***Th**ermally-**I**nduced **E**lectrical **F**ailure (THIEF) Model*

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Simple Response Models in Fire

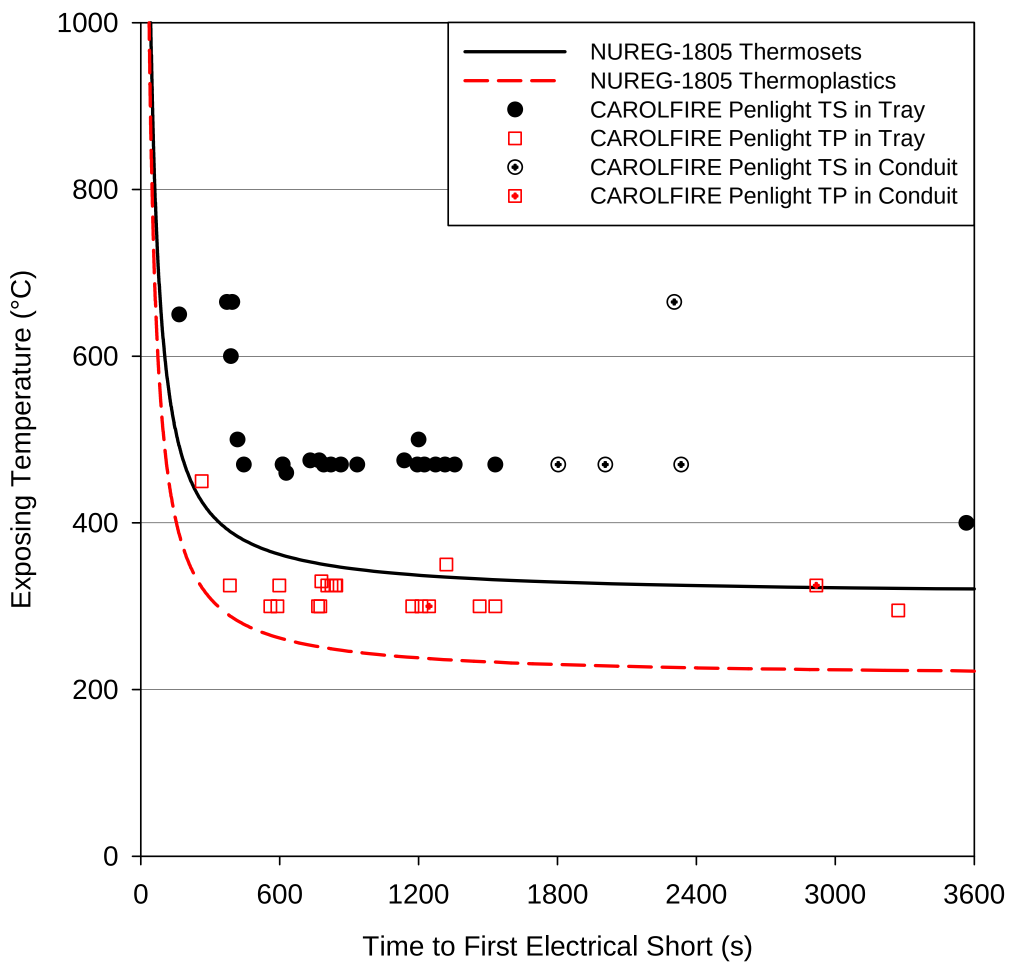
$$\frac{dT_l}{dt} = \frac{\sqrt{|\mathbf{u}|}}{\mathrm{RTI}}(T_g - T_l)$$

Solve for link temperature using velocity **u** and gas temperature from Fire Model. The RTI (Response Time Index) is unique to each sprinkler.
Source: Gunnar Heskestad, Factory Mutual

$$\frac{dY_c}{dt} = \frac{Y_e(t) - Y_c(t)}{L/\mathbf{u}}$$

Solve for smoke chamber concentration using external smoke concentration and velocity **u** from Fire Model. L is a length scale unique to each detector.

Current Methodology for Cable Failure, NUREG-1805



<u>Limitations</u>:

No consideration of bulk cable properties

No accounting for time-dependent exposures

No consideration of conduits, armor jacket, etc.

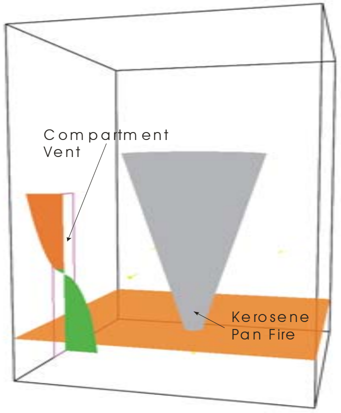
Three Classes of Fire Models

Hand Calculations

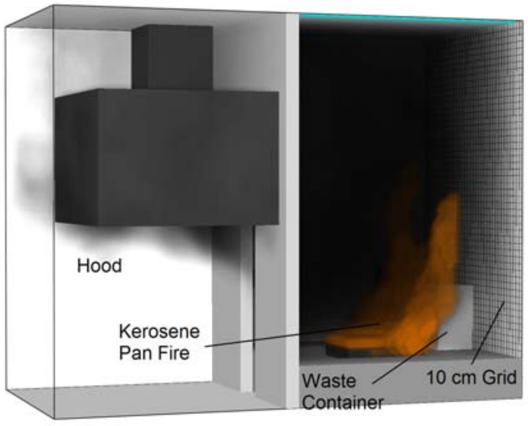
$$T_g - T_\infty = 6.85\left(\frac{\dot{Q}^2}{A_0\sqrt{H_0}h_k A_T}\right)^{1/3}$$

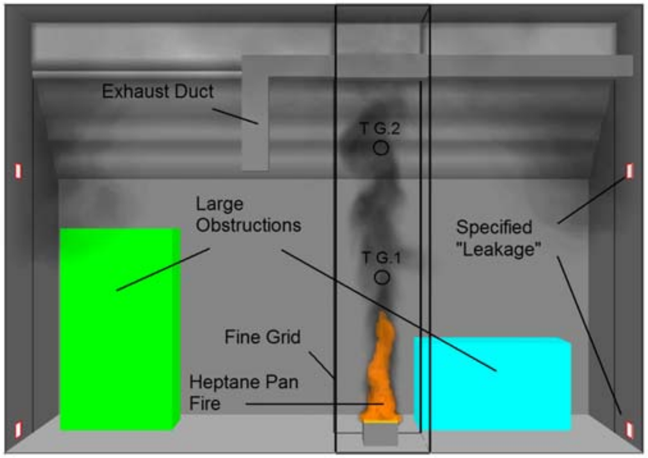
McCaffrey, Quintiere, Harkleroad (MQH)

Two-Zone Models

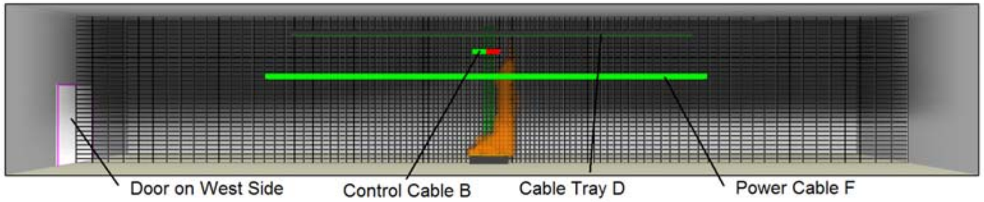


CFD

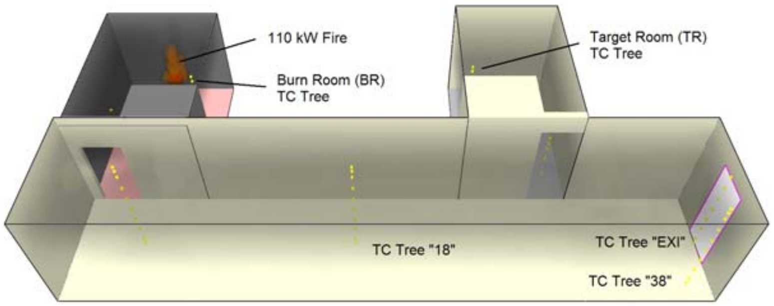




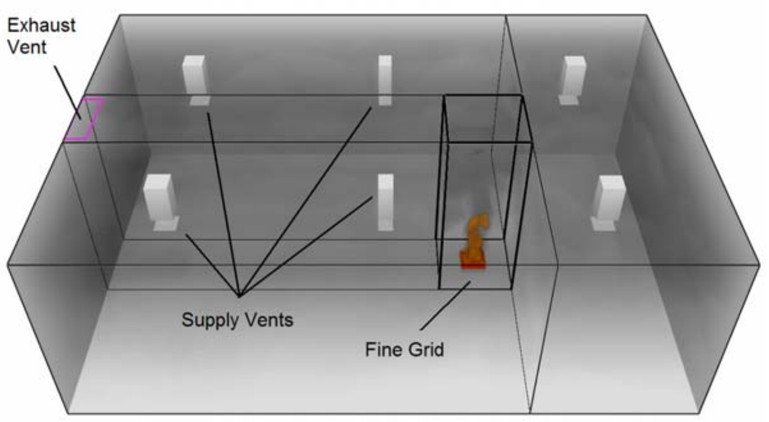
VTT, Finland



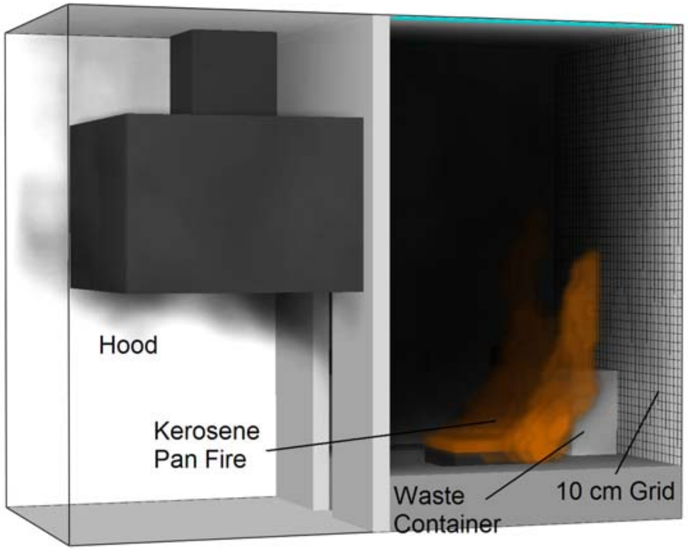
NIST, USA



NBS, USA

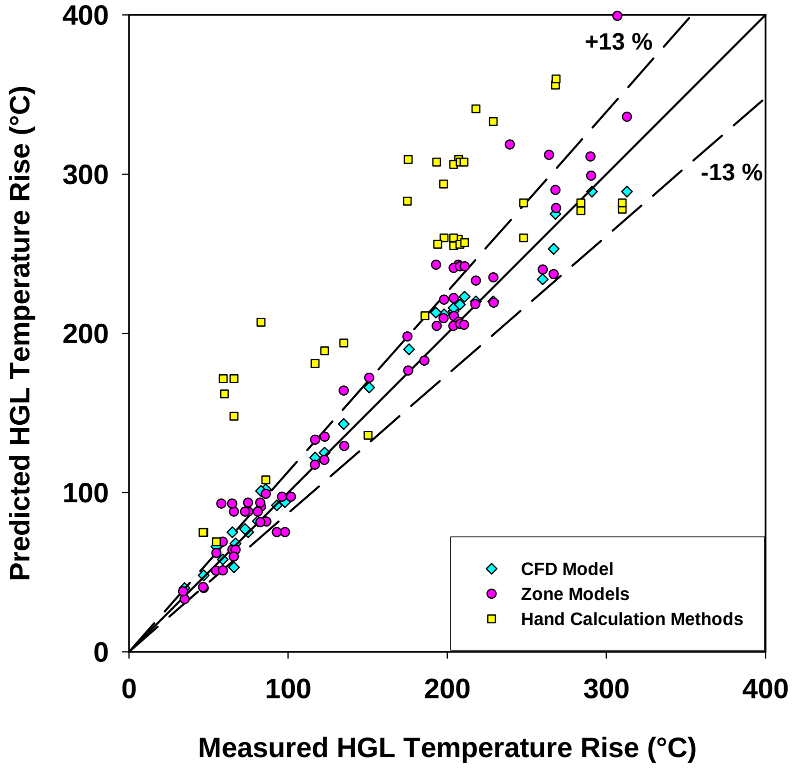


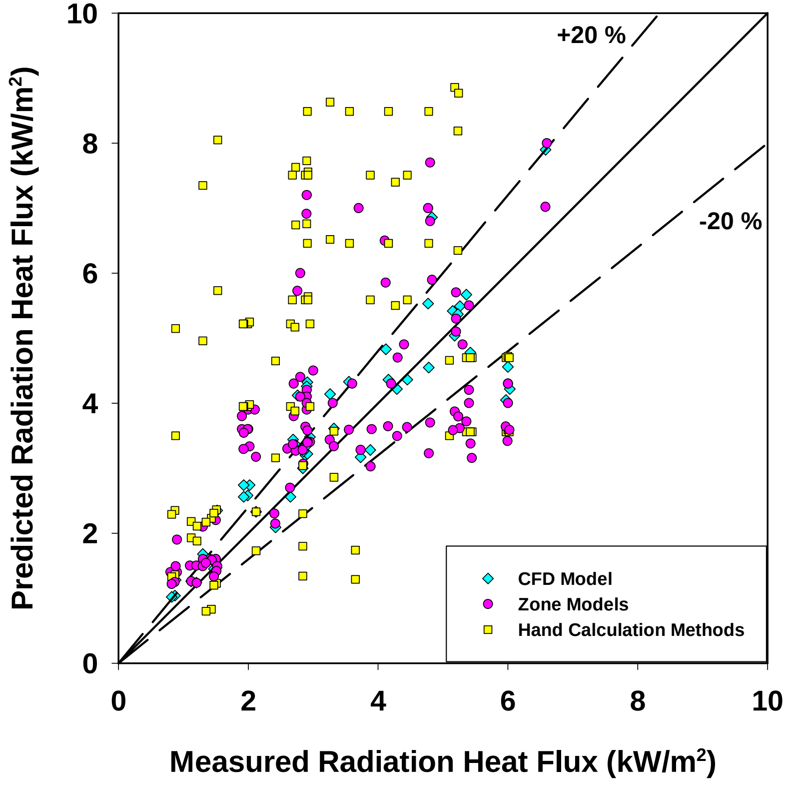
Sandia/FM (USA)



iBMB, Germany

Results of NRC V&V (NUREG 1824)





From *Fire Protection Engineering*, Spring 2007

Office of Nuclear Regulatory Research

THIEF Model

0.2 W/m/K

1.5 kJ/kg/K

$$\rho_s c_s \frac{\partial T_s}{\partial t} = \frac{k_s}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_s}{\partial r}\right)$$

Mass per unit length/Area

$$-k_s \frac{\partial T_s}{\partial r} = \dot{q}_c'' + \dot{q}_r''$$

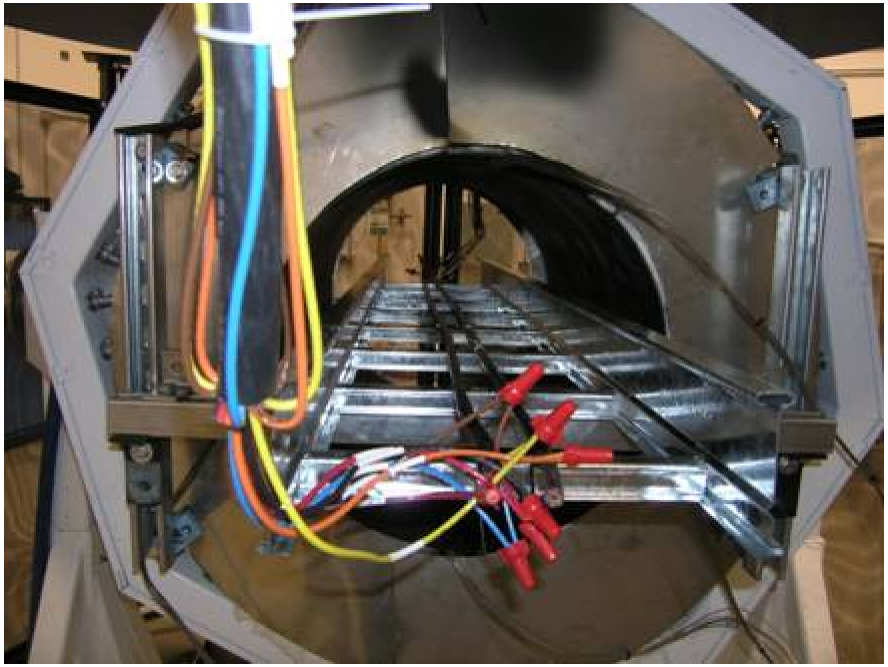
Predicted by Fire Model

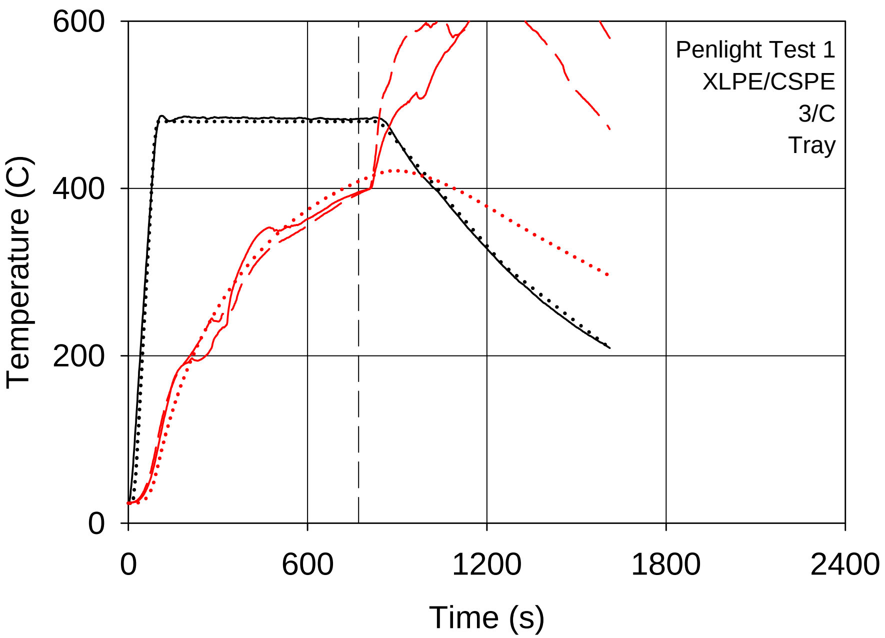
1-D heat conduction into homogenous cylinder. Thermal conductivity (k) and specific heat (c) assumed constant for all cables. Density (ρ) obtained from cable diameter and mass per unit length. Failure temperature obtained experimentally.

The Fire Model provides the convective and radiative heat flux at the cable surface.

Source: Andersson and Van Hees, SP Fire, Sweden.

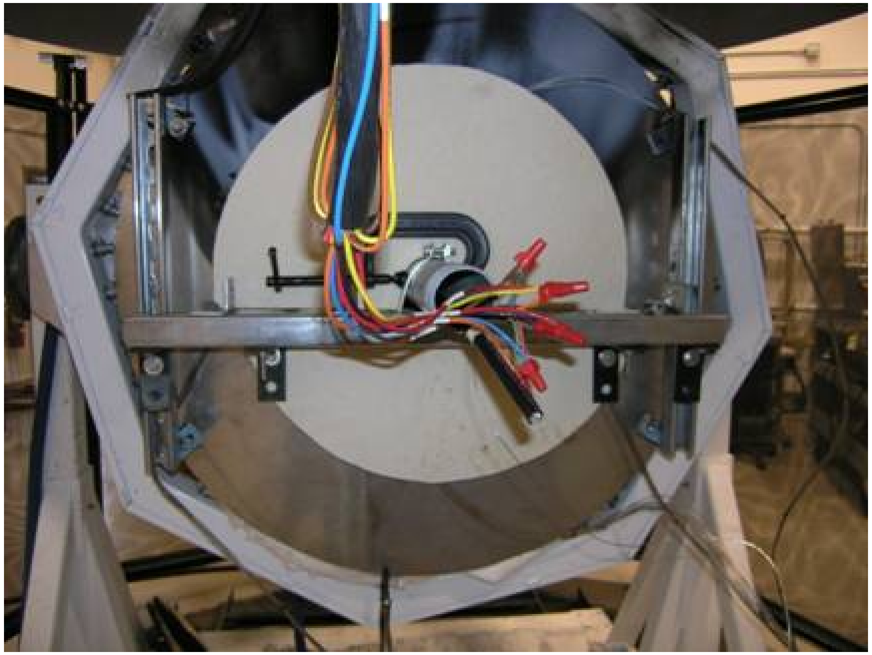
Penlight Results



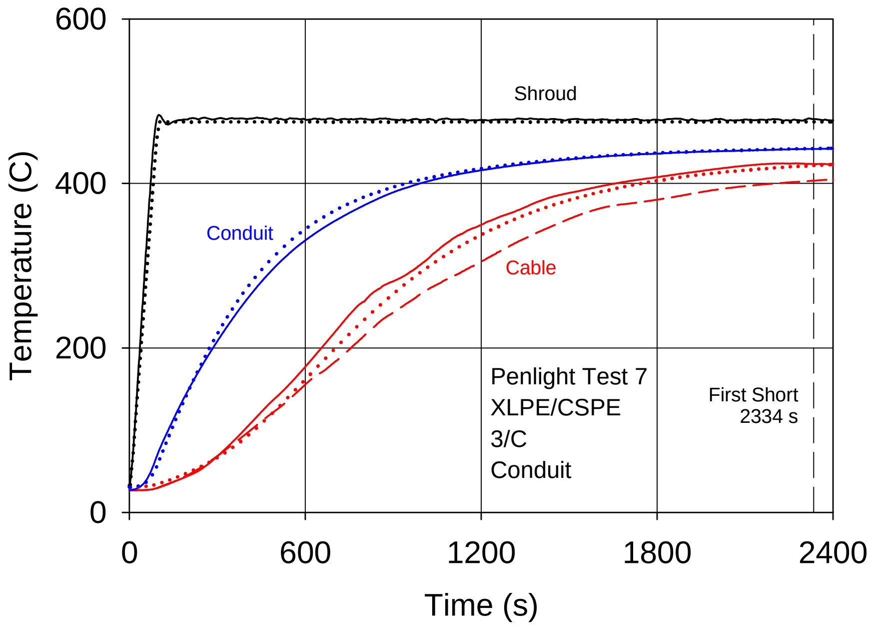


Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory

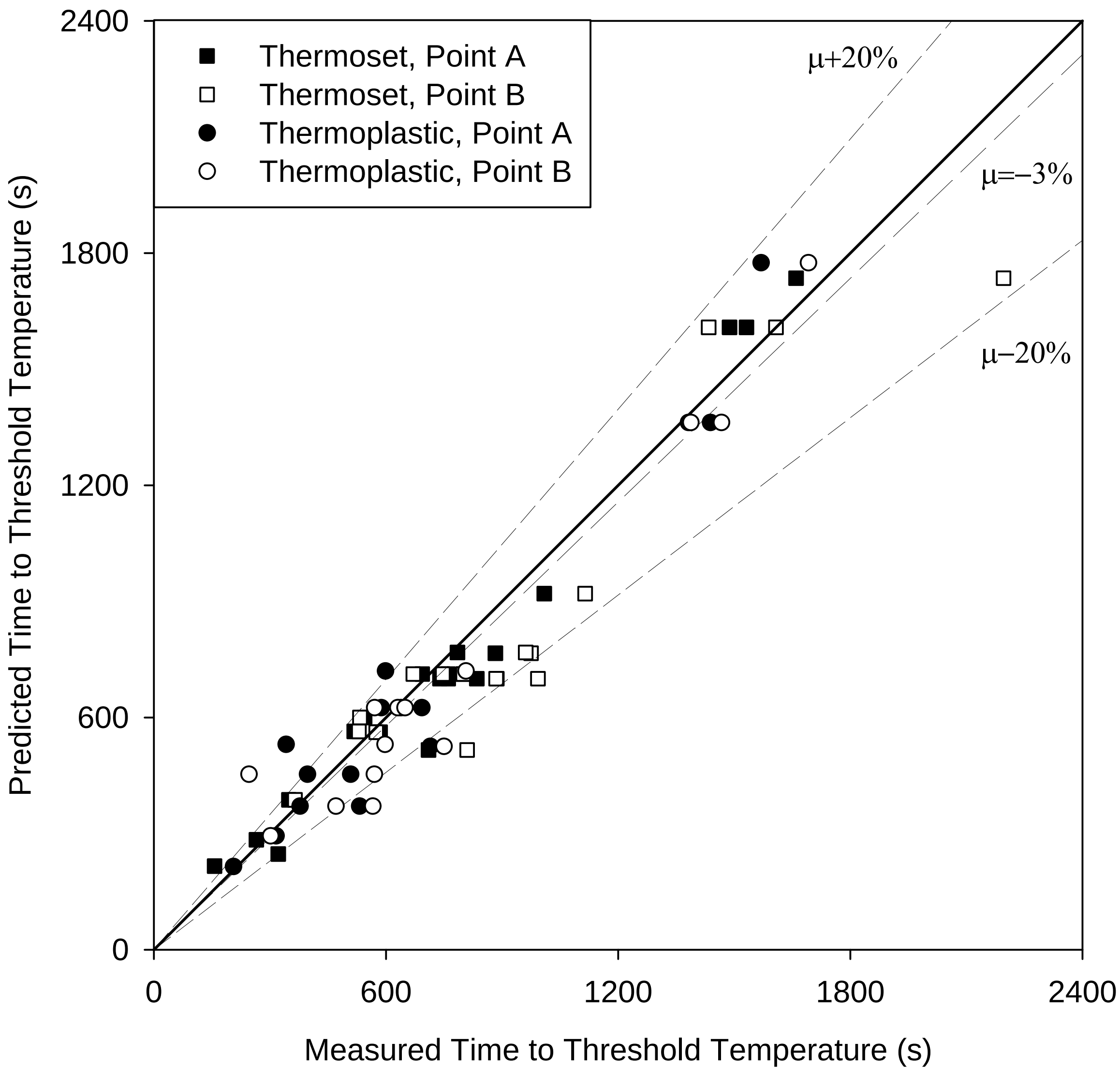
Conduit in Penlight



Courtesy Steve Nowlen and Frank Wyant
Sandia National Laboratory

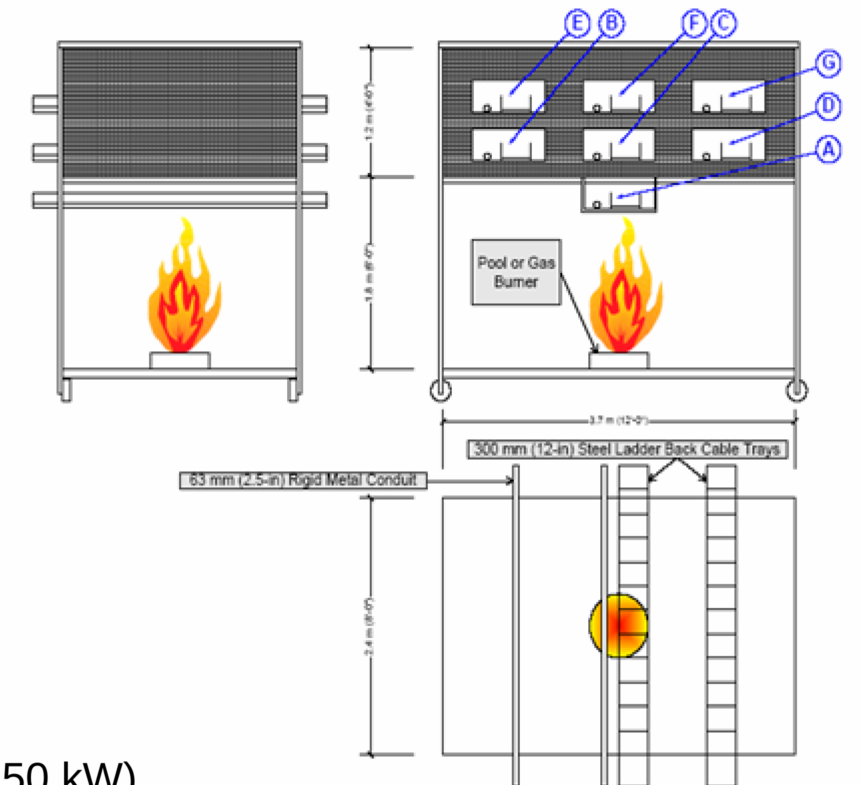


Summary of Penlight Results

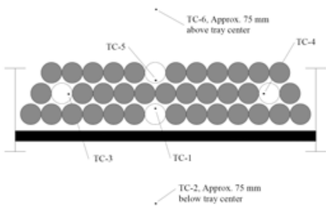


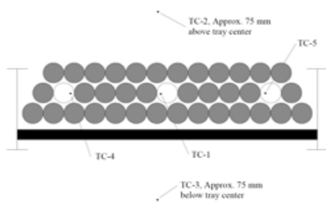
Intermediate-Scale Tests

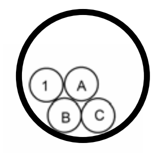
Courtesy Steve Nowlen and Frank Wyant,
Sandia National Labs

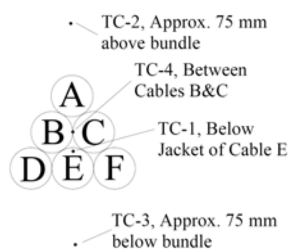


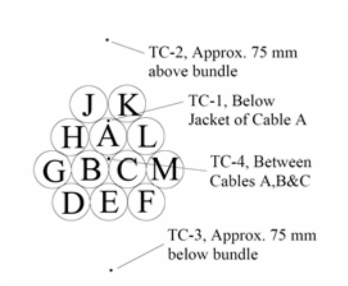
- Less controlled, but a more realistic scale
- Hood is roughly the size of a typical ASTM E 603 type room fire test facility
- Propene (Propylene) burner fire (200 kW to 350 kW)
- Cables in trays, conduits and air drop

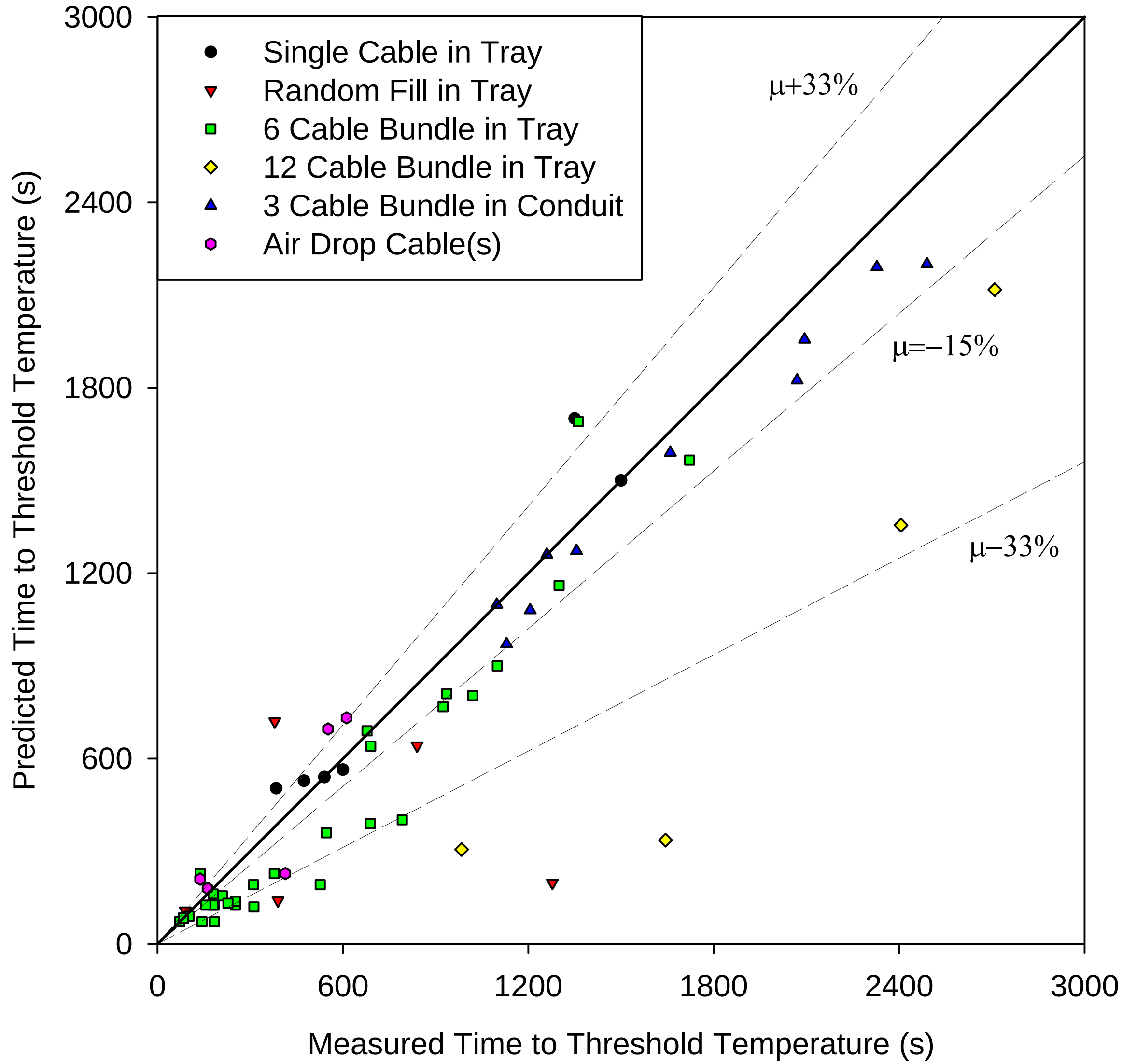

TC-6, Approx. 75 mm above tray center
TC-5
TC-4
TC-3
TC-1
TC-2, Approx. 75 mm below tray center


TC-2, Approx. 75 mm above tray center
TC-5
TC-4
TC-1
TC-3, Approx. 75 mm below tray center


1
A
B
C


TC-2, Approx. 75 mm above bundle
TC-4, Between Cables B&C
A
B
C
TC-1, Below Jacket of Cable E
D
E
F
TC-3, Approx. 75 mm below bundle


TC-2, Approx. 75 mm above bundle
J
K
TC-1, Below Jacket of Cable A
H
A
L
G
B
C
M
TC-4, Between Cables A,B&C
D
E
F
TC-3, Approx. 75 mm below bundle


Single Cable in Tray
Random Fill in Tray
6 Cable Bundle in Tray
12 Cable Bundle in Tray
3 Cable Bundle in Conduit
Air Drop Cable(s)
μ+33%
μ=−15%
μ−33%
Predicted Time to Threshold Temperature (s)
Measured Time to Threshold Temperature (s)
0
600
1200
1800
2400
3000

Summary

- The THIEF (Thermally-Induced Electrical Failure) model is simple, but includes the relevant physical description of cables in a fire environment.
- The THIEF model is currently being implemented in the FDTs (NRC spreadsheet-based fire calculations), CFAST (NIST zone model), and FDS (NIST CFD model).