FAQ Number 13-0006 **FAQ Revision** 0

FAQ Title Modeling Junction Box Scenarios in a Fire PRA

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Purpose of FAQ:

The purpose of this FAQ is twofold: 1) provide a definition for junction boxes that allow the characterization and quantification of junction box fire scenarios in plant physical analysis units (PAU) requiring detailed Fire PRA/Fire Modeling analysis and 2) describe a process for quantifying the risk associated with junction box fire scenarios in such plant locations.

It should be noted that the junction box scenario selection and definition guidance described in this section applies to those fire zones requiring detailed fire modeling analysis only. The fire zones in the Fire PRA modeled as full compartment burn should already include the fire ignition frequency contribution of junction boxes that has been apportioned to the fire zone following the apportioning guidance available in Chapter 6 of NUREG/CR-6850.

Relevant NRC document(s):
R.G. 1.200, Rev. 2; NUREG/CR-6850

Details:

NRC document needing interpretation (include document number and title, section, paragraph, and line numbers as applicable):

Chapter 6 and 11 of NUREG/CR-6850

Circumstances requiring interpretation or new guidance:

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 chapter 11 or any corresponding Appendix material inNUREG/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 PAU 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 explicitly counting junction boxes is not necessary because the number of junction boxes can be estimated based on cable load.

Since NUREG/CR 6850 provides no guidance on how to represent the risk of junction box fire scenarios in fire zones receiving detailed fire modeling analysis, this FAQ provides an alternative to incorporate the risk contribution of such scenarios into the Fire PRA.

Detail contentious points if licensee and NRC have not reached consensus on the facts and circumstances:

None.

Potentially relevant existing FAQ numbers:

None.

Response Section:

Proposed resolution of FAQ and the basis for the proposal:

1.0 The Definition of Junction Box for Fire PRA Applications

Generally, a junction box is defined as a fully enclosed metal box containing terminals for joining or splicing cables. 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 boxes 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.
- Junction boxes may include some items excluded from the count of electrical cabinets if the excluded items meet the above criteria. In particular, the electrical cabinet counting guidance in NUREG/CR-6850 and Supplement 1 to NUREG/CR-6850 states that "simple wall-mounted panels housing less than four switches may be excluded from the counting process" and that "well-sealed electrical cabinets that

have robustly secured doors (and/or access panels)… should be excluded from the counting process." Most junction boxes will meet one or both of these exclusionary criteria. However, exclusion from counting as electrical cabinets does not automatically exclude an item from consideration as a junction box. Since the guidance in this FAQ limits damage to an individual junction box, junction boxes routing Fire PRA target cables should not be excluded from counting as ignition sources as a fire starting in a Fire PRA junction box may be risk contributing.

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.
- Simple wall-mounted panels housing less than four switches, cited previously, that do not meet the inclusionary criteria above are not junction boxes. Such items are small local alarm panels, intercom boxes, radio repeater boxes, emergency light boxes, and other similar small component enclosure boxes. These items are neither junction boxes nor electrical cabinets.
- 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 PAUs in the plant and should be treated as electrical cabinets.
- Pull boxes, used only to aid in the installation of cables, that have no connections, termination points, or splices should not be treated as junction boxes for the purpose of the guidance provided in this analysis.

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 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 electrical enclosures that may not be visible to walkdown analysts 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

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panels are classified as "electrical cabinets" in the generic ignition frequency model and should not be considered junction boxes.

- o 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 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 ignition sources in a PAU results in each electrical enclosure being categorized as belonging to one of three groups:

- 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 well sealed cabinets, and small wall mounted panels with less than 4 switches in the cover which do not contain Fire PRA target cables.
- Junction boxes as defined above are counted per the guidance in Chapter 6 of NUREG/CR-6850.

2.0 Background and Basis

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. In addition, insights that can be gathered for junction box fires from available fire test series is also presented.

2.1 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 CO2 extinguisher was discharged 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); however, the damage was contained to the junction box itself.

2.2 Fire Experiments

A review of previous fire testing was conducted to identify information gained respective to junction box fires. No tests were found that investigated fires initiated in junction boxes specifically. However, one test series was identified which tested flame spread through conduits in fire barriers where junction boxes were used as termination points. This is applicable since one path for fire propagation from a junction box is through cable in conduit emanating from the junction box.

The Internal Conduit Seal Fire Test of One-Hundred One Electrical Conduit Penetrations was performed to determine minimum internal seal requirements for conduits to prevent spread of fire from one side of a rated fire barrier to the other. A test slab incorporated 101 conduit penetrations and was exposed to the ASTM E-119 standard fire exposure for 3 hours. Of the 101 tests performed 18 were conducted using junction boxes as termination points for the conduits on the unexposed side of the rated fire barrier. During the test, no flames propagated though the conduits and no cables were ignited on the unexposed side of the slab. The testing also illustrated the effect cable fill has on the performance of open conduits. The cables restricted the flow of hot gases and smoke and also acted as a heat sink. High Cable loadings (40%) acted as an effective internal penetration seal to the propagation of hot fire and hot gases. Based on the testing, guidelines were developed to address the propagation of fire though conduits. This testing concluded that conduits that terminate in junction boxes or other non-combustible closures need no additional internal sealing. This testing provides further evidence of the difficulty to propagate fires in a limited oxygen environment with metal conduits which have mechanical connections. The testing demonstrated the performance of junction boxes and cable filled conduits in limiting hot gas and flame propagation.

Given these test results, it is reasonable to assume that a fire initiating in a junction box would not spread via the cables in conduits. These tests support treatment of junction box-initiated fires as not spreading beyond the point of origin, as outlined in the following methodology.

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3.0 Selection and Definition of Junction Box Fire Scenarios

Junction box fires generally begin as a 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 of the junction box. This is mostly due to the enclosed configuration of the box. 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.

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 influenced by the cable insulation or jacket type.

This methodology will present two alternative methods for junction boxes contained in a PAU:

1) Junction boxes are identified in the cable and raceway database; Junction boxes can be reliably identified and counted using the cable and raceway database system;
2) Junction boxed are not identified in the cable and raceway database; Junction boxes are not counted or identified from the cable and raceway database system as they may not be explicitly or uniquely labeled as route points.

3.1 Junction Boxes are Identified in the Cable and Raceway Database

Recall that Chapter 6 of NUREG/CR-6850 describes a process for apportioning the generic junction box fire ignition frequency based on the amount of cable (e.g., cable loading, number of cables, cable lengths, etc.) in the different PAUs within the scope of the Fire PRA. This process remains a valid approach and the clarifications and recommendations presented in this FAQ are alternative methods.

This section describes another alternative for counting junction boxes for plants that have them as individual route points in the cable and raceway database system. For such situations, the cable and raceway database system can be "queried" to identify and count the junction boxes in each PAU. Note that the terms "pull box," "terminal box," etc. are often used in cable and raceway database systems to identify junction boxes. This count can be used to apportion the generic ignition frequency of junction boxes using the number of junction boxes in the PAU divided by the total number of junction boxes in the plant. This method is the expected approach for most areas throughout the plant where junction boxes can be reliably counted using the cable and raceway database system. This method is an alternative to using cable loading as discussed in NUREG/CR-6850 and should be used consistently throughout all the PAUs within the scope of the Fire PRA. Only one of the two methods must be used throughout the analysis. Mathematically, this is expressed as

$$\lambda_{\text{PAU,JB}} = \lambda_{\text{JB}} \frac{\text{\# Junction boxes in PAU}}{\text{\# Junction Boxes in Plant}} \cancel{\text{(Plant junction box frequency)}} \tag{1}$$

Where $\lambda_{\text{PAU,JB}}$ = is the junction box frequency for a given PAU, and

λ_{JB} is the generic junction box frequency for the plant.

Under this approach, the analyst should ensure that the database is current and that the definition of junction boxes counted from the cable and raceway database system is consistent with the one described earlier in this FAQ.

Two practical approaches for ensuring that the junction boxes meet the definition described in the previous section include:

1. Review plant specification documents describing the requirements for constructing and installing junction boxes if available; and/or
2. Conduct walkdowns in selected PAUs to sample junction boxes that are readily accessible (i.e., visible) and document the characteristics of the electrical enclosures that will be treated as junction boxes (i.e., these electrical enclosures that are not screened out as ignition sources, and not counted as part of other ignition frequency bins). The walkdowns should be conducted in some of the PAUs that are receiving detailed fire modeling analysis.

Once these junction boxes~~frequencies~~ requiring f~~detailed fi~~re scenario definition~~ and fire modeling analysis~~ are identified , perform a screening process as follows.

Step 1: Preliminary Analysis:

1. For junction boxes that are Fire PRA targets, calculate the conditional core damage probability (CCDP) values assuming the loss (failure) of one junction box at a time in the PAU (i.e., never more than one junction is involved, and there is no sequential fire propagation from the initiating junction box to other intervening combustibles). Junction boxes explicitly listed in the cable and raceway database system should be associated with all the cables in the junction box.
2. Repeat the calculation for every junction box located in the PAU 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 ($CCDP_{max,\ JB}$) and estimate the CDF for the PAU as the product of the PAU fire frequency ($\lambda_{PAU,JB}$) and $CCPD_{max,JB}$, where $CCPD_{max,JB}$ is the highest conditional core damage probability calculated among all the junction boxes in the PAU. .
   a. Check if the junction box is used to route cables only and has no connections, termination points, 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 PAU's total CDF and repeat this process for other PAUs.
3. If the value is too large to meet PRA objective, conduct subsequent screenings as needed.

Step 3: Subsequent Screenings (as necessary):

This step includes the following activities:

1. This step consist of apportioning the total junction box frequency or a PAU to an individual junction box scenario. The apportioning process can be achieved using the ratio of the cables associated with an individual junction box with all the cables associated with all junction boxes in the PAU. This accounts for junction boxes having different levels of loading as well as the ignition sources, electrical connections causing relatively small fires or arcs.

$$W_{jb,i} = \frac{\text{\# of cables entering junction box } i}{\text{\# of cables entering all junction boxes within PAU}} \qquad (2)$$

Where $W_{jb,i}$ = Weighting factor for junction box *i*, within a specific PAU. As a conservative practice, the largest ratio from all the applicable junction boxes in the PAU can be used as representative.

2. Once the weighting factor is available, 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 ($\lambda_{\mathrm{JB,1}}$) and $CCDP_{max,J}$.

$$\lambda_{\mathrm{JB,1}} = \lambda_{\mathrm{PAU,JB}} \times W_{jb,i} \qquad (4)$$

   Where $\lambda_{\mathrm{JB,1}}$ = junction box-specific fire frequency.

3. Identify the junction box with the second largest CCDP value ($CCDP_{JB2,J}$), and calculate the CDF for the remainder of the PAU by assigning the remainder of the room frequency to that CCDP (CDF = (($\lambda_{PAU,JB}$-$\lambda_{JB,1)}$x $CCDP_{next,J}$). Note that the fire frequency should be apportioned based on the guidance provided earlier in this section.
4. The modified PAU CDF is then the sum of the scenario involving the junction box with the highest CCDP (Step 3, Items 1 & 2 above), and the scenario involving all other junction boxes, which is characterize by the junction box with the second highest CCDP (Step 3, Item 3)
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 until the refinement of the risk for these fires reaches the point of diminishing returns.

Under this approach, the screening guidance described in this FAQ applies. That is, more than one junction box may need to be included if the CDF contribution associated with the second, third, etc. highest CCDP junction box are relatively high.

3.2 Junction Boxes are Not Identified in the Cable and Raceway Database System

This section describes another alternative for counting junction boxes for plants where junction boxes are NOT counted or identified from the cable and raceway database system. The proposed method should be used only for cases where walkdowns cannot be easily performed and the cable and raceway database system does not provide the necessary information to use the method described earlier in section 3.1.

Given the unavailability of explicit junction box information in the cable and raceway database, it is necessary to estimate the number of junction boxes per PAU unit based on

- a representative sample obtained from a PAU where junction boxes can be walked down, provided boxes are defined as described earlier in the FAQ, and
- the cable load ratio per PAU

That is, the number of junction boxes in a specific PAU can be assumed to be proportional to the ratio of the number of junction boxes to conduits in a representative, comparable PAU and the cable loading associated with the location. The proportionality constant can be developed by determining the count in a relatively simple PAU (e.g., a PAU where the junction boxes could be counted during a walkdown) and applying the value consistently throughout the plant.

$$\lambda_{\mathrm{PAU,JB}} = \lambda_{\mathrm{JB}} \frac{\text{\# Junction boxes in a comparable PAU}}{\text{\# of Estimated Junction Boxes in Plant}} \qquad (5)$$

Once these frequencies are calculated for a given PAU, perform a screening process as follows.

Step 1: Preliminary Analysis:

1. If junction boxes are not explicitly counted or identified from the cable and raceway database, the analyst should calculate the CCDP for each route point (e.g., cable tray, conduits, etc.) in the PAU.
2. Repeat the calculation for every route point located in the PAU that contains at least one Fire PRA target cable and compile and sort the values in a table. (Note that some route points may not contain Fire PRA target cables.)

Step 2: First Screening Analysis:

1. Identify the route point with the largest CCDP value ($CCDP_{max,\ RP}$) and estimate the CDF for the PAU as the product of the estimated PAU junction box fire frequency ($\lambda_{\text{PAU,JB}}$) and $CCDP_{max,RP}$.

Where $CCDP_{max,RP}$.= the maximum route point conditional core damage probability.

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

Step 3: Subsequent Screenings (as necessary):

1. The weighting factor for the frequency of an individual junction box scenario will be the value of one over the estimated number of junction boxes in a PAU as follows.

$$W_{RP,i} = \frac{1}{\text{Total estimated Fire PRA junction boxes in the PAU}} \quad (6)$$

Where $W_{RP,i}$ = Weighting factor for junction boxes within a specific PAU.

2. Re-estimate a CDF value for the previously identified route point (with the largest CCDP) as the product of the junction box-specific fire frequency ($\lambda_{\text{JB,1}}$) and $CCDP_{max,RP}$.

$$\lambda_{\text{JB,1}} = \lambda_{\text{PAU,JB}} \times W_{RP,i} \quad (4)$$

Where $\lambda_{\text{JB,1}}$ = junction box-specific fire frequency.

3. Identify the junction box with the second largest CCDP value ($CCDP_{RP2,J}$), and calculate the CDF for the remainder of the PAU by assigning the remainder of the room frequency to that CCDP (CDF = (($\lambda_{PAU,JB}$-$\lambda_{JB,1)}$x $CCDP_{next,RP}$). Note that the fire frequency should be apportioned based on the guidance provided earlier in this section.
4. The modified PAU CDF is then the sum of the scenario involving the junction box with the highest CCDP (Step 3, Items 1 & 2 above), and the scenario involving all other junction boxes, which is characterize by the junction box with the second highest CCDP (Step 3, Item 3)
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 until the refinement of the risk for these fires reaches the point of diminishing returns.

4. Final Considerations

The detailed process recommended in this FAQ 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 the 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.

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If appropriate, provide proposed rewording of guidance for inclusion in the next Revision:

Not applicable.