Modeling Junction Box Scenarios in a Fire PRA

1 Background

Chapter 6 of NUREG/CR-6850 includes a generic fire ignition frequency for junction boxes. This classification of junction boxes as an individual ignition source was also previously included in the EPRI Fire PRA Implementation Guide (EPRI, TR-105928, 1995.) because selected fire events data listed junction boxes as the point of fire origin. The identification of junction boxes as ignition sources suggest that the Fire PRA should include the contribution of junction box fires in the risk quantification. However, there is no guidance in NUREG/CR-6850 for characterization, analysis and quantification of junction box fires. Guidance is only available in Chapter 6 of NUREG/CR-6850 for apportioning the generic fire ignition frequency to the plant partitioning elements within the scope of the Fire PRA.

Specifically, Chapter 6 of NUREG/CR-6850 recommends in page 6-17 that "*The number of junction boxes in an area may be difficult to determine. The frequency can be apportioned based on ratio of cable in the area to the total cable in the plant. Therefore, the ignition source-weighting factor of the cables may be used for this bin, as well.*" This guidance is very similar if not identical to the apportioning guidance provided earlier by EPRI in the Fire PRA Implementation Guide (EPRI, TR-105928, 1995.). Notice that the guidance suggests that explicit count junction boxes is not necessary because the number of junction boxes can be estimated based on cable load.

2 Purpose

The purpose of this FAQ is to:

- Provide a definition for junction boxes that allow the characterization and quantification of junction box fire scenarios in plant locations requiring detailed Fire PRA/Fire Modeling analysis.
- Describe a process for quantifying the risk associated with junction box fire scenarios.

3 The Definition of Junction Box for Fire PRA Applications

Generally, a junction box is simply defined as a fully enclosed metal box containing terminals for joining or splicing cables. However, for the purpose of a Fire PRA, this definition must be expanded to clearly differentiate junction boxes from other electrical enclosures. The following characterization for junction box is therefore provided:

- The box must be fully enclosed with metal panels bolted or welded together but not necessarily well sealed per the definition for well sealed panels in Chapter 8 of Supplement 1 to NUREG/CR-6850.
- Cables entering or exiting the junction box should be in metal conduits and have mechanical connections to the metal box.
- The junction box should include only terminals for joining and splicing cables.

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The above definition of junction boxes specifically excludes:

- Boxes containing electrical components other than terminal point or splice such as electronic equipment, relays, switches, breakers, etc should not be considered junction boxes.
- Metal enclosures with indication lights, display panels, switches, buttons, etc on the surface are not considered junction boxes.
- Small well sealed wall mounted panels and other panels that are considered well sealed as those are excluded from the Generic Ignition Frequency model per the guidance in Chapter 8 of Supplement 1 to NUREG/CR-6850.
- Junction boxes containing high voltage circuits above 1000V that have cable splices, voltage connections or elbow style connections. These boxes should be only found in limited Fire PRA compartments in the plant and should be treated as electrical cabinets.
- Relatively large termination panels on the floor with high cable loading intended for joining and splicing cables. Specifically,
    - Similar to the “Electrical Cabinet” ignition source (i.e., Bin 15 in Chapter 6 of NUREG/CR-6850), these termination panels are easy to count and do not present the challenge of counting small junction boxes. Although it is recognized that that the ability to count an ignition source is not part of its definition, it is included as a consideration because the classification of junction boxes intended to capture the risk of relatively electrical enclosures that may not be visible to walkdown analysts and are difficult to count. Consistently, the fire events classified as junction box for the calculation of generic frequencies do not include relatively large floor based termination panels. That is, the fire events data associated with relatively large floor based termination panels are classified as “electrical cabinets” in the generic ignition frequency model and should not be considered junction boxes.
    - Termination panels are typically characterized by high cable loading. Due to the relatively high cable loading, the cables are not routed in or out of the panels with conduits. Instead, cables drop into the panels from cable trays. This configuration is not consistent with the definition of a junction box described earlier.
- Relatively large Junction boxes or termination panels at floor level with doors, or openings, making the content of the panel easily accessible to plant personnel. The intent is to exclude from the junction box fires those events that would be initiated by plant personnel doing routine maintenance or inspection on them during power operation.

In summary, the definition above is intended to clearly differentiate junction boxes from electrical cabinets so that the process of identifying electrical enclosures as ignition sources in a physical analysis unit results in:

- Electrical cabinets that are included as Bin 15 in the Fire PRA model per the guidance in Chapter 6 of NUREG/CR-6850,

- Electrical cabinets that are excluded from the Fire PRA model per the guidance in Chapter 6 of NUREG/CR-6850, and Chapter 8 of Supplement 1 of NUREG/CR-6850. Examples of these include tightly seal cabinets, and small wall mounted panels with less than 4 switches in the cover.
- Junction boxes as defined above counted per the guidance in Chapter 6 of NUREG/CR-6850.

4 Apportioning or Counting Junction Boxes

As mentioned earlier in this FAQ, Chapter 6 of NUREG/CR-6850 describes a process for apportioning the generic junction box frequency based on a consistent indicator for the amount of cable (e.g. cable loading, number of cables, cable lengths, etc) in the different physical analysis units within the scope of the Fire PRA.

This section describes another alternative for counting junction boxes for plants that have junction boxes as individual route points in the cable and raceway database system. For such situations, the cable and raceway database system can be "queried" for identifying and counting the junction boxes in each physical analysis unit. Notice that the terms "pull box", "terminal box", etc are often used in cable and raceway database systems for identifying junction boxes. This count can be used to apportion the generic frequency of junction boxes. Under this approach, the analyst should ensure that the definition of junction boxes counted from the cable and raceway database system is consistent with the one described earlier in this FAQ.

5 Proposed Methodology

Fire events in the EPRI Fire Events Database (FEDB) [1] were examined for historical experience and actual severity data in order to develop an improved methodology for handling these types of fires.

5.1 EPRI Fire Events Database / Industry Experience

The junction box events in EPRI's fire events database listed as challenging or undetermined are incident numbers 665, 745, and 1369. These events have the following descriptions:

- Incident No 665: A bad splice in junction box 529 caused an electric fire. A CO 2 extinguisher was discharge and the power was removed from the cabling in the junction box. Cable splice (480 volt) failed in junction box. Electric arc burned hole in cover. De-energized electrical equipment.

- Incident No 745: Early warning detection alarmed in the control room in the auxiliary building, 752 level. This detection is below the fire area containing the fire source: Smoke travelled down a 4 inch conduit into the control room to set off the detector. Fire discovered inside junction box to fan motor. Aluminum cable connected to copper with single lug. Fan de-energized at breaker.

- Incident No 1369: Crimp in insulation on power cables at lug connection. Power cables/insulation burned. Confined to junction box on motor.

It is unclear if these events listed above happened in electrical enclosures matching the definition for junction boxes described earlier in this FAQ. Nevertheless, these event descriptions suggest that junction box fires can generate immediate damage to the content of the box (e.g. those events associated with electric arcs in junction boxes routing power circuits 480 V or higher), and that the damage was contained to the junction box itself. Based on these characteristics, the following treatment is recommended for incorporating the risk contribution of junction box fires in physical analysis units where detailed fire scenarios are postulated:

6 Proposed Methodology

Junction box fires generally begin as relatively small fire or arc within the electrical enclosure. In most cases these fires do not generate enough heat to be self-sustaining and will self-extinguish prior to spreading outside. This is mostly due to the enclosed configuration of the box and in the cases of those scenarios where the integrity of the box is breached due to relatively low combustible content. In effect, this approach assumes that the zone of influence for these fires is equal to the junction box only. Consequently, the proposed approach provides a method for screening and analysis of such fires without the need for detailed fire growth, damage and suppression modeling.

Fire frequencies for a compartment are estimated using the methods described earlier in this FAQ. It should be noted that junction box frequencies, should be included for both thermoplastic and thermoset cables as the event experience suggests that these fires start due to small arcs generated by bad connections, which is not influence by the cable insulation or jacket type. Once these frequencies are calculated for a given compartment, perform a screening process as follows.

Step 1: Preliminary Analysis:

1. Calculate the CCDP values assuming the loss (failure) of one junction box at a time in the compartment (i.e., never more than one junction is involved, and there is no sequential fire propagation from one raceway to another). Junction boxes explicitly listed in the cable and raceway database system should be associated with all the cables in the junction box. If junction boxes are not explicitly listed as route points in the cable and raceway database system, the analyst should calculated the CCDP for each route point (e.g., cable tray, conduits, etc) in the physical analysis unit.

2. Repeat the calculation for every raceway located in the compartment that contains at least one Fire PRA target cable and compile and sort the values in a table. (Note that some junction boxes may not contain Fire PRA target cables.)

Step 2: First Screening Analysis:

1. Identify the junction box with the largest CCDP value (CCDPmax, J) and estimate the CDF for the compartment as the product of the compartment fire frequency (λIS,J) and CCPDmax,J.
    a. Check if the junction box is used to route cables only and has no connection, termination point or splices. Boxes with no connections, termination points or splices can be screened.

2. If this first screening level estimated CDF is low enough to meet PRA objectives, add this value to the compartment's total CDF and repeat this process for other compartments.
3. If the value is too large to meet PRA objective, conduct subsequent screenings as needed.

Subsequent Screenings (optional)

1. Calculate (partition) the fire frequency applicable to the previously identified junction box (JB) (e.g., λJB1,J) used to arrive at the CCDP max, J above. Use a compartment area ratio based on the plan view area of the target tray to the total area of trays in the compartment (i.e., assume the junction box is uniformly located over the general surface area within the compartment).
2. Re-estimate a CDF value for the previously identified junction box (with the largest CCDP) as the product of the junction box-specific fire frequency (λJB1,J) and CCDPmax,J.
3. Identify the junction box with the second largest CCDP value (CCDPJB2,J), and calculate the CDF for the remainder of the compartment by assigning the remainder of the room frequency to that CCDP (CDF = ((λIS,J-λJB1,J)xCCDPnext,J).
4. The modified compartment CDF is then the sum of these two sub-cases.
5. Repeat the subsequent screening techniques as needed, working junction box by junction box down through the CCDP list, until PRA objectives are met or the analysis reaches the point of diminishing returns.
6. As an alternative, junction boxes may be grouped based on similar CCDP values and treated in groups rather than as individuals. That is, the CDF for a group of junction boxes can be estimated as the group's combined fire frequency times the highest individual CCDP value among the group (but do not compound the CCDPs).
7. It is recognized that some junction boxes will contain no Fire PRA cable targets. For such junction boxes, if it can be confirmed that failure of cables in one or more junction boxes would not cause a plant transient then, consistent with other aspects of the general Fire PRA methodology (e.g., qualitative screening[1]), those junction boxes can be treated as a group having an effective CCDP value of 0.0 and, as such, non-contributors to fire-induced CDF.

This process is intended to drill down only until very small numbers are calculated and the analysis can stop. In the end, the estimated CDF is simply the sum of those cases split out in detail plus the balance applied to the next worst junction box in CCDP ranking table. Note that since the entire junction box is assumed damaged upon initiation of the fire, no credit for suppression to prevent overall junction box damage is allowed in this process.

References

1. Fire Event Database and Generic Ignition Frequency Model for U.S. Nuclear Power Plants. EPRI, 2001. TR-1003111.
2. EPRI Fire PRA Implementation Guide (EPRI, TR-105928, 1995.)
3. NUREG/CR 6850 (2005), "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities Volume 2 Detailed Methodology," EPRI 1011989 Final Report, NUREG/CR-6850, Nuclear Regulatory Commission, Rockville, MD, September, 2005.
4. NUREG/CR 6850 Supplement 1 (2010), "Fire Probabilistic Risk Assessment Methods Enhancements Supplement 1 to NUREG/CR-6850 and EPRI 1011989," EPRI 1019259 Technical Report, NUREG/CR-6850 Supplement 1, Nuclear Regulatory Commission, Rockville, MD, September, 2010.