# Risk Significance of HEMYC® Electrical Raceway Fire Barrier System Failures

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## INTRODUCTION[a]

Approximately fifteen U.S. nuclear power plants (NPPs) employ the HEMYC® Electrical Raceway Fire Barrier System (HERFBS) to protect circuits in accordance with Nuclear Regulatory Commission (NRC) requirements [1]. Recent testing via Standard ASTM-E119 [2] indicated failures to achieve a one-hour fire rating [3-5]. We present a scoping analysis of the potential risk significance.

## PROBABILISTIC MODEL FOR TEST RESULTS

Failures consisting of shrinkage/tearing of the HERFBS covering were observed ≥15 min into the one-hour test, suggesting the following probabilistic model:

1. The HERFBS failure probability (P) for the ASTM-E119 fire ranges from 0 at ≤10 min to 1 at ≥60 min.

2. P is a function of the temperature "T" at time "t" or the area "A" at time "t" under the ASTM-E119 curve, whichever is more severe.

We linearized the ASTM-E119 curve (Fig. 1) and postulated failure thresholds of T = 703.83 ºC and A = 4870 min-ºC at t = 10 min, i.e.:

$$P(T) = (T - 703.83)/(920 - 703.83) \quad (1)$$

$$P(A) = (A - 4870)/(46470 - 4870) \quad (2)$$

where T = 920 ºC and A = 46470 min-ºC at t = 60 min.

[a] This paper was prepared by an employee of the U.S. NRC. The views presented do not represent an official staff position. The U.S. NRC has neither approved nor disapproved its technical content. Supporting material is available in NRC ADAMS (Accession # ML051300052).

## ANALYSIS FOR TYPICAL NUCLEAR POWER PLANT FIRES

The HERFBS will not fail if T ≤ 703.83 ºC, which bounds the temperatures reached by NPP fires where HERFBS is typically installed. However, NPP fires can expose a HERFBS to sufficiently high temperatures for long enough times to exceed the threshold A = 4870 min-ºC. Fig. 1 shows a linearized CFAST® [6] simulation of an Emergency Diesel Generator (EDG) room oil fire with a rapid rise to T = 390 ºC at t = 7.5 min and final T = 440 ºC at t = 60 min, where the threshold value for A occurs at t = 16 min. At t = 60 min, A = 23250 min-ºC and P(A) = 0.442 from Eq. (2).

Assume an older NPP uses a HERFBS for safe shutdown cables in their EDG room to protect against an oil fire, with fast-acting smoke detection and pre-action/deluge sprinkler suppression. Based on the Fire Protection Significance Determination Process (FPSDP) [7], a medium loading of cables, two general electrical cabinets and one EDG yields a fire frequency = 4.8E-4/y + (2)(6.0E-5/y) + 0.0056/y = 0.0062/y. Conservatively we choose the FPSDP's more limiting severity characteristics and manual suppression curves -- "Indoor Oil-Filled Transformer" and "Turbine-Generator" (T-G) fires -- as surrogates for an oil fire severe enough to fail the HERFBS.

The FPSDP recommends a severity factor of 0.1. If we assume that the HERFBS damage fails any enclosed cables, it likely warrants nothing lower than 0.1 for conditional core damage probability (CCDP). We then express the core damage frequency (CDF) as 0.0062/y x 0.1 x 0.1 x P(A) x PNS = 6.2E-5/y x P(A) x PNS, where PNS is the non-suppression probability. For CDF ≤ 1E-6/y, we require P(A) x PNS ≤ 0.016.

We expect rapid smoke detection; and, from the FPSDP, the non-suppression probability for the pre-action/deluge sprinklers is essentially zero, since the time-to-damage (at least 16 min) minus the time-to-suppression (within 1 min) ≥ 10 min. The FPSDP recommends a 0.05 unavailability for a deluge system, thereby requiring manual suppression by the plant fire brigade 5% of the time. PNS for "T-G"

fires, including this unavailability, = 0.05/exp([0.021][$\Delta t$]), where $\Delta t \approx t$ is the difference between times-to-damage and detection. The product P(A) x PNS rises from 0 at t = 16 min to 0.00627 at t = 60 min. Thus, it satisfies P(A) x PNS $\leq$ 0.016, yielding a maximum CDF = (6.2E-5/yr)(0.00627) = 3.9E-7/y.

**Sensitivity Case**

For sensitivity, we assumed that P(T) and P(A) inversely varied quadratically and quartically to represent a rapid rise in the probability of HERFBS failure, followed by a gradual increase. We then calculated the maxima for P(A) x PNS and corresponding maximum CDFs shown in Table I. Even under these conservative bounding assumptions, we essentially satisfy P(A) x PNS $\leq$ 0.016 for CDF $\leq$ 1E-6/y.

**Other Nuclear Power Plant Fires**

The preceding analyses were repeated for two other typical NPP fires, in an electrical switchgear room and make-up pump room. Each linearized CFAST® time-temperature curve, shown in Fig. 1, is less severe than that for the EDG room fire. Table I summarizes these parallel analyses, each of which yields lower CDFs than its EDG room fire counterparts.

**CONCLUSIONS**

The potential risk significance of recently indicated failures to the HERFBS appears to be low for actual NPP fires. This analysis, which included conservative assumptions from the FPSDP, suggests that the corresponding CDF is bounded at 1E-6/y.

**REFERENCES**


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**TABLE I. Analysis Results for Three Typical Nuclear Power Plant Fires in Areas Employing HERFBS**

| | EDG Room (Oil Fire) | | Electrical Switchgear Room | | Make-up Pump Room | |
|---|---|---|---|---|---|---|
| **Analysis Parameters** | Combustible | Frequency | Combustible | Frequency | Combustible | Frequency |
| | Cables (medium loading) | 4.8E-4/y | Cables (high loading) | 0.0014/y | Cables (low loading) | 1.6E-5/y |
| | General electrical cabinets (2) | (2)(6.0E-5/y) = 1.2E-4/y | Electrical switchgear (25) | (25)(6.0E-5/y) = 0.0015/y | General electrical cabinets (2) | (2)(6.0E-5/y) = 1.2E-4/y |
| | Diesel generator | 5.6E-4/y | | | Pumps (6) | (6)(1.0E-4/y) = 6.0E-4/y |
| | Total | 0.0062/y | Total | 0.0029/y | Total | 7.4E-4/y |
| | Fire Severity[b] | Indoor oil-filled transformer | Fire Severity | Large electrical fires | Fire Severity | Large electrical fires |
| | Manual suppression curve | Turbine-generator fires | Manual suppression curve | Energetic arcing fault | Manual suppression curve | All (fire) events |
| | PNS | 0.05/exp(0.021t) | PNS | 0.05/exp(0.051t) | PNS | 0.05/exp(0.069t) |
| | CCDP | 0.1 | CCDP | 0.1 | CCDP | 0.1 |
| | Maximum P(A) x PNS (allowed) | 0.016 | Maximum P(A) x PNS (allowed) | 0.034 | Maximum P(A) x PNS (allowed) | 0.14 |
| **Base Case (Linear)** | Maximum P(A) x PNS (calculated) | 0.00627 (at t = 60 min) | Maximum P(A) x PNS (calculated) | 0.00104 (at t = 37.5 min) | Maximum P(A) x PNS (calculated) | 2.2E-4 (at t = 40 min) |
| | CDF | 3.9E-7/y | CDF | 3.0E-8/y | CDF | 1.7E-9/y |
| **Sensitivity Case (Quadratic)** | Maximum P(A) x PNS (calculated) | 0.0105 (at t = 40 min) | Maximum P(A) x PNS (calculated) | 0.00322 (at t = 27.5 min) | Maximum P(A) x PNS (calculated) | 9.57E-4 (at t = 32.5 min) |
| | CDF | 6.5E-7/y | CDF | 9.3E-8/y | CDF | 7.1E-9/y |
| **Sensitivity Case (Quartic)** | Maximum P(A) x PNS (calculated) | 0.0162 (at t = 27.5 min) | Maximum P(A) x PNS (calculated) | 0.00674 (at t = 22.5 min) | Maximum P(A) x PNS (calculated) | 0.00237 (at t = 30 min) |
| | CDF | 1.0E-6/y | CDF | 2.0E-7/y | CDF | 1.8E-8/y |

[b] The fire severity factor = 0.1.

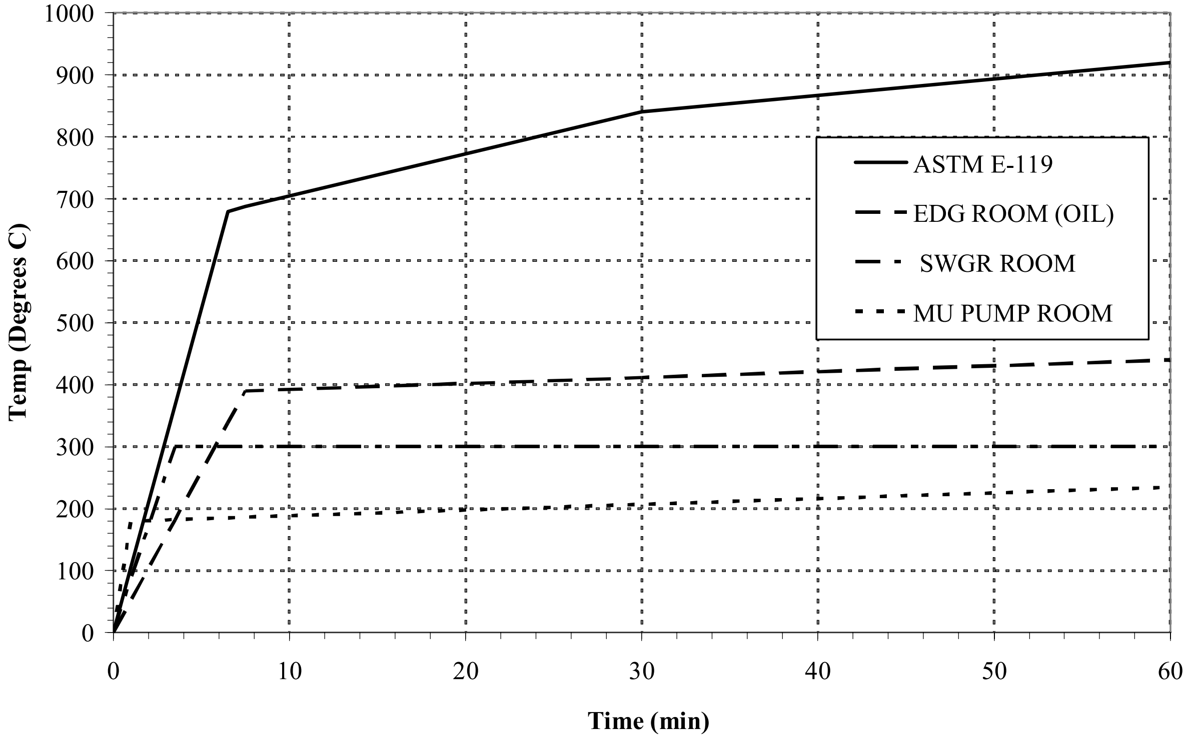


**FIGURE 1. Linearized CFAST Time-Temperature Curves for Selected NPP Fires**