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NUREG-1934/EPRI 1023259
Nuclear Power Plant Fire Modeling Analysis Guidelines

ACRS Committee

July 11, 2012

Mark Henry Salley, NRC/RES

Rick Wachowiak, EPRI

Office of Nuclear Regulatory Research

Fire Research Branch

Purpose of the Meeting

- NRC and EPRI have completed the project
- ACRS PRA Subcommittee – March 21, 2012
- Today we would briefly like to discuss:
  - Need & Use of the Report
  - Stakeholder Involvement
  - Response to Comments
  - Future Work in Fire Modeling
- Request a Letter from the ACRS

Purpose of Report

- Replaces 2001 EPRI Fire Model User's Guide
- Provides updated fire model information, 2007 V&V study enhancements, model validity ranges, uncertainty analysis, more realistic examples
- Serves as the text book for NRC/EPRI Fire PRA Advanced Modeling course
- Provides a consistent framework for reporting the results of fire modeling calculations

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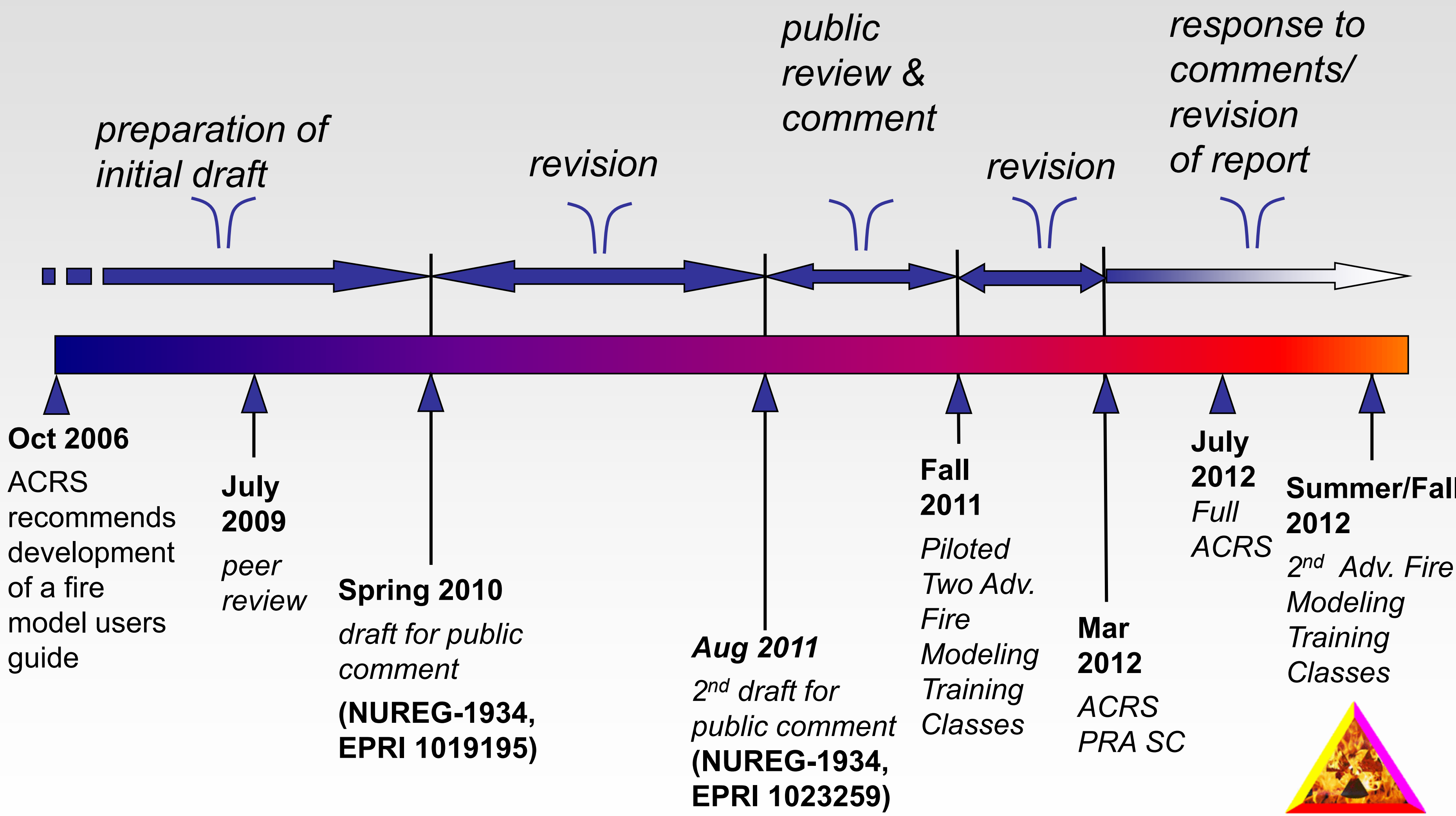
Fire Modeling Team

- NRC/EPRI Memorandum of Understanding
  - Fire Research Addendum
  - Provides for Joint Publication
- Team Composition
  - NRC Experts
  - Industry Experts
    - NSSS Vendors
    - Consultants
  - National Institute of Standards & Technology
  - Universities

Project History



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Today's Presenters

- David Stroup, NRC
- Kevin McGrattan, NIST
- Francisco Joglar, Hughes Associates

Fire Modeling Process

1) Define objective(s)
2) Describe fire scenario(s)
3) Select fire model(s)
4) Calculate fire-generated conditions
5) Conduct sensitivity and uncertainty analyses
6) Document the analysis

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Public Comments

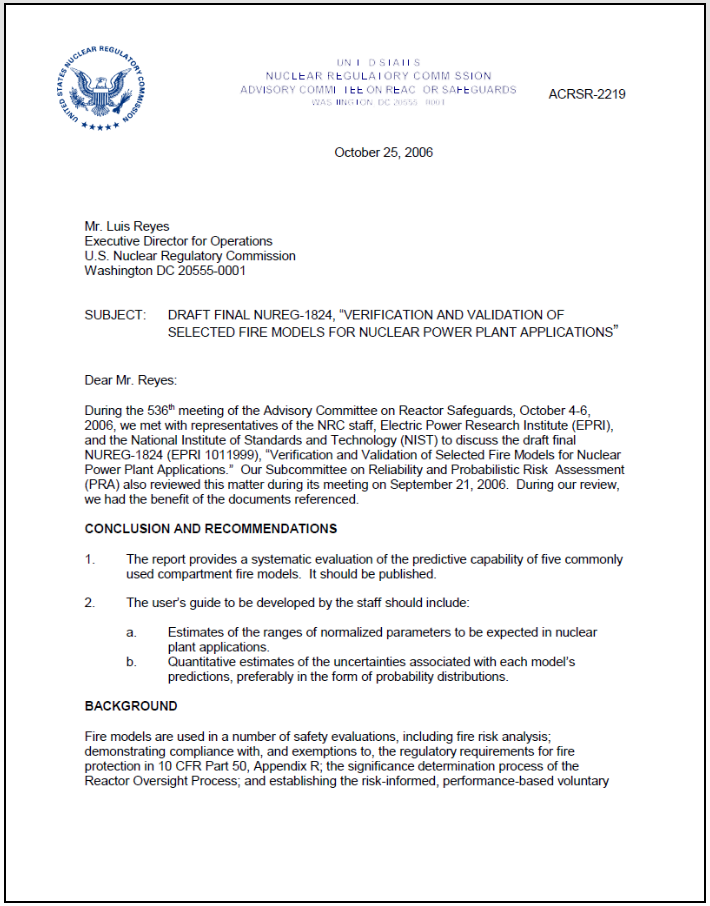
Two Rounds of Public Comments

- Expand uncertainty discussion
- Selection of fire scenarios and model inputs
- Use of fire models beyond their range of validation

ACRS Subcommittee Comments

- Use of Models Outside V&V Range
- New Models (THIEF, FLASHCAT)
- Consistent Selection of Models
- Sensitivity Analysis – Conservative
- Parameter Uncertainty Propagation
- Clarity
- Editorial

ACRS Review of NUREG-1824



UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

ACRSR-2219

October 25, 2006

Mr. Luis Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington DC 20555-0001

SUBJECT: DRAFT FINAL NUREG-1824, "VERIFICATION AND VALIDATION OF SELECTED FIRE MODELS FOR NUCLEAR POWER PLANT APPLICATIONS"

Dear Mr. Reyes:

During the 536th meeting of the Advisory Committee on Reactor Safeguards, October 4-6, 2006, we met with representatives of the NRC staff, Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) to discuss the draft final NUREG-1824 (EPRI 1011999), "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications." Our Subcommittee on Reliability and Probabilistic Risk Assessment (PRA) also reviewed this matter during its meeting on September 21, 2006. During our review, we had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATIONS

1. The report provides a systematic evaluation of the predictive capability of five commonly used compartment fire models. It should be published.

2. The user's guide to be developed by the staff should include:

   a. Estimates of the ranges of normalized parameters to be expected in nuclear plant applications.
   b. Quantitative estimates of the uncertainties associated with each model's predictions, preferably in the form of probability distributions.

BACKGROUND

Fire models are used in a number of safety evaluations, including fire risk analysis; demonstrating compliance with, and exemptions to, the regulatory requirements for fire protection in 10 CFR Part 50, Appendix R; the significance determination process of the Reactor Oversight Process; and establishing the risk-informed, performance-based voluntary

ACRS Recommendation 1:

The user's guide should provide estimates of the ranges of normalized parameters to be expected in nuclear plant applications.

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Fire Research Branch

Normalized Parameters

Quantity	Normalized Parameter	Validation Range
Fire Froude Number	$\dot{Q}^* = \dfrac{\dot{Q}}{\rho_\infty c_p T_\infty D^2 \sqrt{gD}}$	0.4 – 2.4
Flame Length Ratio	$\dfrac{H_f + L_f}{H_c}$ $\dfrac{L_f}{D} = 3.7\,\dot{Q}^{*2/5} - 1.02$	0.2 – 1.0
Ceiling Jet Distance Ratio	$\dfrac{r_{cj}}{H_c - H_f}$	1.2 – 1.7
Equivalence Ratio	$\varphi = \dfrac{\dot{Q}}{\Delta H_{O_2} \dot{m}_{O_2}}$ $\dot{m}_{O_2} = \begin{cases} 0.23 \times \frac{1}{2} A_0 \sqrt{H_0} & \text{(Natural)} \\ 0.23\, \rho_\infty \dot{V} & \text{(Mechanical)} \end{cases}$	0.04 – 0.6
Compartment Aspect Ratio	L/H_c or W/H_c	0.6 – 5.7
Radial Distance Ratio	$\dfrac{r}{D}$	2.2 – 5.7

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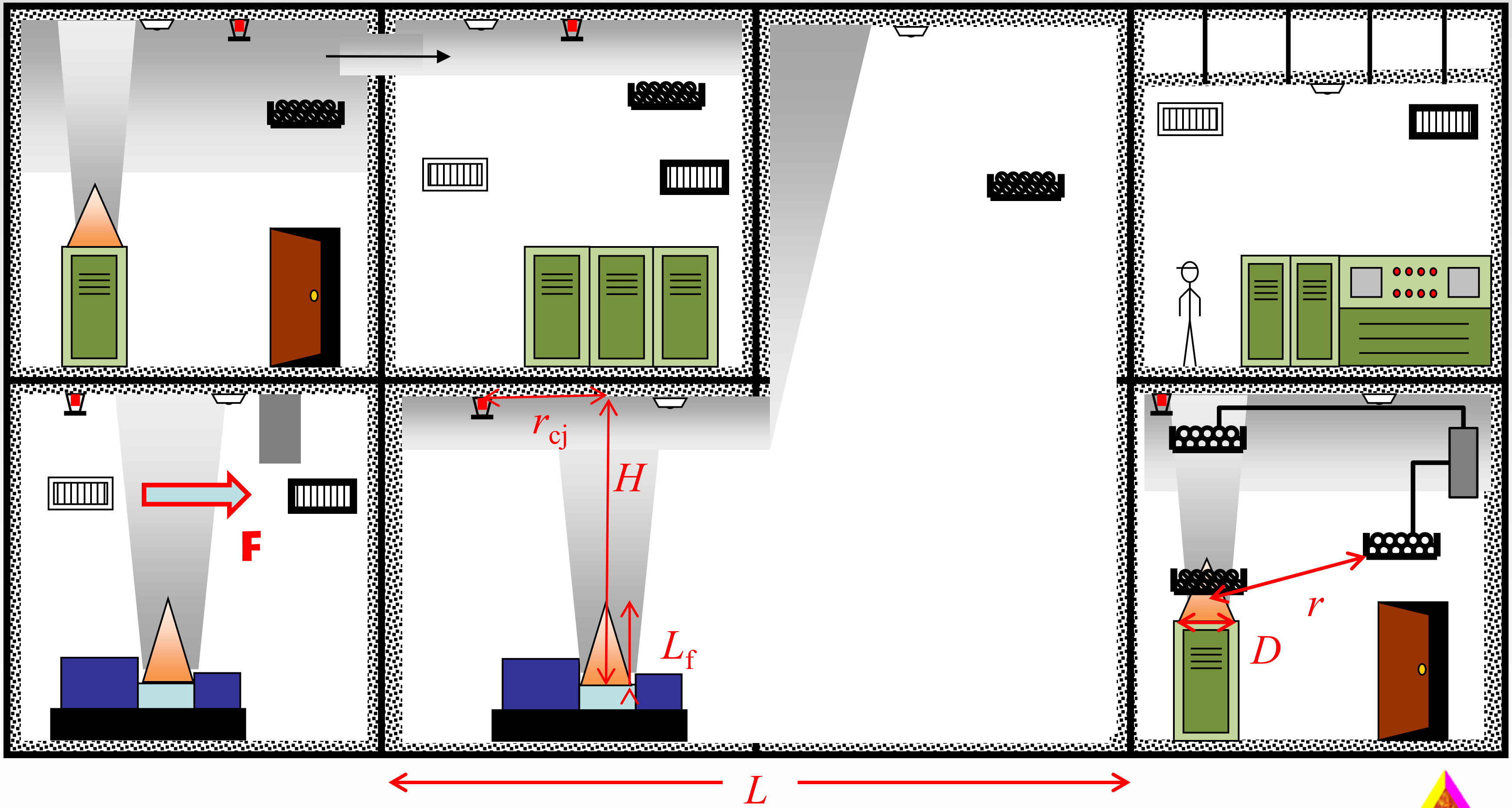
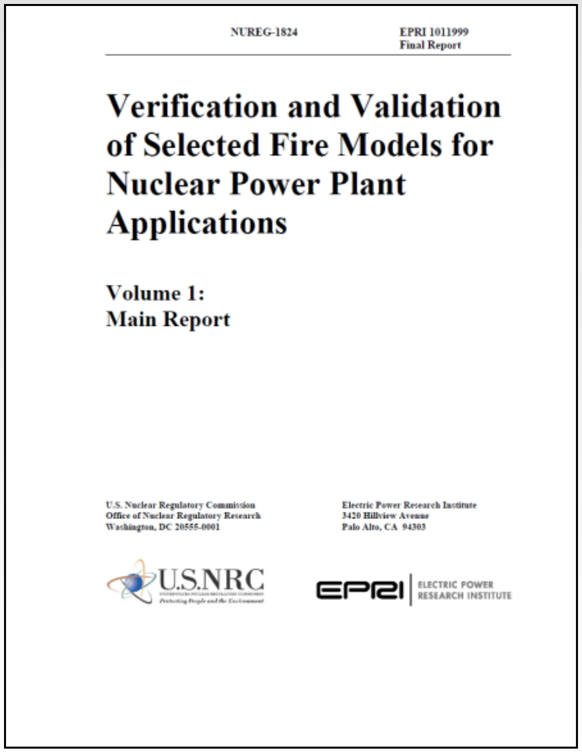
Typical fire scenarios and important parameters



Summary of NUREG-1824 V&V Study


NUREG-1824 EPRI 1011999
Final Report

Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications

Volume 1:
Main Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94303

Table 3-1: Results of the Validation & Verification of the Selected Fire Models for Nuclear Power Plant Fire Modeling Applications

Parameter[5]		Fire Model				
		FDT[s]	FIVE-Rev1	CFAST	MAGIC	FDS
Hot gas layer temperature ("upper layer temperature")	Room of Origin	YELLOW+	YELLOW+	GREEN	GREEN	GREEN
	Adjacent Room	N/A	N/A	YELLOW	YELLOW+	GREEN
Hot gas layer height ("layer interface height")		N/A	N/A	GREEN	GREEN	GREEN
Ceiling jet temperature ("target/gas temperature")		N/A	YELLOW+[2]	YELLOW+	GREEN	GREEN
Plume temperature		YELLOW–	YELLOW+[2]	N/A	GREEN	YELLOW
Flame height[3]		GREEN	GREEN	GREEN	GREEN	YELLOW[1]
Oxygen concentration		N/A	N/A	GREEN	YELLOW	GREEN
Smoke concentration		N/A	N/A	YELLOW	YELLOW	YELLOW
Room pressure[4]		N/A	N/A	GREEN	GREEN	GREEN
Target temperature		N/A	N/A	YELLOW	YELLOW	YELLOW
Radiant heat flux		YELLOW	YELLOW	YELLOW	YELLOW	YELLOW
Total heat flux		N/A	N/A	YELLOW	YELLOW	YELLOW
Wall temperature		N/A	N/A	YELLOW	YELLOW	YELLOW

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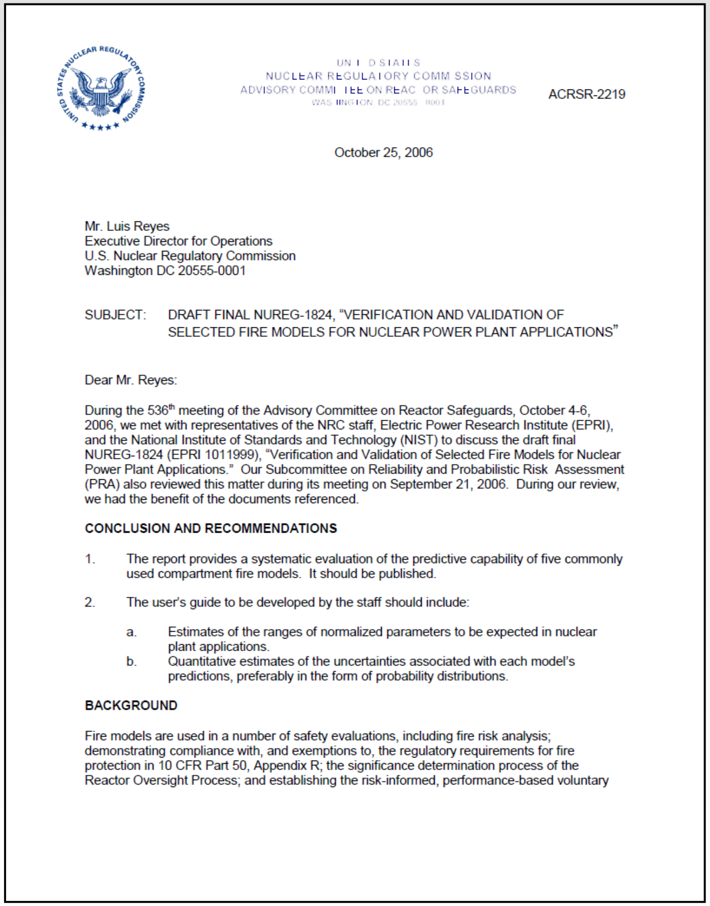
ACRS Review of NUREG-1824



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ACRS Recommendation 2:

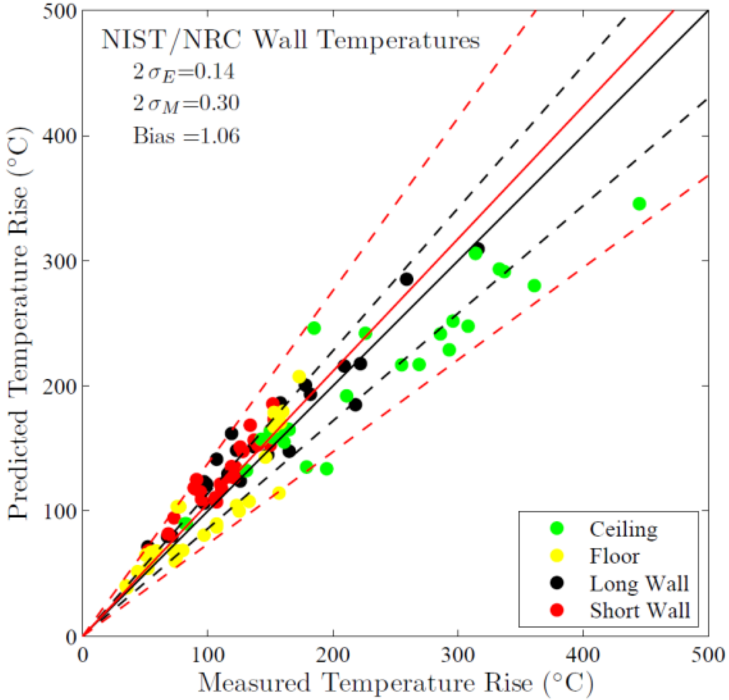
The color designations provide no quantitative estimate of the intrinsic uncertainty.

Improved Model Uncertainty Metrics

Table 4-1. Results of the V&V study, NUREG-1824 (EPRI 1011999).

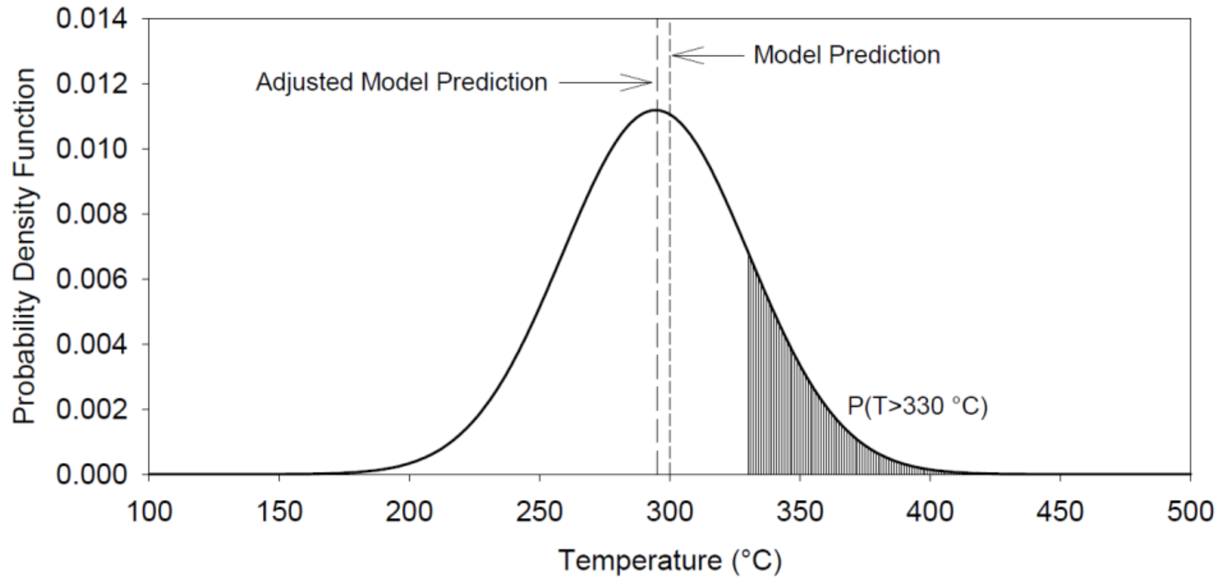
Output Quantity	FDTs		FIVE		CFAST		MAGIC		FDS		Exp
	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	$\tilde{\sigma}_E$
HGL Temperature Rise*	1.44	0.25	1.56	0.32	1.06	0.12	1.01	0.07	1.03	0.07	0.07
HGL Depth*	N/A		N/A		1.04	0.14	1.12	0.21	0.99	0.07	0.07
Ceiling Jet Temp. Rise	N/A		1.84	0.29	1.15	0.24	1.01	0.08	1.04	0.08	0.08
Plume Temperature Rise	0.73	0.24	0.94	0.49	1.25	0.28	1.01	0.07	1.15	0.11	0.07
Flame Height**	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.
Oxygen Concentration	N/A		N/A		0.91	0.15	0.90	0.18	1.08	0.14	0.05
Smoke Concentration	N/A		N/A		2.65	0.63	2.06	0.53	2.70	0.55	0.17
Room Pressure Rise	N/A		N/A		1.13	0.37	0.94	0.39	0.95	0.51	0.20
Target Temperature Rise	N/A		N/A		1.00	0.27	1.19	0.27	1.02	0.13	0.07
Radiant Heat Flux	2.02	0.59	1.42	0.55	1.32	0.54	1.07	0.36	1.10	0.17	0.10
Total Heat Flux	N/A		N/A		0.81	0.47	1.18	0.35	0.85	0.22	0.10
Wall Temperature Rise	N/A		N/A		1.25	0.48	1.38	0.45	1.13	0.20	0.07
Wall Heat Flux	N/A		N/A		1.05	0.43	1.09	0.34	1.04	0.21	0.10

I.D. indicates insufficient data for the statistical analysis.
N/A indicates that the model does not have an algorithm to compute the given Output Quantity.
Underlined values indicate that the data failed a normality test because of the relatively small sample size.
* The algorithm used to compute the layer temperature and depth for the model FDS is described in NUREG-1824.
** All of the models except FDS use the Heskestad Flame Height Correlation (Heskestad, *SFPE Handbook*). These models were shown to be in qualitative agreement with the experimental observations, but there was not enough data to further quantify this assessment.

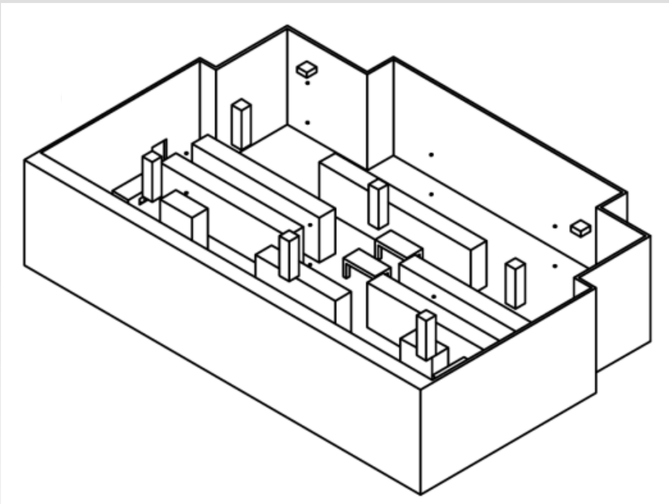


(Left) Typical results from a validation study. The black lines indicate the experimental uncertainty and the red lines indicate the model uncertainty.

(Below) Given a model prediction of 300 °C, what is the probability that the actual temperature might exceed 330 °C, the failure temperature of the given target?



How Model Uncertainty is Applied



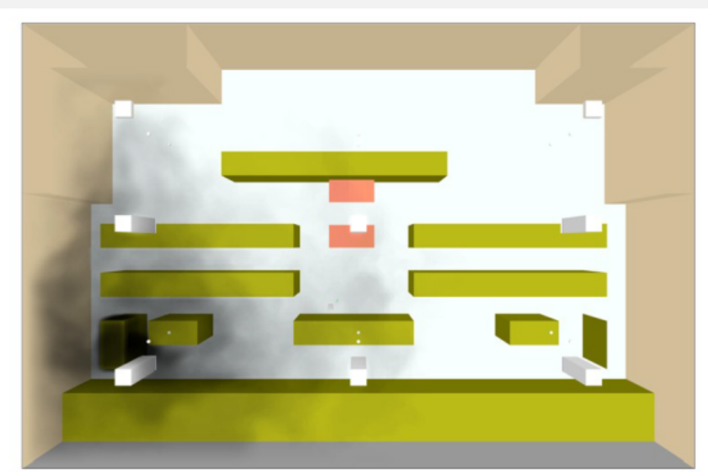
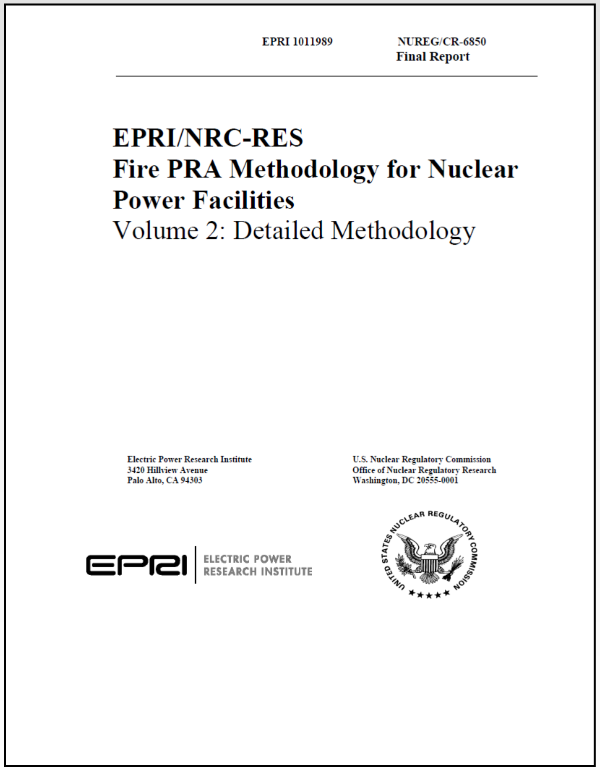


Table A-4. Summary of the model predictions of the MCR scenario.

Model	Bias Factor, δ	Standard Deviation, $\tilde{\sigma}_M$	Ventilation	Predicted Value	Critical Value	Probability of Exceeding
Temperature (°C), Initial Value = 20 °C						
FIVE (FPA)	1.56	0.32	Purge	70	95	0.000
CFAST	1.06	0.12		60	95	0.000
FDS	1.03	0.07		48	95	0.000
CFAST	1.06	0.12	No Vent.	82	95	0.009
FDS	1.03	0.07		70	95	0.000
Heat Flux (kW/m^2)						
FIVE	1.42	0.55	Purge	0.4	1	0.000
CFAST	0.81	0.47		0.1	1	0.000
FDS	0.85	0.22		0.2	1	0.000
CFAST	0.81	0.47	No Vent.	0.6	1	0.228
FDS	0.85	0.22		0.4	1	0.000
Optical Density (m^{-1})						
CFAST	2.65	0.63	Purge	6.5	3	0.362
FDS	2.7	0.55		0.5	3	0.000
CFAST	2.65	0.63	No Vent.	47	3	0.906
FDS	2.7	0.55		31	3	0.909

Parameter Uncertainty Propagation


EPRI 1011989 NUREG/CR-6850
Final Report

EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 2: Detailed Methodology

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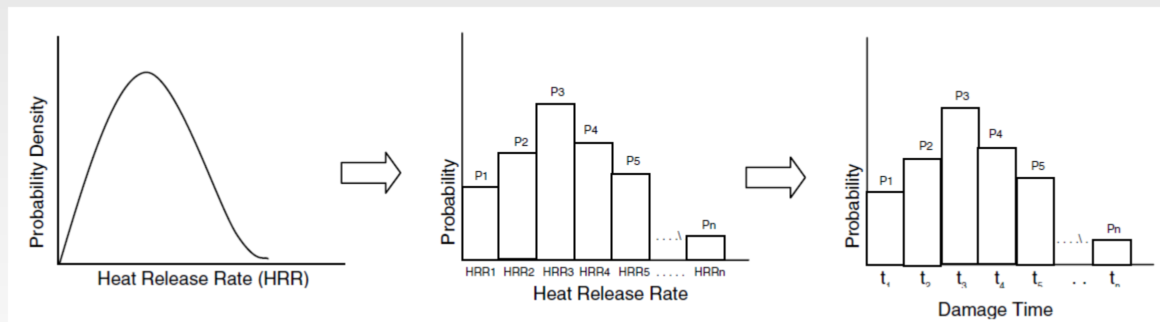
APPENDIX FOR CHAPTERS 8 AND 11, SEVERITY FACTORS



Currently, NUREG/CR-6850 contains a simple method for propagating parameter uncertainty. Several examples have been added to the Fire Model User's Guide.

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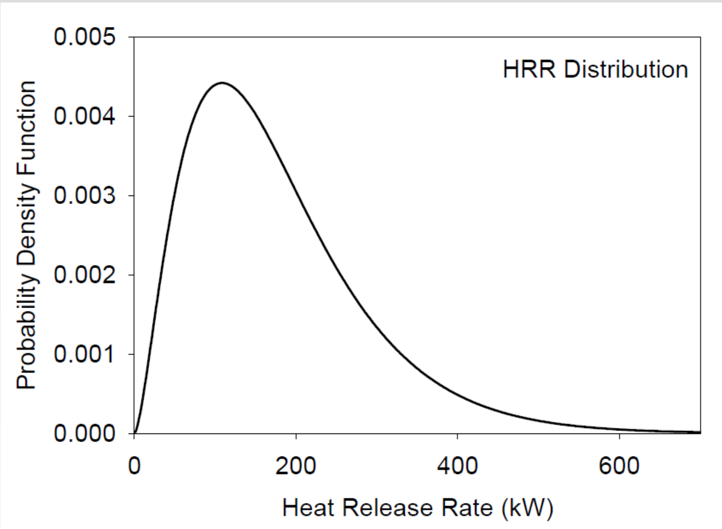
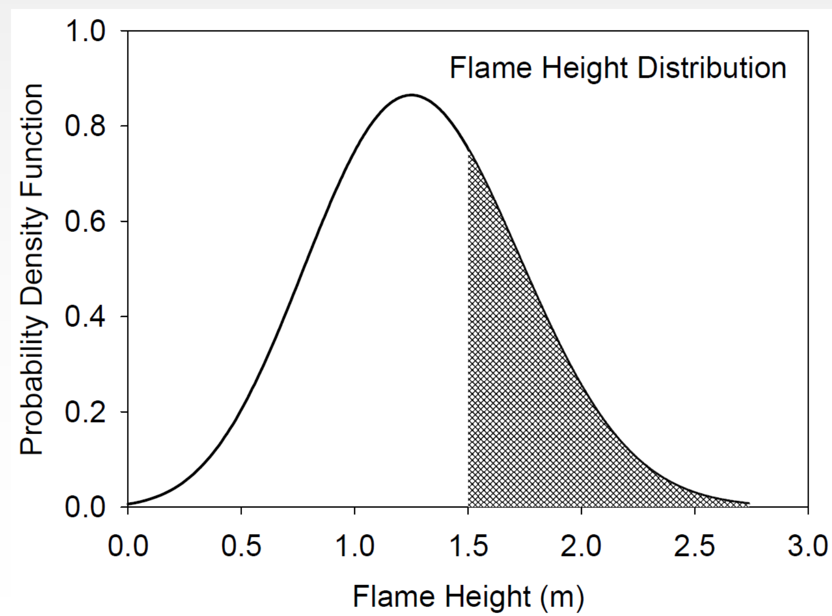
Model Input Parameter Distribution



Model: Flame Height Correlation

$$L_f = 0.235\,\dot{Q}^{2/5} - 1.02\,D$$

Model Output Distribution



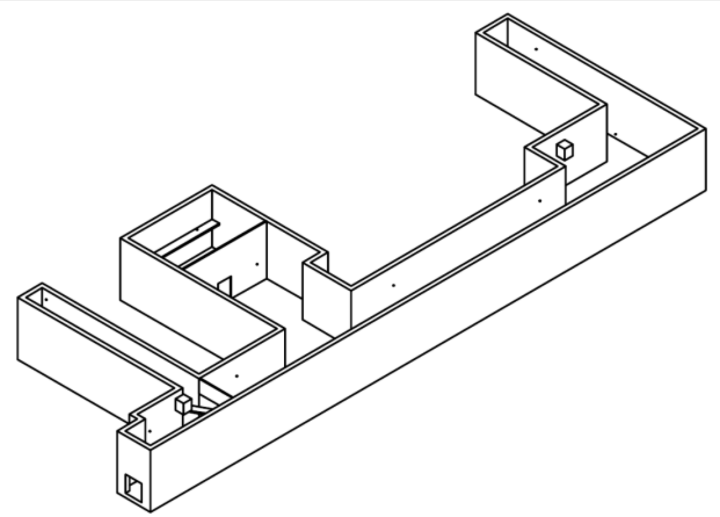
Question: What is the probability that the flames from a particular type of cabinet fire will reach a target 1.5 m above the cabinet?

What to do if the scenario is out of the validation range?

1. Sensitivity Analysis – Perform a calculation for a similar scenario that is more severe yet in range.

2. Reference other validation studies performed by model developers or others (i.e. universities, professional societies)

Example of Sensitivity Analysis



Problem: The corridor length to ceiling height ratio (L/H) is outside of validation range.

Solution: Redo calculation (or apply a simple correlation) to determine if a similar (yet more challenging) scenario increases the probability of failure.

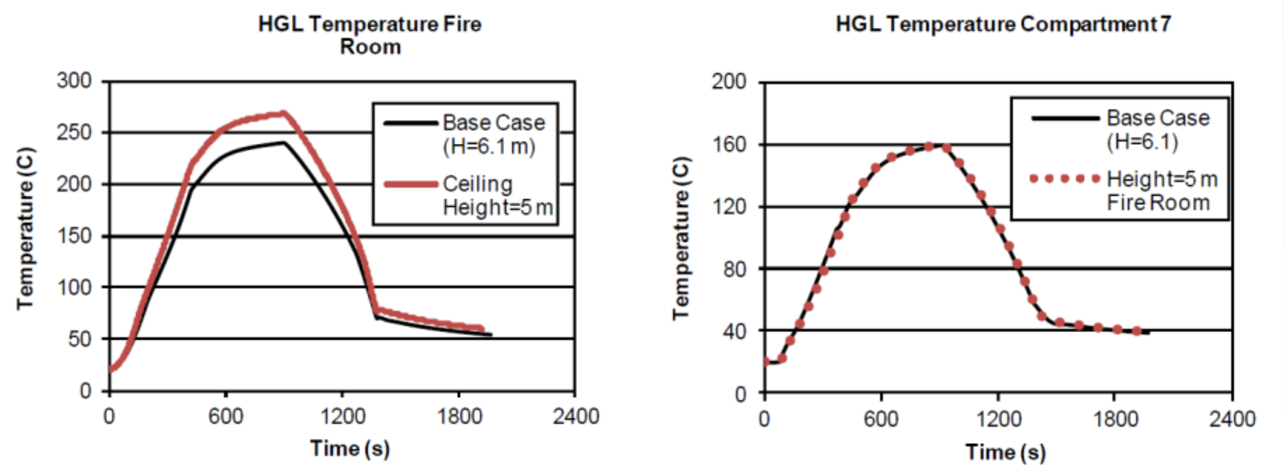


Figure G-10. Hot Gas Layer Temperature for Reduced Ceiling Height by MAGIC.

Appendices

- Eight example applications, each documented in an individual appendix
  - Based on typical fire scenarios in NPP’s
  - Serve as a template for consistency in the analysis and documentation of fire modeling calculations
  - Consider the fire modeling requirements of NFPA 805
  - Cover the routinely used capabilities of the fire models

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Conclusion

- Team believes NUREG-1934/EPRI 1023259 ready for publication:
  - Fulfills the need to support Quality Fire Model Implementation and Review
  - Fulfills the need to support Education and Training
  - Request a ACRS Letter
- Future Fire Modeling Projects
  - Fire Model Material Properties Catalogue
  - Revisit Fire Model V&V - NUREG-1824 Update