Presentation ID SH147

Validation of Updated Two-Layer Zone Model BRI2-CRIEPI Applicable to Fire PRA for Nuclear Power Plants

NRRC (Nuclear Risk Research Center)
CRIEPI (Central Research Institute of Electric Power Industry)

Koji Shirai, Toshiko Udagawa
shirai@criepi.denken.or.jp

PSAM 18, July 2026, Pittsburgh, Pennsylvania, USA

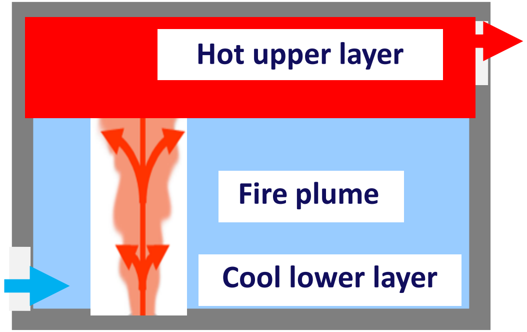
Contents

- Update the fire modeling “BRI2-CRIEPI”
- Existing Experiment Study
  - ➢ PRISME Fire Projects
  - ➢ PRELUDE/PML Project
- Data Processing to validate zone code
- Analysis results by BRI2-CRIEPI and Discussion
- Conclusion

* This research project was conducted as a joint project of nuclear power plant owners in Japan (Leader: Tokyo Electric Power Company (EPC) Holdings, Participants: Hokkaido EPC, Tohoku EPC, Hokuriku EPC, Chubu EPC, Kansai EPC, Chugoku EPC, Shikoku EPC, Kyushu EPC, Electric Power Development Company and the Japan Atomic Power Company).

Update the fire modeling "BRI2-CRIEPI"

- **BRI2-CRIEPI: Two-Layer Zone Smoke Transport Model (Zone Model) widely used due to the brevity and reliability of its calculation routine**
- **Improved by CRIEPI to apply fire scenarios in NPP facilities under mechanically ventilated conditions based on the international OECD Fire projects**



Zone Model

BRI2 developed by Dr. Tanaka when he was a guest scientist at NIST

Japanese construction industry and academia

BRI2002

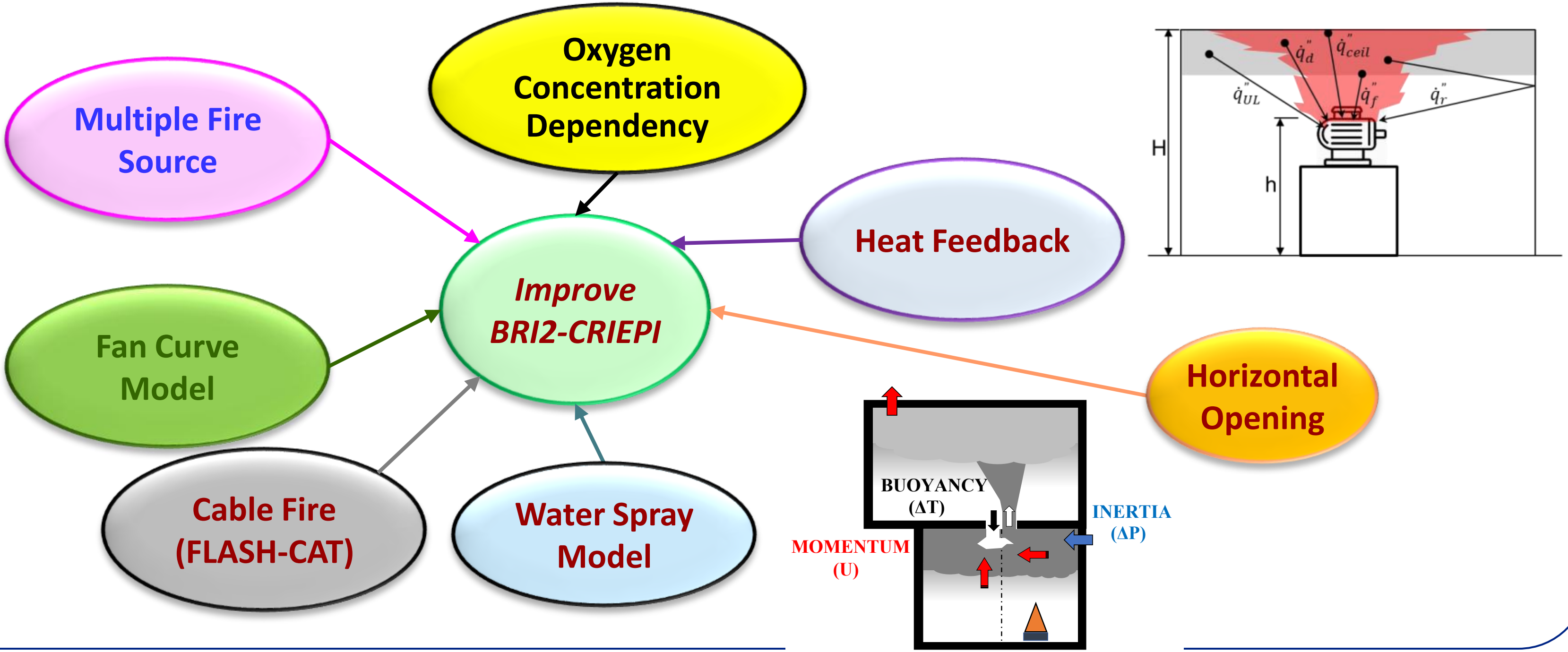
Apply to NPP facility configuration, 2022 (Ver.1)

BRI2-CRIEPI

CFAST

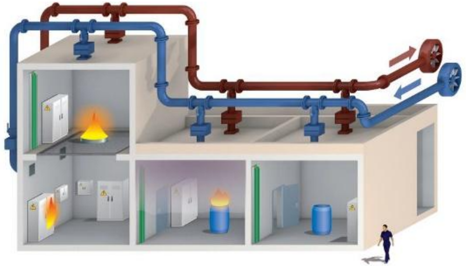
Improvement of the BRI2-CRIEPI

- Conduct the calculation under the same conditions as the full-scale fire tests obtained in PRISME, PRISME3 and PRELUDE/PML projects



OECD/NEA PRISME projects

- International joint research program by the OECD/NEA
- To study fire characteristics in a complex, multi-compartment facility with forced mechanical ventilation



DIVA facility (ASNR)

PRISME (2006-2011)

- Effect of under-ventilated conditions on pool fire
- Smoke propagation (door) in a facility (with mechanical ventilation)

PRISME2 (2011-2016)

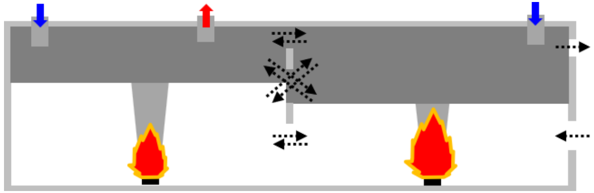
- Smoke propagation (door & horizontal opening) in a facility (with mechanical ventilation)
- Cable fire spread / Electrical cabinet fire spread
- Fire Extinguishing system

PRISME3 (2017-2021)

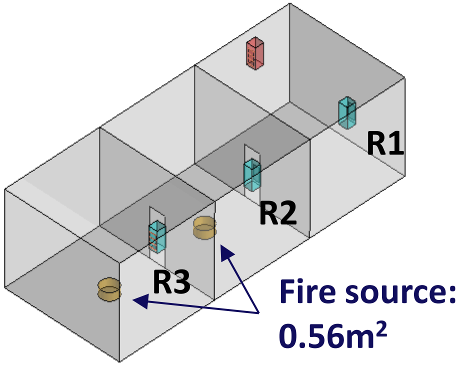
- More realistic fire scenarios
  - ✓ Cables fire spread
  - ✓ Electrical cabinet fire spread to another one
- Smoke propagation (door & horizontal opening) in a facility (with/without mechanical ventilation)

PRISME Source and PRISME3-S3 test campaign

- PRISME Source fire tests; PRS-Si-D1~D6
  - Fire behavior in a single compartment with a single fire source
- PRISME3-S3 fire tests; PRS-S3-A1~A2,B0~B2,C1
  - Smoke spread behavior (3S; Smoke, Strafication, Spread) in multiple compartments with a single or multiple fire sources



Test No.	Test case	Pan area (m^2)	Fuel	Note
PRS-Si	D1~D4	0.4	TPH	Reference case
	D5	0.2		Small fire source
	D6	0.4		Lower air supply
PRS-S3	A1/A2	0.4/1.0	Lubricant Oil	Horizontal- Opening
	B0	0.56	Dodecane	Reference case
	B1/B2	0.56		Multiple fire source
	C1	0.56		Elevated fire source

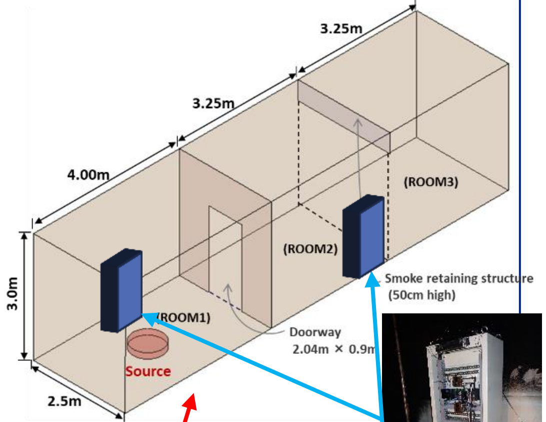


(PR3-S3-B2)

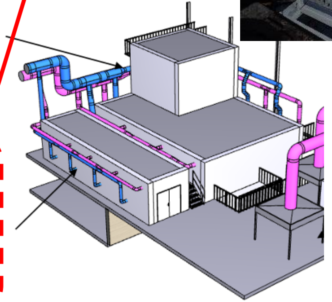
PRELUDE/PML test campaign

- **PRELUDE program launched by EDF R&D on the IGNIS platform**
- **Designed for large-scale fire tests in confined environments**
- **PML campaign conducted as part of the joint test program between EDF and CRIEPI**
- **Effects of both soot concentration and thermal feedback on *an electrical target located in the fire room or the adjacent room***
- **Test Matrix (Total six tests)**
  - **Fire source; Diesel Fuel with Pan area 0.38 m^2**
  - **Ventilation; Air renewal rate of $10h^{-1}$**

Test No.	Principal Load Factors for the target
Test5	Soot effect
Test6	Soot and temperature effect
Test7	Soot, temperature and radiation effect



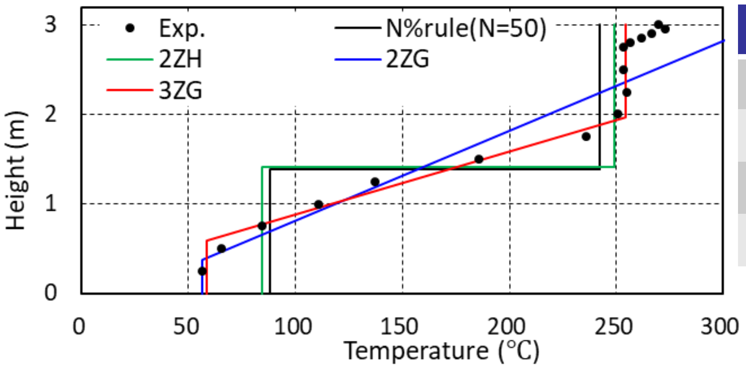
- ME1
  - Large volume facility
  - 12 x 8.5 x 6 m + 5 x 5 x 10 m (tower)
  - Can be split to several rooms
  - Controlled ventilation system
  - Renewal rate : up to 16 vol/h
  - Optical fibers inside the walls : temperature measurements
- ME2
  - Gallery
  - 12 x 2.5 x 3 m
  - Can be split to several rooms
  - Controlled ventilation system
  - Optical fibers inside the walls : temperature measurements



IGNIS fire safety experimental platform
*** Installation grandeur nature incendie sûreté**

Data processing to validate zone code

- Use ASNR's data regression method to estimate the Hot Gas Layer Temperature (HGLT)
  - Type 2ZH: Two homogeneous thermal layers approach
  - Type 2ZG: One homogeneous for lower layer and constant gradient for upper layer
  - Type 3ZG: Two homogeneous for lower and upper layers with a constant gradient
  - Reference N% Rule (N=50): Mid-point temperature by using thermocouple arrays
  - Selected the method at each time step to minimize the sum of C_T and C_ρ



Type	HGLT
2ZH	249°C
2ZG	187°C
3ZG	199°C
N=50	242°C

PRELUDE/PLM: Multi-compartment with doorway

C_T; Temperature conservation parameter over the height of the room

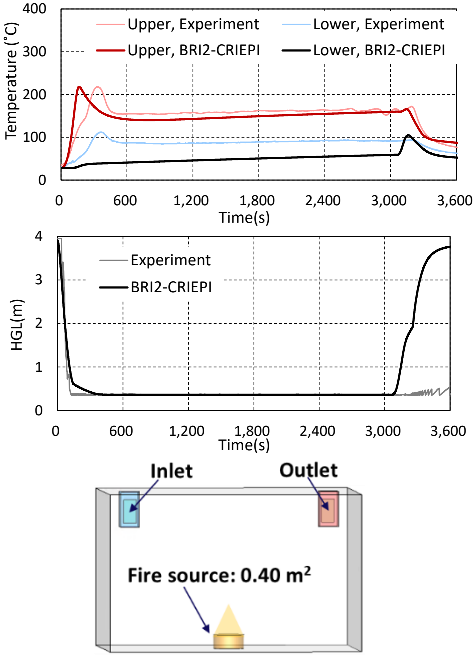
$$\mathbf{C}_T = \left(\int_0^H |T^{exp}(z) - T^{type}(z)|dz\right) \Big/ \left(\int_0^H T^{exp}(z)dz\right)$$

C_ρ; Mass conservation parameter

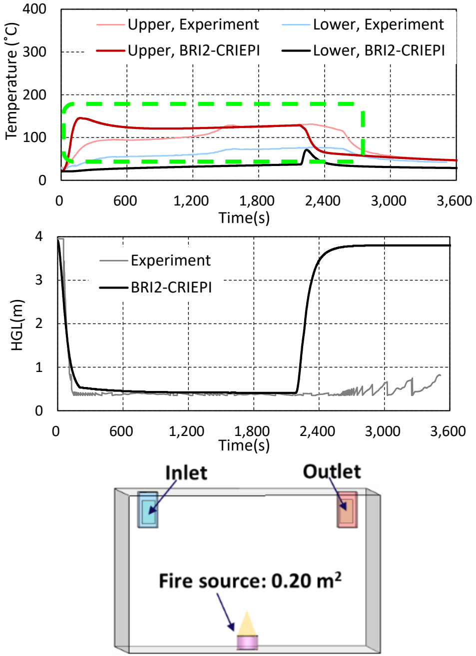
$$\mathbf{C}_\rho = \left(\int_0^H \left|\frac{1}{T^{exp}(z)} - \frac{1}{T^{type}(z)}\right| dz\right) \Big/ \left(\int_0^H \frac{1}{T^{exp}(z)} dz\right)$$

Analysis Results - Single compartment

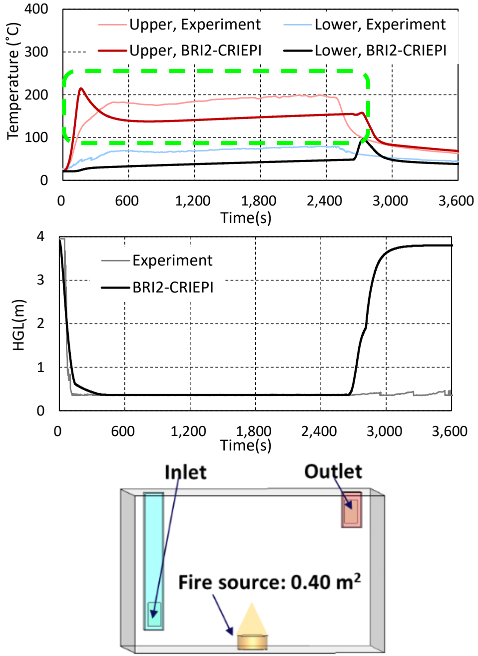
- HGL Height (HGLH) estimation seems to be good. However, in the case of
  - Small fire source (D5): HGLT is higher, and duration time is shorter
  - Lower air supply (D6): HGLT is lower, O_2 concentration model potentially need to be improved



(PRS-Si-D1,D2,D3,D4)



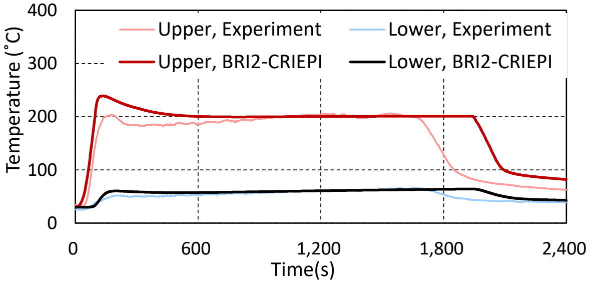
(PRS-Si-D5,D5a)

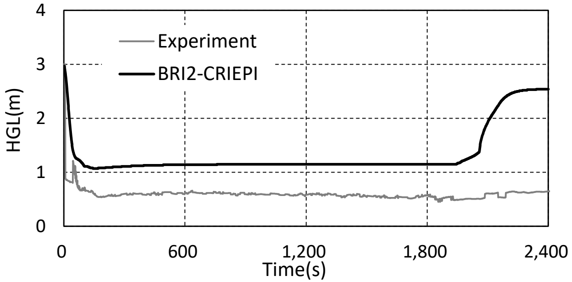


(PRS-Si-D6,D6a)

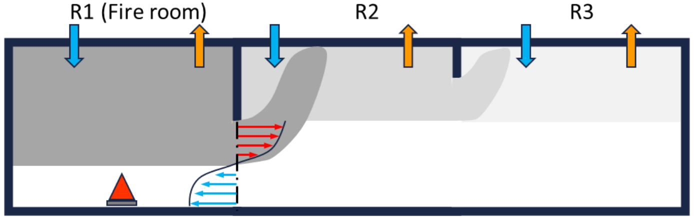
Analysis Results - Multi-compartment -

- Predicting smoke movement and propagation involves two physical mechanisms; *Natural convection* induced by high smoke temperature, and *Forced convection* induced by ventilation
- HGLH estimation method may not be applicable to smoke propagation in multi-compartment fires





Comparisons between experimental and analytical results



Smoke propagation in the multi-compartment configuration

(60 s)

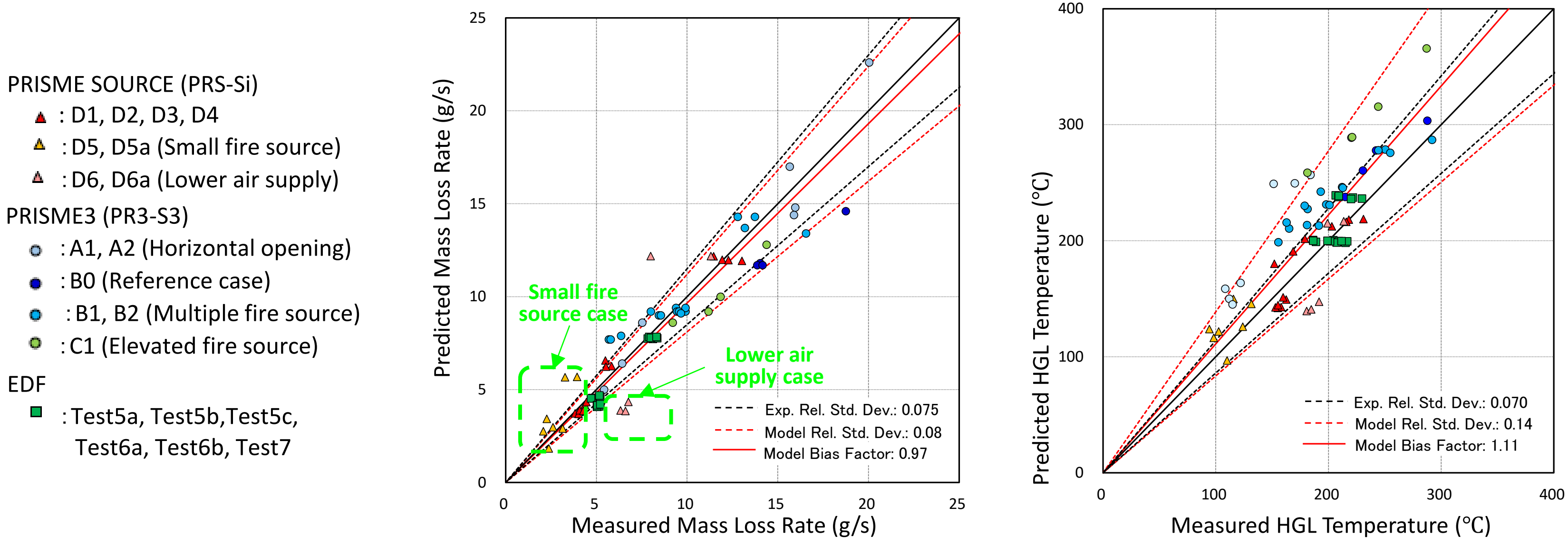
(240 s)

Visual observation of the flame and smoke

(PRELUDE/PML Test 5a)

Discussion on Validation

- Update the PML results on the validation results published in the Fire Safety Journal using the re-executed post-data according to the data regression method of ASNR
- No particular systematic trend, however, HGLT slightly overpredicts with a relatively small fire source (PRS-Si D5) and slightly underpredicts with a lower air supply (PRS-Si D6)



(MLR) (HGL-Temperature)

Conclusions

- **Twenty fire test results from the full-scale compartment test series obtained during the PRISME Source, PRISME3, and PRELUDE/PML campaigns were re-evaluated using the data regression method proposed by ASNR (France)**
- **The validation results for the HGLT, an important metric in the fire PRA, show that**
  - **No obvious bias in the model predictions (model bias factor of 1.11) or particular systematic trend (model relative standard deviation of 0.14), except for *small fire sources* and *lower air supply***
  - **BRI2-CRIEPI zone code is a useful tool for estimating compartment temperatures in a practical manner**
- **Physical phenomena that require further understanding to improve in the BRI2-CRIEPI**
  - **Soot predictions in multi-compartment cases**
  - **Interactions between multiple fires**
  - **Horizontal ceiling flow in vertically connected rooms**
  - **More realistic mass loss rates, especially in complex compartments such as corridors or shafts**

Thank you for your attention

- Any question, please contact as follows
  - ✓ Koji SHIRAI, NRRC/CRIEPI
  - ✓ E-mail: shirai@criepi.denken.or.jp