OECD/NEA
THAI Program
for Containment
Safety Research:
main Insights and
Perspectives
Introduction

➢ Overall objectives of OECD/NEA THAI projects:

- To provide *containment specific experimental data bases* for development and validation of *Lumped Parameter* and *CFD Codes* used in the area of reactor safety analyses to investigate specific issues for *LWR under severe accident conditions*:
  - Thermal hydraulics and water pool hydrodynamics,
  - Hydrogen distribution, combustion and mitigation, and
  - Aerosol and Iodine (Fission product) behavior.

● National THAI project(s) running since 1998

● OECD/NEA projects:
  - THAI-2 August 2011 – July 2014
  - THAI-3 February 2016 – July 2019
THAI Overview
THAI⁺ – Multi-compartment Test Facility (upgrade in 2015)

- Extended experimental investigations to mimic generic two-room system in containments with different but coupled thermal-hydraulics

- Operated in close co-operation with AREVA (Erlangen) & GRS (Cologne, Garching)

<table>
<thead>
<tr>
<th></th>
<th>THAI</th>
<th>PAD</th>
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<tbody>
<tr>
<td>Volume (m³)</td>
<td>60</td>
<td>18</td>
</tr>
<tr>
<td>Height (m)</td>
<td>9.2</td>
<td>9.8</td>
</tr>
<tr>
<td>Diameter (m)</td>
<td>3.2</td>
<td>1.6</td>
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</tbody>
</table>

P/T: 1.4 MPa / 180°C
Stainless steel 22 mm walls

- Configurable sub-compartment
- Pressure resistant for H₂-deflagrations
- Licensed for use of radiotracer I¹²³
THAI/THAI⁺ – Experimental Configurations (Examples)

Example 1: Multi-compartment iodine behaviour
- 5-compartment geometry
- Painted surfaces: 10 m²
- I-123

Example 2: PAR performance testing (AREVA, AECL, NIS)
- PAR performance
- Upto 3 bar, 140 °C, I-123, Aerosol
- Ignition (Tgas local) ~ 1000 °C

Example 3: H₂-combustion and flame propagation
- Hydrogen combustion
- Defined gas flows
- Different ignition points
THAI – General Experimental Research Topics

More than 200 experiments performed in National and OECD/NEA THAI

- H2-Deflagration in Turbul. Flows
- PAR in Countercurrent Flow
- Natural Convection & Stratification
- ISP-47: HM-Benchmark He- & H2-Distribution
- ISP-49: H2-Deflagration Spray Interaction
- PAR Behaviour:
  - Low Oxygen
  - AECL, AREVA, NIS
- Interaction of PAR & CsI:
  - I2-Formation
  - PAR-Poisoning
- Dry Resuspension of I2 and Aerosol
- Wet-Resuspension from Hot Pools
- Dry Resuspension of Aerosol Material by H2-Deflagration
- I2 Release Flashing Jet
- FP Resuspension from Boiling Sump
- Complex Aerosol/I2 Test in Multi-Compartment
- I2 Transport & Mass Transfer (Single- & Multi-Compartment)
- I2 Adsorption & Desorption on Steel & Paint
- Washdown of Iodine & Aerosols
- Iodine-Ozone Reaction: IOx Aerosols
- Iodine-Spray and Aerosol Spray Interaction
- Iodine-Aerosol Interaction

finalised current German National Program current OECD-NEA THAI 3 Program
## OECD/NEA THAI – Experimental Research Topics

### OECD/NEA THAI (2007-2009), 9 countries

- TH: H₂/He stratification & break-up by steam plume
- PAR performance → onset, ignition, O₂ starvation
- PAR poisoning by FP
- Hydrogen (slow) deflagration
- Impact of PAR on I₂ in-containment source term
- Aerosol (CsI) wash-down by wall condensate

### OECD/NEA THAI-2 (2011-2014), 11 countries

- PAR performance under O₂ lean atmosphere → onset, ignition
- Hydrogen (slow) deflagration + Spray
- I₂ deposition on aerosol particles → SnO₂, Ag
- I₂ release from flashing jet

### OECD/NEA THAI-3 (2016-2019), 16 countries

- PAR performance under counter-current flow conditions
- Hydrogen (slow) deflagration + two-vessel system
- Fission product re-entrainment from water pool
- Aerosol and iodine re-suspension from deposits by hydrogen deflagration

### OECD/NEA THAI (Partners):

Canada, Czech Republic, Finland, France, Germany, Hungary, Republic of Korea, Netherlands, Sweden, Switzerland, and the United Kingdom

### OECD/NEA THAI-2 (Partners):

Canada, Czech Republic, Finland, France, Germany, Hungary, Republic of Korea, Netherlands, Sweden, Switzerland, and United Kingdom

(Still some additional partners under discussion)
OECD/NEA THAI – Analytical Working Group (AWG)

- **Always application of LP** (COCOSYS, GOTHIC, ASTEC, MELCOR) and **CFD codes** (CFX, FLUENT, GASFLOW)

- **Thermal hydraulic: H₂/He distribution & material scaling**
  - OECD/NEA THAI: HM-2 Benchmark following ISP-47

- **Hydrogen recombination (PARs)**
  - OECD/NEA THAI: PAR model set-up and validation
  - OECD/NEA THAI-2, THAI-3: continuation of validation, **blind benchmark**

- **Hydrogen deflagration**
  - OECD/NEA THAI: **ISP-49 on HD-22** together with ENACEFF France
  - OECD/NEA THAI-2: analyses of HD-30 – HD-32 tests with spray
  - OECD/NEA THAI-3: analyses of two-vessel tests, **blind benchmark**

- **Aerosol and Iodine behaviour**
  - OECD/NEA THAI: AW-1 aerosol wash-down test analyses
  - OECD/NEA THAI-2: Iod-25 & Iod-26 pre- and post-test calculations
Summary of Results
THAI – Thermalhydraulic
He/H₂ Material Scaling Test & Code Benchmark

- Build-up of light gas (He/H₂) stratification in the containment and dissolution by steam/gas jet

- HM experiments (HM-1: He/ HM-2: H₂) done in THAI; demonstrated transferability of He results to H₂ distribution problems
- Stratification erosion successfully predicted by majority of the codes; significant progress as compared to the results of former ISP-47
- Main improvements: model development/validation, user experience …
THAI+ – Thermalhydraulic Commissioning Test

- Generation of light gas stratification in a steam-air mixture in both vessels and erosion by natural convection

- Test of new facility features based on known phenomena as gas stratification and wall heating/cooling effects on gas convection

- Selected as national/international double blind benchmark

- Participation by 12 partners, including Code users and developers

- Participating codes:
  - ASTEC, MELCOR, COCOSYS, and GOTHIC
  - CFX, FLUENT, GASFLOW
THAI+ – Thermalhydraulic Commissioning Test – Code Benchmark Results

- 2.5 day test includes seven individual phases: Steam and He injection and different thermal gradients by wall heating

He concentr. in upper connecting pipe

Pressure

- Generally good prediction of pressure and temperature evolution
- Differences caused by uncertainties in heat losses (late phase)
- Still larger discrepancies in prediction of formation and erosion of He stratification in 2 vessels
# THAI/THAI$^+$ – Hydrogen Deflagration

## OECD/NEA THAI

**Single compartment**
- Premixed and stratified gas atmosphere
- Effect of burn direction
- 140 °C, 1.5 bar, 6 - 12 vol.% H$_2$

## OECD/NEA THAI-2

**Single comp. + Spray**
- Premixed gas atm.
- Interaction of combustion and spray
- Spray induced turbulence effect

## OECD/NEA THAI-3

**Multi compartment**
- H$_2$ deflagration under superimposed natural convection

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### OECD/NEA THAI

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Description</th>
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<tr>
<td>Single</td>
<td>Premixed and stratified gas atmosphere, Effect of burn direction, 140 °C, 1.5 bar, 6 - 12 vol.% H$_2$</td>
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### OECD/NEA THAI-2

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Value</th>
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<tbody>
<tr>
<td>Pressure</td>
<td>1.5 bar</td>
</tr>
<tr>
<td>Temperature</td>
<td>90 °C</td>
</tr>
<tr>
<td>H$_2$</td>
<td>10 vol%</td>
</tr>
<tr>
<td>Steam</td>
<td>25 vol%</td>
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**EUROSSAFE 2016**
**THAI – Hydrogen Deflagration**

- **Effects of slow combustions – upward and downward incl. steam**
  - More regular flame front in case of low steam content while more irregular flame front with increasing steam content
  - Steam content reduces flame front propagation and pressure peak; higher H$_2$ concentration needed for downward flame propagation
Effect of spray induced convection and turbulence on flame propagation

- **Upward flame** propagation: slightly lower pressure and flame propagation
- **Downward flame** propagation: slightly higher pressure, faster flame propagation

**Code Assessment:**

difficulties in reproducing turbulence enhancing effect by spray on combustion processes in most codes

- **Upward flame propagation**
  - $P = 1.5 \text{ bar}, T_{\text{gas}} = 90 \degree \text{C}, C_{\text{H}_2} = 10 \text{ vol.\%}, C_{\text{steam}} = 25 \text{ vol.\%}, T_{\text{water}} = 20 \degree \text{C}$

- **Downward flame propagation**
  - $P = 1.5 \text{ bar}, T_{\text{gas}} = 90 \degree \text{C}, C_{\text{H}_2} = 12 \text{ vol.\%}, C_{\text{steam}} = 25 \text{ vol.\%}, T_{\text{water}} = 90 \degree \text{C}$
THAI – Hydrogen Recombination (PAR Database)

- Performance testing (start-up, low oxygen, ignition)
- Qualification under SA scenario (fission products)
- Interaction between PAR and containment thermal-hydraulics
- Database for development/validation of PAR models
THAI – Hydrogen Recombination (PAR Database)

PAR operation
- Overall PAR “efficiency” 50 - 75%
- Optimal recombination for $O_2$ surplus ratio $(2x \frac{O_2}{H_2}) > 2.3$

PAR induced ignition
- Ignition observed for plate type PAR, “glow worms” for pellet type PAR,
- Small band of necessary conditions

Initially air-filled atmosphere

Graph showing:
- $H_2$ release
- $H_2$ concentration in the bulk and at PAR inlet
- Onset of recombination
- $H_2$ recombination
- $H_2$ concentration at PAR outlet

Graph scales:
- Time: 0 to 90 min
- $H_2$ concentration: 0 to 8 vol%
THAI – Hydrogen Recombination (PAR Database)

PAR operation in O₂ lean atmosphere
- O₂ surplus ratio: (2x O₂/H₂) <2.3:
  - no ignition, reduction in catalyst efficiency and plate temperature
- H₂ recombination continues at O₂ concentration as low as 0.05 vol.%

PAR interaction with fission product
- No poisoning observed
- Thermal decomposition of metal iodides (additional in-containment I₂ source-term)
- Results → 1 – 3 % conversion

Poisoning test: PAR plates post test visual inspection
Model Validation and PAR Concept Analyses at GRS

- **COCOSYS PAR model validation:** use of THAI data for model improvement and validation

- **PWR Concept confirmation:** detailed analyses of different SA scenario and assessment of remaining combustions

**HR-5 no steam**

![Graph showing recombination rate](image)

**HR-12 with steam**

![Graph showing recombination rate](image)

**LB-LOCA**

**SBO**

![Diagram showing recombination rate](image)
THAI⁺ – Hydrogen Recombination – Ongoing

- PAR operation under counter-current flows

Flow field in pipe

Six vane wheels

IR-Camera - PAR-outlet temp.
THAI – Aerosol Wash-down

- Transport mechanisms of soluble aerosol deposits by draining condensates – wash-down
  - Additional tests using non-soluble SnO$_2$ aerosol conducted in National THAI

Procedure
- CsI injection in superheated gas atm.
- Deposition on horizontal / vertical surfaces
- Steam injection and condensation on walls (no volume condensation)
- CsI concentration in condensate – wash-down fraction quantification

Results
- Flat surfaces: rivulet formation and complete and fast removal of aerosol
- Puddle: stratification and delayed removal
THAI – Gaseous I$_2$/Aerosol Interaction

- I$_2$/Aerosol interaction tests – inert SnO$_2$ and reactive Ag aerosols

Test procedure
- Injection of Gaseous I$_2$
- I$_2$/surface interaction
- 2 aerosol injection phases
- Measurement of atm. I$_2$ concentration

Iod-25 = "inert" SnO$_2$ aerosol:
- small, but significant I$_2$ depletion by SnO$_2$ aerosol

Iod-26 = "reactive" Ag aerosol:
- strong I$_2$ depletion by Ag aerosol

✓ With Ag aerosol, I$_2$ depletion is faster by a factor ~25 than with SnO$_2$ aerosol
**THAI+ – Fission Product Experiments – Planned**

**FP re-entrainment from water pool**
- Aerosol/Iodine re-entrainment from water pool due to:
  - continuous heat-up of the pool,
  - depressurization induced boiling

**FP resuspension test ("Integral")**
- Aerosol and iodine re-suspension from deposits by hydrogen deflagration ("delayed source term")
Conclusions and Perspectives

- THAI provided already many useful findings with regard to phenomena relevant in severe accidents, e.g. for qualification of components (PAR), and improved understanding.
- THAI+ will enhance experimental possibilities and database for phenomena related to thermal-hydraulics, hydrogen, aerosols and iodine.
- OECD/NEA THAI projects partners benefit from comprehensive high quality experimental data to assess and further develop CFD and LP codes for SA phenomena.
- OECD/NEA THAI-3 project is currently ongoing with growing international interest.
- Continuation of analytical activities in THAI-3 – blind and open code benchmarks for most experimental series.
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