Module III – Fire Analysis

Task 11: Special Models Part 3: Self Ignited and Hot Work Cable Fires (FAQ 13-005), Junction Boxes (FAQ 13-006)

Joint EPRI/NRC-RES Fire PRA Workshop

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A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

Background
Self-ignited and welding-ignited cable fires

- 6850/1011989 Appendix R (Section R.1) provides a method to calculate fire intensity based on an initial burning area plus spread
  - Initial fire area equal to square of tray width
  - Growth per linear spread rate and tray-to-tray fire spread model
- Historical fire experience shows only one case where fire spread as predicted by this model, and that case is an outlier
  - San Onofre – February and March, 1968 (2 fire events)
- Experimental measurements demonstrate cable fires with low ignition energy stay small and do not transfer/generate enough heat to sustain flame spread or fire growth beyond the immediate vicinity of ignition

Background
Historical Fire Events

- EPRI FEDB:
  - Cable fires caused by welding and cutting:
    - 10 fire events
    - 3 classified as non-challenging
    - The other 7 were very small, quickly suppressed and saw only localized damage with not significant fire spread
  - Self-ignited cable fires:
    - 46 fire events total classified as self-ignited cable fires
    - 25 events state that fires self-extinguished once the power source was removed (others not clear)
    - Damage was limited to the initiating cables in all but two cases
    - Significant exceptions were 2 fire events at San Onofre Nuclear Generating Station (SONGS) in 1968

Background
SONGS Historical Fire Events

- FEDB #2: February 7, 1968, approximately 4:45AM
  - Alarms received in the MCR
  - Loud noise was heard in the plant
  - Responders immediately observed a fire in cables at a containment electrical penetration assembly head area
  - The fire was extinguished quickly
    - Full report indicates suppression within 2 minutes although the FEDB indicates a duration of 30 minutes.
  - The fire confined to penetration head assembly but damaged all of the cables associated with that penetration
  - Fire did not spread and did not cause damage to any other cables outside head assembly
  - Root cause: cable overheating caused by a lack of air circulation within a weather protection cowl at the head of the electrical penetration assembly.

Background
SONGS Historical Fire Events

- FEDB #3 and #4 : March 12, 1968
  - Smoke was seen coming from a 480 V switchgear room
  - Indications of electrical faults 5-10 minutes before smoke was seen
  - Plant personnel lacked the equipment needed to enter the smoke-filled room
  - Firefighting support requested from U.S. Marine Corp firefighting unit
  - Off-site firefighters arrived but the pump on their fire truck failed to start
  - An alternate plant systems pump (an engine driven screen wash pump) used to supply water
  - Fire extinguished within 4 minutes
  - Utility report indicates fire burned unchecked for at least 35 minutes
  - Fire damaged a substantial section of three stacked cable trays (about 15 feet long)
  - Root cause: long term cable overheating

Background
SONGS Historical Fire Events

- Factors Contributing to Severity
  - Delays in fire suppression efforts caused by lack of breathing apparatus and pump failure
  - Electrical protection scheme only cleared on one phase resulting in a continual feed back heating source
  - Cables were per vintage design criteria, but severely overloaded by current standards (45A vs. 32A)
  - Cable temperature were roughly 150 °C, far in excess of 90 °C rating
  - Severe and premature degradation of the insulation
- More than 15 linear feet of three cable trays damaged in second fire
- However, no overheating to the grating and beams located 38 inches above the cable tray
- The SONGS events are considered outliers
  - Standards for cable ampacity, tray loading levels and circuit protection all updated

Background
SONGS Historical Fire Events – Recreation Tests

- Utility performed tests to recreate fire conditions
  - Reproduced actual plant conditions including both the electrical and physical loading conditions.
  - Simulated phase-to-phase short circuit and allowed for the power back-feed condition to persist as it did in the actual fire
- The tests did produce flaming combustion
- Information on cable operating temperatures as cited in previous slide
  - i.e., 150°C versus 90°C rated
- Verified that cable ampacity, while within allowed limits at the time, was excessive for tray loading conditions
- Insights eventually led to an entirely new approach and standards for tray installation ampacity ratings

Background
One foreign event of interest

- Fire event in France aggravated by ventilation limited configurations:
  - May 16, 2004
  - Cable fire in fire-resistant penetration carrying 6.6 kV electrical power cables between electrical building and turbine hall
  - Other important safety-related cables were also routed through this penetration, including 380 V power supply cables for line protection equipment and turbine bypass system actuators
  - Fire caused by overheating of the 6.6 kV cables - cables were undersized with a rated power of 9 MW
  - Cable penetration was closed at both ends allowing a build-up of heat causing an ‘oven’ effect and carbonization of the cables
  - Root cause: confinement of the cables in penetrations with inadequate natural circulation to cool cables

Background
Other Experimental Results

- 1976 RES/SNL cable fire testing:
  - Examined the potential for the development of self-ignited fire in qualified cables
  - Found that none of these experiments involving qualified cables resulted in propagation of fire beyond the tray of origin
  - Resulted in the NUREG/CR-6850 methodology not calling for postulated self-ignited cable fires in qualified cabling
- 1977 RES/SNL
  - Molten slag does not have heat capacity to sustain a minimum critical heat flux to act as an ignition source in cable fire experiments
  - For an open flame gas burner, minimum exposure time of 5 minutes is required to establish sustained combustion in a single cable tray
  - Relatively small flames resulting from a single over-heated cable cannot generate/transfer enough heat to propagate a substantial cable fire

Background
Other Experimental Results

- 2007 Braunschweig Technical University testing
  - Assessed the impact of cable preheating on fire behavior
  - Observed significant increases in both the peak fire heat release rate and the rate of fire spread for the preheated cables
    - Relevant to behavior seen in SONGS fires – preheated cables
- 2012 CHRISTIE-Fire testing
  - Provided the results of small, intermediate and full-scale cable fire testing in horizontal trays
  - Confirmed that a substantial external fire was necessary to ignite and sustain burning of cables within a single tray
  - Confirmed that a fire within a single tray containing unqualified thermoplastic cable does not radiate enough energy to the unburned portion of the cables within the tray to initiate spread beyond the point of origin

FAQ 13-0005
Status and Methodology

- FAQ 13-0005
- Basic assumption is that a self-ignited or hot work-initiated cable fire will not spread or cause damage beyond the raceway of fire origin
  – One tray and one tray only for any given fire scenario
  – Assume loss of all cables in that one tray
  – A tray containing multiple fire PRA cables might have a relatively high CCDP

FAQ 13-0005
Status and Methodology

- Observations on the new approach:
  - Far simpler than original method
    - No need to model cable fire growth and spread
    - No need to model fire suppression (inherent in the empirical model)
      - No independent credit for fire suppression before damage
      - You always assume loss of one raceway and one raceway only with appropriate fire frequency
      - *Do not add additional suppression credit to this model*
  - Presents a more realistic empirical model of fire behavior and impact
    - Reduces conservatism that may have arisen from original methods

Methodology

- Before you get here…
  - You apportioned plant-wide fire frequency bins to individual PAUs
  - Already covered under Task 6 – no changes here
- Preliminary Analysis Steps:

1. Calculate CCDP values for each raceway in PAU_J
   - Assume loss (failure) all cables in each raceway, one raceway at a time
     - Note that conduits are also raceways
   - Calculation is repeated for every raceway located in the PAU that contains *at least one fire PRA target cable*
   - Raceways that do not contain any fire PRA target cables and may be neglected
     - i.e., You don't have to assume a plant transient for every case
2. Compile the values and sort from highest to lowest CCDP

Methodology, cont.

- First Screening Analysis:

1. Identify the raceway (Raceway-1,J) with the largest CCDP value ($CCDP_{max,J}$)
2. Estimate the screening CDF for the compartment as the product of the compartment fire frequency and $CCPD_{max,J}$

$$CDF_{IS,J} \approx \lambda_{IS,J} \times CCPD_{max,J}$$

   - Nominally repeat for self-ignited and welding cable fires, but in practice, their frequencies can be summed in this step

3. If this first screening level estimated CDF is low enough to meet PRA objectives, add this value to the PAU's total CDF and move to the next PAU
4. If the screening CDF value is too large to meet PRA objectives, conduct subsequent screenings as needed/desired for PAU_J

Methodology, cont.

- Subsequent (Iterative) Screening Steps: drill down CCDP sort list…

1. Apportion frequency from PAU_J down to just the last raceway analyzed
   - "Raceway-1,J" in first iteration, "Raceway-n,J" in subsequent iterations
   - For self-ignited cables, use cable volume ratio:
     - Weighting factor is the volume of Raceway-n vs. total cable volume for the PAU
     - $\lambda_{SICF,Raceway\text{-}n,J} = \lambda_{SICF,J} \times \{ V_{Raceway\text{-}n,J} / V_{Cable,J} \}$
   - For cable fires caused by welding and cutting, use an area ratio:
     - Weighting factor is plan area of Raceway-n vs. total plan area of all raceways in the PAU
     - $\lambda_{CWF,Raceway\text{-}n,J} = \lambda_{CWF,J} \times \{ A_{Raceway\text{-}n,J} / A_{Cable,J} \}$

2. Re-calculate CDF contribution for tray just analyzed using its own frequency value and CCDP:

$$CDF_{IS,Raceway\text{-}n,J} = \lambda_{IS,Raceway\text{-}n,J} \times CCPD_{Raceway\text{-}n,J}$$

Methodology, cont.

3. Identify the raceway with the next largest CCDP value

   $CCDP_{Raceway\text{-}2,J}$ or, more generally, $CCDP_{Raceway\text{-}n,J}$

4. Calculate the residual of the PAU fire frequency (not yet assigned to specific raceways) and calculate a new screening CDF for the rest of the PAU

   $$CDF_{Screening(n+1),J} = \left(\lambda_{IS,J} - \sum \lambda_{Raceway\text{-}i,J} \right) \times CCDP_{Raceway\text{-}(n+1),J}$$

   Sum over: i =1,n

5. The modified compartment CDF is then the sum of the accumulated sub-cases plus the latest screening contribution

   $$CDF_{IS,J} \approx \sum CDF_{IS,i,J} + CDF_{Screening(n+1),J}$$

   Sum over: i =1,n

6. *Repeat "subsequent screening step" as many times as needed/desired…*
   – Each iteration you resolve/refine contribution of last tray, calculate new screening contribution based on next tray and residual fire frequency

Summary

- A new method for both self-ignited cable fires and cable fires caused by welding and cutting has been developed
  - Much easier and faster to apply
- Method assumes one raceway only in any single scenario
- A progressive screening method allows you to refine PAU CDF contribution by drilling down through the raceways present based on CCDP
- FAQ 13-0006 is similar but applied to Junction Boxes
  - Similar technical basis as self ignited cable fires and cable fires due to hot work
  - Fire is limited to one junction box
  - Apportioning of junction box fires
  - Junction box cable content