NEA NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK:

Success Stories and Opportunities for Future Developments

9-13 January 2023

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Welcome

Day 4 – Thursday 12 January

NEA NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK:
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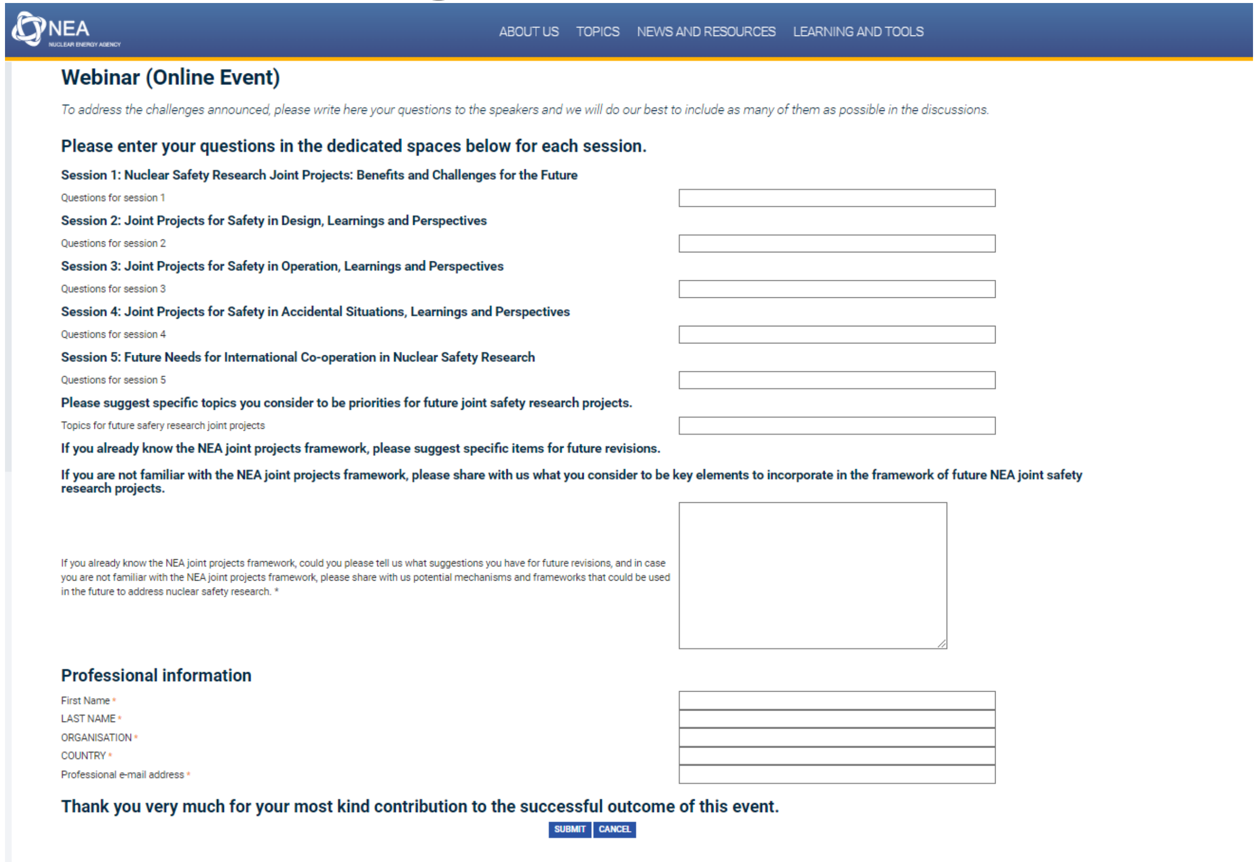
Questions: Questions, feedback and suggestions

Event public page: Nuclear Energy Agency (NEA) - NEA Nuclear Safety Research Joint Projects Week: Success Stories and Opportunities for Future Developments (oecd-nea.org)

Form: [Questions, feedback and suggestions](#) link available in the registration confirmation email



NEA

ABOUT US TOPICS NEWS AND RESOURCES LEARNING AND TOOLS

Webinar (Online Event)

To address the challenges announced, please write here your questions to the speakers and we will do our best to include as many of them as possible in the discussions.

Please enter your questions in the dedicated spaces below for each session.

Session 1: Nuclear Safety Research Joint Projects: Benefits and Challenges for the Future

Questions for session 1

Session 2: Joint Projects for Safety in Design, Learnings and Perspectives

Questions for session 2

Session 3: Joint Projects for Safety in Operation, Learnings and Perspectives

Questions for session 3

Session 4: Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

Questions for session 4

Session 5: Future Needs for International Co-operation in Nuclear Safety Research

Questions for session 5

Please suggest specific topics you consider to be priorities for future joint safety research projects.

Topics for future safery research joint projects

If you already know the NEA joint projects framework, please suggest specific items for future revisions.

If you are not familiar with the NEA joint projects framework, please share with us what you consider to be key elements to incorporate in the framework of future NEA joint safety research projects.

If you already know the NEA joint projects framework, could you please tell us what suggestions you have for future revisions, and in case you are not familiar with the NEA joint projects framework, please share with us potential mechanisms and frameworks that could be used in the future to address nuclear safety research. *

Professional information

First Name *

LAST NAME *

ORGANISATION *

COUNTRY *

Professional e-mail address *

Thank you very much for your most kind contribution to the successful outcome of this event.

SUBMIT CANCEL

NEA NUCLEAR ENERGY AGENCY

NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK

Success Stories and Opportunities for Future Developments

9-13 January 2023

Session 4

Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

SESSION MODERATOR

Dr Hideo NAKAMURA

Technical Associate, Japan Atomic Energy Agency (JAEA), Japan

Dr Hideo NAKAMURA was born in 1956 at Nagoya, Japan and he received BA in Nuclear Engineering (1979), MS in Crystalline Material Engineering (1981) and PhD in Nuclear Engineering (1992), all from Nagoya University. He joined the former Japan Atomic Energy Research Institute (JAERI) at Tokai, Japan in 1981 to work for the ROSA (Rig-of-Safety Assessment) programme to study accident thermal-hydraulic phenomena for both BWR & PWR with prototypical integral-effect tests and separate-effect tests as well as safety analysis code/model developments. He was the head of the Thermo-hydraulic Safety Research Group from 2001 to 2013 involving DBA, BDBA and SA, and the head of operating agent for the NEA ROSA and ROSA-2 joint projects with LSTF experiments for LWR safety assessments from 2005 to 2012. The project was terminated to concentrate on analyses of the Fukushima Daiichi accident in 2011. He was an executive editor of *Nuclear Engineering and Technology* from 2015 to 2020. Currently, he is a Technical Associate at the Japan Atomic Energy Agency (JAEA), where he has served since 2018, and Chair of the NEA Working Group on Analysis and Management of Accidents (WGAMA) since 2022.

Session 4

Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

► Examples of Containment Thermal-Hydraulics, Mitigation Systems and Hydrogen Risk Management Projects

THAI/THEMIS

Dr Sanjeev GUPTA,

Deputy General Manager, Head of Reactor Safety & Engineering, Becker Technologies, Germany

Dr Sanjeev GUPTA is Deputy General Manager, and Head of the Reactor Safety and Engineering divisions of Becker Technologies in Eschborn, Germany. He obtained his PhD in Fluid Mechanics from the École des Mines de Nantes, France. Dr Gupta joined Becker Technologies GmbH in 2008 as Head of the Experimental Programme. Before joining Becker Technologies, he worked with the French Atomic Energy Commission (CEA), France and the Paul Scherrer Institut (PSI), Switzerland, on large scale, experimental test facilities in hydrogen safety and nuclear reactor thermal-hydraulics. The current focus of his work is on severe accident research in LWRs with particular focus on combustion risk and source term issues. His current work responsibilities include the development and management of international R&D and industry projects. He is programme manager for the ongoing international joint nuclear safety project NEA THAI Experiments on Mitigation measures, and source term issues to support analysis and further Improvement of Severe accident management measures (THEMIS) and actively involved in NEA activities such as the Working Group on Analysis and Management of Accidents (WGAMA). Dr Gupta is also co-ordinating the ongoing international in-kind project IPRESCA related to source term research. He is Governing Board member of the European SNETP Association and actively involved in IAEA activities as an Expert and Lecturer.

Examples of Containment Thermal-Hydraulics, Mitigation Systems and Hydrogen Risk Management Projects

–THAI/THEMIS –

Dr. Sanjeev Gupta
Becker Technologies GmbH, Germany

January 12, 2023

Overview of THAI/THEMIS project

- Experimental research to investigate specific issues for **LWR containment under severe accident conditions:**
  - ✓ to provide data for validation and further improvement of safety analyses tools,
  - ✓ to support in SAM analyses.

- Area of experimental research:
  - **Thermal hydraulics** and **hydrodynamics** of water pools,
  - **Hydrogen** (combustible gases) distribution, combustion and recombination, and
  - **Aerosol and Iodine** (Fission product) behavior.

- **Performance testing of active and passive mitigation systems,** e.g. Passive Autocatalytic Recombiners (PARs), Pressure suppression pool, Spray, Filtered Containment Venting System

Overview of THAI/THEMIS project

On behalf of:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

of the Federal Republic of Germany

OECD/NEA THAI/THEMIS projects

- ✓ Ongoing since 2007
- ✓ Current THEMIS project phase (2020 - 2024)

THAI National project

- ✓ Ongoing since 1998
- ✓ Current project phase (2021 - 2023)
  - *includes tests on safety of LW-SMRs*

- **OECD/NEA THAI** project phases
  - OECD/NEA THAI (2007 – 2009), 9 countries
    - *Canada, Czech Republic, Finland, France, Germany, Hungary, Korea, Netherlands, Switzerland*
  - OECD/NEA THAI-2 (2011 – 2014), 11 countries
    - *Canada, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Netherlands, Sweden, UK*
  - OECD/NEA THAI-3 (2016 – 2019), 16 countries
    - *Belgium, Canada, China, Czech Republic, Finland, France, Germany, Hungary, India, Japan, Korea, Luxembourg, Slovak Republic, Sweden, Switzerland, UK*
  - OECD/NEA THEMIS (2020 – 2024), 14 countries
    - *Belgium, Canada, China, Finland, France, Germany, Japan, Korea, Russia, Slovak Republic, Spain, Sweden, Switzerland, UK*

Highlights:

Data sharing: Selected data for analytical activities from national projects shared with OECD/NEA project partners

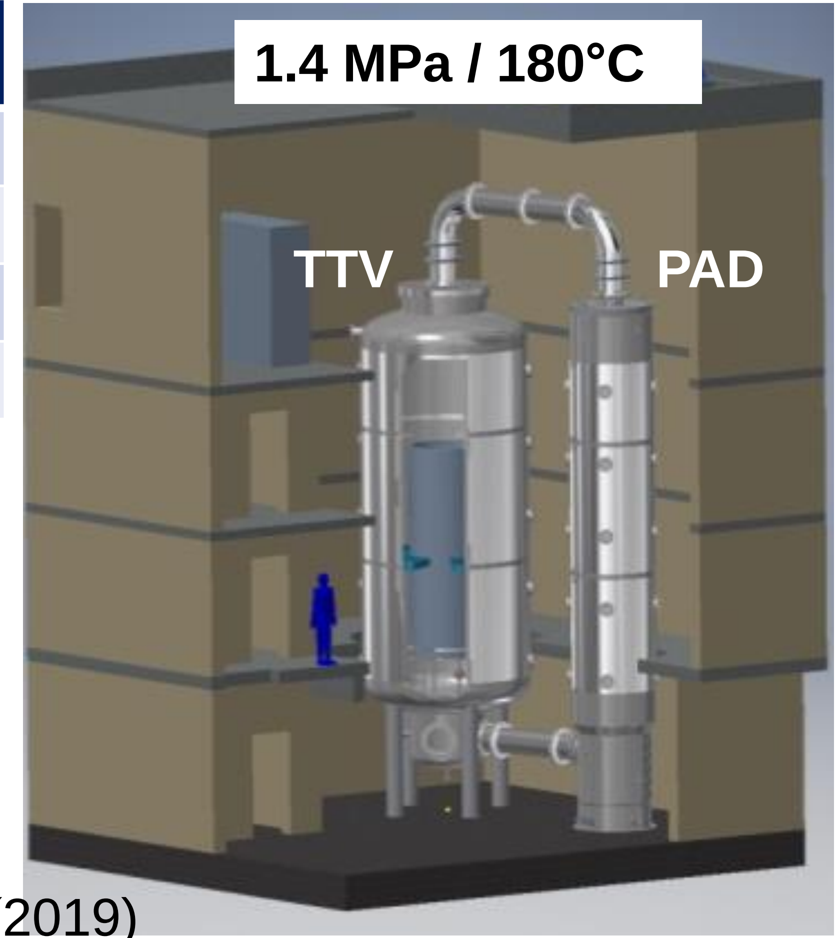
Facility upgrade: Generally done in national project frame prior to proposing in OECD/NEA projects

THAI+ – multi-compartment test facility

THAI+: Thermal-hydraulics, Hydrogen, Aerosols, Iodine, + Multi-compartment

	THAI	PAD
Height	9.2 m	9.8 m
Diameter	3.2 m	1.6 m
Volume	60 m^3	18 m^3
Upper and lower connecting pipes: DN 500		

- Configurable sub-compartments
- Large top openings to install test components
- Pressure resistant for (slow) H_2-deflagrations
- Licensed for use of radiotracer I^{123}



TTV: THAI Test Vessel
PAD: Parallel Attachable Drum

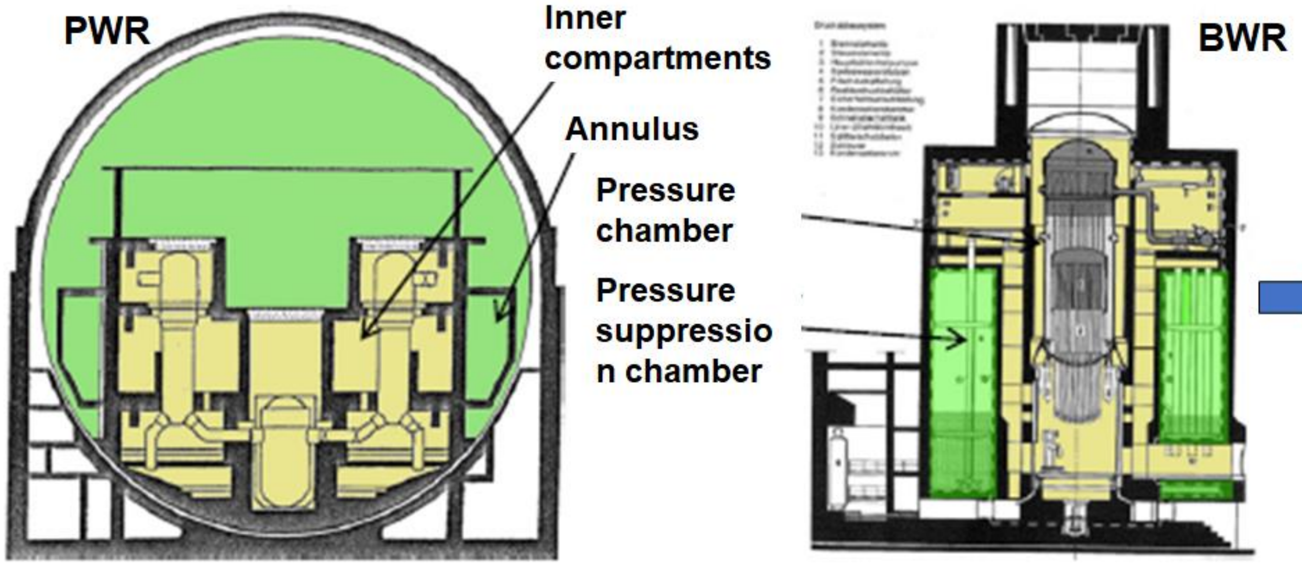
Recent upgrades:

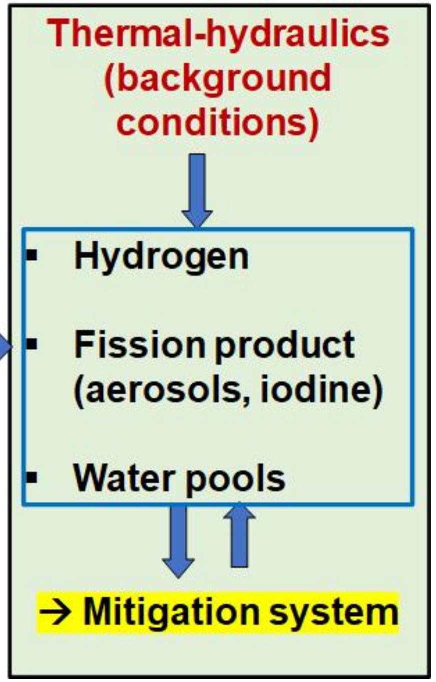
- Extension to two-vessel system (+PAD) (2015)
- Licensed to perform tests with Carbon Monoxide (2019)
- Provision arrangements to perform first LW-SMR tests (2021)

Experimental hardware – extrapolation to reactor scale

Focus of THAI experimental research

- Generic “containment” research – e.g. PWR, BWR, PHWR
- Reactor typical “configurations”, “flow regimes”, etc.
- Coupled-effect tests – “phenomena”, “mitigation systems”, etc.
- Representative boundary conditions, e.g. P, T, gas composition & concentration, well-mixed/stratified conditions, etc.
- Measurement systems for measuring test parameters of interest – application for code/model validation, mitigation systems performance quantification, etc.

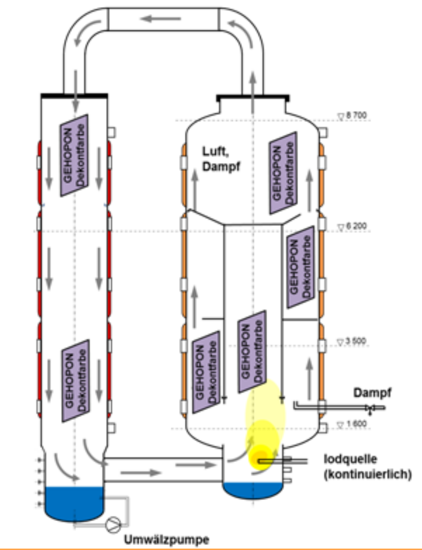




Experimental hardware – project specific developments

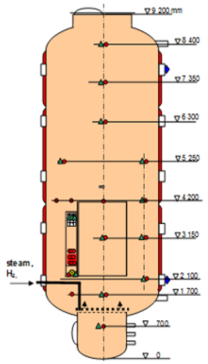
Test configurations

Example 3: Gaseous iodine distribution under natural circulation



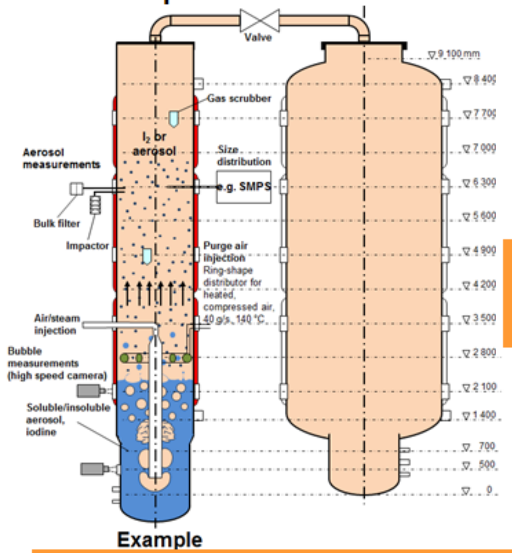
- **Long term iodine release behaviour**
- **Interaction with containment typical surfaces**

Example 1: PAR performance testing (Framatome, AECL, NIS)



- PAR performance
- Up to 3 bar, 140 °C, ^{123}I, aerosol
- Ignition ($T_{gas\ local}$ ~ 1000 °C)

Example 2: Fission product release from water pools

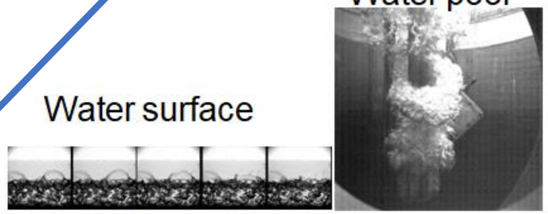


Example

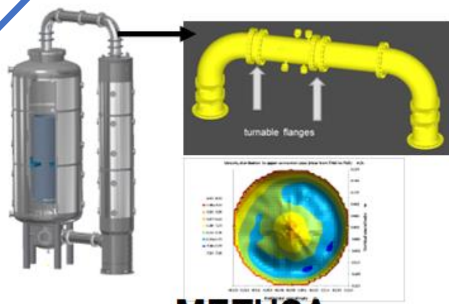
- **Water pool hydrodynamics**
- **Gaseous iodine and aerosols release behaviour**

Instrumentation

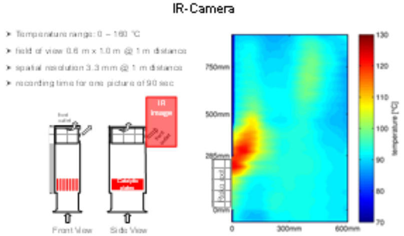
Cascade impactor



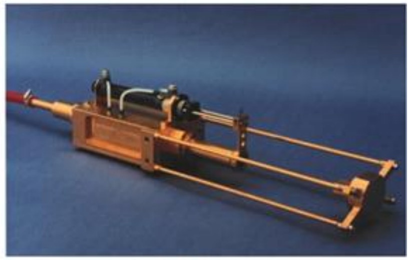
High speed imaging
Measurement of bubble/ and droplets size distribution in hot/boiling water pools



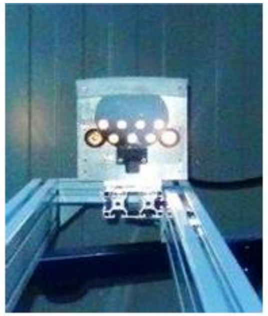
METUSA
Turnable flange for velocity-field measurement



Infrared Camera
Hot gas plume temperature measurement

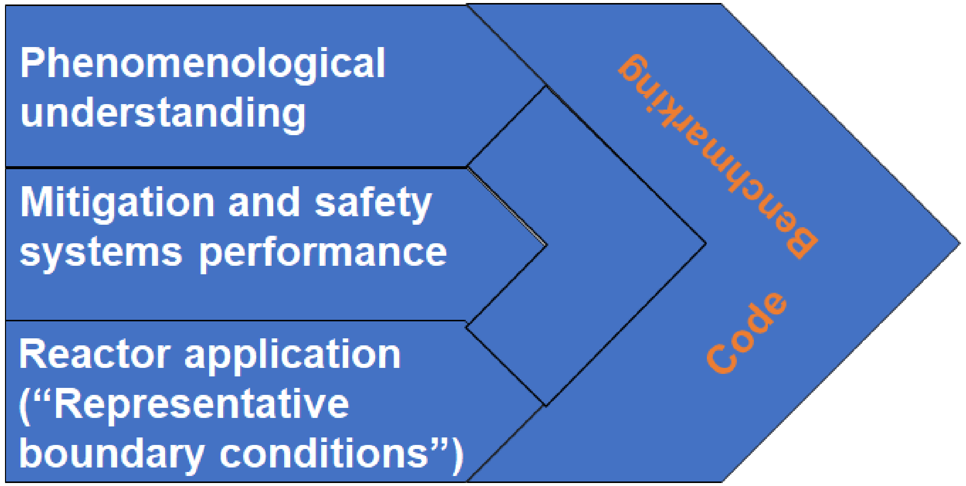


FASP
airborne liquid water droplets measurement



LASI
Spectrometry for gaseous iodine and steam concentration measurement

Nuclear Safety Applications (1)



❖ Code Benchmarking

ISP-47 (Test TH-13)	**– Containment thermal-hydraulics & Stratified atmosphere**
ISP-49 (Test HD-22)	**– Hydrogen deflagration**
OECD/NEA Benchmark HM-2	– Hydrogen/Helium scaling, Stratified atmosphere
OECD/NEA Benchmark HR-35	– Hydrogen recombiner “O_2-lean”
OECD/NEA Benchmark HR-49	– Hydrogen recombiner
OECD/NEA Benchmark HD-44	– Hydrogen deflagration
OECD/NEA Benchmark HR-57	**– Hydrogen recombiner “CO effect”**
OECD/NEA Benchmark WH-33	**– Pool scrubbing “jet regime”**

❖ Code benchmarking - highlights

- Majority of THAI code benchmarks consisted of both “blind” and “open” phases
- Specification reports prepared by OA (AWG) including details on initial and boundary conditions
- Project technical reports documenting comparison between experiment and codes results
- Open joint publications (conferences/journals) on code benchmark results and the remaining open issues

Benefits: New validation “common” database, modelling improvement and extension, reactor applications and others.

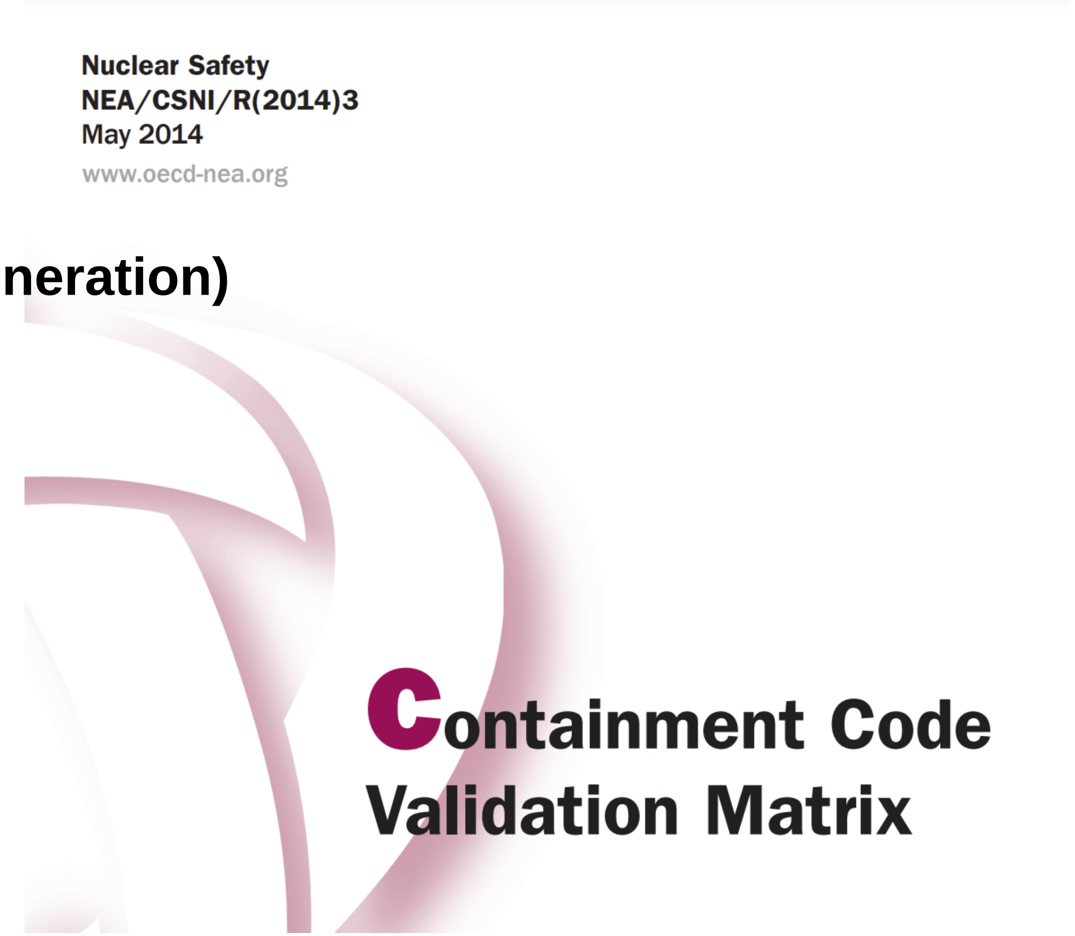
Nuclear Safety Applications (2)

❖ Use of project results by partners (selection)

Organization	THAI results	
GRS (Germany)	Hydrogen distribution and PAR tests Aerosol washdown	▪ Basis for development of **nodalization guidelines for LP code uses** for stratified gas atmosphere in containments ▪ Re-evaluation of **PAR concept in German PWRs** with revised PAR model ▪ Development and validation of **aerosol washdown from surfaces of containment walls under accident conditions** (AC^2/COCOSYS)
UJV (Czech Republic)	Hydrogen distribution and PAR tests	To support in designing a **PARs based mitigation system installation in the Temelin NPP** containment (MELCOR code)
IRSN (France)	▪ Fission product re-entrainment (with and without impurities) tests ▪ PAR tests ▪ Iodine flashing	▪ Assessment of aerosol re-entrainment impact on **^{137}Cs source term of the Fukushima Daiichi** accident (ASTEC code) ▪ Extension of PSA studies and accident modelling by including **PAR-induced ignition behaviour** results (SPARK/ASTEC) ▪ Identification of lack of validation of existing **iodine chemical models in the aqueous phase – high temperature chemistry** (ASTEC)
JAEA (Japan)	Iodine/Aerosols interaction	Estimation **of gaseous iodine adsorption velocity on aerosols derived based on tests data** for application in BWR SA analysis (ART code)
AERB (India)	PAR tests	Development of CFD code (FLUENT) for **hydrogen risk analyses in PHWRs**

Nuclear Safety Application (3)

❖ Containment thermal-hydraulic



❖ Hydrogen Behaviour (Combustion, Mitigation and Generation)

❖ Aerosol and Fission Product Behaviour

❖ Iodine Chemistry Experiments

Networking – common basis on safety issues

- **Stakeholders (selection)**

Research centres
PSI (Switzerland), CEA (France), KAERI (Korea), Kurchatov Inst (Russia), CIEMAT, (Spain), CNL (Canada), IBRAE (Russia), CIAE (China), UJV (Czech Republic), FZJ & KIT (Germany)

Industry
EDF (France), Framatome (Germany), NIS-Siempelkamp (Germany), Rosatom (Russia), KHNP (Korea), NPCIL (India), CNPE (China), CNPRI (China)

Universities
IIT (India), University of Luxembourg, RUB (Germany), Uni. Stuttgart (Germany), UPM (Spain), VKI, (Belgium)

TSOs
JAEA (Japan), IRSN (France), GRS, (Germany), KINS (Korea), Bel-V (Belgium), BARC (India), VTT (Finland), SEC NRS, Russia

Regulators
CNSC (Canada), CSN (Spain), AERB ((India), ONR (UK), UJD (Slovak Republic), SSM (Sweden), STUK (Finland)

- **Contribution in establishing common basis on safety issues**

→ **Analytical activities** performed by project partners: pre-test assessments, result evaluations, benchmarking of codes and extrapolation of results to reactor conditions

→ Collaboration on development of **experimental infrastructure** in countries of project partners

Networking – competence development & maintenance

❖ **Experts hosting at Becker Tech., PhDs/Post-docs, Students training (selection)**

THAI THEMIS project

✓ **Competence and expertise maintenance**

Young Scientists/Experts

- **Korea Atomic Energy Research Institute (KAERI):** Support in design of technical scale test facilities, instrumentation/measuring systems
- **Atomic Energy Research Board (AERB), India:** Validation of CFD tools for hydrogen mitigation strategy in Indian PHWRs
- **China Institute of Atomic Energy (CIAE):** Uncertainty calibration of aerosol measurement system

PhDs/Post-Docs

Hydrogen combustion (**VKI/Bel-V**), Spray/Aerosols interaction (**Uni Stuttgart**), Fission product re-entrainment (**RUB, Bochum**), Hydrogen combustion (**RUB Bochum**), Aerosol washdown (**KIT**), Fission product re-entrainment (**University Luxembourg**), etc.

Internship/Training

- Université de Lorraine, France

Values

❖ Dissemination of Major Outcomes

- Data of concluded joint THAI projects transferred to NEA databank for further distribution as per NEA rules
- Project summary reports (CSNI approved) published in public domain
- Organization of the final project seminars - generally organized one year after the project end to discuss about “reactor application” of project results by the project partners:

  - ✓ OECD/NEA THAI Seminar (6 – 7 October 2010, Paris)
  - ✓ OECD/NEA THAI-2 Seminar (18 – 19 November 2014, Frankfurt)
  - ✓ OECD/NEA THAI-3 Seminar (6 – 8 October, 2021, Online Meeting)

- Providing contribution in CSNI Status/SOAR reports, WS summary reports, e.g.:
  H_2 management status report (2014), Iodine WS (2015), Source Term WS (2019), H_2/CO SOAR (ongoing),

- Several conference and journal papers by operating agent and project partners including joint papers on project outcomes/code benchmark results (see Appendix)

Future R&D Needs and Trends (1/2)

- A follow-up of ongoing THEMIS project is currently under discussion

- First "informal" technical exchange meeting held on 8th November 2022 (NEA Boulogne-Billancourt)
  - ✓ Meeting organised s a dedicated session at the 4th THEMIS PRG meeting

– **Focus on "Large- LWRs"**
  - ✓ *Risk informed approach should be adopted*
  - ✓ *Scaling (not only facility size but also boundary conditions to facilitate extrapolation of results to reactor scale)*

– **Focus on "LW-SMRs"**
  - ✓ Strong interest on LW-SMRs mainly towards "safety assessment" (support to regulators)
    - DBA, DEC-A, DEC-B
  - ✓ Support in code benchmarks for computer modelling, V&V for SMR designs ("code validation database")

Anticipated co-operation beyond project consortium: e.g. counter-part test, link to OECD/NEA NEST, organization of an international code benchmark, etc

Future R&D Needs and Trends (2/2)

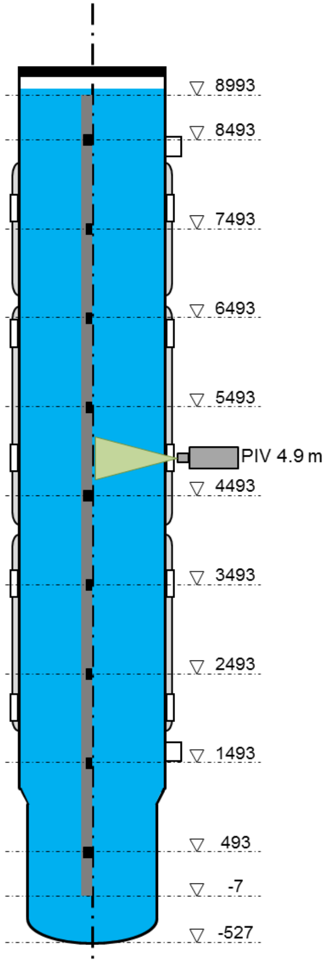
Future R&D programme utilizing the THAI experimental infrastructure

LW-SMRs safety assessment related tests part of the ongoing national THAI project

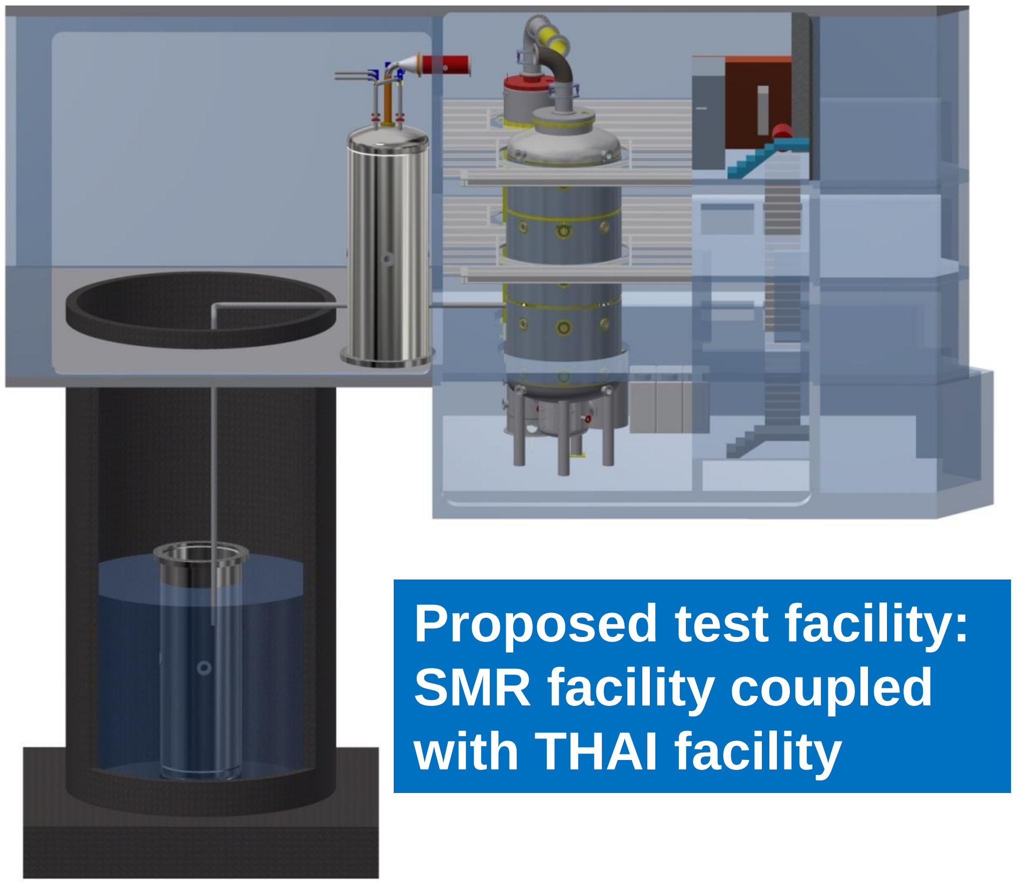
– Existing experimental infrastructure employed
  - Heat removal in large water bodies (high Rayleigh number flows) - see figure
  - Natural convection of passive heat removal systems

Proposal for extension of the THAI test facility

- Proposal passed technical evaluation
- Presently under discussion with responsible national authorities



THAI test: 9 m high containment wall simulator



Proposed test facility: SMR facility coupled with THAI facility

Main challenges in establishing new joint projects

- **Continuous evolving scenarios of nuclear power**
  - Political decisions: continuation/reduction/end of operation of nuclear power reactors
  - Operation extension of current fleet of reactors – Long Term Management
  - Decision on selecting new technologies like LW-SMRs, AMRs (In progress)

- **Advanced technologies (LW-SMRs) - timely identification of R&D needs**
  - Enhanced focus on deployment needs rather on identifying R&D issues to be tackled – DBA and DEC
  - Lack of “design specific” data in public domain – need of commonly agreed “generic” phenomena/BCs
  - ✓ Identification/prioritization of R&D needs is important to support timely “safety assessment“

- **Diverse range of data needs - code development/validation**
  - Depending on maturity of codes/models and needs as per domestically available reactor designs
  - ✓ International joint activities, like PIRT & code validation matrices could pave the way for identifying “common” R&D needs

- **Optimal utilization of existing and planned experimental infrastructure with overlap in their application**
  - Existing facilities – critical infrastructure and the associated competence needs to be maintained
  - Recently constructed or planned facilities – complementary design features/operation details to be utilized

Final remarks

- THAI programme
  - Experimental database produced within joint nuclear safety THAI projects provide **valuable support for validation and further improvement of safety analyses codes**
  - **Opening to other research areas (e.g. SMRs)** which could be adequately addressed in the THAI facility with eventual development of new features
- Perspectives for nuclear safety research
  - **Global approach** – execution of joint projects covering different topics as per test facilities design features but linked to an umbrella topic of common interest (e.g. SMRs)
  - Inclusion of **counter-part tests in joint NEA projects** to better utilize capability of different test facilities towards producing database for reactor application (e.g. scaling, differing boundary conditions) - **input for ISPs**
  - **Mobility programs** should be encouraged (e.g. OECD/NEA NEST framework) - Young scientists and experts
  - Need of implementing an effective strategy at CSNI/WGAMA, CSNI and NEA level to provide a guidance on **research priorities and strategic research needs**, e.g. periodic review of NEA activities (joint projects/WSs etc.) outcomes and publishing TOPs (shorter time period than other reports, e.g. Status/SOAR) on strategic research needs (***CSNI/WGAMA level***); safety technical areas for global approach (***CSNI level***); consolidation of priorities between various related committees (***NEA level)***

ACKNOWLEDGMENT

- The financial support by the countries participating in the OECD/NEA THAI, THAI-2, THAI-3 and the ongoing THEMIS project

- The financial support by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) to the THAI programme

OECD AEN NEA

On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

of the Federal Republic of Germany

Appendix: Project publications (selection)

Operating Agent

- OECD/NEA THAI Project, “Hydrogen and fission product issues relevant for containment safety assessment under severe accident conditions”, Final report, NEA/CSNI/R(2010)3, 2010.
- OECD/NEA THAI-2 Project, “Aerosol and iodine issues, and hydrogen mitigation under accidental conditions in water cooled reactors - Thermal-hydraulics, Hydrogen, Aerosols and Iodine (THAI-2) Project” - Final Report, NEA/CSNI/R(2016)8, 2016.
- OECD/NEA THAI-3, “Fission product behaviour, hydrogen mitigation, and hydrogen combustion in water cooled reactors under severe accident conditions. OECD/NEA THAI-3 Project” – Final Report NEA/CSNI/R(2021)8
- S. Gupta, M. Freitag, G. Poss, THAI experimental research on hydrogen risk and source term related safety systems, Frontiers in Energy, 2021.

Project partners

- L. Lebel, Z. Liang, GOTHIC simulations of OECD/NEA THAI multi-vessel hydrogen deflagration tests, Annals of Nuclear Energy,Volume 150,2021,
- T. Jankowski, M. Koch, Simulation of wet resuspension phenomena during venting operation in a large scale test vessel, Proceedings of NURETH-19 conference
- C. Kaltenbach, E. Laurien, CFD Simulation of aerosol particle removal by water spray in the model containment THAI, Journal of Aerosol Science,Volume 120, 2018
- H. S. Kang et al , CFD Analysis for H2 Flame Propagation during Spray Operation in the THAI Facility, Trans. Of KNS. Meeting, 2015.
- J. Ishikawa, H. Itoh, Y. Maruyama, Influence of adsorption of molecular iodine onto aerosols on iodine source term in severe accident , ICONE-23, 2015.

Joint publications

S. Gupta et al, Main outcomes of OECD/NEA THAI-2 project and its use for code validation and containment safety assessment under accident conditions, in-preparation for NURETH-20 conference.

M. Freitag et al., CFD and LP code benchmark evaluating the onset of par operation in case of extremely low oxygen concentration, Nuclear Engineering and Design, Volume 400, 2022

S. Gupta et al., Main outcomes and lessons learned from THAI passive autocatalytic recombiner experimental research and related model development work”, 17th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-17), Xi’an, China, September 3-8, 2017.

S. Schwarz et al., Benchmark on Hydrogen Distribution in a Containment Based on the OECD-NEA THAI HM-2 Experiment, Nuclear Technology, 2011,

HYMERES/PANDA

Dr Domenico PALADINO

Leader, Experimental Thermal-Hydraulics Group, Paul Scherrer Institute, Switzerland

Dr Domenico PALADINO is Leader of the Experimental Thermal-hydraulics group at the Paul Scherrer Institute, Switterland. He graduated in Nuclear Engineering from la Sapienza Università di Roma in Italy and he holds a PhD in Energy Technology from the KTH Royal Institute of Technology in Sweden. He works at the Paul Scherrer Institute in Switzerland as Leader of the Experimental thermal-hydraulics group and manager of projects with experiments carried out in the the Multipurpose Integral Test Facility for LWR Safety Investigations (PANDA) thermal-hydraulics facility. His research activities imply nuclear safety, containment thermal-hydraulics experiments and analyses.

PAUL SCHERRER INSTITUT PSI

Examples of Containment Thermal-Hydraulics, Mitigation Systems and Hydrogen Risk Management Projects

HYMERES and PANDA projects

Domenico Paladino

NEA NUCLEAR ENERGY AGENCY

NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK

Success Stories and Opportunities for Future Developments

9-13 January 2023

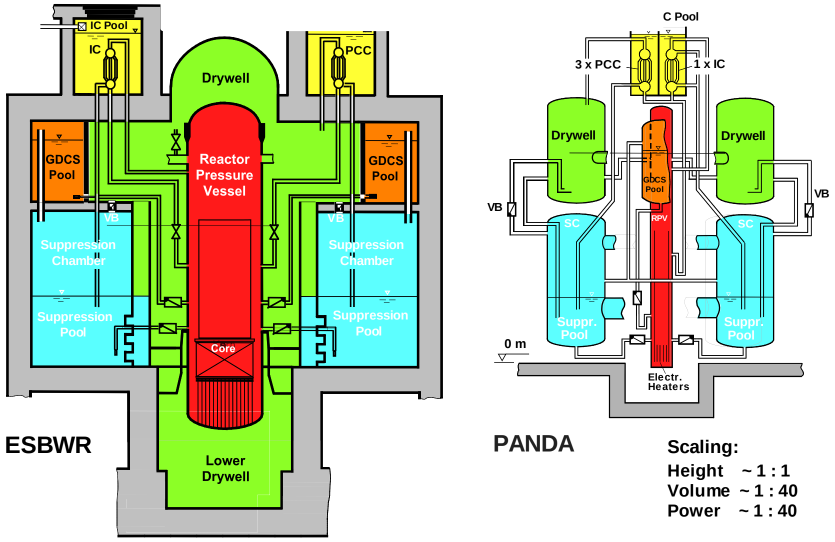
PAUL SCHERRER INSTITUT

Outline

- PANDA Facility
- Overview of PANDA projects
- The HYMERES and PANDA projects
- Facility upgrading (HYMERES-2)
- Benchmark activities
- Project deliverables and publications
- Nuclear Safety Applications
- Activities within the OECD/NEST framework
- Feedbacks and main challenges related to the Project Development
- Outlook for future research activities
- Conclusions and perspectives

PANDA facility

The PANDA facility consists of 6 Vessels RPV (Reactor Pressure Vessel), GDCS (Gravity Driven Cooling System), DW1-2 (Drywell), WW1-2 (Wetwell), 4 Condensers (3 PCC1-3 Passive Cooling Condenser, IC - Isolation Condenser), system lines e.g. MSL (Main Steam Line), PCC vent lines, VB (Vacuum Breaker) lines, etc. and auxiliary system lines



- Large Scale:
- ✓Height: 25 m
- ✓Volume: 515 m^3
- ✓Power: 1.5 MW.
- Specifications:
- ✓0-10 bar
- ✓up to 200 ^{o}C

G. Yadigarouglu and J. Dreier, ***Passive Advanced Light Water Reactor Design and the ALPHA Programme at the Paul Scherrer Institute*** *Kerntechnik* 63 1-2 pp. 39-46, (1998).

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Overview of PANDA projects (in grey NEA)

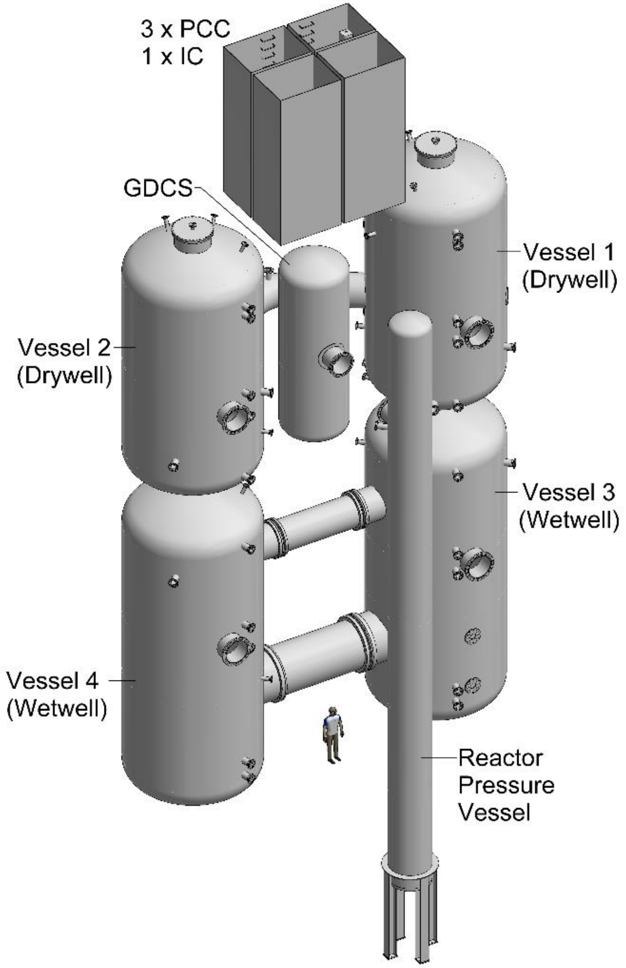
	Program	Investigations
	1991-1995 EPRI/GE	Investigation of passive decay heat removal systems for **SBWR**
	1996-1998 EC-4th FWP	European BWR-R&D-Cluster for Innovative Passive Safety Systems (i.e. **SWR1000-KERENA tests**) (**IPPS Project**) and **ESBWR** (**TEPSS Project**)
IC/PCCS	**1998-2002 OECD/NEA ISP-42**	Passive Containment Cooling System (PCCS) performance in very challenging situations, represented in six different phases (**ISP-42**)
	1999-2004 EC-5th FWP	Effect of hydrogen distribution on passive systems (**TEMPEST Project**) and investigation of BWR natural circulation stability (**NACUSP Project**), **ESBWR**
	2002-2006 OECD/NEA	Gas mixing and distribution in LWR containments (**SETH Project**)
	2007-2010 OECD/NEA	Resolving LWR containment key computational issues (**SETH-2 Project**)
Basic phenomena	2010-2014 EU 7th FWP	Containment thermal-hydraulics of current and future LWRs for severe-accident management (**ERCOSAM-SAMARA Project**)
	2012-2013 Swissnuclear	Experimental program on **Spent Fuel Pool**
	2012-2014 OECD/NEA	**PANDA benchmark** (CFD4NRS-5)
	2013-2016 OECD/NEA	To resolve complex safety issues for the analysis and mitigation of a severe accident leading to hydrogen release into a nuclear containment (**HYMERES Phase 1 project**)
+pool	**2017-2021 OECD/NEA**	To resolve complex safety relevant issues for the analysis and mitigation of a severe accident leading to hydrogen release into a nuclear plant containment and suppression pressure pool system issues (**HYMERES Phase 2 project**)
+SMRs	**2021-2025 OECD/NEA**	PANDA experiments addressing complex safety issues for current water reactors and small modular reactors (SMRs) (**PANDA project**)

The HYMERES and PANDA projects

OECD/NEA HYMERES (Phases 1 and 2) joint projects

The experiments addressed:

- **Hydrogen distribution** on configuration with jet impacting plates or grating platforms,
- **Hydrogen distribution** under the effect of activation of safety components e.g. spray, coolers, heat sources
- **Thermal radiation effect on hydrogen distribution**
- **Pressure suppression pool phenomena**



PANDA rendering

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The HYMERES and PANDA projects (2)

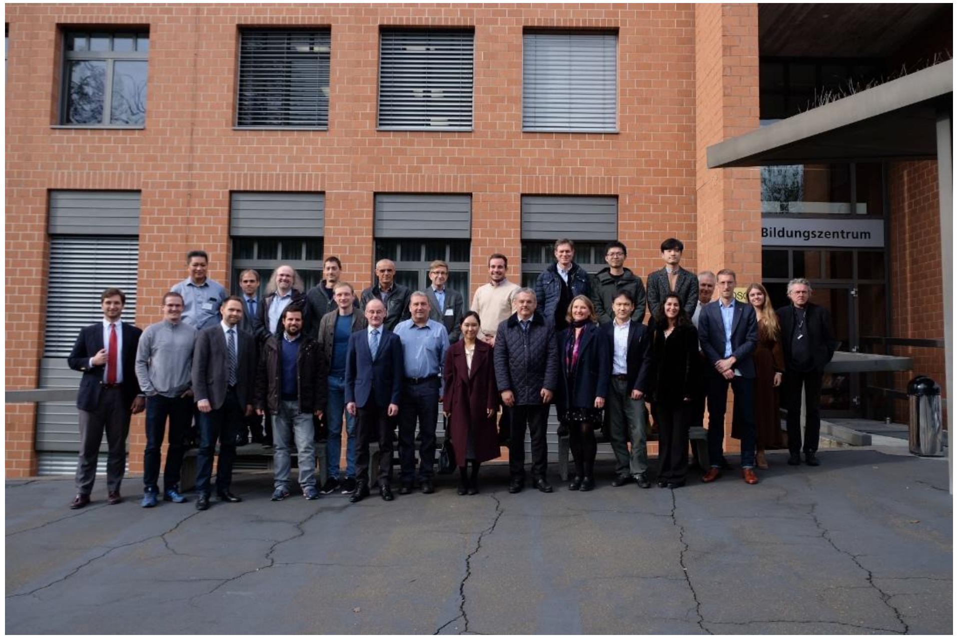
- OECD/NEA **PANDA project**: **PANDA experiments addressing complex safety issues for current water reactors and small modular reactors**

Topic 1: Extend the database at large scale on flow interacting with containment internal structures and on thermal radiation			
P1A1	Jets or plumes impacting complex compartments		Steam generator compartment model
P1A2	Radiative heat transfer		Complex conditions
Topic 2: Extend the database on activation of PWR containment spray system			
P1A3	Complex connected compartments and spray		Two steam generator compartment
Topic 3: Small Modular Reactor (SMR) system tests			
P1A4	Passive Containment Cooling System (PCCS)		System tests
P1A5	PANDA tests addressing natural convection heat transfer (HT) from the external wall of the containment to the water pool		Natural convection at large scale
Topic 4: Extend the database on suppression pool of BWR (and IRWST of PWR)			
P1A6	Various scenarios with/without containment pressurization / depressurization and with/without the interplay of containment compartments		Component and system tests
	Number of PANDA nominal tests:	**24**	

The HYMERES and PANDA projects (3)

❖ OECD/NEA **PANDA project**: **PANDA experiments addressing complex safety issues for current water reactors and small modular reactors**

- Period: **July 2021-June 2025**
- Organizations: **12 Organizations from 9 Countries: *Canada, Finland, France, Germany, Korea, Spain, Sweden, USA, Switzerland***
- Synergies:
  - **THAI experiments related to the SMRs;**
  - **EURATOM SASPAM-SA (Safety Analyses of SMR with Passive Mitigation strategies - Severe Accident) Horizon Euratom Project;**
  - **ATLAS-CUBE containment spray**



3rd PRG and MB meeting was held at PSI on the 2-3 November 2022

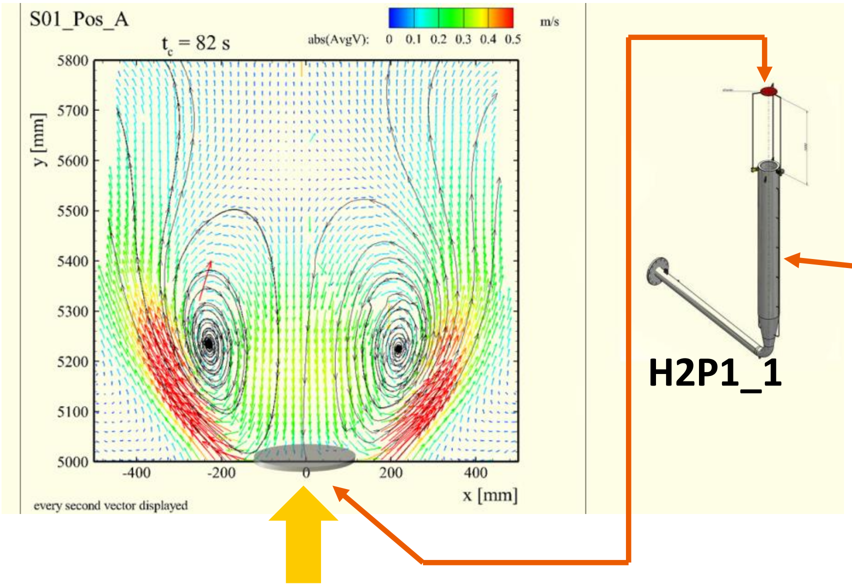
Facility upgrading (HYMERES-2)

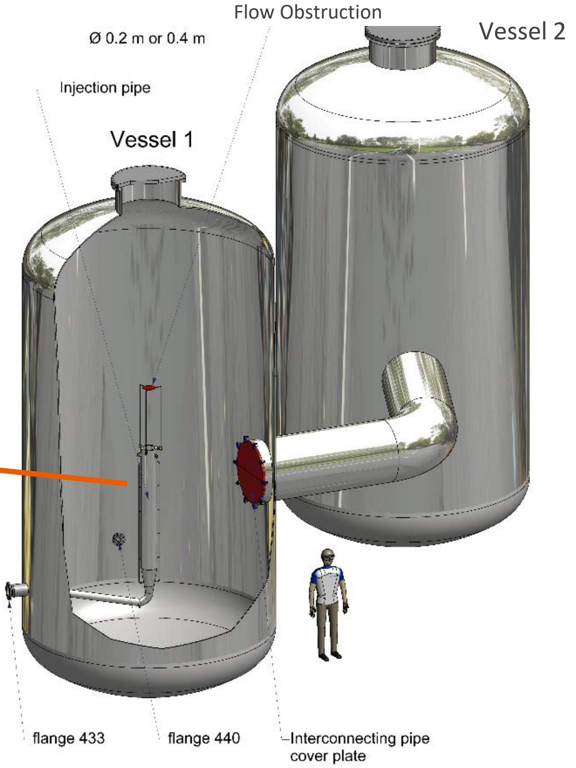
❖PANDA Upgrading: the main upgrading were related to:

➢**DAS, Control Systems, Instrumentation, new components:**

- **H2P1 series**: Flow obstructions such as plates and grating platforms; injection lines.
- **H2P2, H2P5, H2P6 series**: cover plate (10 bar specifications) to close the Vessel 1-Vessel 2 interconnecting pipe.
- **H2P2 series**: new helium line and flow obstruction-flow diffuser.

Flow velocities measured with PIV above the flow obstruction



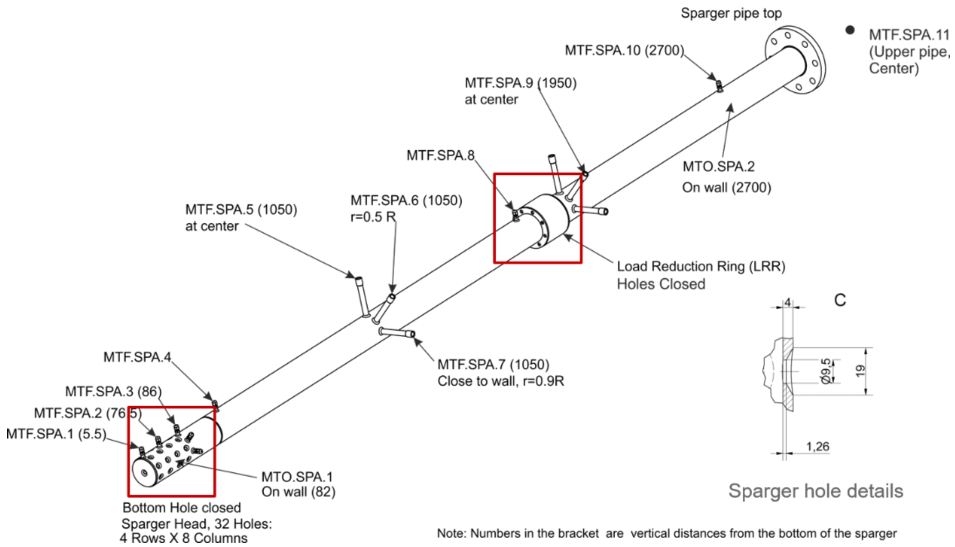


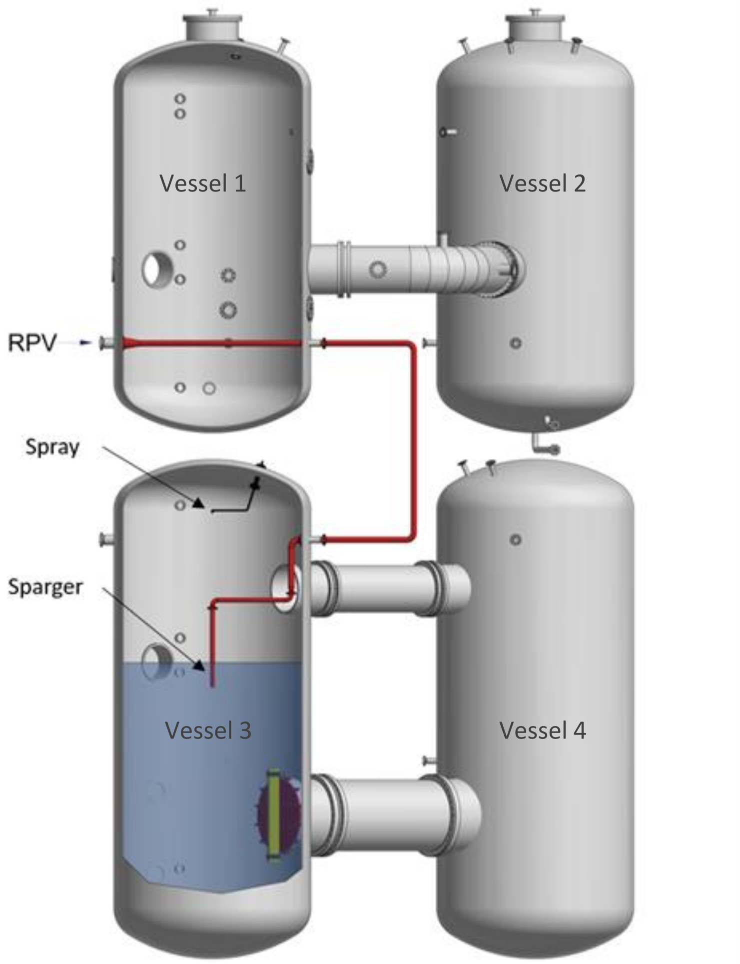
Facility upgrading (HYMERES-2)

❖ PANDA Upgrading: the main upgrading were related to:

➢ **DAS, Control Systems, Instrumentation, new components:**

- **H2P3 series**: sparger and sparger feeding pipe to locate the sparger a different radial positions), calibration targets for 2D/3D PIV.
- **H2P4 series**: sparger and sparger feeding pipes to locate the sparger at different elevations; spray nozzle and spray feeding line; covering plate for the Vessel 3 – Vessel 4 interconnecting pipes.



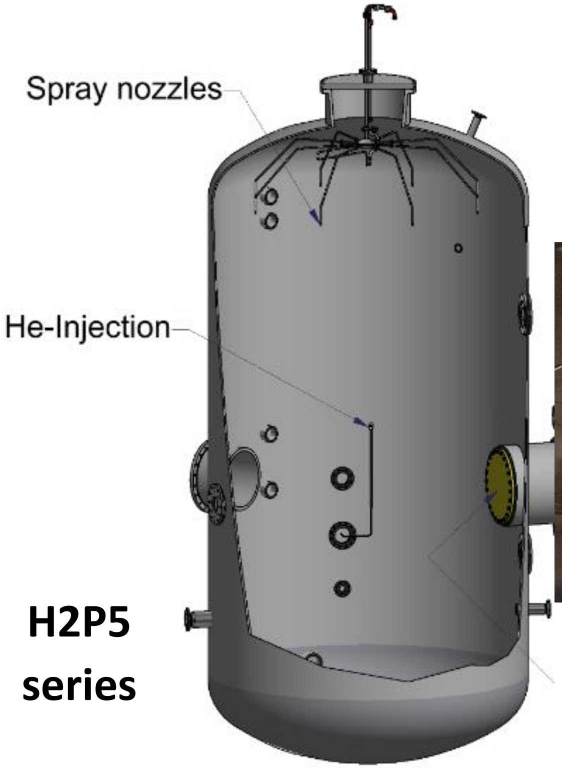


H2P3 and H2P4 series

Facility upgrading (HYMERES-2)

❖PANDA Upgrading: the main upgrading were related to:

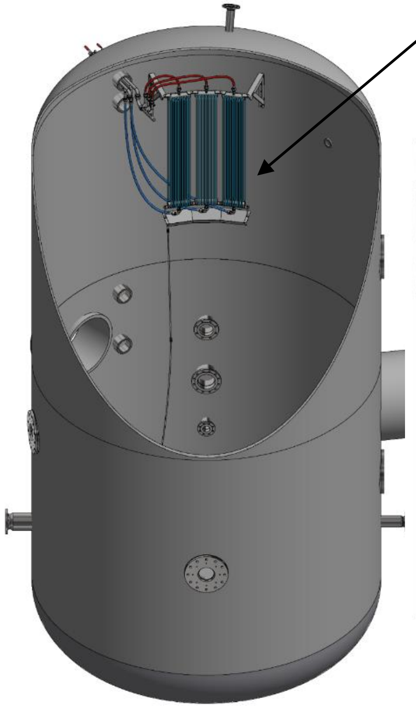
- **H2P5 series**: spray systems (one spray nozzle and nine spray nozzles configurations) and spray feeding line
- **H2P6 series**: cooler systems (one cooler and three coolers configurations) and cooler feeding/return lines.



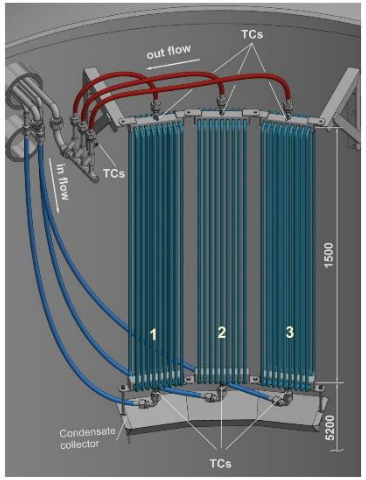
H2P5 series

Spray testing

Cooler arrays



3 D rendering



H2P6 series

Benchmark activities

- The analytical activities are carried out by the Operating Agent and by the Project Participants:
- LP, CFD or CFD type codes are used, depending also by test characteristics

➢**Scoping analyses** (to design the experiments and to define instrumentation layouts, to identify the test initial and boundary conditions (IBC))

➢**Pre –test analyses** (based on the final test configuration and nominal IBC

➢**Post –test analyses** (based on the actual IBC)

➢**Benchmark analyses** (blind and open phases to compare modeling, code and user effects)

Basic phenomena in an empty multi-compartment containment

OECD/NEA SETH buoyant Jet/plume; Stratification build-up	**OECD/NEA SETH-2** Negative buoyant Jet/plume Erosion of stratification
Benchmark: Tests 9-17 (EU ECORA)	Benchmarks: ST1_7, CFD4NRS

Basic phenomena in a multi-compartment containment with obstructions

OECD/NEA HYMERES phase 1 Horizontal/vertical plates	**OECD/NEA HYMERES phase 2** Inclined grid
Benchmark: HP1_6	Benchmark: H2P1_10_2

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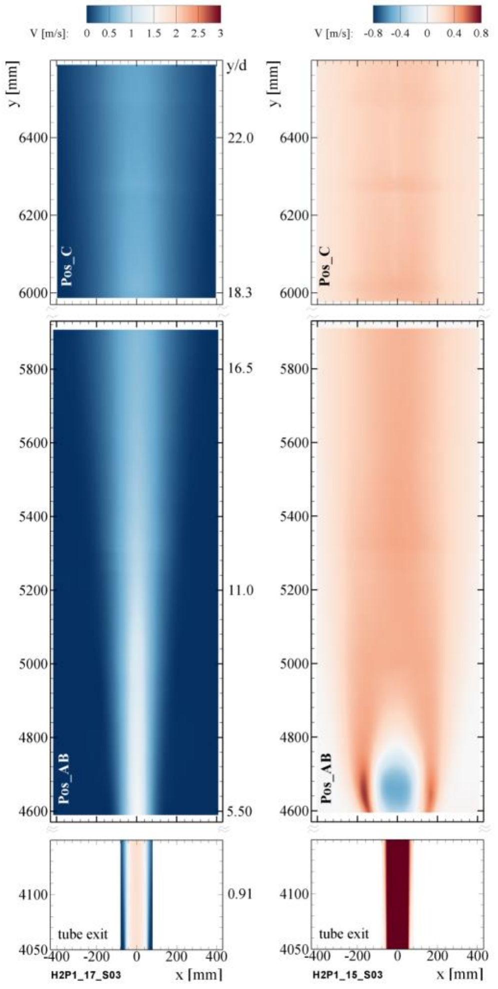
Project deliverables and publications

- **Project deliverables and publications:**
  - ➢The PANDA experimental data and technical reports (**project deliverables**) are distributed to the NEA and to the project participants
- **Analytical workshops (AW) are organized back to back with most of the PRG meetings, the experiments are analyzed with a variety of tools, e.g. LP, CFD (commercial; open source solvers), NEK5000.**
- **Dissemination of Project Outcomes to the Scientific Community:**
  - ➢The main outcomes from the experimental program and from the analytical activities are published by the Operating Agent and/or the project participants in **journal articles** and **conference papers**

Re=10000



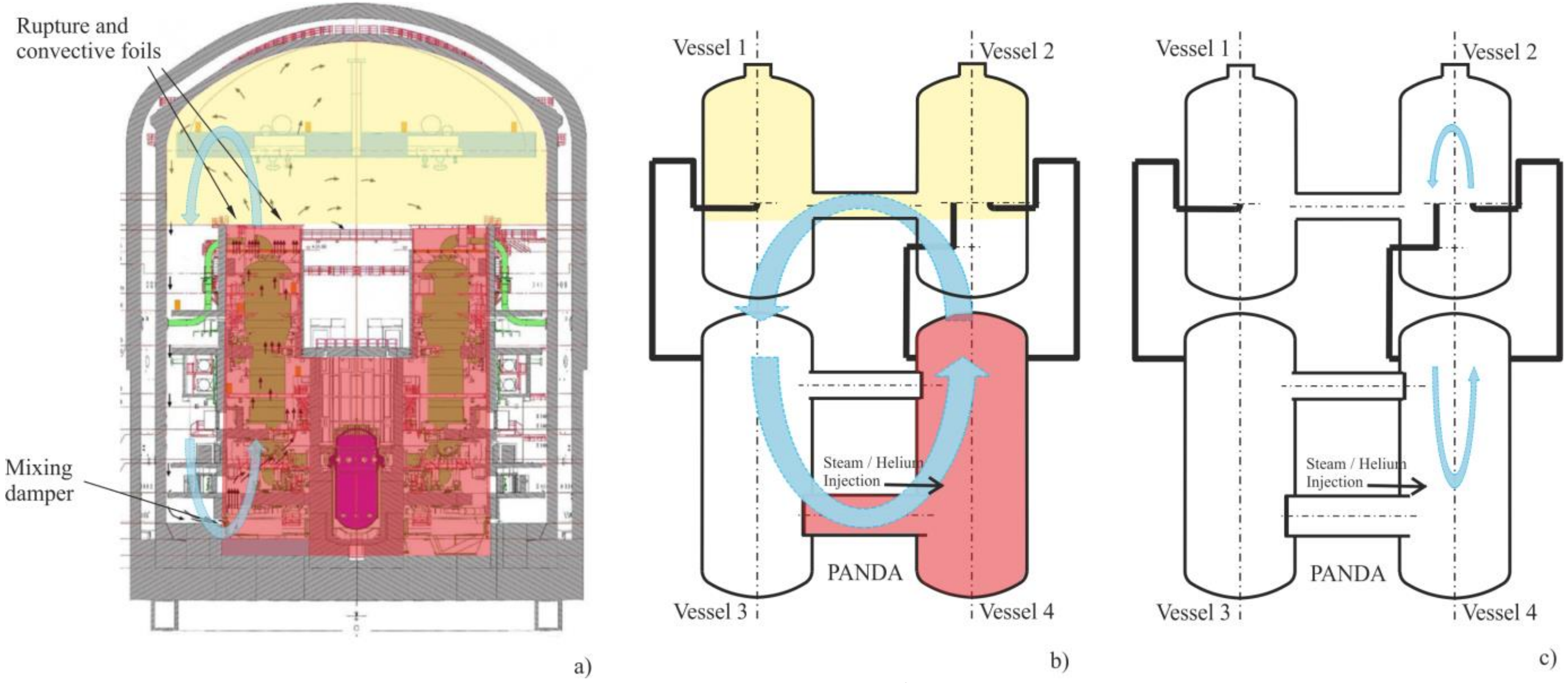
H2P1_17 and H2P1_15

Analyzed with NEK5000

Nuclear Safety Applications

- The approach is first to assess and validate computational models against PANDA experiments and then use the experience gained during the validation process to analyze postulated accident scenario in real nuclear power plants
- Experiments/Analyses were made, e.g. related to two-room type containment, and as well to other containment types

Example of PWR applications



Two-room type containment

OECD/NEA HYMERES phase 1 PANDA HP6 series

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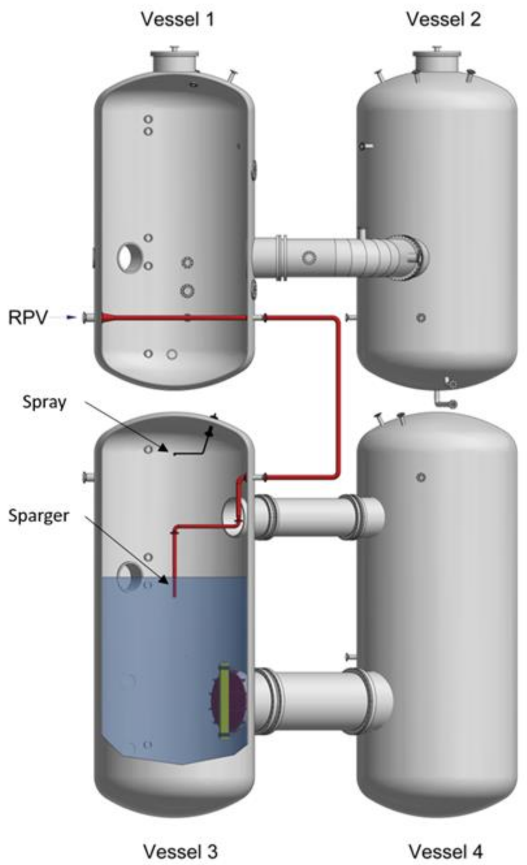
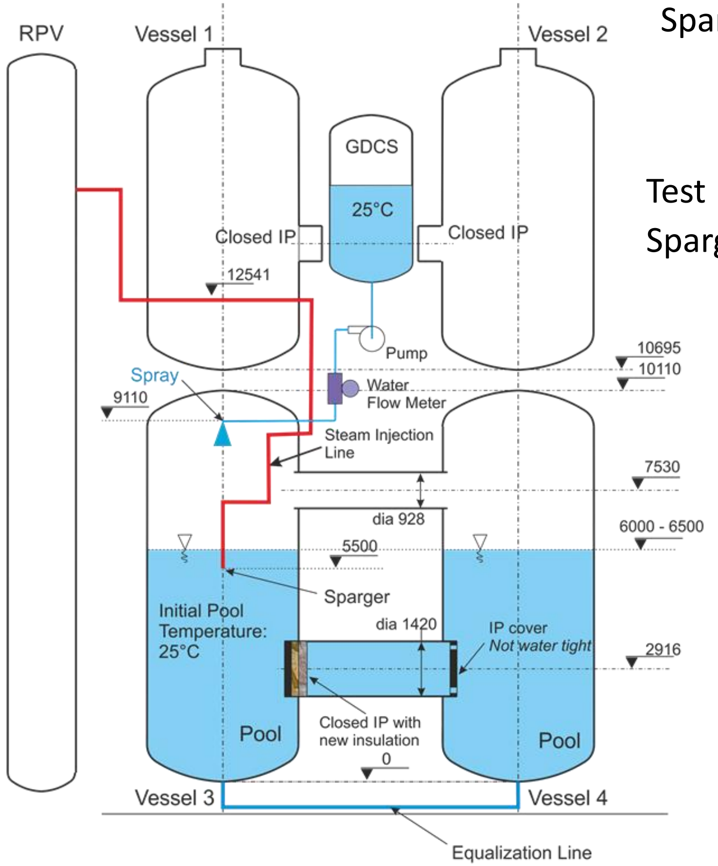
Nuclear Safety Applications (2)

Example of BWR applications

The PANDA experiments investigated the effect of thermal stratification phenomena in the suppression pool of BWRs on the containment pressurization





Test H2P4_2:
Sparger submergence: 1.2 m

Test H2P4_3:
Sparger submergence: 0.5 m

OECD/NEA HYMERES-2 project (H2P3 and H2P4 series)

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Activities within the OECD/NEST framework

Nuclear Education, Skills and Technology (NEST) Framework

- NEST promotes the mobility of Fellows (MSc, PhD, Post-doctoral)
- Research activities are carried out by each Fellow in one or more Institutions

https://www.oecd-nea.org/jcms/pl_24321/nest-hymeres

- The objectives of the NEST Fellows activities are to:
  - **Contribute** with computational analyses to the definition of PANDA tests and to identify the optimal configurations to reach the objectives of the individual series
  - **Gain** insight into the computational modelling needs to represent containment phenomena in compartments or structures or also related to SMRs
  - **Develop** methodologies for processing the experimental data which enhance the understanding of phenomena during specific tests
  - **Perform** complementary experiments in small and medium scale facility (**at PSI and also in other Institutions**) which provide a broader understanding of the phenomena investigated in the project

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Feedbacks and Main Challenges related to the Project Development

- To maintain large facility in operation ideally there should be time continuity between project phases
- The research topics for the new project should be identified one to two years before the end of a running project
- However, usually the research needs are identified as results of the research activities and therefore it is challenge to identify them before the end of running projects
- Project opportunities may come out of on-going WGAMA activities
- Synergies with other projects (OECD/NEA) or projects in other frameworks (National, EURATOM, IAEA) whenever possible, can lead to cross-activities of mutual interest (e.g. benchmarks, etc.)
- Involvement of NEST Fellows in experimental and/or computational activities are highly beneficial.

Outlook for future research activities

- Foreseen follow-up, i.e. OECD/NEA PANDA-2 (2025-2029):
  - Research investigations in PANDA for:
    - **BWR**: suppression pool phenomena, integral test, interaction of safety systems and compartments
    - **PWR**: containment safety systems (active and passive), representation of steam generator towers
    - **SMR**: phenomena of interest for BWR and PWR SMRs, passive safety systems and interaction of primary and secondary circuit
  - Experimental data to be suitable for **CFD codes, LP and System codes**
  - Counter-part/complementary experiments **in other experimental facilities (scaling effects) at PSI and/or in other Institutions**
  - Synergies for defining selected experiments and benchmarks **with other OECD/NEA Joint projects and EURATOM projects**

Conclusions and perspectives

- PANDA projects within the OECD/NEA framework allowed the creation of unique experimental database on containment phenomena with safety relevance
- The PANDA experiments have been analyzed over the years to assess a variety of computational tools and this has contributed to advance the knowledge on containment phenomena and on the modeling needs
- In perspective we foreseen that PANDA will be operated for system and integral tests for BWRs, PWRs, SMRs, with configurations requiring more compartments/vessels (RPV, DW, IC/PCC)
- Synergies and sharing information with other OECD/NEA joint projects and with projects in other framework (i.e. EURATOM, IAEA), whenever possible, will be beneficial for defining the new experiments and computational analyses

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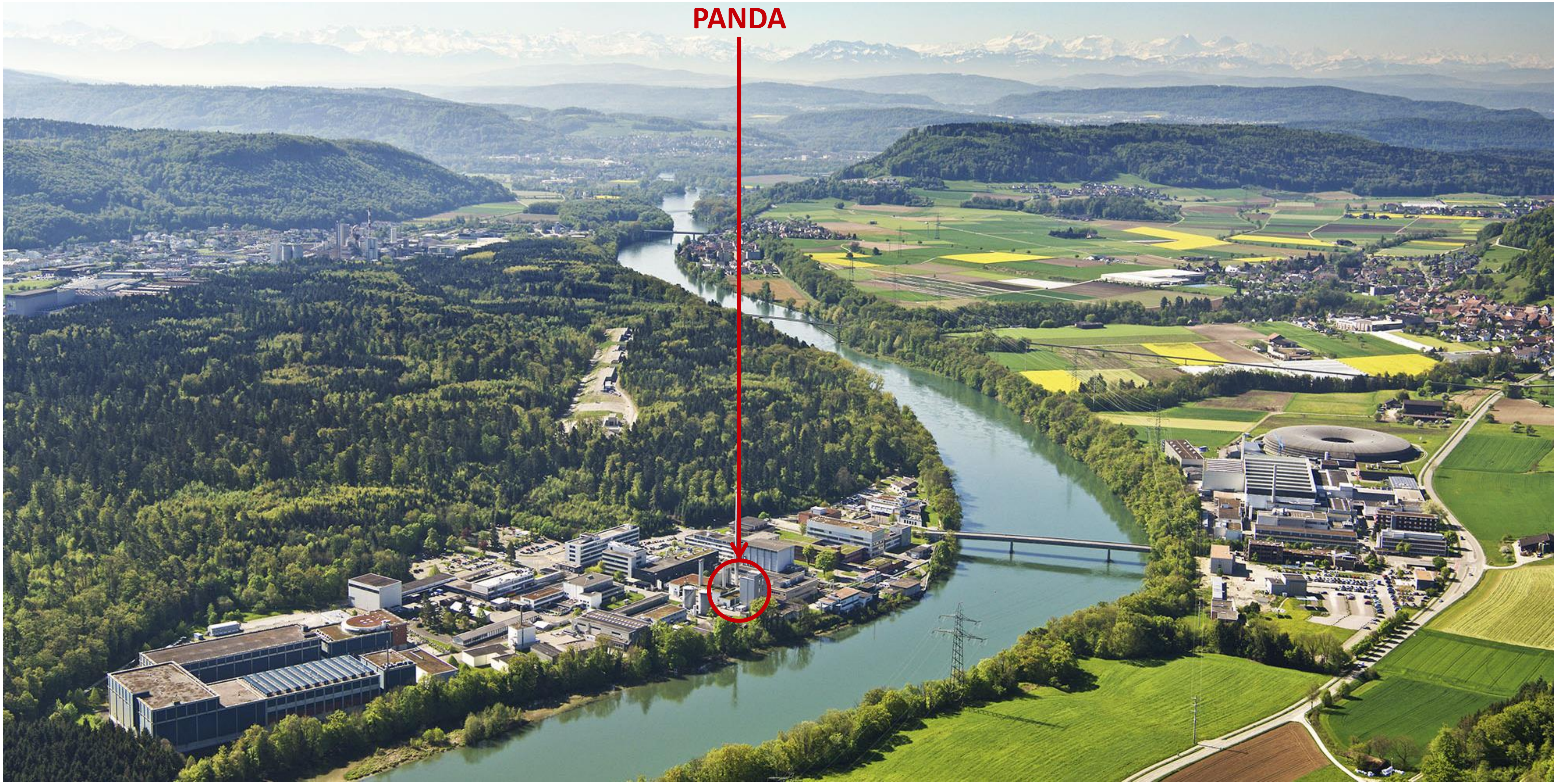
Wir schaffen Wissen – heute für morgen



Session 4

Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

► Example of an Accident Progression and Melt Coolability In-Vessel and Ex-Vessel Project

ROSAU

Dr Jeremy LICHT

Nuclear Engineer, Principal Investigator for the ROSAU Project, Argonne National Laboratory, United States

Dr Jeremy LICHT is a Nuclear Engineer in the Nuclear Science and Engineering Division at Argonne National Laboratory. One of his roles at Argonne is principal investigator for the NEA ROSAU project that is the focus of this conference's presentation. He received his BS in Physics and MS/PhD in Nuclear Engineering and Engineering Physics from the University of Wisconsin. Following this, Jeremy worked at the Canadian Nuclear Laboratories (formally AECL) for five years supporting CANDU-related experiments and analyses in reactor safety. In 2013 he moved back to the United States to work at Argonne, where he has since been supporting reactor safety and non-proliferation activities.

NEA NUCLEAR ENERGY AGENCY

NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK

Success Stories and Opportunities for Future Developments

9-13 January 2023

Example of an Accident Progression and Melt Coolability In-Vessel and Ex-Vessel Project

ROSAU

JEREMY LICHT (jlicht@anl.gov)

Nuclear Science & Engineering Division
Argonne National laboratory

OUTLINE

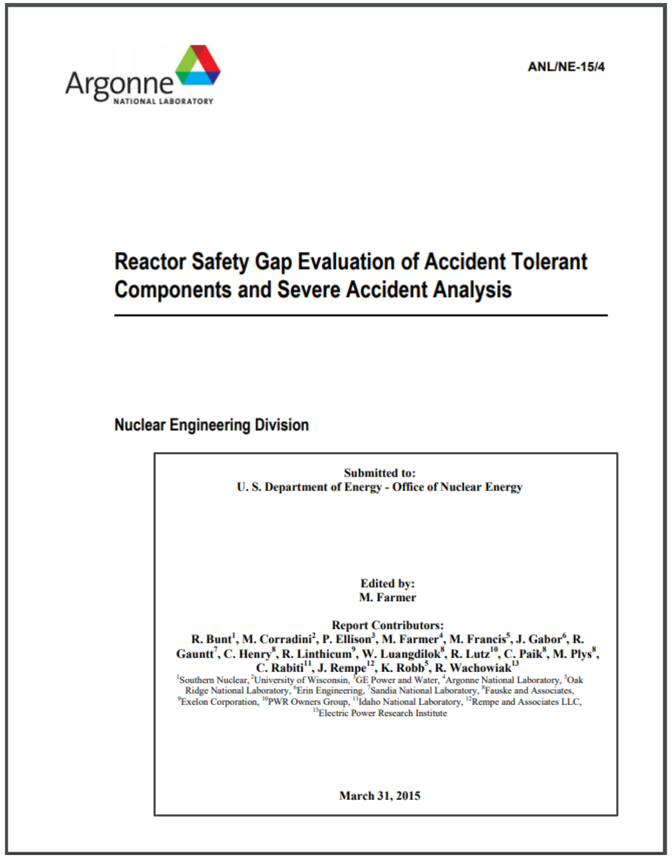
1. Overview of ROSAU Project
2. Main Outcomes and Benefits
3. Feedback on Main Challenges
4. Insights on Future R&D
5. Conclusion

OVERVIEW OF ROSAU PROJECT (1/2)

OECD/NEA Reduction of Severe Accident Uncertainties (ROSAU) International Joint Project

High level program objective:

- Reduce uncertainties in ex-vessel core melt progression and melt coolability by providing data to validate codes, aid in the Fukushima decommissioning efforts, and better inform severe accident management
  - **Operating Agent:** US NRC under the auspices of OECD/NEA
  - **Performing Lab:** Argonne National Laboratory
  - **Participants:** 20 Organizations from 8 countries
  - **Duration:** September 2019 - 2024


Argonne NATIONAL LABORATORY

ANL/NE-15/4

Reactor Safety Gap Evaluation of Accident Tolerant Components and Severe Accident Analysis

Nuclear Engineering Division

Submitted to:
U. S. Department of Energy - Office of Nuclear Energy

Edited by:
M. Farmer

Report Contributors:
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[1]Southern Nuclear, [2]University of Wisconsin, [3]GE Power and Water, [4]Argonne National Laboratory, [5]Oak Ridge National Laboratory, [6]Erin Engineering, [7]Sandia National Laboratory, [8]Fauske and Associates, [9]Exelon Corporation, [10]PWR Owners Group, [11]Idaho National Laboratory, [12]Rempe and Associates LLC, [13]Electric Power Research Institute

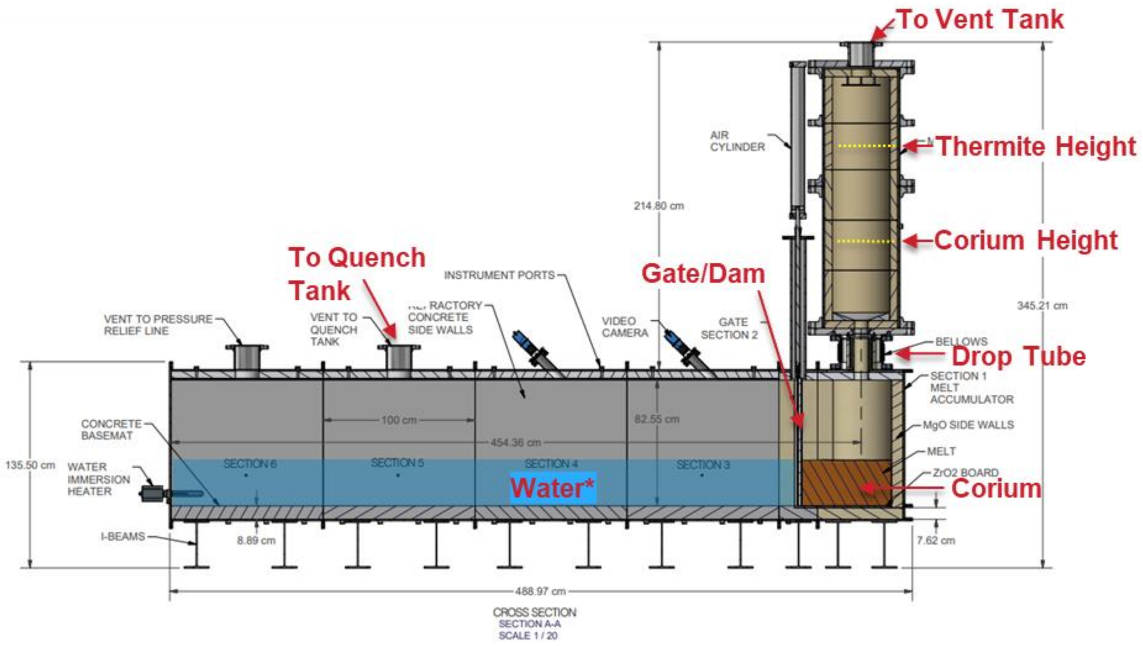
March 31, 2015

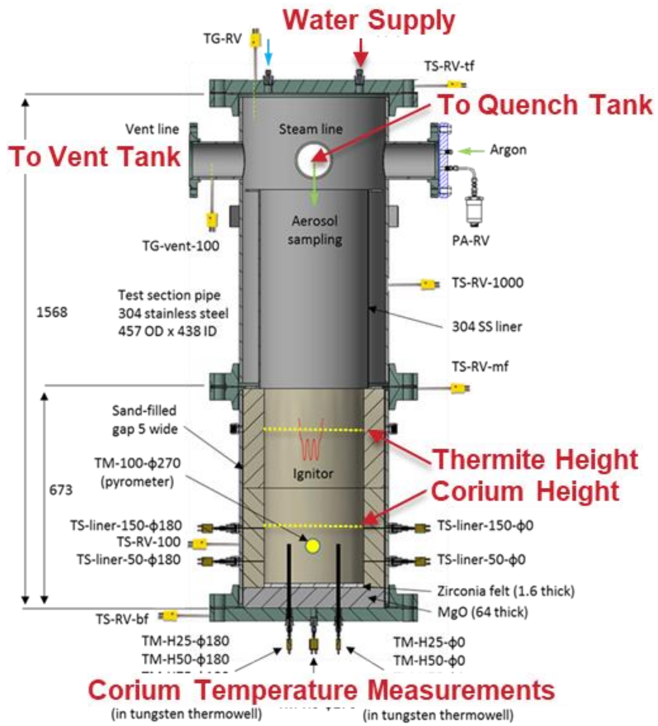
OVERVIEW OF ROSAU PROJECT (2/2)

Two test programs are being carried out to meet program objectives:

Melt spreading: Address uncertainties in the nature and extent of under water spreading of prototypic core debris and provide data for validating severe accident codes

Debris coolability: Fill data gaps regarding coolability and H_2 production for prototypic melts containing metal content for both in-vessel and ex-vessel conditions



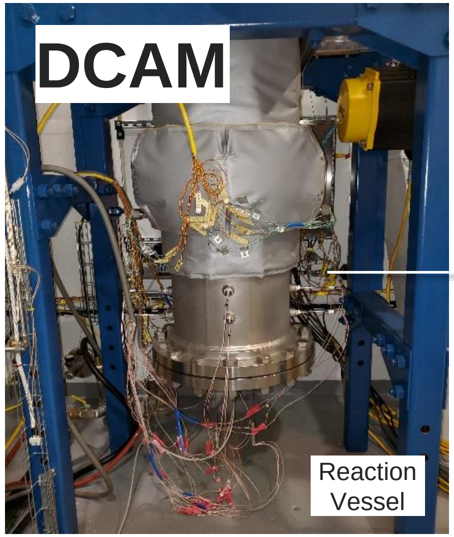


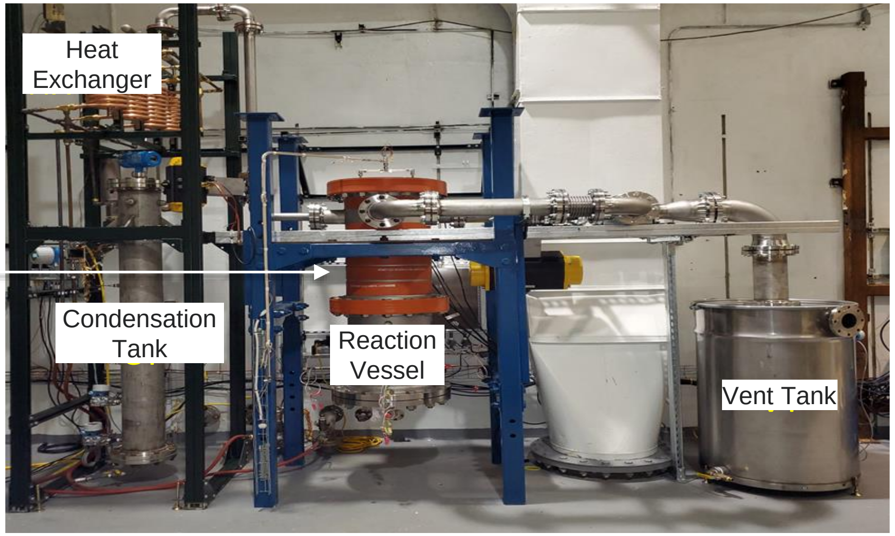
FACILITIES AND COMPETENCIES (1/2)

The ROSAU project has provided the opportunity to refine existing experiment facilities and to develop new experiment capabilities to address new phenomena

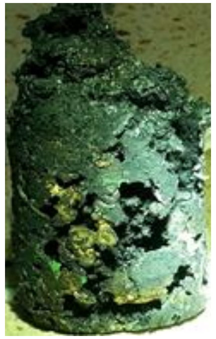
- **The Melt Spreading Test (MST) facility** has been newly developed to, for the first time, investigate at large scale the extent and nature of prototypic core debris spreading under water.

- **The Debris Coolability and MCCI (DCAM) facility** has been ungraded to provide measurements of hydrogen evolution and aerosol scrubbing during debris quench of prototypic reactor materials.

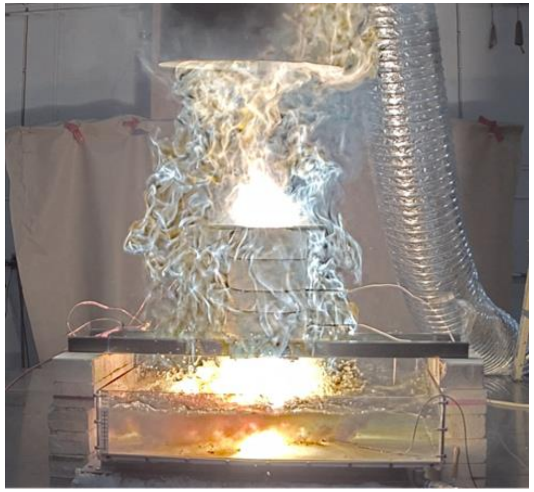




FACILITIES AND COMPETENCIES (2/2)



Competencies developed among the project staff in the areas of design, fabrication, operation, data interpretation, and modeling related to large-scale, high-temperature prototypic corium compositions



- Thermite development and testing for high temperature corium generation (containing UO_x-ZrO_x, Fe/Zr/Cr metals, and concrete constituents)
- Development and experience with new measurement techniques (hydrogen, aerosols, debris morphology, high temperature melts)
- Code use and model development (e.g. COREQUENCH and MELTSPREAD)
- Engaged university student in the development of tools for post-test examination.
- Knowledge transfer among ANL staff and project partners

NUCLEAR SAFETY APPLICATIONS (1/2)

- Knowledge gaps exist in ex-vessel melt progression and coolability; important gaps include lack of MCCI data with melt compositions containing unoxidized metal and data on melt spreading under water
- Resulting uncertainties in debris cooling by water can be significant, and the efficacy of current severe accident management actions may not be adequate
- ROSAU data will contribute to reduction of uncertainties in ex-vessel melt coolability and enhancement of severe accident management actions

NUCLEAR SAFETY APPLICATIONS (2/2)

- Results from ROSAU tests with prototypic metal-oxide melt compositions would support in-vessel core recovery actions involving core reflood
- Results from ROSAU tests with concrete-rich melt compositions would support investigation of long-term* debris coolability
- Existing melt spreading database is practically void of underwater spreading of prototypic core melt; results from ROSAU melt spreading tests would support development of improved melt spreading model(s) for incorporation into severe accident analysis codes

*(hours to tens of hours)

NETWORKING (1/1)

- Various stakeholders are participating in the ROSAU project.
  - **Regulators:** NRC (USA; also the project Operating Agent), NRA (Japan), SSM (Sweden)
  - **TSO:** Bel V (Belgium), IRSN (France), KINS (Korea)
  - **Research Institutions/Labs:** CNL (Canada), CEA (France), UJV (Czech Republic), KAERI (S. Korea), JAEA & AdvanceSoft (Japan), KTH (Sweden), ANL (USA)
  - **Industry:** Tractebel (Belgium), EdF (France), KEPCO & KHNP (Korea), TEPCO (Japan), EPRI (USA)
- Method for establishing a common basis for test program definition and resolution of safety issues
  - Active development of models for new phenomena and validation against test data.
  - Pre- and posttest analysis activities conducted by project participants
  - Specifications for each test are arrived at by consensus decision from project participants.
- In-kind contributions among partners, for example:
  - Experiment and modeling work performed at KTH
  - Supporting analyses (e.g., thermodynamic database evaluations by UJV and IRSN)

VALUES (1/1)

- Transfer of Data to NEA Data Bank
  - ROSAU project is nearly halfway in the project milestones;
    - Debris Coolability and MCCI (DCAM): 3 tests completed, 2 tests remaining;
    - Melt Spreading Tests (MST): 1 test completed (commissioning), 1 test immanent, 4 tests remaining
  - All information (reports, data, videos) currently archived at ANL
    - Discussions underway to define transfer to the NEA data bank by end of project
- Reporting of Project Outcomes
  - Prepared reports for all completed experiments; reports are disseminated to project partners through dedicated OECD/NEA ROSAU website
  - Project outcomes reported at PRG meetings held every six months; presentations and other documentations archived in the ROSAU website
  - Published a technical paper at the ANS Proceedings; present progress at the annual CSARP technical meetings (Cooperative Severe Accident Research Program)
- Distribution of updated codes, such as MELTSPREAD and COREQUENCH

FEEDBACK ON MAIN CHALLENGES (1/2)

- Dynamic Nature of Project **Scope**
  - ROSAU included both the refurbishment of a previous experiment (DCAM) and development of a new experiment (MST), which is not typical of other projects
  - ROSAU test matrices (for DCAM and MST) have been continually evolving throughout the project
  - Changes are the result of:
    - Competing needs and priorities of partner organizations, which are also evolutionary in nature
    - Lessons learned from the completed experiments and recalibrating the remaining experiments accordingly
    - Ongoing discussions about what is or is not technically feasible from an experiment capability perspective
  - These changes, whether implemented or not, can impact both schedule and budget; should be accounted for before the project starts

- Partner **engagement**
  - More analyses by partners are needed to exercise data and identify modeling/code deficiencies, including engagement on development of model improvements

FEEDBACK ON MAIN CHALLENGES (2/2)

- Budget and Schedule
  - Challenges of an OECD/NEA project:
    - Approved budget was less than funding needed to execute the full ROSAU scope (Late decision by some participants to not join project)
    - Discrepancy in the project start time (agreement signatures vs. funding available to start work)
    - Actual time for participant funds to reach performing lab can be significant
    - Differences/irregularities in participant funding cycles difficult to accommodate (including exchange rate)
  - Challenges due to COVID-19:
    - The COVID-19 pandemic occurred ~9 months after the start of ROSAU
    - Time and effort needed to restart limited and normal operations at ANL
    - Fabrication delays as well as shop outages due to COVID-19 outbreaks
    - Acquisition of equipment and instrumentation significantly delayed
    - Project meetings held by remote video conferencing (typically 4 hrs in duration maximum) rather than multiple day, in-person interactions

INSIGHTS ON FUTURE R&D NEEDS & TRENDS (1/2)

- Trends in ROSAU
  - Valuable insights gained from the 4 completed MST and DCAM experiments and it should be assumed the same will be true for remaining 7 experiments.
  - Already identified needs for model developments and improvements in both the MELTSPREAD and COREQUENCH codes
- Trends in Future Reactor Designs
  - Advanced reactor concepts have gained considerable ground in recent years; among the leading design candidates for commercialization are: LWR SMR varieties, LMRs and others
  - Some designs reportedly have the options of employing both conventional fuels and accident tolerant fuels

INSIGHTS ON FUTURE R&D NEEDS & TRENDS (2/2)

- Future R&D Needs
  - For ROSAU, the number of DCAM and MST experiments that could contribute to reduction of severe accident uncertainties potentially far exceeds what is possible in the current ROSAU project
  - For advanced designs, coupled with advanced fuel types, these may require same or similar type of confirmatory investigations as required for the conventional designs and fuel types
- Role of ANL facility to meet the future R&D Needs
  - With minimal changes, ANL facilities can be utilized to perform:
    - Additional experiments related to scope identified in the current ROSAU project,
    - Perform new types of experiments related to advanced designs, e.g., investigating the SA performance of FeCrAl type cladding materials
  - The ANL team and experimental facilities supporting ROSAU will be fully mature at the conclusion of the current program; preserving these capabilities will be beneficial to the SA community

CONCLUSIONS

- The ROSAU project is successful in developing / maintaining critical facilities and competencies of project partners and generating data needed for code development and validation useful to project partners in
  - Informing severe accident management and mitigation
  - Confirming needs for improved material properties data (e.g., TCOFF and proposed COPS projects)
- However, the budget shortfall, in combination with the COVID-19 pandemic, constrains the benefits that could be realized for ROSAU project partners:
  - Reduced scope to accommodate budget shortfall and COVID-19 delays
  - Funding (magnitude and frequency) insufficient to cover ANL staff needed to perform this work and inadequate for maximizing knowledge transfer opportunities
- With nuclear reactors being phased out in some countries, the burden to keep facilities and related expertise falls on fewer partners.
  - However, with greater emphasis on reducing carbon footprint, there is a renewed interest in nuclear energy which provides hope that a healthy research program will be maintained in the future
- Similar SA work related to advanced reactors yet to be realized at ANL

THANK YOU FOR LISTENING!

Session 4

Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

► Example of a Source Term Project

STEM/ESTER

Mr Christophe MARQUIE

Deputy Head of the Experimental Department, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France

Mr Christophe MARQUIE graduated in 1996 from Centrale-Supelec engineering school with a specialty in nuclear engineering. Since then he has been working at the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), first as test director on the CABRI reactor devoted to the study of reactivity accidents, as well as on FBR and PWR reactors. He participated to the REPNA-1 task force implemented under the NEA's aegis. In 2001, he became project engineer for the CABRI project in charge of experimentation and hot lab co-ordination for the NEA CIP Project. In 2005, he was nominated as head of the engineering laboratory in charge of the design of test devices for IRSN safety research like CABRI test devices (CIP project) or CHIP facility (STEM Project). In 2015, he became project leader for the ODOBA (project devoted to concrete ageing) and DENOPI (spent fuel pool accidents project). As such, he participated to the NEA CAPS ASCET (concrete ageing) and the NEA PIRT on Spent Fuel Pool. Since 2019, he is deputy head of the experimental department in Cadarache in charge of severe accident and ageing projects. He is also project leader of the ESTER project.

RÉPUBLIQUE FRANÇAISE
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INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

CSNI STEM/ESTER PROJECTS

Nuclear Safety Research Joint Projects Week

MEMBRE DE ETSON

Source Term R&D

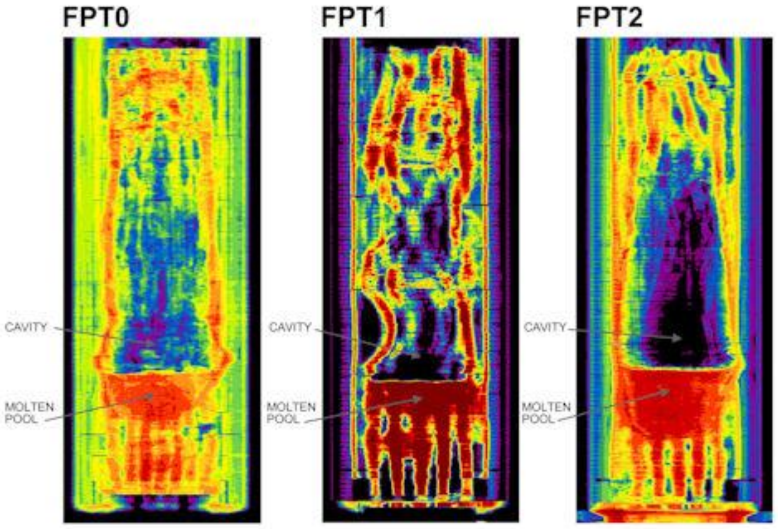
[CONTEXT

- Knowing radioactive releases during a Severe Accident is of paramount importance to assess the consequences of such accident and to support public authority decisions (population displacements, distribution of stable iodine pills).

- At the end of 1980's, IRSN launched the international PHEBUS FP program to study the full sequence of a SA from the fuel degradation to fission products (FP) transport.

- Concerning FP, PHEBUS tests evidenced large discrepancies between calculations and experimental results.

- A large international effort to better understand PHEBUS results (and later Fuskushima Daiichi observations) with the support of OECD/NEA or EU : ISTP, PASSAM, BSAF, THAI, BIP, **STEM, ESTER**… + expert meetings, PIRTs, workshops…



STEM/STEM-2 Projects (Source Term Evaluation and Mitigation)

[IDENTITY CARD

- STEM :
  - 2011-2015
  - Operating Agent : IRSN
  - Partners : CNL (Canada), UJV (Check Republic), VTT (Finland), EDF (France), GRS (Germany), KINS and KAERI (South Korea), NRC (USA)
  - Budget : 3,5 M€
  - Main Objective : iodine behavior (iodine/paint interactions) under radiation in containment + ruthenium chemistry and transport in RCS in oxidative conditions

- STEM-2 : Follow-up of STEM (initiated after 2015 NEA iodine workshop)
  - 2016-2019
  - Operating Agent : IRSN
  - Partners : CNL (Canada), VTT (Finland), EDF (France), GRS (Germany), NRA (Japan), KINS and KAERI (South Korea), NNL (UK), SSM(Sweden), NRC (USA)
  - Budget : 2,5 M€
  - Main Objective : iodine behavior (paint ageing and iodine aerosol stability) under radiation in containment + ruthenium chemistry and transport in RCS in oxidative conditions

STEM/STEM-2 Projects

MAIN SCIENTIFIC OUTCOMES

- Data for enhancing models calculating formation and transportation of iodine and ruthenium species
- Data /models implemented in SA code (ASTEC) which result in better calculation of iodine volatile fractions in experiments and release in real accidents
- BUT :
- Still underestimation of I-Org formation by an order of magnitude for PHEBUS tests
- Poor calculation of long-term Cs releases during the Fukushima Daiichi accident (BSAF-2 project)
- Both justified the need of a new project: ESTER

ESTER Project (Experiments on Source Term for delayed Releases)

IDENTITY CARD

ESTER :

- 2020-2024 (initiated after 2020 NEA Source Term Workshop)
- Operating Agent : IRSN with some experiments performed by CEA
- Partners : VTT (Finland), CEA and EDF (France), GRS (Germany), NRA and JAEA (Japan), KINS (South Korea), SSM (Sweden), NRC (USA)
- Budget : 3,14 M€
- Main objective : chemical remobilization of FP deposits in the RCS and other sources of formation of organic iodides than interaction with paints

Status of ESTER Project

- Concerning formation of organic iodides under radiation (5 tests performed – 2 remaining to be performed in 2023), tests showed
  - a limited influence of Volatile Organic Compounds
  - A strong effect of carbon "pollution" of SS surfaces

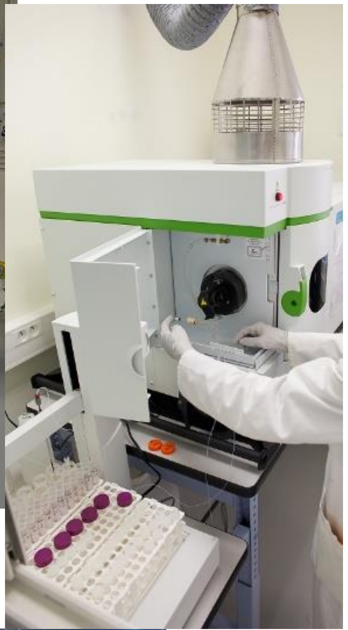
- Concerning revaporization of FPs deposits in the RCS
  - PhD on analytical tests is completed: conditions of CsI, CdI_2 and Te revaporization were identified
  - 1st semi-analytical tests planned in January 2023 : deposition phase (early stage of the accident) in the primary circuit and then revaporization phase due to change of environmental conditions planned
  - Confirmatory tests with prototypic deposits planned in April 2023

STEM/ESTER Projects

SUPPORT TO DEVELOP, UPGRADE AND MAINTAIN UNIQUE EXPERIMENTAL PLATFORM

CONSIDERED AS “STRATEGIC” FACILITIES BY OECD/NEA SESAR GROUP FOR NUCLEAR SAFETY RESEARCH

- START TGT



- EPICUR γ-irradiator + LEAR hot-Lab

STEM/ESTER Projects

[SUPPORT TO DEVELOP NUMERICAL CODE

- In each STEM/ESTER project, analytical activities were conducted in a dedicated working group : benchmarks with ASTEC (VTT/IRSN), COCSYS (GRS), RAIM (KINS), INSPAIR(NNL) codes

- They allow to :
  - develop and validate models
  - to exchange “good practices” between partners
  - To identify lack of knowledge/discrepancy with experiences (like PHEBUS FP tests) or real accident (like Fukushima-Daiichi) and then reorient experimentation and research effort

- Common recommendations were reached with BIP-3 AWG

STEM/ESTER Projects

[SUPPORT TO COMMUNITY AND DISSEMINATION OF KNOWLEDGE

- Project data are transferred to the NEA data bank at the end of the “embargo” (3 years) period and available to NEA members

- In connection with other projects, workshop were organized to assess knowledge status and need for new research like the NEA 2020 workshop on Source Term

- Journal and conference papers have been published based on projects results : at least 12 for STEM and 13 for STEM-2

Complementarity with other projects

EXAMPLE : OECD/NEA THAI/THEMIS PROJECTS

- THAI/THEMIS (Becker Technologies) projects have addressed hydrogen (PAR, mixing …) and ST issues

- On ST topic, both facilities are complementary
  - THAI facility (big containment) can cover some issues relative to aerosol physics, pool-scrubbing or coupling H_2 deflagration/iodine behaviour for instance
  - CHROMIA IRSN platform is focused on high temperature PFs behaviour (RCS), radiation effects and chemical effects not depending on the scale effect.

  → For instance, for iodine oxides, nucleation was studied in THAI and chemical stability in CHROMIA

OTHER INTERNATIONAL PROJECTS : OECD/NEA BIP, EU PASSAM, ISTP...

STEM/STEM-2/ESTER Projects

MAIN CHALLENGES

- Difficulties to find partners for ESTER project:
  - Scientific interest is present (see 2020 NEA ST Workshop) but economic constraints from partners
  - Geopolitical considerations : e.g. Russian participation was planned but stopped with war with Ukraine
  - reduced participation from former projects (STEM/STEM-2): hence a slight reduction of the program

- Technical challenges linked to complex test devices :
  - Retrofit of CHIP facility
  - Preparation of tests on VERDON samples …

- Indirect geopolitics impact on the project: Russian war led to difficulties to import ^{60}Co for the EPICUR irradiator (solved)

- OECD/NEA Agreement was rather a smooth process

STEM/STEM-2/ESTER Projects

CONCLUSIONS

- Fruitful projects that lead to improve understanding, knowledge of source term in case of SA within an international frame
- Development and validation of models in the ASTEC code – benchmarks within the AWGs
- “Closed” item : Ru transport under LWR SA conditions
- Nearly “closed” item on Iodine behavior but still needs to understand/quantify different ways of organic iodide formation and delayed FPs releases = aim of the ESTER project.

STEM/STEM-2/ESTER Projects

INSIGHT ON FUTURE R&D NEEDS AND TRENDS

- No clear view today of a follow up to the ESTER project (still more than 2 years in the project)

- General context toward a decrease of effort concerning SA research

- Trends for IRSN with ST issue are focused mainly on (subject to be or under discussion with partners) :
  - ATF fuel (impact of Cr…),
  - SMR (specificities like impact of inert gas injection, larger ratio of metallic surfaces…)
  - “liquid ST” (long term operations with lixiviation of corium and evolution of solution / decontamination of water) – a project will be proposed within next EU call (VTT lead) on Cs

Panel SESSION 4: Joint Projects for Safety in Accidental Situations, Learnings and Perspectives

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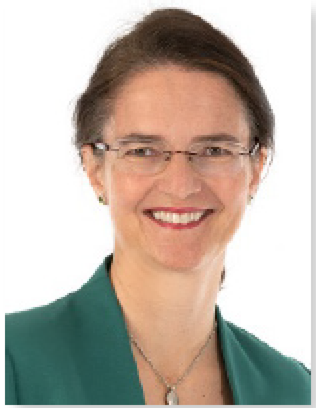

Dr Katharina STUMMEYER is Head of the Project Management Agency at the Gesellschaft fuer Anlagen- und Reaktorsicherheit (GRS) gGmbH. This specialised division of GRS implements and co-ordinates nuclear safety research programmes on behalf of German Federal Ministries. The topics covered range from reactor safety research programmes to research on waste management and on nuclear decommissioning. She has extensive experience in research management and a profound overview of the German nuclear safety research community. She is engaged in the German Alliance for Competence in Nuclear Technology and the current spokesperson of the German Network of Project Management Agencies in Research Funding. On the international level, she is vice-chair of the NEA Nuclear Education, Skills and Technology (NEST) Framework, member of the NEA Gender Balance Task Group, member of the Committee on the Safety of Nuclear Installations (CSNI) and active in several joint projects. She graduated in 2000 from the Leibniz University in Hanover and holds a Doctoral degree in Natural Sciences (Dr. rer. nat). She was active as researcher at the MH Hannover (X-Ray Crystallography and radiation protection) before she joined GRS in 2009.

Dr Won-Pil BAEK

Senior Research Fellow, Korea Atomic Energy Research Institute (KAERI), President of Korean Nuclear Society, Korea

Dr Won-Pil BAEK is a senior research fellow at the Korea Atomic Energy Research Institute (KAERI) and President of the Korean Nuclear Society. Dr Baek graduated from nuclear engineering department of Seoul National University in 1982 and completed his master and PhD degrees in nuclear engineering at KAIST in 1984 and 1991, respectively. Dr Baek worked for Doosan Heavy Industries as an engineer and for KAIST as researcher and research professor before joining KAERI. In 2001, he was invited by KAERI to lead the Thermal Hydraulics Safety Research Group. In 2007 his role was expanded to include severe accident and heavy water reactor safety R&D. He promoted to Vice President for Nuclear Safety Research in 2010, Executive Vice President in 2015, and Acting President for several months in 2019. In particular, he led the design, construction and initial operation of the ATLAS facility. Dr Baek chaired the Committee on the Fukushima Accident as well as the Thermal Hydraulics and Safety Division of the Korean Nuclear Society. He has also served as member of the advisory committees of several government ministries including MSIT, MOTIE, NSSC, MOFA and MOIS. Dr Baek has been very active in NEA working groups and committees since 2002. He was a member of the Working Group on Analysis and Management of Accidents (WGAMA), the Programme Review Group as well as the Bureau of Committee on the Safety of Nuclear Installations (CSNI). He is now a Vice Chair of the NEA Steering Committee on Nuclear Energy. He was also a key player in establishing the NEA SERENA project, ISP-50, and ATLAS projects. Dr Baek co-authored several books (all in Korean), including *Critical Heat Flux*, *Nuclear Safety*, *Nuclear Debate*, and recently *Controversy and Truth of Fukushima Nuclear Accident*.

Day 5 – Friday, 13 January 2023

Session 5: Future Needs for International Co-operation in Nuclear Safety Research

Moderator: William D. MAGWOOD, IV, Director-General, Nuclear Energy Agency

Introduction **13:00-13:10**	➢ Didier JACQUEMAIN, NEA/SAF, Senior Nuclear Safety Specialist ➢ William D. MAGWOOD, IV
13:10-13:30	▸ ***Post-Fukushima Daiichi Co-operative Safety Research Projects and Opportunities for Future Research***, *Toyoshi FUKETA, Advisor, Nuclear Regulation Authority (NRA), Japan*
13:30-13:50	▸ ***Nuclear Innovation-2050: An NEA Initiative to Foster Innovations in the Nuclear Sector***, *Fiona RAYMENT, OBE FREng, Chief Science and Technology Officer, National Nuclear Laboratory (NNL), the United Kingdom*
13:50-14:10	▸ ***Addressing Future Research Prioritisation under the NEA Committee on the Safety of Nuclear Installations (CSNI) Auspices***, *Vesselina RANGUELOVA, Deputy Head of the NEA Division of Nuclear Safety Technology and Regulation*
14:10-14:30	▸ ***Better Addressing the Challenge of Joint Projects Data Preservation and Dissemination***, *Didier JACQUEMAIN*
14:30-14:45	**Break**
14:45-15:00	▸ **Brief summary of the key outcomes of workshop sessions,** Didier JACQUEMAIN
15:00-16:00	▸ **Concluding panel discussion** • *What mechanisms to establish priorities for future international co-operation in nuclear safety research? Which frameworks to address future safety research?* • **Panellists:** William D. MAGWOOD, IV; Jess GEHIN, Associate Laboratory Director, Nuclear Science and Technology, Idaho National Laboratory, United States; Fiona RAYMENT; Jean-Christophe NIEL; Toyoshi FUKETA; Aline DES CLOIZEAUX, Director, Division of Nuclear Power, Department of Nuclear Energy, International Atomic Energy Agency (IAEA); Roger GARBIL, Head of the Fission Section, Euratom Research Unit, Directorate General for Research and Innovation, European Commission

NEA NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK:
Success Stories and Opportunities for Future Developments

9-13 January 2023

Thank you for your participation today and see you all tomorrow!

Questions, feedback and suggestions

Event public page: Nuclear Energy Agency (NEA) - NEA Nuclear Safety Research Joint Projects Week: Success Stories and Opportunities for Future Developments (oecd-nea.org)