Passive system Evaluation by using Integral thermal-hydraulic test facility

#537, Rui-Chang Zhao, SNPTRD

PSAM12 International Conference
- Briefly introduction of SNPTRD
- Engineered safety system & Ongoing T-H test research
- Evaluation by integral T-H test
Briefly introduction of SNPTRD
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- SNPTRD (State Nuclear Power Technology R&D Center) was founded in 2008, a platform for advanced research of AP1000, CAP1400
- Founded by industry leader SNPTC (65%) and research pioneer Tsinghua University (35%)
- A national nuclear R&D center in China
  - Passive Core Cooling System (PXS) research
  - Passive Containment Cooling System (PCCS) research
  - Severe accident research
  - Nuclear safety research
  - Reactor physics research
  - Key equipment research
Engineered safety system & Ongoing T-H test research
Passive core cooling system: (height scale 1/3)

ACME (Advanced Core-Cooling Mechanism Experiment)

**Role of ACME**
- To simulate the operation of passive core cooling system of CAP1400 for SB-LOCA
- To validate the engineering design of the passive core cooling system
- To collect thermal-hydraulic data for safety code assessment
Test Facilities for Engineered Safety System

Integral Effects Test (IET)

Passive Containment Cooling System: (height scale 1/8)
CERT(Containment safety verification via integral Test)

Role of CERT
- To validate the applicability of WGOTHIC (safety code for containment assessment)
- To verify the engineering design of the passive containment cooling system
- To scaled-simulate the physical process in accident scenario, and the performance of passive containment cooling system of CAP1400
Test Facilities for Engineered Safety System

Separate Effects Tests (SETs)

- In-Vessel Retention (IVR) related:
  - Metal Layer Heat Transfer Experiment
  - Key Factors of Improving CHF Experiment

- Verify Globe-Dropkin
- Relationship Obtain a proper correlation
- Investigate the behavior of the coupled heat transfer in metal layer
- Investigate the key factors of CHF
- Obtain the influence of chemical solution to CHF
- Testify the effects of surface characteristic to CHF
Test Facilities for Engineered Safety System

Separate Effects Tests (SETs) of CAP1400 Large Passive Plant

- **PCCS related:**
  - WAter Distribution Experiment facility (WADE)
  - Steam Condensation on Old Plate Experiment facility (SCOPE)
  - Inner Steam Condensation coupled Outer Evaporation experiment facility (ISCOE)

- Study water cover area rate with the flow rate
- The period of the establishment of stable water film from the top to the bottom
- The effect of weir design to the water film
- To provide data on condensation heat and mass transfer in the presence of a non-condensable gas
- To validate the correlation of heat and mass transfer of condensation, which used in the assessment model
Evaluation by integral T-H test
Passive system evaluation process

- Best estimate code Evaluation Model (Relap5, Gothic ... )
- Results Uncertainty ...
  \textit{By code calculations}
- Prototype Passive System characteristics
Passive system evaluation process

TEST:
- Separate Effect Tests
- Integral Effect Tests
  - scaled
  - non-scaled

Best estimate code Evaluation Model
(Relap5, CATHARE, Gothic...)

Results Uncertainty
... By code calculations

Prototype Passive System characteristics
Passive system evaluation process

TEST:

Separate Effect Tests

Integral Effect Tests
  scaled
  non-scaled

Best estimate code Evaluation Model
  (Relap5, CATHARE, Gothic...)

Results Uncertainty
  ... By code calculations

Prototype Passive System characteristics

Sub-scaled test facilities
Scaling Analysis Methods
H2TS method: hierarchical, two-tiered scaling

TRY to evaluate the system performance by IET(CERT) DIRECTLY
Passive system evaluation process

TEST:

Separate Effect Tests

Integral Effect Tests

scaled
non-scaled

Sub-scaled test facilities
Scaling Analysis Methods
H2TS method: hierarchical, two-tiered scaling

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Prototype Passive System characteristics

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Passive system evaluation process

Best estimate code Evaluation Model (Relap5, Gothic ...)

Results Uncertainty ... By code calculations

Prototype Passive System characteristics

Sub-scaled designed Integral test (APEX, ACME, CERT...)

Results Uncertainty ... By experiments data
Evaluation by integral T-H tests

**Scaled methodology**: H2TS *(hierarchical, two-tiered scaling)*

PIRT → System → Critical Physical Phen./Proc → Component → Field → Dimensionless Groups

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**Stage 1**
**SYSTEM DECOMPOSITION**

*Provide:* System hierarchy

*Identify:* Characteristic: concentrations, geometries, processes

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**Stage 2**
**SCALE IDENTIFICATION**

*Provide:* Hierarchy for: volumetric concentrations, area concentrations, process time scales

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**Stage 3**
**TOP-DOWN/SYSTEM SCALING ANALYSIS**

*Provide:* Conservation equations

*Derive:* Scaling groups and characteristic time ratios

*Establish:* Scaling hierarchy

*Identify:* Important processes to be addressed in bottom-up/process scaling analyses

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**Stage 4**
**BOTTOM-UP/PROCESS SCALING ANALYSIS**

*Perform:* Detailed scaling analysis for important processes

*Derive and validate:* Scaling groups

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**H2TS flow diagram** fr. Novak Zuber and etc.
Evaluation by integral T-H tests

Dimensionless value \( i \) of specific physical process \( j \):

Prototype dimensionless:

Test dimensionless:

For best simulation to the prototype:

\[
\frac{\Pi_T}{\Pi_P} \rightarrow 1
\]

Energy conservation equation:

\[
\pi_{p,v}XV \frac{dP}{dt} = \dot{m}_{brk}(h_{brk} - h_{stm}) - \sum_{i=1}^{N} [A(\pi_{p,con,i} \dot{m}_{stm,i}) + (\pi_{p,q,i} h_{q,i} A_i \Delta T_{if,i})]
\]
Evaluation by integral T-H tests

Dimensionless value `i` of specific physical process `j`:

Prototype dimensionless: \( \pi \)

Test dimensionless: \( \pi _ T \)

For best simulation to the prototype: \( \frac{\pi _ T}{\pi _ P} \rightarrow 1 \)

Energy conservation equation:

Energy caused inner pressure change

Released by steam brk.

Absorbed by convection of \( i \)th comp.

Absorbed by condensation on \( i \)th comp.

\[
\frac{\pi _{p/c}XV}{dt} = \Delta h_{brk} (h_{brk} - h_{atm}) - \sum_{i=1}^{N} \left[ A(\Delta h_{cond,i} + \Delta T_{if,i}) + (\Delta h_{q,i} A_i \Delta T_{if,i}) \right]
\]
Evaluation by integral T-H tests

Dimensionless value `$i$' of specific physical process `$j$':

Prototype dimensionless: $(\pi)^P$

Test dimensionless: $(\pi)^T$

For best simulation to the prototype:

\[
\frac{(\pi)^T}{(\pi)^P} \rightarrow 1
\]

Pressure expression deduced fr. Energy equation:

\[
\frac{dp}{dt}_P = \left( \frac{\pi_{p,t} XV dp}{\pi_{p,t} XV}_P \right)_T - \left( \Lambda \sum_{i=1}^{N} (\pi_{p,cond,i} h_{stm,i})_P \right) T - \left( \Lambda \sum_{i=1}^{N} (\pi_{p,cond,i} h_{stm,i})_T \right) P
\]

Quantitative relationships between the test model and prototype PCCS of NPP.

`$x_i$' represents the $i$th parameter of relative measurement variables

Uncertainty analysis

\[
\Delta p_{\text{max}} = \Delta p(t)|_{t=t_{\text{pmax}}} = \sqrt{\sum_{i=1}^{N} \left( \frac{\partial p(t,x_i)}{\partial x_i} \Delta x_i \right)^2 |_{t=t_{\text{pmax}}}}
\]

\[
P[\text{fail of PCCS}] = \text{Prob}[p_{\text{max}} > p_{\text{crit}}]
\]
Thank you!