PSAM 14, 16-21 September 2018, Los Angeles CA.

# Monte Carlo Simulation of NUREG/CR 6850 Appendix L Model for Main Control Board

# Fires and Resulting Insights

September 17, 2018- Internal Hazards PRA I

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# MCB fire growth & suppression modeling-Background

1. Multiple functions and electrical divisions are present
2. Minimal physical of spatial separation
3. Reliability of alternate shutdown methods (independent of the MCB) often unreliable
4. Fire risk potentially very significant

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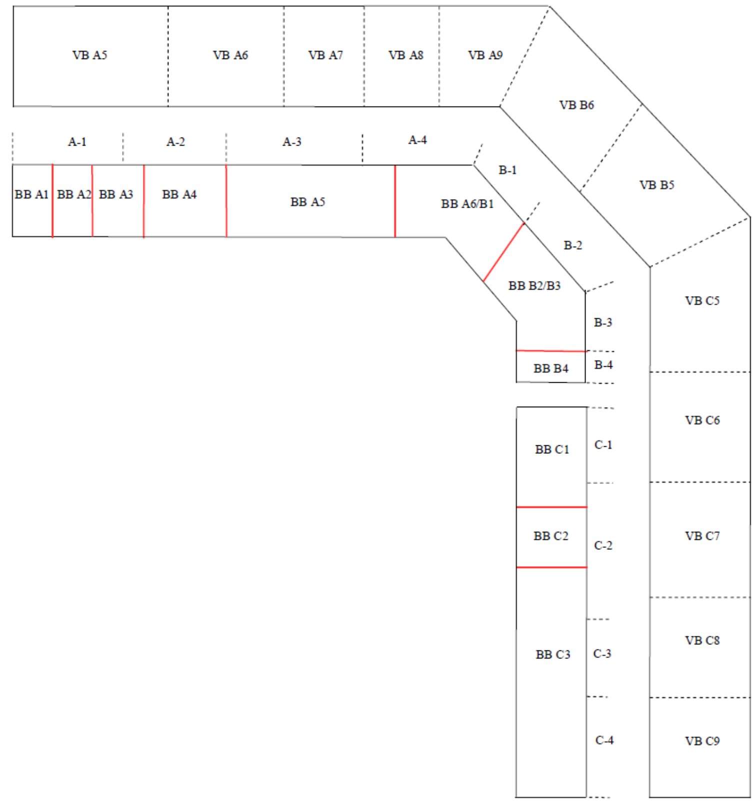
# NUREG/CR 6850
# Appendix L Model

- Current state of the art PSAs use a statistical approach which embodies
  - Alpert's Plume correlation
  - t2 fire growth
  - Peak Heat Release Rate gamma distribution
  - Exponential expression of fire non suppression as a function of time

- Acknowledged as not V&V

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# Aims of the paper

- Summarize the formulation of 6850 Appendix L model and modifications presented in FAQ & NEI white paper[1]
  - new cabinet HRRs and mean suppression rate
  - resolution of errors in original model solution
- Describe more flexible solution using Monte Carlo method
- Evaluate impact of simplifying assumptions in the Appendix L formulation.
- Explore use of MC solution to address more complex (realistic) configurations

[1] prepared by Jensen Hughes & reviewed by Jacobsen



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# Fire Source – Target Configuration on MCB fascia

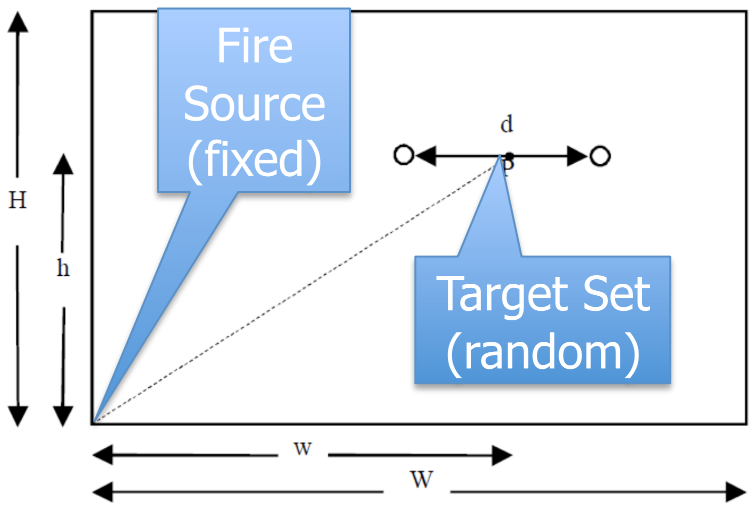
## Appendix L Representation

$$Q(d,w,h) = \frac{1}{k}\left[\frac{\Delta T \cdot r(d,w,h)^{5/3}}{16.6}\right]^{3/2}$$

$$t_{Dam}(d,w,h) = 12\left(\frac{Q(d,w,h)}{Q_{Peak}}\right)^{0.5}$$

$$P_{NS}(d,w,h) = e^{-\lambda \cdot t_{Dam}(d,w,h)}$$

$$SF(d,w,h) = 1 - \int_{0}^{Q(d,w,h)} f(Q_{Peak})\,dQ_{Peak}$$




$$r(d,w,h) = \frac{d}{2} + \sqrt{w^2 + h^2}$$

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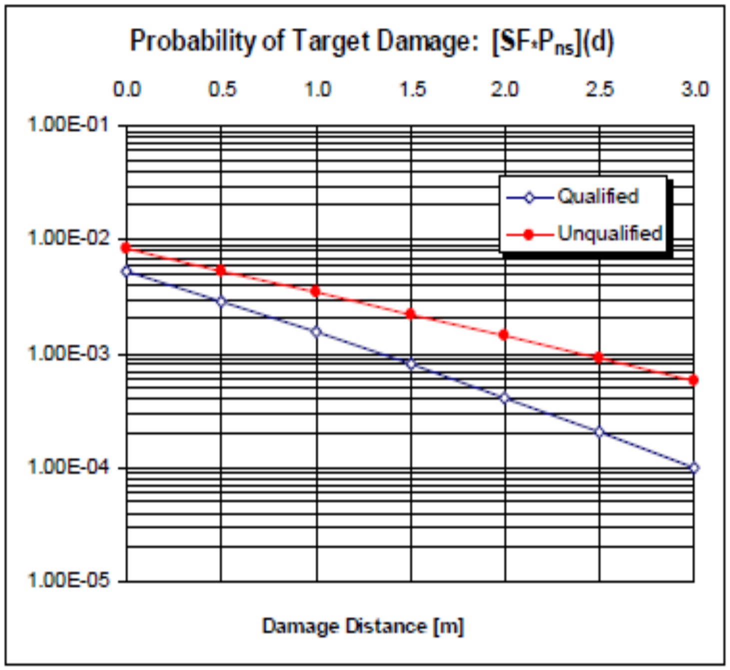
# NUREG/CR 6850
# Appendix L Model




$$[SF \cdot P_{ns}](d) =$$

$$\frac{1}{H \cdot W} \int_0^H \int_0^W SF(d, w, h) \cdot P_{ns}(d, w, h) dwdh$$



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# Update to account for solution errors & NUREG 2178 HRRs

## FAQ-16-00X(draft) & NEI White Paper (July 2017)

- Review of draft FAQ identified solution errors carried forward from NUREG/CR 6850 – potential under estimation of risk
  - The Eqn for Q(d,w,h,Tdam) was incorrect, it should include a factor of (1/k) not (1/k)^(3/2)
  - The integral for Pns should have been evaluated over the range of "surviving" Qp values capable of causing damage, i.e. it should be an average over Qpeak values that run from Q(w,h) to infinity, not zero to infinity

- Conservative features of model identified
  - Plume model K factor reduced from 2 to 1 [1]
  - Peak HRR capped at 98$^{th}$ percentile of gamma distribution

- Removal of conservative modelling features and incorporation of 2178 HRRs more than cancelled earlier solution errors

[1] consistent with the work presented in EPRI TR-3002005303
[2] consistent with practice in other areas of detailed fire modelling.

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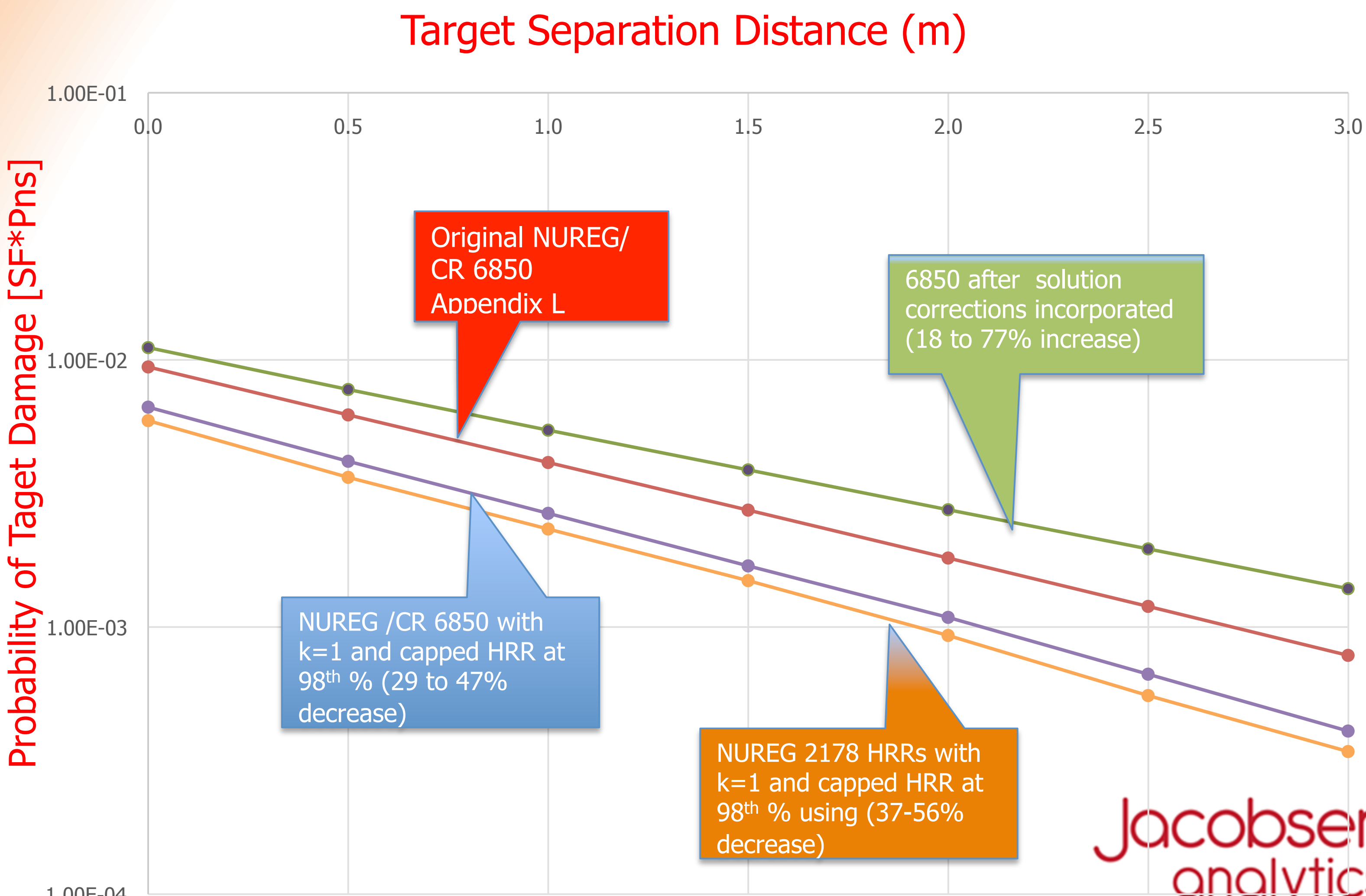
# Result of Appendix L Model Update for Thermo Plastic cables

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# Monte Carlo Simulation

- Model described so far requires solution of double integral over allowed values of w & h
  - Python code available for download at http://www2.jacobsen-analytics.com
- A more flexible approach is to use a relatively simple Monte Carlo simulation
  - implemented with MS EXCEL© add-in "Crystal Ball©"
- Accessible without knowledge of highly technical and specialized codes
- Allows customised application of MCB fire growth model as discussed by FAQ 14-008 e.g.
  - Non standard sized MCBs
  - Targets / Ignition sources away from MCB fascia

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# Monte Carlo Simulation within Crystal Ball©

| Run number / Worksheet * | Enclosure Ventilation (Open/ Closed) | Fuel Type* (TS/TP Cables) | Alpha | Beta | 98th %tile (kW) | HRR capped at 98th% HRR? | NUREG 6850 'k' value |
|---|---|---|---|---|---|---|---|
| 3 | Closed | TP | 0.52 | 145 | 400.44 | Yes | 1 |

| d (m) | w (m) | h (m) | r (m) | Qp (kW) | t (mins.) | Q (kW) | T (°C) | Fail? | [SF.Pns] |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.288 | 3.048 | 18.5402602 | 216 | 3.00 | [illegible]3.5 | 20.74 | 0 | 3.42E-03 |
| 0.5 | | | 18.7[illegible]02602 | | | [illegible]3.5 | 20.7[illegible]2 | 0 | 1.76E-03 |
| 1 | | | 19.[illegible]402602 | | | [illegible].5 | 20.7 | 0 | 8.98E-04 |
| 1.5 | | | 19[illegible]902602 | | | [illegible].5 | 20.6 | 0 | 4.84E-04 |
| 2 | | | 1[illegible]5402602 | | | [illegible]5 | 20.6 | [illegible] | 2.34E-04 |
| 2.5 | | | [illegible].7902602 | | | [illegible]5 | 20.6 | [illegible] | 1.22E-04 |
| 3 | | | [illegible]0.0402602 | | | [illegible]5 | 20.6 | [illegible] | 5.00E-05 |

Number of hits / total number of trials

Target mid point location coordinates randomly selected from normal distribution

$$r(d,w,h)=\frac{d}{2}+\sqrt{w^2+h^2}$$

Peak HRR randomly selected from Gamma distribution

Time to suppression randomly selected from exponential distribution

HRR at time of suppression based on t squared growth with time to peak at 12 mins capped at 98th percentile

Temperature at target at time of suppression

T>/= Tdam = 1
T< Tdam = 0

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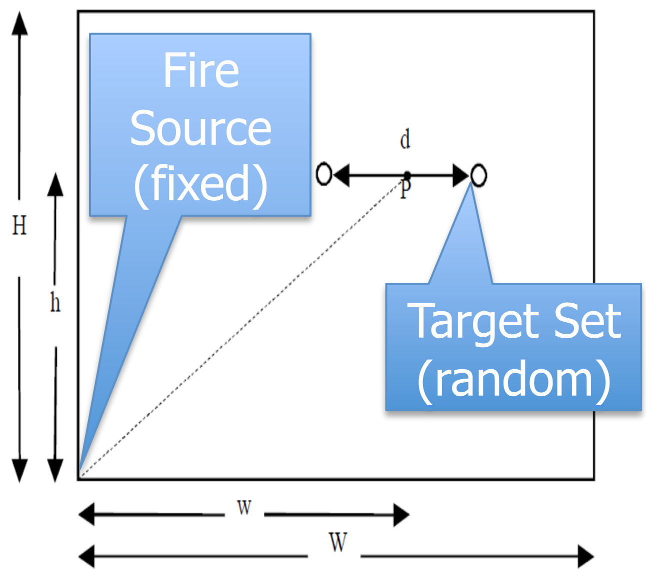
# Evaluation of Impact of Target Set Location within MCB (1)

**Appendix L Model**

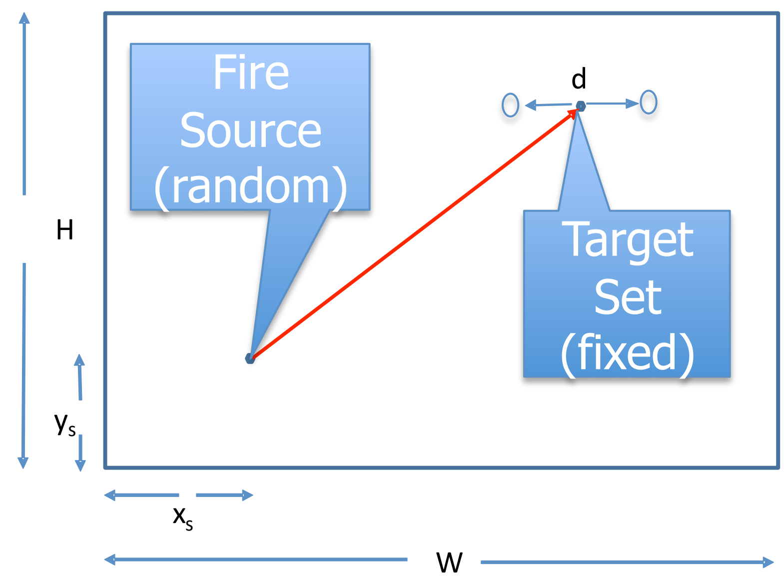



- Appendix L provides one model solution with the fire always fixed at the origin and the target set location as a random variable
- (Mathematically for any given case its irrelevant whether the source of target is fixed)
- By only considering one fire (or target) location, **at an extremity of the cabinet,** over all values of w & h the average distance between the source and target is maximised and the probability of damage underestimated

# Evaluation of Impact of Target Set Location within MCB (2)

- As analyst its more rational to think of the specific target set being evaluated as having known and fixed location and the fire location being a random variable
- Of course the next target set evaluated also has a fixed (but at different location)
- So now lets do the analysis for different fixed target locations

**More Representative Situation**

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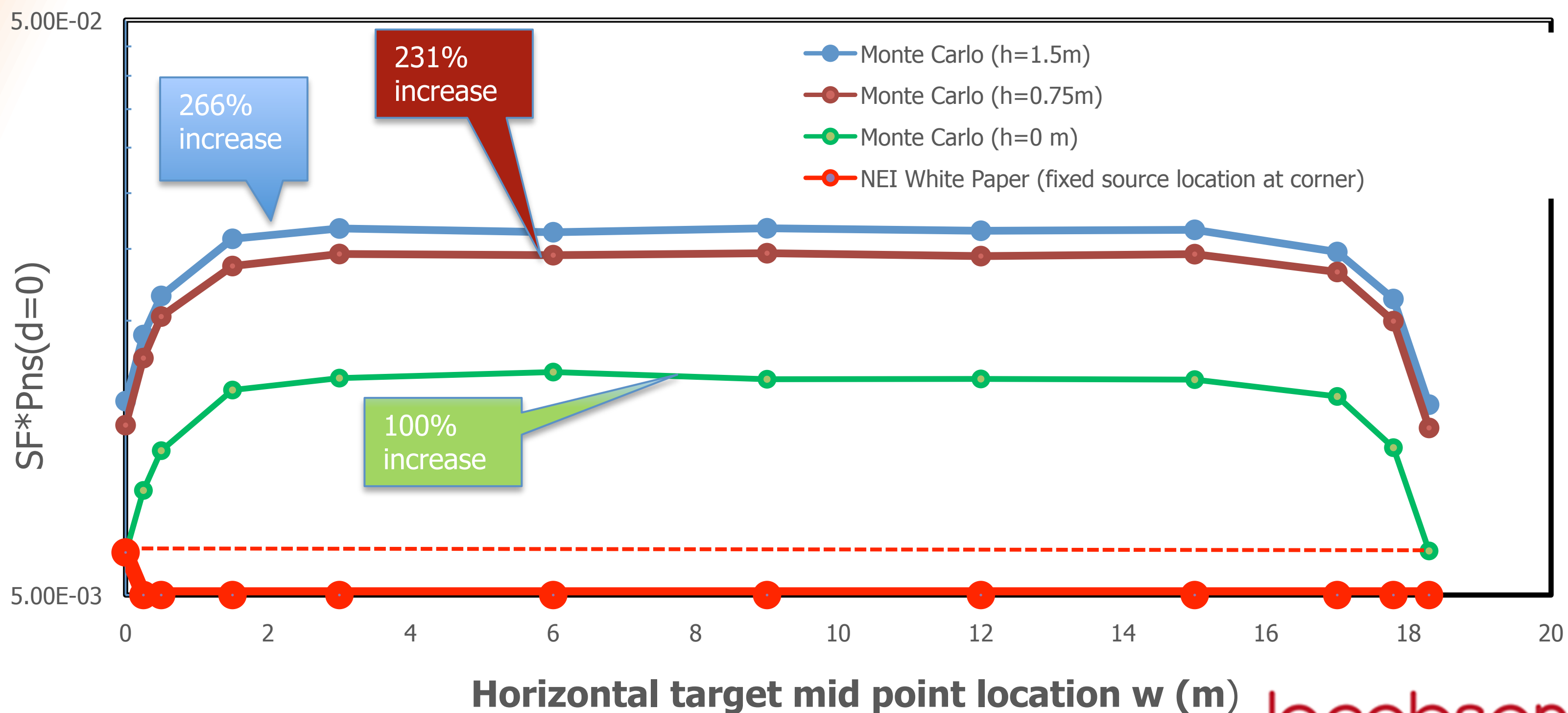
# Evaluation of Impact of Target Set Location within MCB (3)
## (Thermo Plastic Cable d=0)

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# Application of Monte Carlo Modeling in 3D modeling of

# Main Control Board (1)



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# Application of Monte Carlo in 3D modeling of Main Control Board (2)

1. Fire source assumed to be on control board fascia
2. As fire grows additional components on control board fall within expanding zone of influence.
   - Probability of target set damage is determined according to Appendix L based on maximum separation of controls on the fascia.
3. Zone of influence based on radiant damage model extends to upper or lower raceways serving associated cabinet section.
   - The distance *r (fire source to raceway)* is calculated as the closest point to the fire on the section of the cable raceway being considered
   - Further spread of damage along control board fascia becomes irrelevant
   - Model solved using Monte Carlo solution with random selection of fire location
   - Included possibility of damage to raceways associated with two adjacent cabinet sections.
4. Care taken to derive mutually exclusive fire scenario frequencies to avoid double counting

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# Conclusions

- NUREG/CR 6850 Appendix L solution has been corrected and updated to include NUREG 2178 HRRs (as described in NEI white paper)
- An very flexible Monte Carlo solution method has been described and benchmarked
- Sensitivity studies using MC method show overall effect of Appendix L simplifying assumptions may lead to a misleading prediction of the MCB fire risk
  - Conservative factors such as the likelihood of fire progression beyond the incipient stage and the axi symmetric plume model may compensate
- MC method has been extended to address selected cable routes which compromise spatial separation and serves as a method to address FAQ 14 008 and physical barrier effectiveness (see paper)
- Further applications may be used to address, for example
  - Non homogenous ignition source frequency, multiple in cable types (e.g. pilot wire and TP cable)
  - Parameter and modelling uncertainty propagation