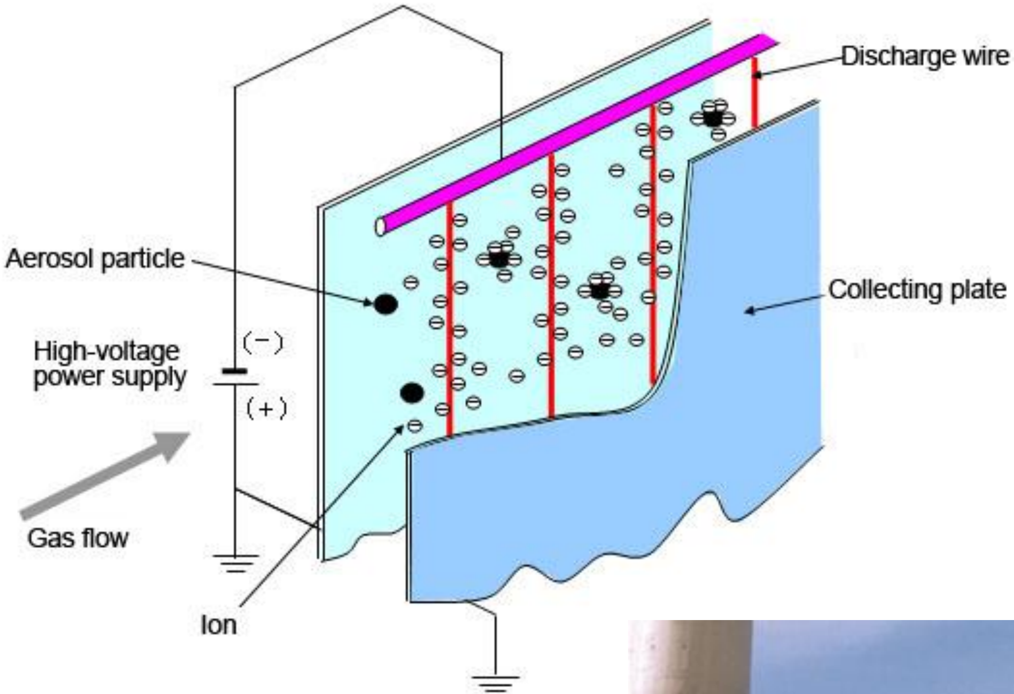
SCRUPOS facility for Spray Agglomerator tests

- ***WP4.2 (SPRAY): Spray agglomeration systems (leader RSE)***

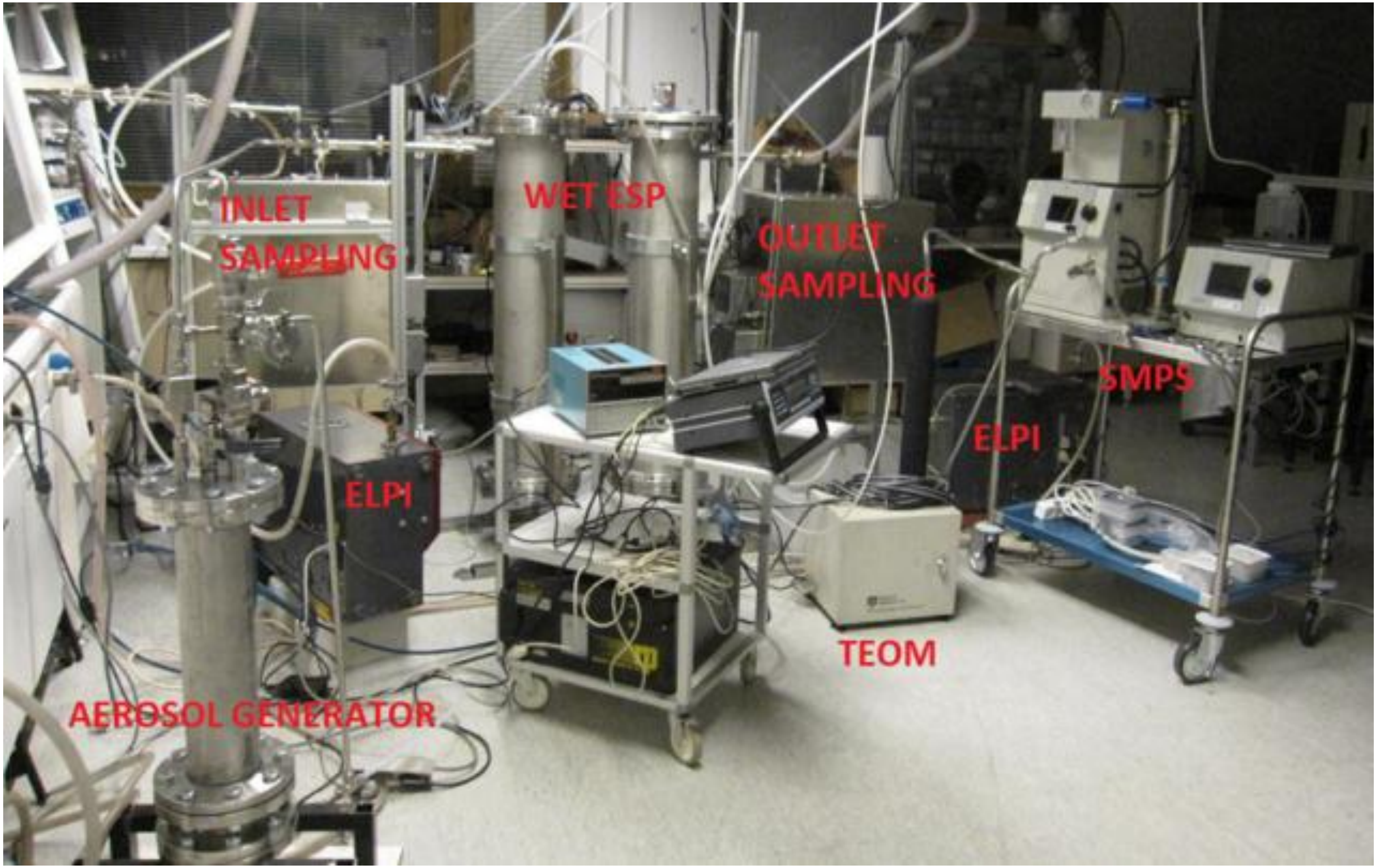
  Objectives: Improving the retention efficiency of FCVS by agglomerating aerosol particles upstream of the filtration device (either in the containment building or in the venting line).

  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



Wet ElectroStatic Precipitator (WESP) test facility

- ***WP4.3 (ELEC): Electric filtration systems (leader VTT)***

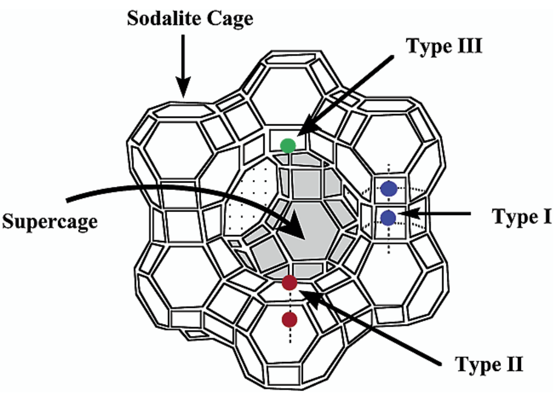
  Objectives: Use of existing industrial systems (with potential improvements) to severe accident conditions and determination of the best strategy (location of the filters).

  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.

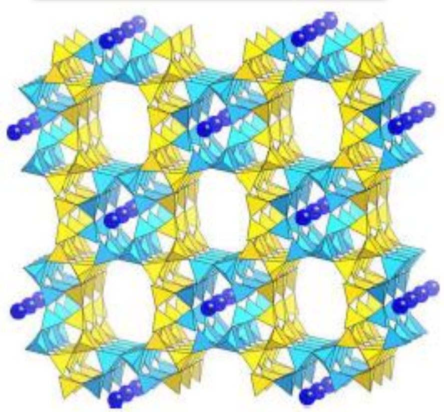
  - Gaps in knowledge to be examined
    - Trapping of gaseous iodine
      - Oxidation of iodine to particles
      - Dissolution of iodine to water
      - Iodine chemistry in an electric field
    - WESP operation with saturated or superheated steam

    - *The facility has been set-up and preliminary tests have started in April 2014 using Wet ElectroStatic Precipatator (WESP) at room conditions.*
    - *Experimental phase in more representative conditions has began recently using TiO_2 aerososls 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.*

Faujasite (3D)

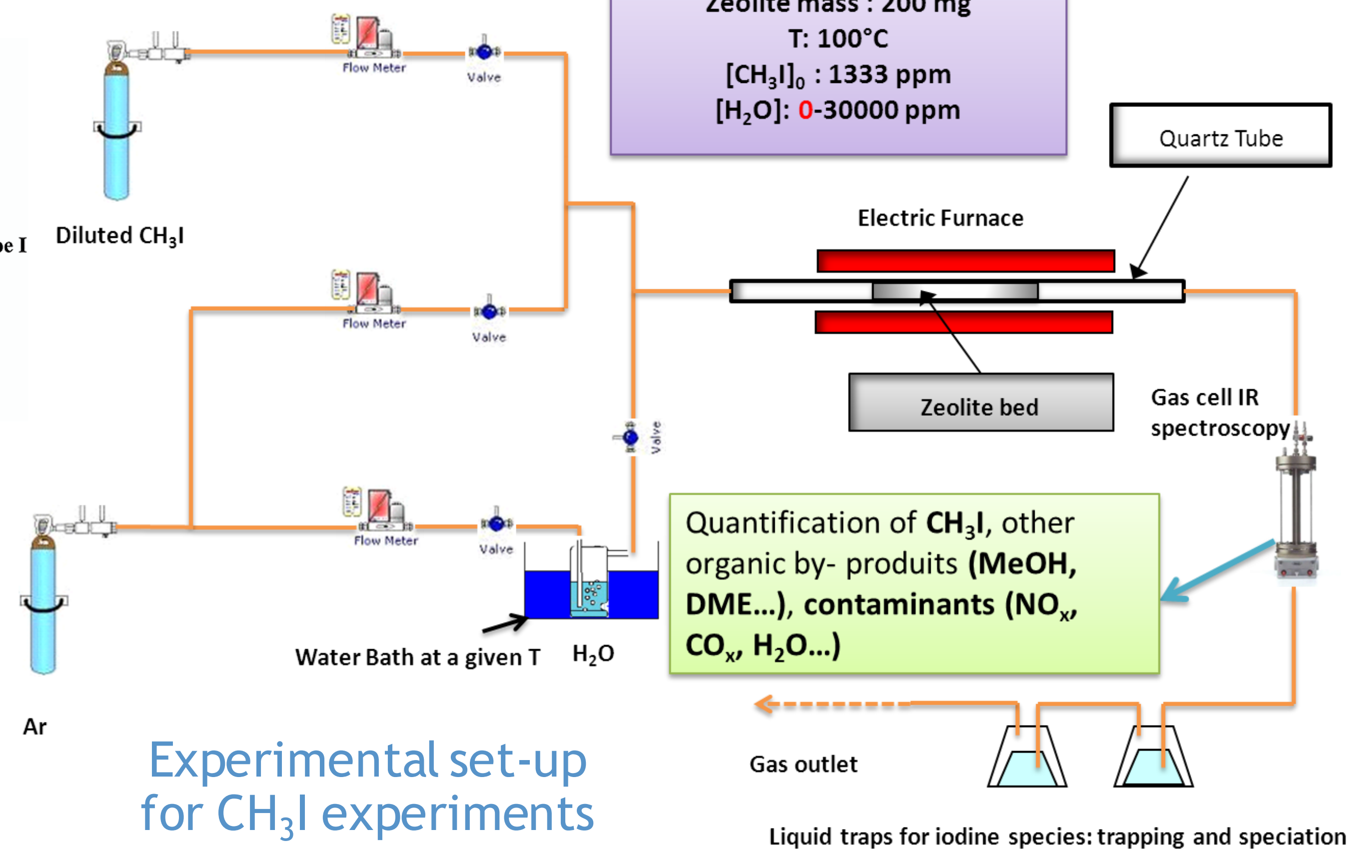


Mordenite (1D)



Examples of targeted zeolite structures

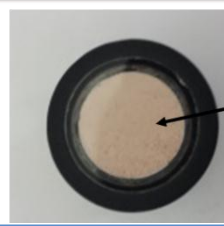
Total flow rate: 150 ml/min
Zeolite mass : 200 mg
T: 100°C
$[CH_3I]_0$: 1333 ppm
$[H_2O]$: 0-30000 ppm



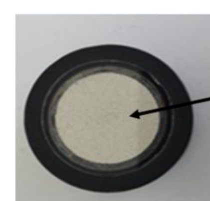
Experimental set-up for CH_3I experiments

Zeolite Ag-FER before test	Zeolite Ag-FER after I_2 test	Zeolite Ag-FER after CH_3I test

White



Pink



Pale yellow

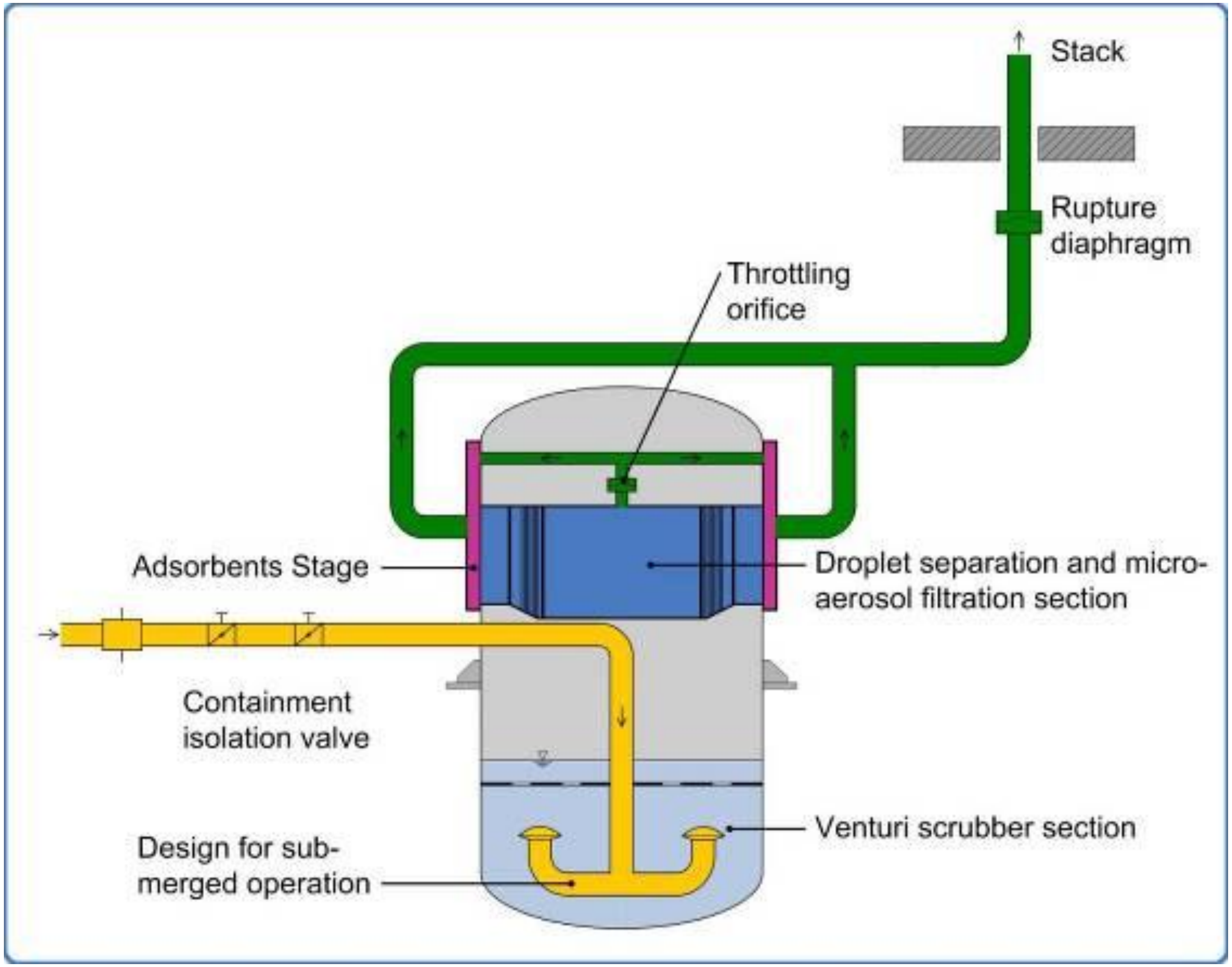
- ***WP4.4 (ZEOL): Improved zeolite filtration systems (leader IRSN)***

  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_3I 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

- ***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_3I 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:*
    - *Retention efficiency of zeolite depends upon many parameters: Sorbent material, Geometry / Flow dynamics, Superheating / Relative humidity, Heat repartition, Residence time, Gas composition, Flow velocities, Etc.*
    - *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).***
  - Redaction of a paper of general presentation of the project.
  - Elaboration of the general communication action plan.
  - Creation of a web site: https://gforge.irsn.fr/gf/project/passam/.
  - 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.
  - Publication of several papers in scientific journals or conferences.
  - 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 2016or early 2017) to present the major outcomes of the project.

- ***WP5.2 (SYNTH): Project synthesis (leader IRSN).***
  - 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.
- The authors thank the European Atomic Energy Community' (Euratom) for showing a strong interest in the PASSAM Project, and for funding it in the frame of the 7th framework programme FP7/2007-2013 under grant agreement n° 323217.

And many thanks to all of you for your attention !!!