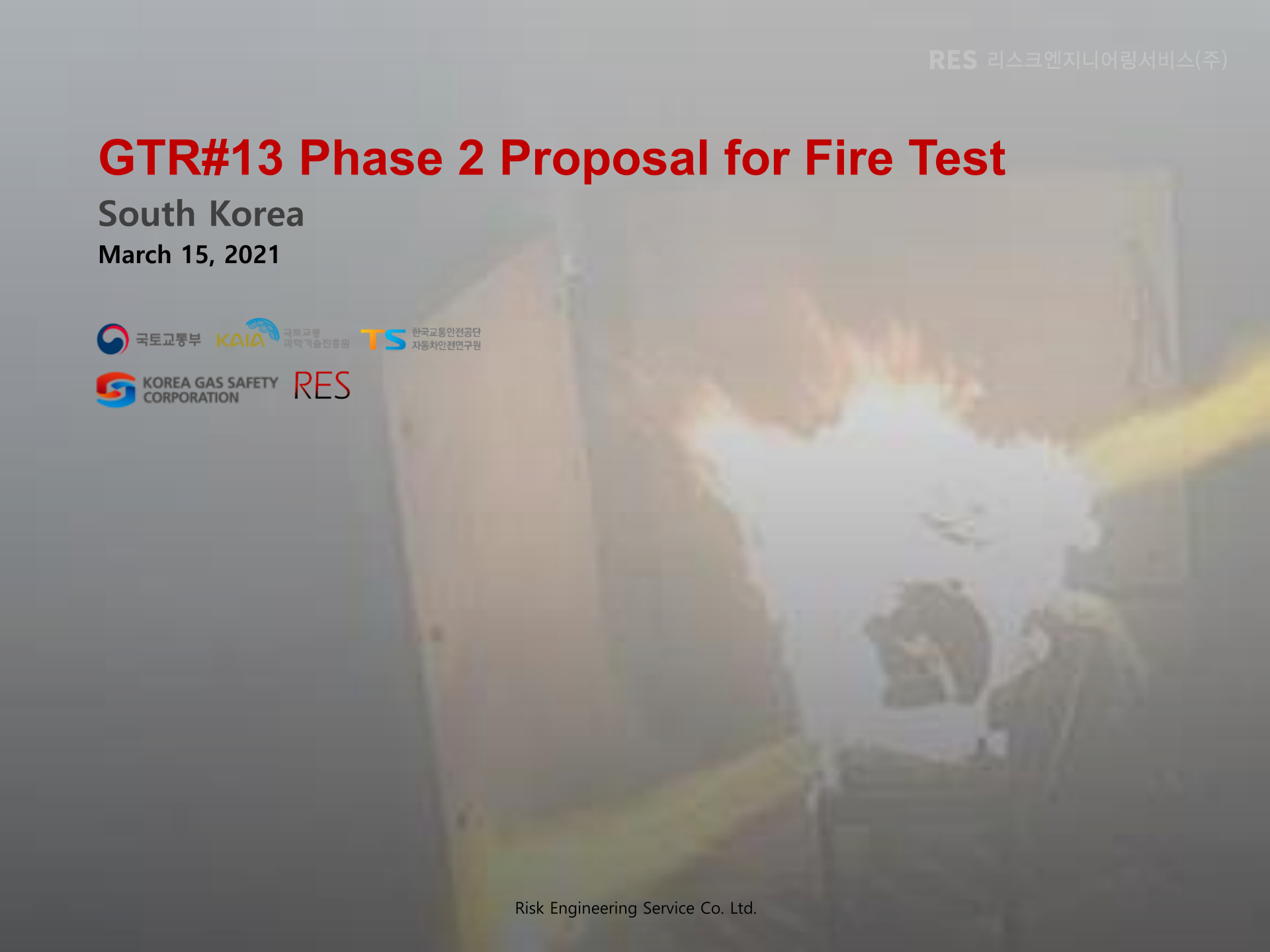
GTR#13 Phase 2 Proposal for Fire Test

South Korea

March 15, 2021



Risk Engineering Service Co. Ltd.

Overview

RES

1. Background
2. Analysis
3. Proposal
4. Appendix

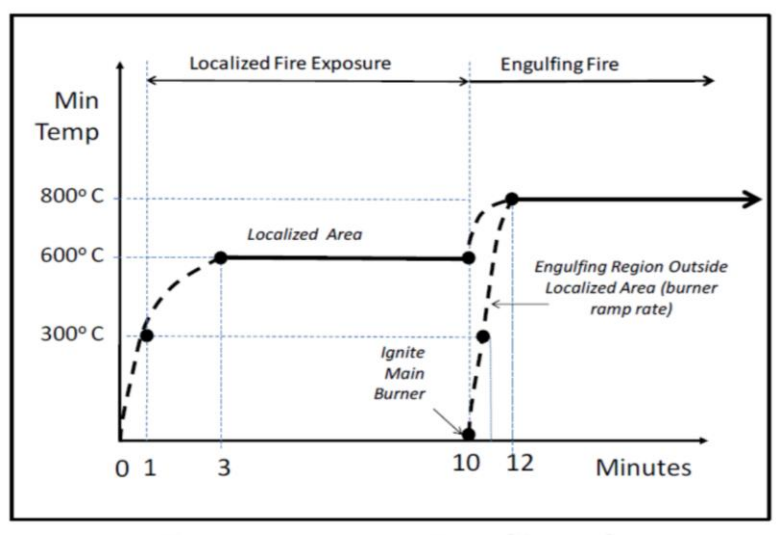


Figure 7. Temperature profile of fire test
(from Fire Test Working Draft 03122021)

Background

Temperature-based Test Condition Evaluated

- GTR#13 Phase 1 utilizes **temperature-based fire test condition**
- GTR#13 Phase 2 **added** HRR per unit area condition of burner to existing & additional temp conditions
- Most important in PASS/FAIL fire tests is actual heat energy/flux applied to test specimen (NOT temp)
- At LOW heat flux, surface temperature may be high enough to show thermal degradation, but thermal wave cannot penetrate due to not enough heat energy (temp NOT reliable)
- In many fire tests, the importance of energy-based approach has been considered (e.g., room corner test, cone calorimeter test, etc.)

Table 2c

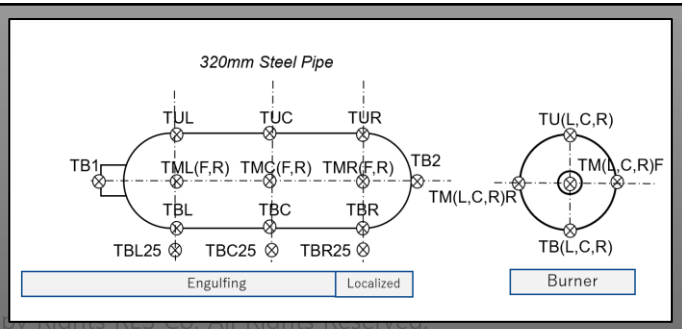
Criteria for Acceptance of Localized and Engulfing Burners using Alternative Burner Configurations

Fire Stage	*Allowable Temperature Range on Bottom of Container*	*Allowable Temperature Range on Sides of Container*	*Allowable Temperature Range on Top of Container*
Localized	450 °C < TB_{LOC} < 700 °C	TMF_{LOC} < 700 °C and TMR_{LOC} < 700 °C	100 °C < TU_{LOC} < 300 °C
Engulfing	TB_{ENG} > 600 °C		260 °C < TU_{LOC} < 750 °C

Table 2b

Allowable Range of Operation and The Proposed Settings For The Prescribed Burner

Fire Stage	*Allowable Range of Specific Heat Release Rate (HRR/A)*	*Proposed Setting of Specific Heat Release Rate (HRR/A)*
Localized Burner	230-360 kW/m^2	320 kW/m^2
Engulfing Burner	395-760 kW/m^2	685 kW/m^2



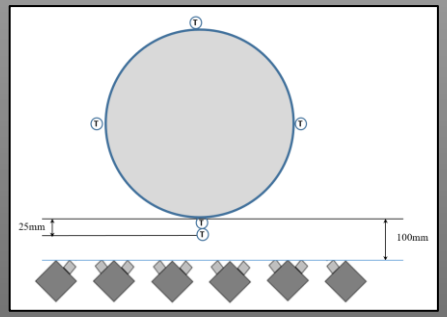
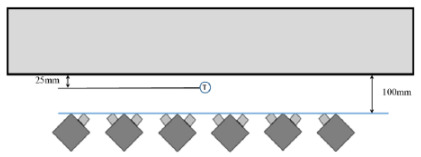


Figure 6k

Position the Bottom of the Conformable Container Relative to the Burner



Analysis (1)

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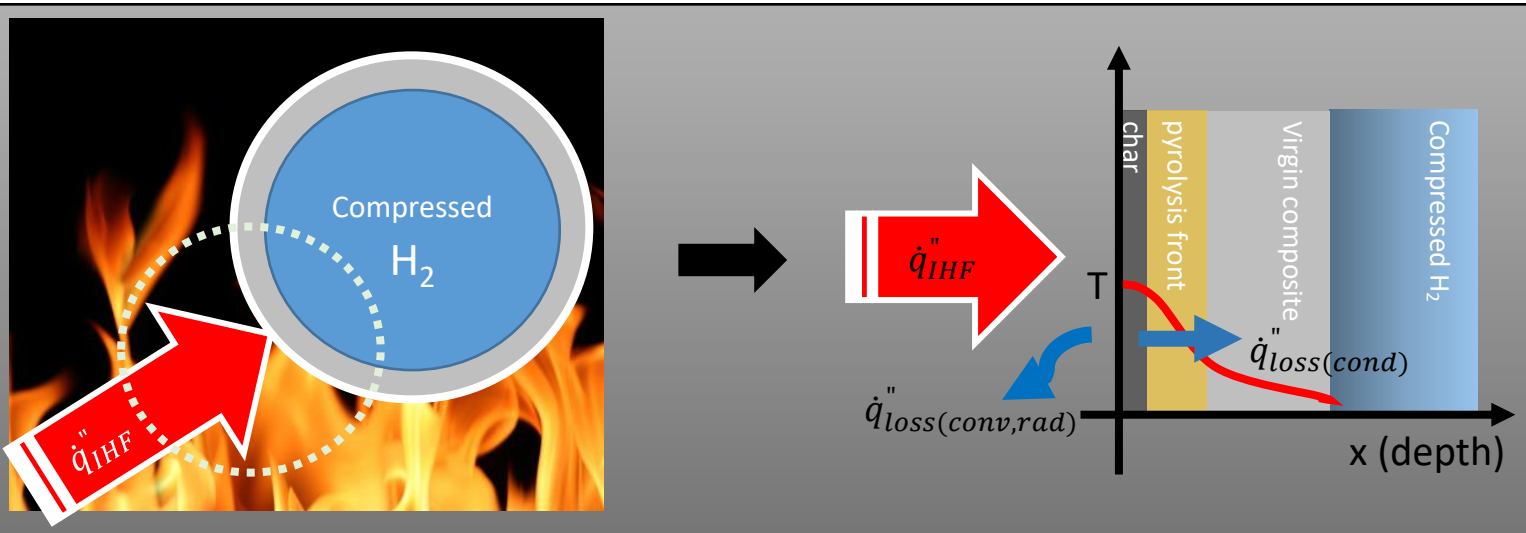
Actual Heat Energy Applied to Specimen Surface

- Energy Balance Equation at Surface:

  Net energy applied to surface (energy storage, $\dot{q}''_{net}$) = Applied heat energy ($\dot{q}''_{IHF}$) - Loss ($\dot{q}''_{loss}$)

- Applied Heat Energy: $\dot{q}''_{IHF} = \dot{q}''_{rad} + \dot{q}''_{conv}$
- Convection: $\dot{q}''_{conv} \propto T_g - T_{surf}$
- Radiation: $\dot{q}''_{rad} = func\,(T_g$, configuration, soot concentration, radiative fraction, fuel velocity, premixing, etc.) → hard to control with T_g only



Analysis (2)

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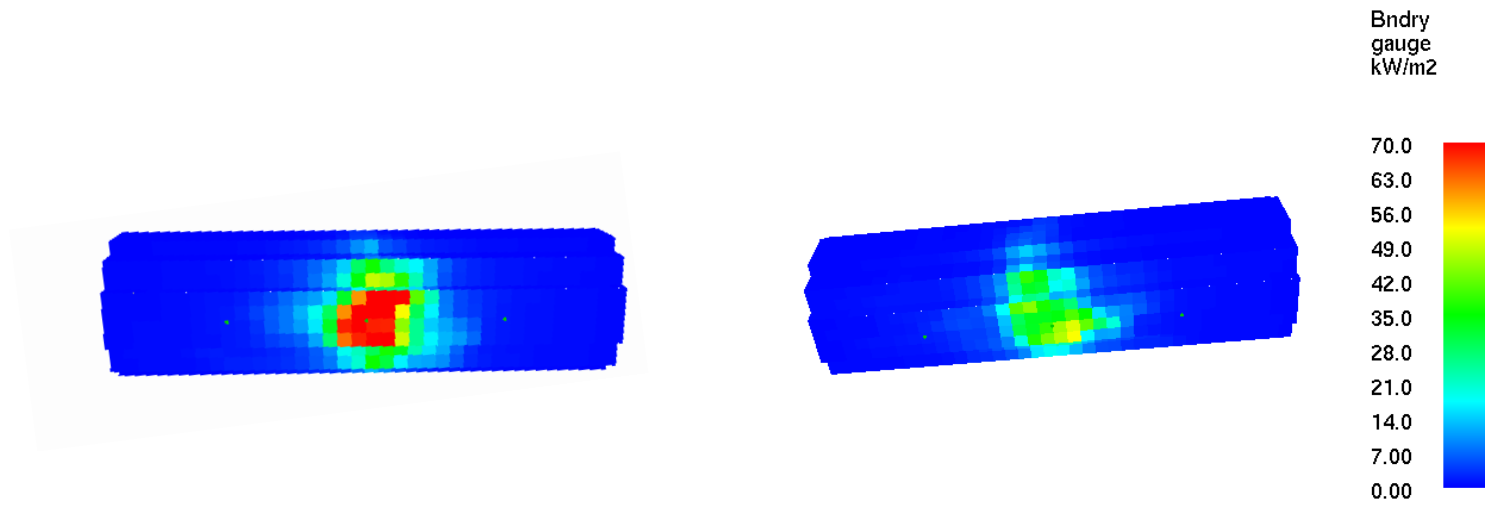
Effect of Radiative Fraction in GTR#13 Fire Test

- FDS modeling results of GTR#13 fire test with 1.8 m long CHSS Tank
  - ✓ TPRDs are place at each end; therefore, flame was placed at center
  - ✓ Radiative fraction of the fire is changed from 0.3 to 0.1
  - ✓ Total Heat flux at surface reduces from red to green during local fire (70 to 30 kW/m^2, see below)
  - ✓ For FRP composite (~20mm thick), this may alter PASS/FAIL



Proposal

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Setting-up for High R&R Fire Test

- To address repeatability(test-to-test) & reproducibility(lab-to-lab) of GTR#13 fire test, we need to set consistent fire test conditions throughout
- In the current working draft, we have temperature data & HRR/area(burner) data to match
- Need to fix radiative heat/energy transfer condition to sample surface → utilize heat flux measurements
- Why? Cannot control all the variables that may affect flame radiation to sample surface
  - ✓ E.g., Different laboratories have different source of LNG (variation in composition)
- **Make heat flux measurements (total & radiative) during pre-test checkout and/or before each test: 6.2.5.1.4.5 Pre-test Checkout Process**

Table 2c

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Allowable Heat Flux Range on Bottom & Sides & Top of Container

Measurements from RR

Measurements from RR

Appendix (1)

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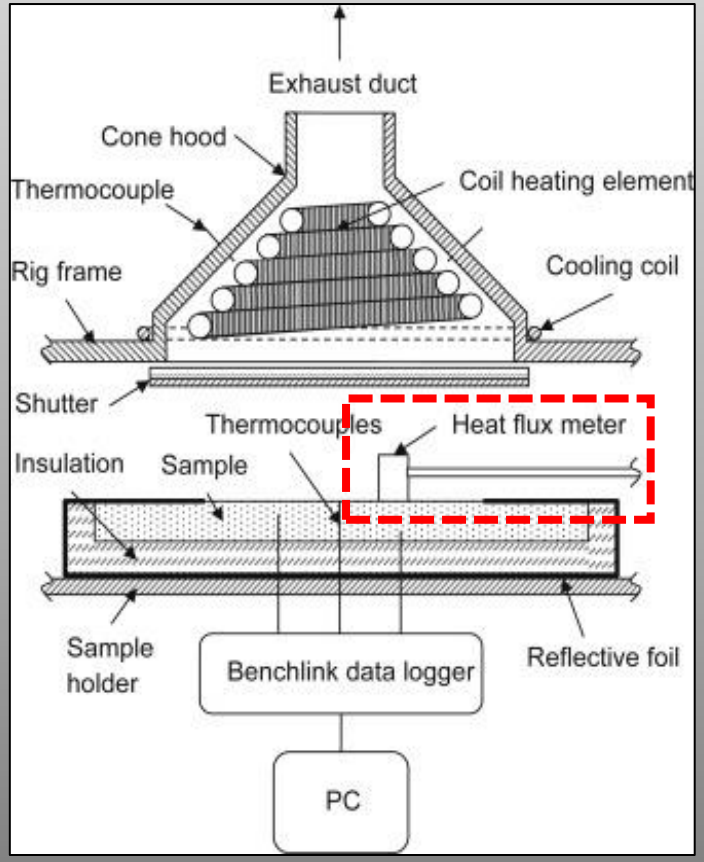
Other Fire Tests Considering Energy-based Test Conditions

- Cone Calorimeter (ASTM E 1354, ISO 5660)
  - ✓ Bench-scale test for material flammability (used for fundamental research & regulations)
  - ✓ Cone heater temperature is set to fix thermal condition
  - ✓ Although temperature is set, applied heat flux level is checked via calibrated heat flux gauge (total →)
  - ✓ Why? Temperature setting does not always result in same heat flux level



Right figure from: Fan, M., A. Naughton, and J. Bregulla. "Fire performance of natural fibre composites in construction." *Advanced high strength natural fibre composites in construction*. Woodhead Publishing, 2017. 375-404.

Appendix (2)

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- Other fire tests
  - ✓ When fire testing for material's fire behavior, heat flux is considered as the most important boundary condition at the gas-phase & condense-phase interface
  - ✓ Almost always **heat flux mapping** is conducted
  - ✓ See below: room corner test (ISO 9705), flame spread test (ASTM E84), manikin flame engulfment test (ISO 13506, calibration targets for 84kW/m^2 avg), and more.

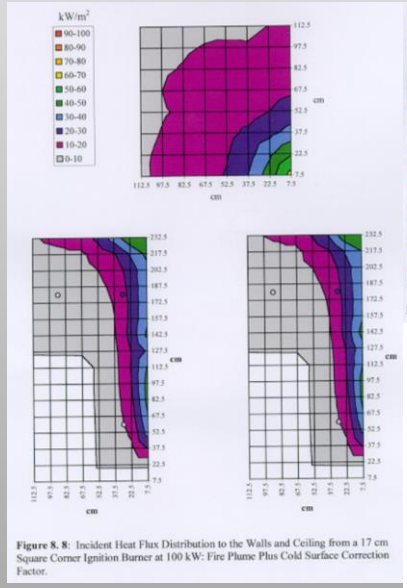


Figure 8. 8: Incident Heat Flux Distribution to the Walls and Ceiling from a 17 cm Square Corner Ignition Burner at 100 kW: Fire Plume Plus Cold Surface Correction Factor.

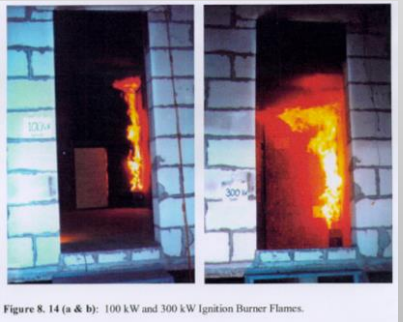
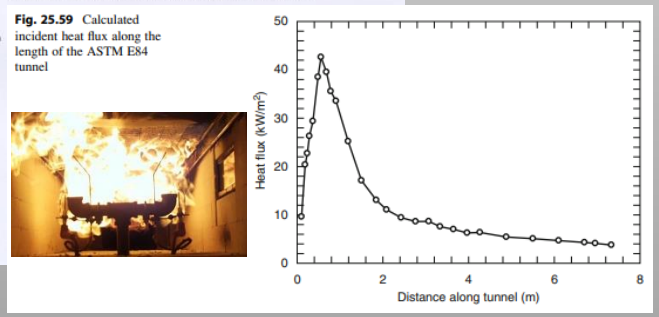


Figure 8. 14 (a & b): 100 kW and 300 kW Ignition Burner Flames.

Dillon, S. E. "Analysis of the ISO 9705 Room/Corner Test: Simulations, Correlations and Heat Flux Measurements." (1998).



Intertek(left) & Lattimer B.Y. (2016) Heat Transfer from Fires to Surfaces. In: Hurley M.J. et al. (eds) SFPE Handbook of Fire Protection Engineering. Springer, New York, NY. https://doi.org/10.1007/978-1-4939-2565-0_25 (right)

https://www.empa.ch/web/s401/henry

Thank you