AMHYCO

Enhancing H_2 & CO Combustion Risk Management

AMHYCO PROJECT – ADVANCES IN H_2/CO COMBUSTION, RECOMBINATION AND CONTAINMENT MODELLING

Jiménez, G. (UPM), Reinecke, E.-A. (FZJ), Herranz, L.E. (CIEMAT), Bentaib, A. (IRSN), **Chaumeix, N. (CNRS)**, Kelm, S. (FZJ), Braun, M. (FRAMATOME), Koch, M.K..(RUB), Kljenak, I.(JSI), Sevbo, O.(ENERGORISK), Visser, D.(NRG), Liang, Z.(CNL), Lazarevic, M.(LGI)

This project has received funding from the European Union's EURATOM Horizon 2020 research and innovation programme grant number: 945057. The content of this document reflects only the author's view. The European Commission is not responsible for any use that may be made of the information it contains.

AMHYCO general data

- Full Project Name: Towards An Enhanced Accident Management Of The Hydrogen/CO Combustion Risk
- EURATOM Work Programme 2019 “NFRP-02: Safety assessments for Long Term Operation (LTO) upgrades of Generation II and III reactors”
- Project No: 945057
- Start Date: 01/10/2020
- Project Duration: 48 months
- EU contribution: 3 974 402.50 €

AMHYCO partners

#	Participant organisation name	Country
1 (Coordinator)	Universidad Politécnica de Madrid (UPM)	Spain
2	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)	Spain
3	L'Institut de Radioprotection et de Sûreté Nucléaire (IRSN)	France
4	Centre National de la Recherche Scientifique -Orleans (CNRS)	France
5	Forschungszentrum Jülich (FZJ)	Germany
6	Framatome GmbH (FRG)	Germany
7	Ruhr-Universität Bochum (RUB)	Germany
8	Jožef Stefan Institute (JSI)	Slovenia
9	Energorisk, Ltd. (ER)	Ukraine
10	Nuclear Research and Consultancy Group (NRG)	Netherlands
11	Canadian Nuclear Laboratories (CNL)	Canada
12	LGI Consulting (LGI)	France







AMHYCO objectives

The AMHYCO project main objective is **to propose innovative enhancements on the way combustible gases are managed in case of a severe accident in currently operating reactors.**

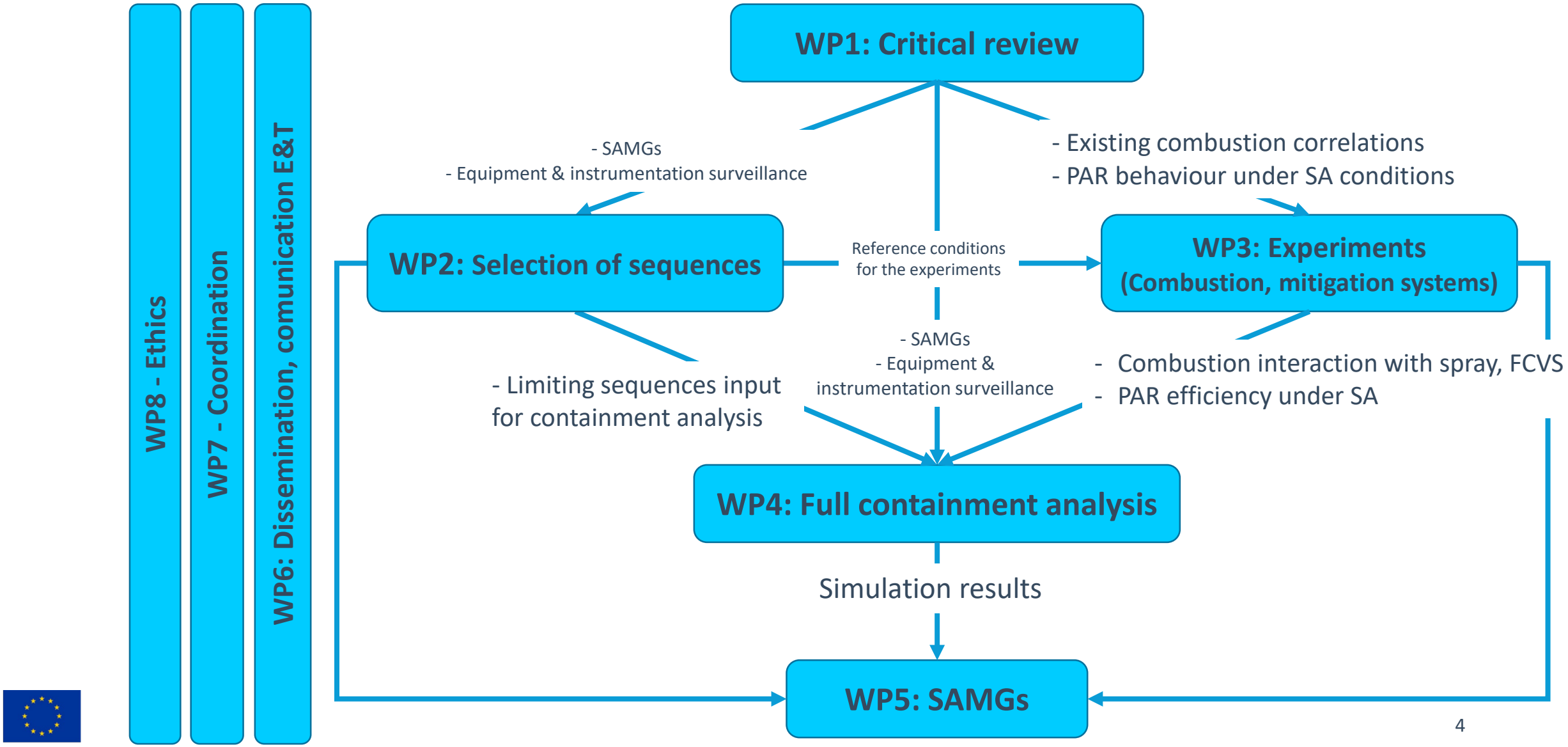
To reach this main objective, the AMHYCO project has three main specific objectives:

Objective 1: To experimentally investigate phenomena that are difficult to predict theoretically: H2/CO combustion and PARs (Passive Autocatalytic Recombiners) behavior under realistic accidental conditions, taking into account their interaction with safety systems. Reducing the uncertainties in the phenomena is a remarkable way of enhancing the severe accident safety.

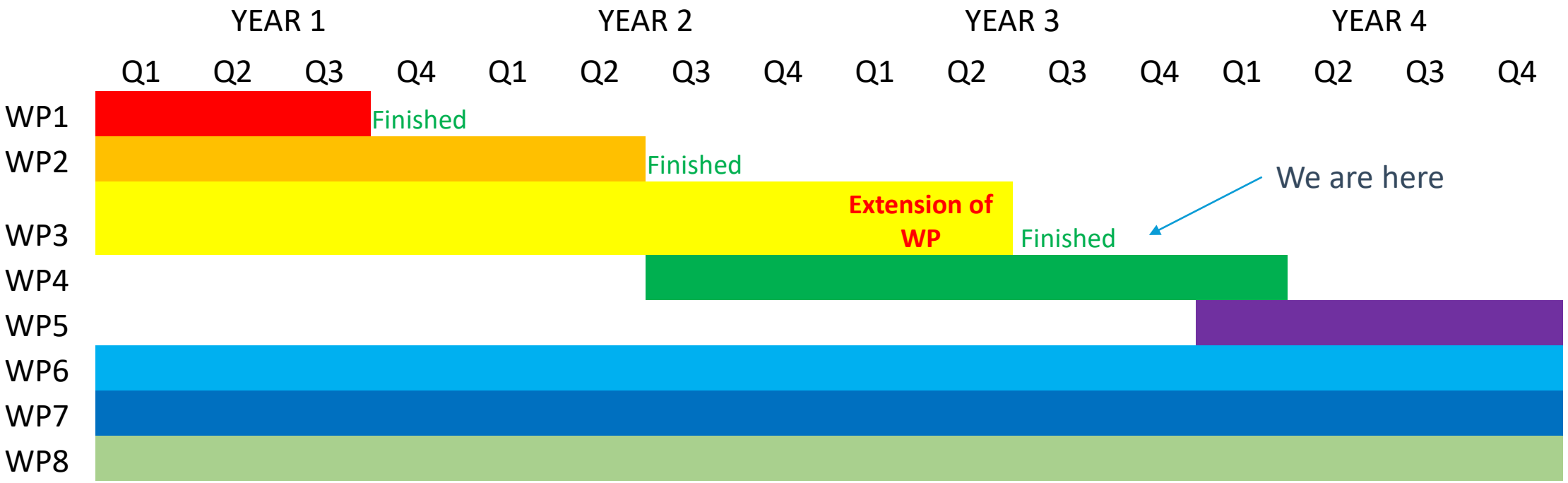
Objective 2: To improve the predictability of analysis tools - Lumped Parameter (LP), 3D and Computational Fluid Dynamic (CFD) codes - used for explosion hazard evaluation inside the reactor containment and providing support to SAMGs design and development.

Objective 3: To improve the Severe Accident Management Guidelines for both in-vessel and ex-vessel phases with respect to combustible gases risk management, using theoretical, simulation and experimental results.

AMHYCO workflow



Schedule (October 2020 – September 2024)



Connection with other ongoing international projects

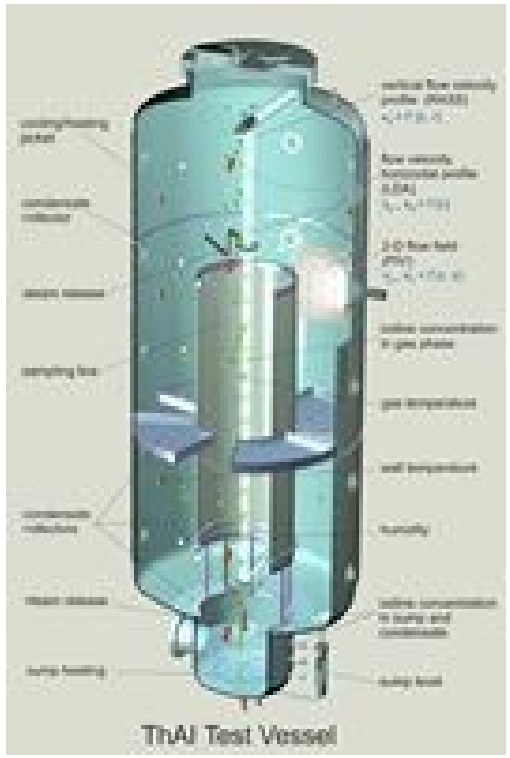
PANDA

PAUL SCHERRER INSTITUT

PSI

THEMIS

NEA
NUCLEAR ENERGY AGENCY



BECKER TECHNOLOGIES

SAMHYCO-NET

SAMHYCO NET

NUGENIA
Nuclear Generation II&III Alliance

WP1 – Critical review – Finished

Image credit: Pixabay

A critical review of the available literature to form the basis for the project regarding:

(1) PAR efficiency under ex-vessel conditions.

(2) Existing PWR EOPs and SAMGs regarding containment risk management.

(3) H_2/CO combustion and the available engineering correlations for combustion risk estimation.

(4) Equipment & instrumentation surveillance under SA conditions.

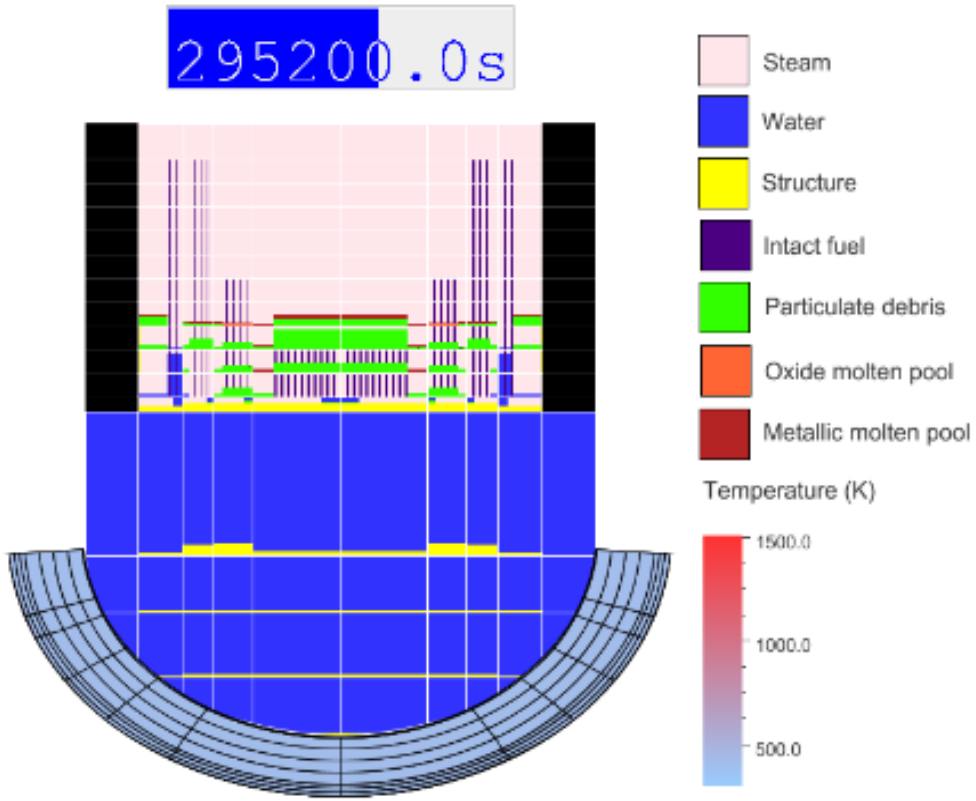
WP1 Critical Review

Main outcomes

- Review of the existing PWR SAMGs regarding containment risk management (e.g. spray, fan-coolers and FCVS actuation)
- Review of the containment equipment qualification criteria and instrumentation surveillance under severe accident conditions
- Review of existing experiments and models on recombiner behavior in representative conditions of a late phase of a severe accident in PWR
- Review of the existing H2/CO combustion risk engineering correlations

D1.1 was approved by the EC (09/22); it was distributed to the EUG and the AB and will be distributed to the general public.
This WP is completed.

WP2 – Selection of severe accident sequences



Ref: UPM

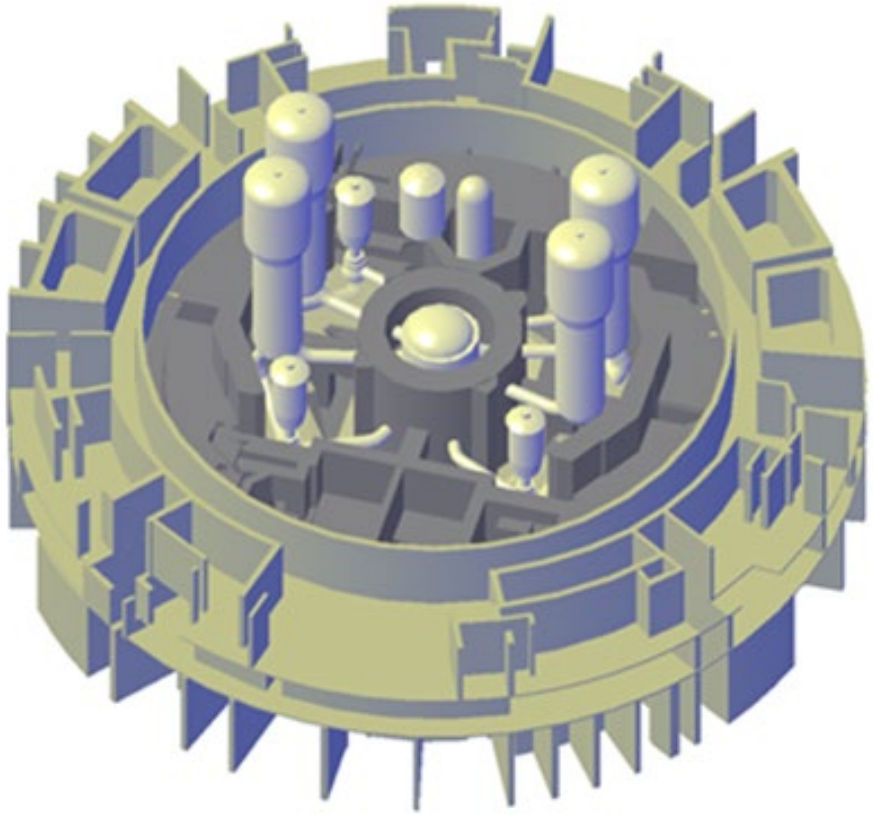
- The intention is to identify **accident sequences in which the combustible gases risk might jeopardize containment**, to establish a set of cases for evaluating the combustion risk in different scenarios later on (WP4).
- Different PWR reactor designs will be addressed (**PWR-W; PWR-KWU; PWR-VVER**)
- As a result, the output of the WP will be a **database with generic PWR input decks** that will feed activities to be conducted within WP4.

WP2 Selection of Severe Accident Sequences - Finished

Main deliverables and milestones achieved:

- Milestones achieved.
- Deliverables under EC approval
- Energorisk did their best despite the war in Ukraine

Generic containments have been developed (PWR-KWU, PWR-W and PWR-VVER) and severe accident sequences have been calculated.



Ref: **Development of a detailed 3D CAD model of a generic PWR-KWU containment as a basis for a better assessment of H2/CO combustion risk**. Serra, Luis; Domínguez-Bugarín, Araceli; Estévez-Albuja, Samanta; Vázquez-Rodríguez, Carlos; Jiménez, Gonzalo; Kelm, Stephan and Herranz, Luis E. Proceedings of the European Nuclear Young Generation Forum ENYGF'21. September 27-30, 2021, Tarragona, Spain

WP3 – Experimental investigations - Finished

The objective of this WP· is to investigate experimentally phenomena that are difficult to predict theoretically: H2/CO/H2O combustion and PARs behavior under realistic accidental conditions, taking into account the safety systems interaction. Two main tasks:

- **Combustion of flammable H2/CO/H2O mixtures**, led by the CNRS, that will target the missing fundamental combustion parameters taking into account spray and venting with the goal to provide engineering correlations to the safety tools and improving the numerical codes;
- **PAR performance under severe accident boundary conditions** led by JUELICH

Deliverables under review

WP3 – Experimental investigations

CNRS: combustion experiments

- Spherical bombs:
  - BS-I: 8 l, max. pressure: 50 bar, max. temp: 100ºC
  - BS-II: 56 l, max. pressure: 50 bar, max. temp: 100ºC
  - BS-III: 93.43 l, max. pressure: 200 bar, max. temp: 250ºC
- ENACCEF-2:
  - internal diameter – 0.23 m,
  - height – 7.65 m,
  - max. pressure: 234 bar

WP3 – Experimental investigations

REKO platform (JUELICH): PAR experiments

REKO-1 (Cylindrical vertical flow channel)

- Diameter: 40..70 mm, Length: 1 m
- Performance of catalyst specimens

REKO-3 (Rectangular vertical flow channel)

- Cross section: 146 x 46 mm, Length: 1 m
- Performance of PAR catalyst section

REKO-4 (Pressure vessel)

- Diameter: 1.4 m, Height: 3.7 m
- Volume: 5.4 m^3
- Max. operating pressure: 2.3 bar @ 280 °C

REKO-Fire (Vertical flow channel)

- Combination of cylindrical flow channel with cable fire aerosol generator

WP3 Experimental Investigations

The **experimental characterization of the combustion** regimes that may occur during the late phase accident has started in BS-I, BS-III and ENACCEF-II: the flammability limits, laminar, and turbulent flames are assessed for normal air and under oxygen starvation conditions. Experiments with H2/CO with air and 6.5%O2 are carried out three H2/CO concentrations. Flame acceleration in 11-26%{H2/CO}/Air condition

The **experimental program on PAR operation** in severe accident atmosphere has started in the REKO facilities.

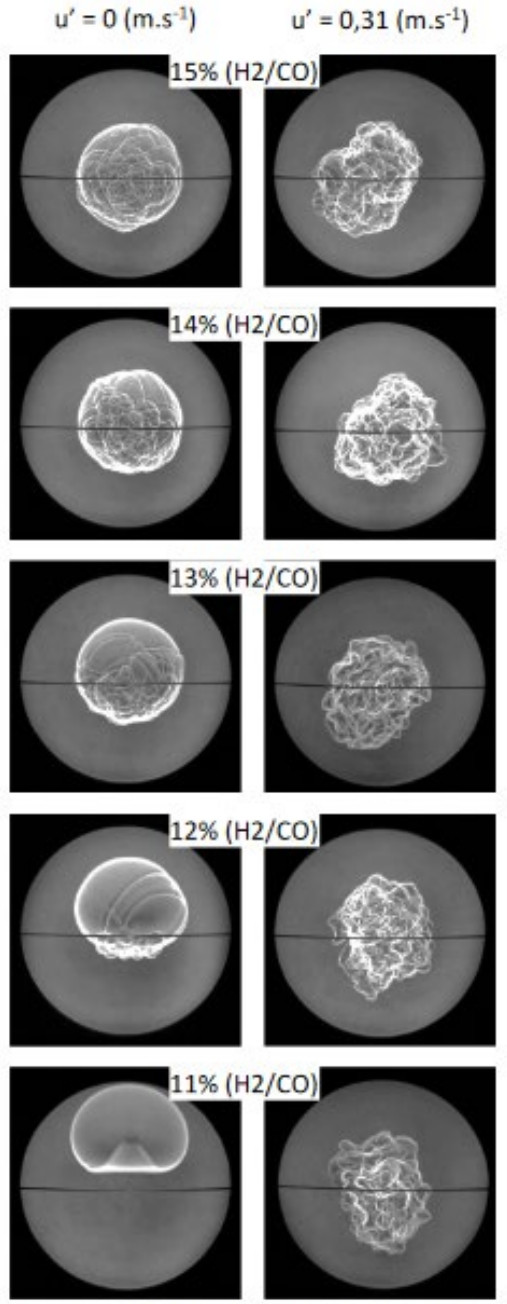


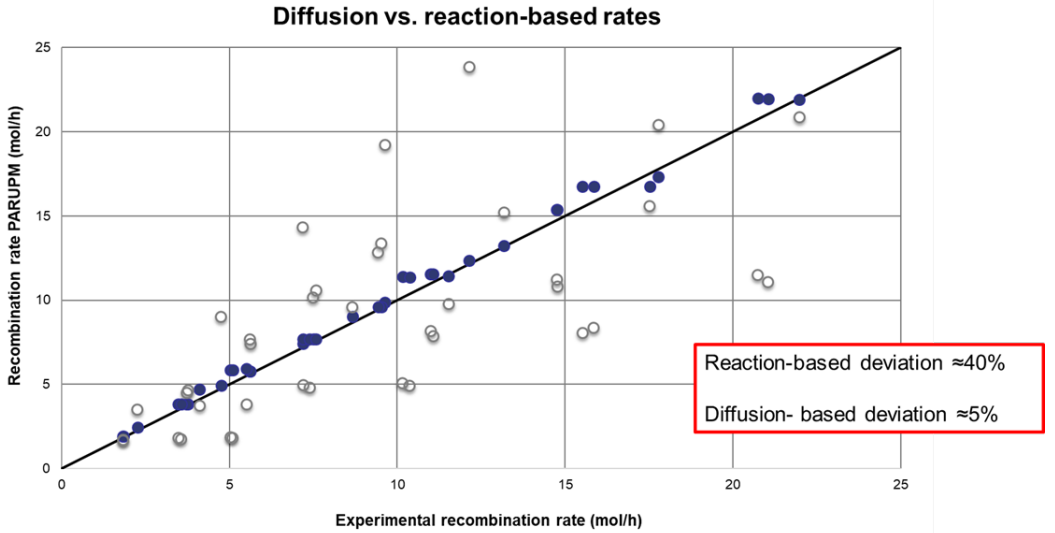
Fig. 6. Flame visualizations for a mean radius of 50 mm.

REF: **Turbulent flame speed of H2-CO-Air mixtures for conditions relevant to late phase accident scenario**. Anthony Desclaux, Gustav Nyrenstedt, Mahmoud Idir, Nabiha Chaumeix, Alexandre Bleyer, Ahmed Bentaib. 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics NURETH 19. Virtual meeting | March 6-11, 2022.

WP3 – Results (examples)

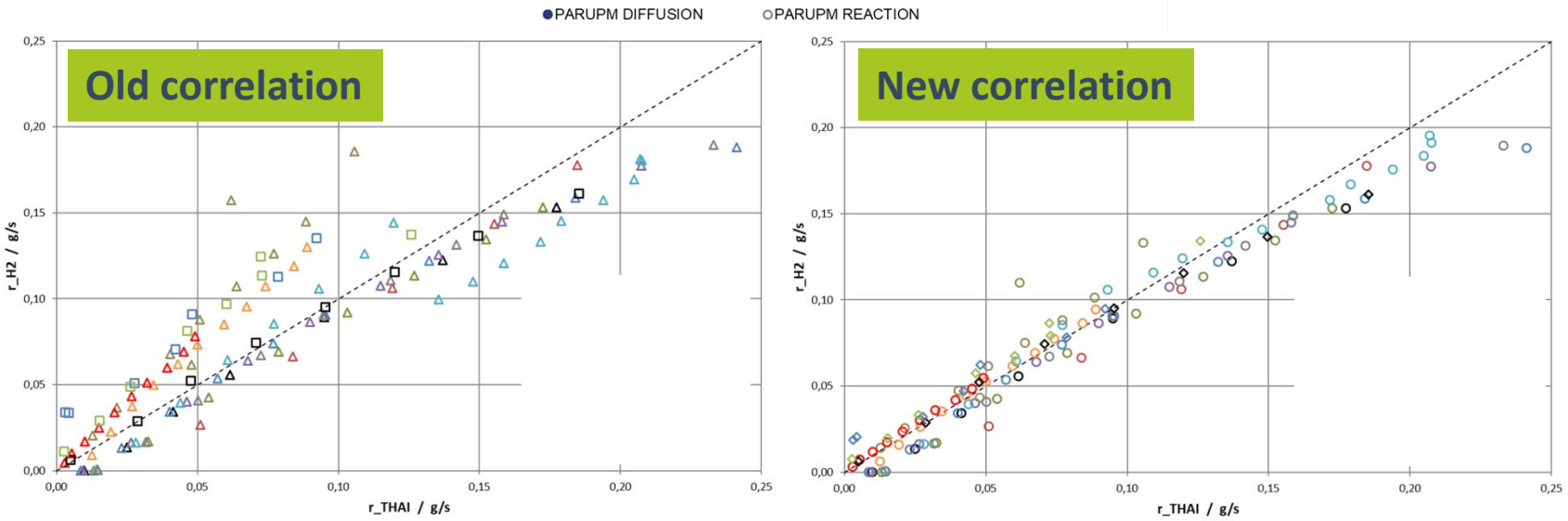
PARUPM

- Chimney model
- Mass transfer-controlled reaction model
- Significant improvement of simulation results



Framatome correlation

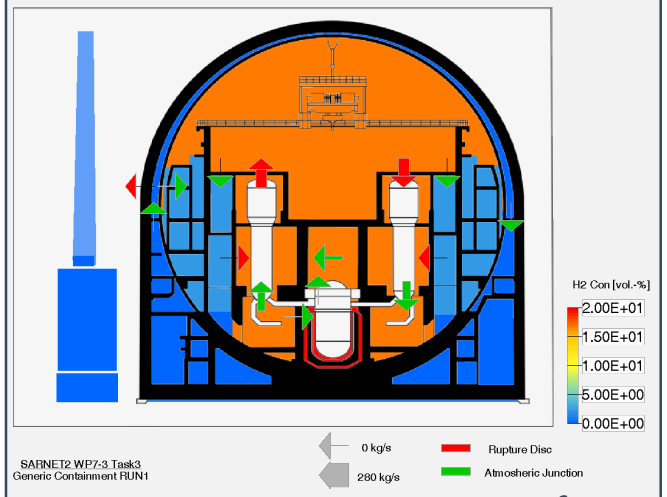
- Modified correlation proposed
- Validation against entire THAI-database
- Implementation in LP codes on-going in WP4



WP4 Full Containment Analysis - Ongoing

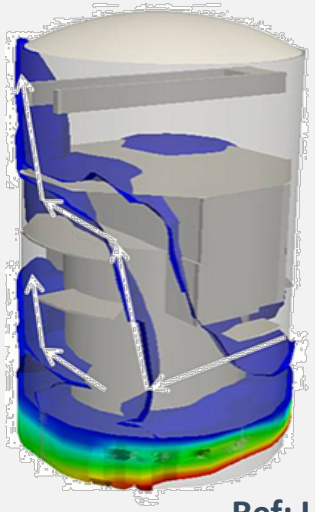
- Development and implementation of new engineering criteria and correlations
- Analysis of Containment response, combustion risk and effectiveness of mitigative measures are be conducted in three levels of detail

LP / System codes
(most penalizing scenarios from WP2)



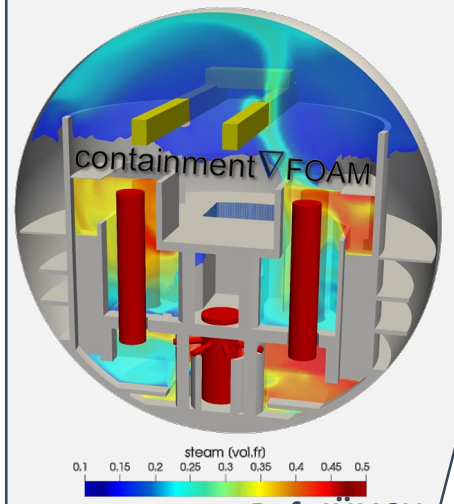
Ref: RUB

GOTHIC-3D
(Selected transients)



Ref: UPM

CFD
(Selected compartments)

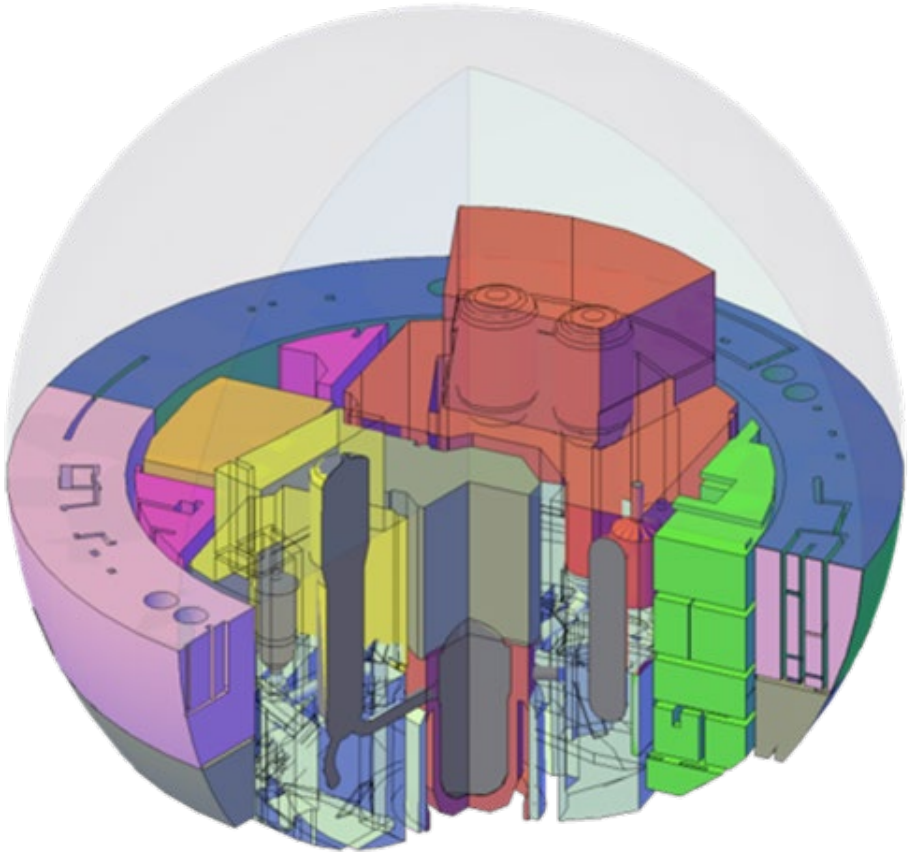


Ref: JÜLICH

- Summary of experience / lessons-learned in code specific guidelines

WP4 Full Containment Analysis

- Officially started in M19
- Needs inputs from WP2, and WP2 is not yet finished (reports are being reviewed)
- Preparation work began:
  - Transfer of WP3 insights to engineering models and correlations (Task 4.1)
  - Definition of a calculation matrix for PWR-KWU and PWR-W, two sequences per plant:
    - A LOCA sequence is selected to have an early ex-vessel phenomenology (high H2+CO with limited O2 starvation).
    - A SBO scenario is related to high pressure and steam concentrations for a FCVS assessment and late re-activation of the emergency cooling systems



Ref: **Development of a detailed 3D CAD model of a generic PWR-KWU containment as a basis for a better assessment of H2/CO combustion risk**. Serra, Luis; Domínguez-Bugarín, Araceli; Estévez-Albuja, Samanta; Vázquez-Rodríguez, Carlos; Jiménez, Gonzalo; Kelm, Stephan and Herranz, Luis E. Proceedings of the European Nuclear Young Generation Forum ENYGF'21. September 27-30, 2021, Tarragona, Spain

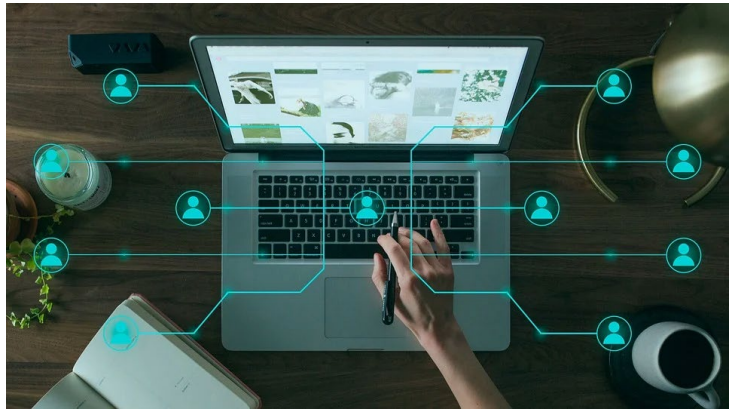
WP5 – Enhancement of Severe Accident Management Guidelines – Not started yet

This WP aims to identify enhancements of safety procedures (e.g. EOPs) and severe accident management guidelines (SAMGs) to reduce the H2/CO combustion risks to the containment.

The output of this WP will be:

- Enhanced technical AM measures based on results achieved in the project,
- A translation into practical AM measures in which human error is minimized as far as possible,
- Recommendations for LTO upgrades to comply with the proposed AM measures above.

WP6 – Dissemination, Communication, Education and Training

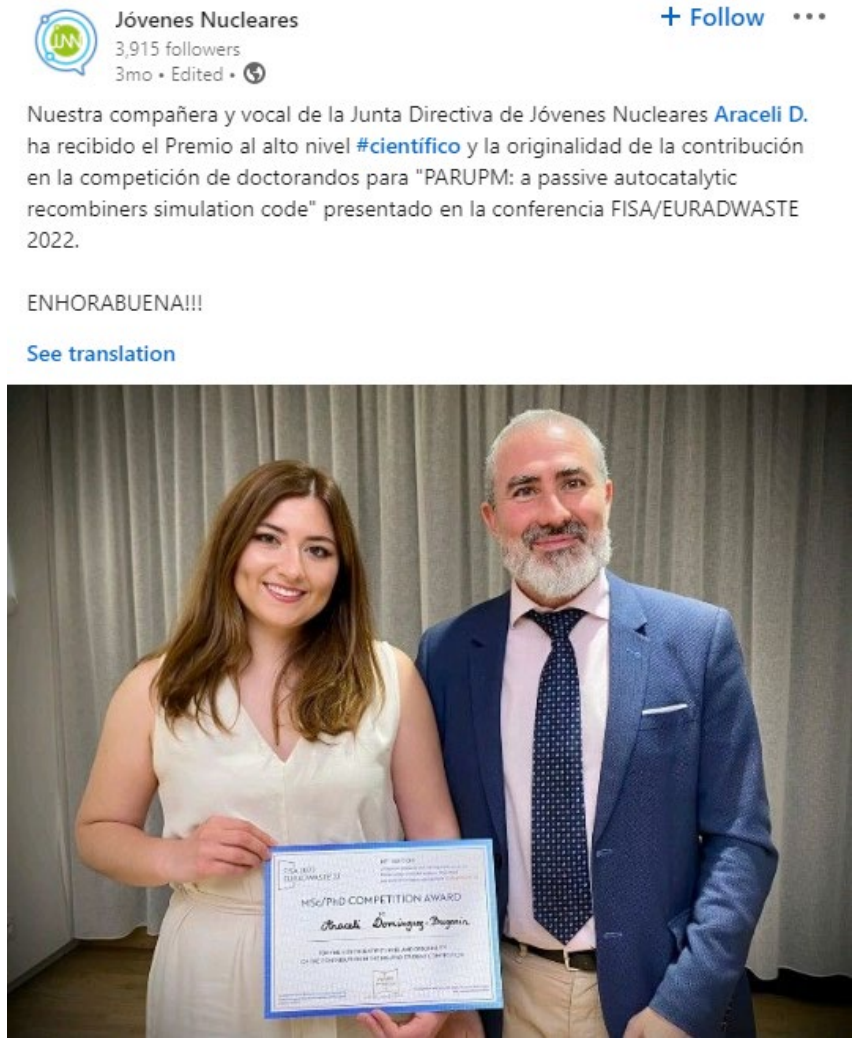


Images credit: Pixabay

- **Communication activities**: preparation of brand identity, website, poster, roll-up, newsletter, videos, and commercial brochures
- AMHYCO project will support the publication in **golden open access** approach
- The project will set up and manage an international **End-User Group** to reach out on the AMHYCO achievements, seek feedback when relevant, and attract potential future users and developers
- **Students Mobility Program**: to promote students mobility between organizations
- **Two international workshops** (M36 and M48)

WP6 Dissemination, Communication, Education, and Training - Progress

Conference papers published or in a pipeline: >20
Conferences: NURETH19, ENYGF2021, ICHS2021, FISA, ERMSAR2022, KERNETCHNIK2022, CSARP, NURETH23, ENYGF2023, SNE2021, SNE2022, SNE2023



European prize for the best PhD presentation (FISA2022)

AMHYCO video

https://vimeo.com/776134461

First AMHYCO journal papers

PARUPM: A simulation code for passive auto-catalytic recombiners

Araceli Domínguez-Bugarín, Miguel-Ángel Jiménez, Ernst-Arndt Reinecke and Gonzalo Jiménez

EPJ Nuclear Sci. Technol., 8 (2022) 32

Published online: 22 November 2022

DOI: https://doi.org/10.1051/epjn/2022046

Towards an optimized management of accidents

Luis E. Herranz, Gonzalo Jiménez and Francesco S. Nitti

EPJ Nuclear Sci. Technol. 8, 43 (2022)

Published online: 21 December 2022

DOI: https://doi.org/10.1051/epjn/2022019

AMHYCO End-user group

- **NPP Owners:**
  - Iberdrola (co-owner of several PWRs, Spain),
  - Electricité de France (56 PWR-W, France),
  - Krško NPP (1 PWR-W, Slovenia),
  - Almaraz and Trillo NPPs (2 PWR-W, 1 PWR-KWU, Spain),
  - Ascó and Vandellós NPPs (3 PWR-W).
- **SAMGs developers**:
  - Tecnatom (PWR-W, Spain),
  - PWR Owners Group,
  - EPRI (PWR-W, USA),
  - Fortum (PWR-VVER, Finland)
- **Code developers**:
  - Zachry (USA, GOTHIC developers)

WP7 – Project coordination and management

- **Project coordination, quality management and project secretariat.**
- Contractual & Financial Management
- **Advisory Board,** which will be constituted of high-ranking professionals from organizations in and/or outside Europe

Image credit: Pixabay

AMHYCO AB members

- **Prof. Dr. Joseph E Shepherd** (USA), C.L. “Kelly” Johnson Professor of Aeronautics and Mechanical Engineering, California Institute of Technology.
- **Dr. Juan Manuel Martín-Valdepeñas** (Spain), Senior Inspector at Probabilistic Safety Analysis, Consejo de Seguridad Nuclear (Spanish Nuclear Regulatory Body).
- **Dr. Berthold Schramm** (Germany), Expert in containment CFD modelling, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)
- **Dr. Sanjeev Gupta** (Germany), Head of Reactor Safety Research, Becker Technologies.
- **Dr. Samuel Gyepi-Garbrah** (Canada), Canadian Nuclear Safety Commission, Ottawa (CNSC)
- **Martina Adorni** (Italy), Nuclear Safety Specialist, Nuclear Energy Agency (OECD-NEA)

WP8 – Ethics

Image credit: Pixabay

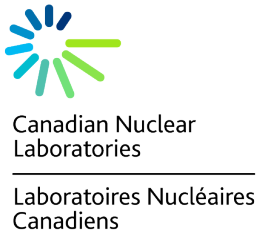
First AMHYCO open workshop

ORLEANS, France

Save the date: October 16-17, 2023

Register soon!!

AMHYCO Partners



Thank you
Connect with us for more information:

gonzalo.jimenez@upm.es

http://amhyco.eu

@amhyco