Enclosure 6

FAQ-1600XX Cable Tray Ignition

Meeting Summary of the11/30/2016 Meeting with NRC/Nuclear Energy Institute

Dated January 19, 2017

FAQ Number	**16-00XX**	**FAQ Revision**	**0**
FAQ Title	**Cable Tray Ignition**		

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Purpose of FAQ:

This FAQ clarifies the guidance in NUREG/CR-6850 associated with damage and ignition of cables subjected to fire generated conditions in order to provide a more realistic characterization of fire propagation in stacks of cable trays. Specifically, this FAQ establishes guidance for identifying the conditions necessary for cable tray ignition and propagation through an arrangement of cables trays.

This FAQ updates in part the guidance available in Chapters 8, 11 and Appendices H and R of NUREG/CR-6850. The guidance provided by this FAQ is not intended to be applicable to Section R.4.2.2 of NUREG/CR-6850 on fire propagation through a cable tray stack after ignition or for cable tray ignition under high energy arcing fault scenarios in Appendix M of NUREG/CR-6850.

Is this Interpretation of guidance? [Yes] / No

Proposed new guidance not in NEI 04-02? [Yes] / No

Details:

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

The guidance in NUREG/CR-6850 (e.g., see Section 8.5, Appendix H, and Appendix R) conservatively assumes that cable ignition and cable damage occur simultaneously. This assumption is based in part on testing of energized cables for investigating electrical shorts between conductors. These shorts can create the spark (i.e. the ignition source) necessary to ignite the heated cables. At the same time, relatively recent testing de-energized cable tray fires suggests that further characterization for the process of cable tray ignition and promoting

fire propagation to nearby cable trays is necessary as a relatively strong sustained fire near the cable tray arrangement is necessary for generating fire propagation through a cable tray stack. Therefore, differentiating between cable damage and/or ignition, and the conditions necessary for a cable tray fire to propagate through a stack is necessary to add realism to the scenarios included in the Fire PRA.

Circumstances requiring interpretation of guidance or new guidance:

The guidance in NUREG/CR-6850 associated with damage or ignition of cables needs clarification for two reasons. First, in some instances it assumes that the damage criteria and ignition criteria are the same. At the same time, the guidance suggest that these are distinctly different events. For example,

- Section 8.5.1.2 states, "For cables, the ignition and damage criteria can be assumed to be the same. Heat flux and temperature criteria for damage and/or ignition are provided in Table 8-2. More detail on damage criteria is provided in Appendix H." Although Table 8-2 is entitled "damage criteria", the heading includes the word "ignition". The table is reproduced here for completeness purposes:

  Table 8-2
  Damage Criteria for Cables

Screening Criteria to Assess the Ignition and Damage Potential of Electric Cables		
Cable Type	Radiant Heating Criteria	Temperature Criteria
Themoplastic	6 kW/m^2 (0.5 BTU/ft^2s)	205°C (400°F)
Thermoset	11 kW/m^2 (1.0 BTU/ft^2s)	330°C (625°F)

  This information is repeated in Appendix H which states, "For cables, the ignition and damage criteria will be assumed to be the same. Generic heat flux and temperature criteria for damage and/or ignition are identified in Table H-1." Like Table 8-2, Table H-1 is entitled "damage criteria" but includes the word "ignition" in both a subtitle and heading. It should be noted that both of these tables (i.e., Table 8-2 and Table H-1) cite Appendix F of Inspection Manual Chapter 0609 as the source of the damage criteria.

- Second, there is no guidance in NUREG/CR-6850, Supplement 1 to NUREG/CR-6850, or applicable FAQs describing the conditions necessary to propagate a fire in a stack of cable trays. Consequently, current Fire PRAs conservatively assume that if a cable is ignited it will be capable of propagating through a cable tray stack. Under this current approach, the time between cable ignition and growth through the first cable tray to a size that can sustain and promote propagation is not credited in the analysis. The practical implication of this approach is that any cable exposed to elevated gas temperatures generated by a fire is assumed to be capable of propagation at the time it takes for heating the cable to its damage or ignition temperature.

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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:

This section primarily describes the proposed criteria for determining if a cable tray fire will be capable of propagating through a stack and the corresponding technical basis supporting the criteria.

Definitions

For clarity purposes, the following terms are defined first:

- Cable damage: refers to a cable no longer able to perform its function due to exposure to fire generated conditions. In this context, a "damaged cable" is assumed not to be ignited. In practice, a damaged cable in the Fire PRA produces a functional equipment failure. A damaged cable does not contribute to the heat release rate in the compartment where the fire is postulated.
- Cable ignition: for the purposes of this FAQ, cable ignition refers to "localized ignition" of a cable or adjacent cables subjected to fire generated conditions. This localized ignition is assumed to be triggered by sparks generated by shorts between conductors once the cable jacket and/or insulation are damaged by the fire. Under this definition, "cable damage" and "cable ignition" have the same practical effects in the Fire PRA analysis. The cables produce a functional equipment failure but do not contribute to the heat release rate in the compartment where the fire is postulated as the heat contribution is assumed to be small given that ignition is localized. Heat release from cable ignition may be capable of promoting flame spread among adjacent cables within a tray but is incapable of promoting fire propagation without an external heat exposure such as the one generated by an ignition source.
- Cable tray ignition: for the purposes of this FAQ, the term "cable tray ignition" refers to a full section of a cable tray (i.e., most of the cables routed in the cable tray section) ignited. Under this definition:

    1. Full cable tray ignition capable of sustaining a fire and promoting propagation requires a sustained exposure from the ignition source as localized cable ignition

alone will not provide enough energy to trigger the fire propagation process through secondary combustibles.

2. All the cables in the cable tray section are already damaged or ignited for the purposes of Fire PRA modeling,
3. It represents a fire large enough to be capable of propagating to other intervening combustibles (e.g., propagate to nearby cable trays), and
4. All the cables within the cable tray along the length that is on fire are contributing to the combined heat release rate in the compartment. The length and width of the initial cable tray ignited used to calculate the heat release rate contribution should be determined following the guidance in Appendix R of NUREG/CR-6850 and/or NUREG/CR-7010 volumes 1 and 2.

- Fire Propagation: refers to the process of fire growth through sequential ignition of separate (i.e., individual) secondary combustibles. For example, fire propagation through cable trays refers to ignition of different cable trays (i.e., sequential ignition of cable trays in a stack of horizontal cable trays).
- Flame spread: for the purposes of this FAQ, flame spread refers to a continued set of ignitions generating fire growth within the same combustible (e.g., fire growth/spread along a tray).

Proposed Resolution

This FAQ proposes the following two clarifications to the existing guidance for determining if fire propagation through a cable tray arrangement needs to be postulated in a Fire PRA:

1. The existing guidance in Appendix H of NUREG/CR-6850 refers to both “cable damage” and “cable ignition” as defined earlier in this FAQ. That is, the assumption that both processes happen at the same time is appropriate as it is based on experimental observations where cables exposed to fire conditions can spark and generate the ignition source necessary to generate flames. The time at which damage or ignition occurs is dependent on the thermal exposure and can be calculated using fire modeling tools as is recommended in existing guidance (e.g., using Tables H-5 through Table H-8 in NUREG/CR-6850 or other analytical heat transfer methods).

2. “Cable tray ignition” is necessary to promote fire propagation throughout an arrangement of cable trays. This guidance supplements the damage criteria available in Appendix H of NUREG/CR-6850 by establishing the conditions governing fire propagation among cable trays. The guidance is specifically applicable to fire scenario configurations involving cable trays relatively near an ignition source. Recall that the term cable tray ignition represents a relatively large established fire in a cable tray section with enough energy to sustain propagation. It is assumed that all the cables routed in the cable tray section are ignited at the time of cable tray ignition as the cables have exceeded the ignition temperature. It should be noted that the time for cable damage or ignition occurs before cable tray ignition that triggers propagation to other secondary combustibles. In practice, it is expected that cables will fail at the table of cable damage or ignition based on cable damage or ignition criteria listed below in Table 1.

The following table summarizes the criteria for cable damage, cable ignition, and cable tray ignition and is proposed as a replacement for Tables 8-2 and H-1 in NUREG/CR-6850.

Table 1: Cable Damage/Ignition and Cable Tray Ignition Criteria

	Cable Damage/Ignition Criteria		Cable Tray Ignition Criteria*	
Cable Type	Radiant Heating	Temperature	Radiant Heating	Temperature
Themoplastic	6 kW/m^2	205°C	25 kW/m^2	500˚C
Thermoset	11 kW/m^2	330°C		

*Assume bulk of cable insulation within the cable tray is ignited and contributes to the heat release rate as a secondary combustible for room heating (e.g. hot gas layer temperature calculations) calculations when any of these thresholds are reached or exceeded. Below these criteria, ignition is assumed to be localized and is not contributing to the overall heat release rate within the compartment.

The following timeline provides a conceptual representation of the proposed scenario development for FPRA modeling purposes:

1. Ignition: Fire starts at ignition source generating a zone of influence affecting nearby cables in cable trays or conduits.
2. Cables in cable trays are damaged and ignited when exposed to thermal conditions exceeding the cable damage and ignition threshold listed in Table 1. Assume cables are damage/ignited regardless of their location within a cable tray/conduit arrangement if the thermal conditions at the location of the cable tray exceed the cable damage and ignition threshold listed in Table 1.
3. Cable tray ignition when thermal condition exceeding the cable tray ignition threshold listed in Table 1. The length and width of the initial cable tray ignited used to calculate the heat release rate contribution should be determined following the guidance in Appendix R of NUREG/CR-6850 and/or NUREG/CR-7010 volumes 1 and 2.

4. Subsequent fire propagation and flame spread through a cable tray stack arrangement consistent with the guidance in NUREG/CR-7010, Vol 1.

The above time line is recommended for growing fires only. The timeline is not applicable for high energy arcing fault fire scenarios. Figure 1 provides a pictorial representation of the recommended timeline.

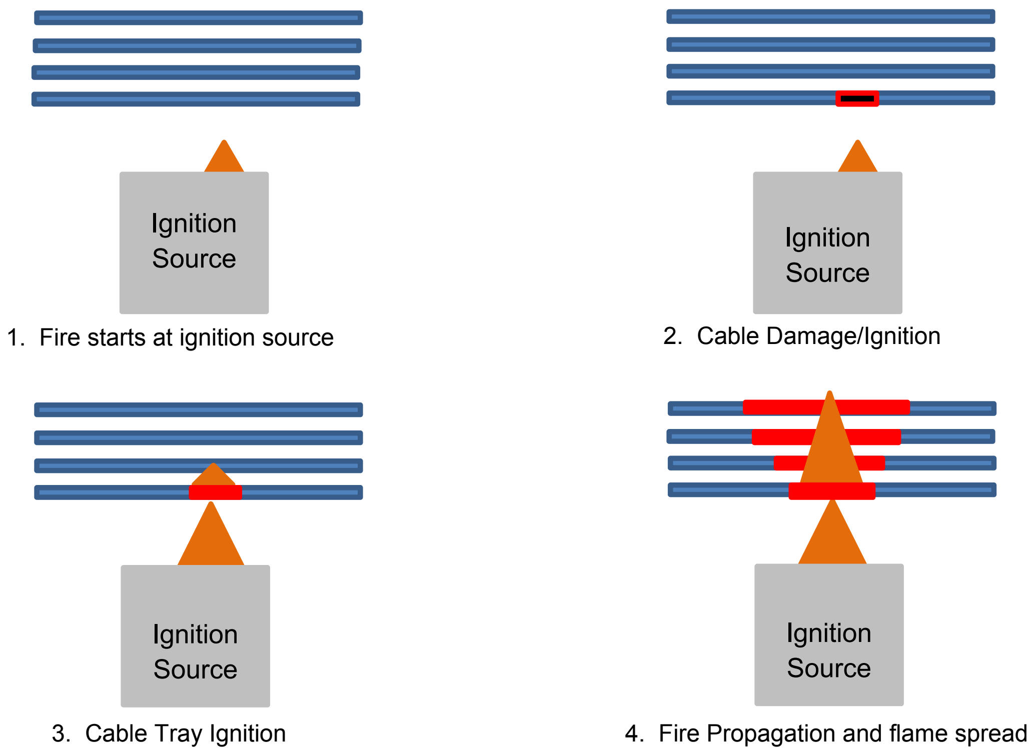

Figure 1:Pictorial representation of the fire scenario development including cable damage/ignition, cable tray ignition and fire propagation. Figure is not drawn to scale and is not intended to replace guidance on flame spread and fire propagation available in Appendix R of NUREG/CR-6850 and/or NUREG/CR-7010 volumes 1 and 2.

NOTE: Modeling of fire propagation in vertical trays should follow the guidance in Appendix R of NUREG/CR-6850 and/or NUREG/CR-7010, Vol 2.

Technical Basis

The available full scale test data that supporting the empirical fire propagation model for cable tray fires, as described in NUREG/CR-6850 and validated in NUREG/CR-7010, are documented in EPRI-NP-1881 (Sumitra tests), NUREG/CR-0381 (Klamerus tests) and NUREG/CR-7010, Volume 1 (NIST tests). These reports document the results of about thirty-five to forty open configuration, unprotected cable tray fire tests. The cables in trays were not energized. In all cases, the ignition source for the lowest cable tray within a stack was a gas burner or liquid fuel pan fire that causes flame impingement on the lowest cable tray in the stack. Further, the

reports presented no case where thermal plume above the flame tip alone was sufficient for igniting a cable tray.

A quantitative indication of the conditions necessary for fire ignition and surface spread is also provided in Section 3.4.7 of NUREG/CR-5384. Burn mode evaluations for both non-rated (thermoplastic) and low flame spread (thermoset) cables are presented and indicate that for thermoplastic cables, which bound the results for thermoset cables, a surface temperature of 538˚C and an internal fuel temperature of 577˚C are necessary for surface flames to develop.

Based on cone calorimeter tests summarized in NUREG/CR-7010, Volume 1, Section 10.2, a heat flux exposure of 25 kW/m^2 (2.2 $Btu/s\text{-}ft^2$) is minimally sufficient to cause ignition for all types of cables considered, including the thermoplastic cables which bound the results of thermoset cables. NUREG/CR-7010, Volume 1 further states that at this heat flux, ignition was achieved but without sustained burning in many cases. Therefore, 25 kW/m^2 establishes a threshold that can be assumed for critical heat flux to postulate ignition of cable trays capable of propagating to other secondary combustibles.

Figure 4.11 in "Enclosure Fire Dynamics" (Karlsson & Quintiere, Enclosure Fire Dynamics, CRC Press, 2000) conveniently describes fire generated conditions at and near the flames. This figure consists of a plot of flame and fire plume temperature data forming the basis for the McCaffrey fire plume temperature correlation. These data suggest turbulent flame temperatures in the order of 800 ^oC, which is higher than the temperatures identified in NUREG/CR-5384 as necessary for surface flames to develop. This is an indication that fire plume conditions outside the flames may be capable of cable tray ignition. At the same time, temperatures in the order of 500 ^oC can be experienced in the "intermittent" region of the fire plume, which is the region above the flames where broken flames may extend/exist for brief periods of time. This characterization suggests that cable tray ignition needs to be postulated when cable trays are exposed to either flame impingement, or a region in close proximity to the flames. In order to define the specific thermal conditions, a heat balance equation is formulated assuming a critical heat flux for cable tray ignition of 25 kW/m^2 as follows:

$$\dot{q}''_{crit} = \dot{q}''_{rad} + \dot{q}''_{con}$$

Where the critical heat flux includes radiative and convective contribution as the cable tray may be in the fire plume region near the flames. The equation above is expanded as follows:

$$25 = \epsilon\sigma T_{plume}^4 - \epsilon\sigma T_{amb}^4 + h\left(T_{plume} - T_{amb}\right)$$

Where ε is the emissivity assumed as 1.0, σ is the Stephan Boltzmann constant (5.67E-11 kW/m^2K^4), h is the convective heat transfer coefficient assumed as 0.01 kW/m^2K (see Chapter 2 NUREG/CR-6931 Vol. 3), T_{amb} is the ambient temperature assumed as 20 °C (293 K), and T_{plume} is the plume temperature. Notice that this is the same external heat flux equation used in NUREG/CR-6931 Vol. 3 for the development of the THIEF model. Solving numerically for T_{plume}, a value of 503 °C is obtained, which is similar to the values observed in NUREG/CR-5384 discussed earlier in the FAQ, is between 500 and 600 °C. Conservatively, a temperature criterion of 500 °C is selected for cable tray ignition.

Implementation

The cable damage/ignition criteria are applicable for determining if cables are postulated damaged or ignited in the Fire PRA. The criteria in this FAQ however are recommended for determining cable tray ignition and propagation to secondary combustibles. The time to cable damage or cable ignition can be calculated with currently available fire modeling tools. For cases where cables in trays are exposed to cable damage/ignition criteria, all the cables in the trays will be assumed damaged and ignited. Under this assumption, cable ignition means that sparks generated from shorts can start a fire but not immediately propagate through a cable tray promoting propagation.

The cable tray ignition criteria should be used for determining if cable tray ignition is capable of sustaining fire propagation. In addition,

- Direct flame impingement will generate conditions that meet the criteria for cable tray ignition fire propagation.
- Fire plume, flame radiation, and hot gas layer temperature conditions at the location of the cable trays need to be evaluated using fire modeling tools to determine if the criteria for cable tray ignition are exceeded. Cables exposed to the cable damage/ignition criteria are assumed failed regardless of location within a cable tray or conduit arrangement.
- No ignition would be postulated for qualified cables protected by solid bottom cable trays for both open and obstructed fires. Consistently, the guidance in Appendix Q of NUREG/CR-6850 associated with solid bottom trays is not affected by the information in this FAQ.
- The guidance provided in Section R.4.2.2 of NUREG/CR-6850 would still be used to determine the timing of cable tray ignition above the first cable tray and fire propagation to adjacent trays once the lowest tray is ignited, unless additional fire modeling can show those fire conditions at the location of the cable trays do not meet the cable tray ignition criteria.

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

Revisions to NUREG/CR-6850

In Section 8.5.1.2

Replace: "For cables, the ignition and damage criteria can be assumed to be the same."

With: " For cables, the ignition and damage criteria can be assumed to be the same. Additional criteria is available for determining cable tray ignition to support fire propagation through cable tray arrangements."

Replace: "More detail on damage criteria is provided in Appendix H."

With: "More detail on cable damage and ignition as well as cable tray ignition is provided in Appendix H."

Replace: Table 8-2 with:

Table 8-2

	Cable Damage/Ignition Criteria		Cable Tray Ignition Criteria*	
Cable Type	Radiant Heating	Temperature	Radiant Heating	Temperature
Themoplastic	6 kW/m^2	205°C	25 kW/m^2	500˚C
Thermoset	11 kW/m^2	330°C		

*Assume bulk of cable insulation within the cable tray is ignited and contributes to the heat release rate as a secondary combustible for room heating (e.g. hot gas layer temperature calculations) calculations when any of these thresholds are reached or exceeded. Below these criteria, ignition is assumed to be localized and is not contributing to the overall heat release rate within the compartment.”

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In Appendix H

Replace: "For cables, the ignition and damage criteria will be assumed to be the same."

With: "For cables, the damage criteria may be assumed for both damage and ignition, or separate criteria may be used for cable tray ignition and damage."

Replace: Table H-1 with:

Table H-1

	Cable Damage/Ignition Criteria		Cable Tray Ignition Criteria*	
Cable Type	Radiant Heating	Temperature	Radiant Heating	Temperature
Themoplastic	6 kW/m^2	205°C	25 kW/m^2	500˚C
Thermoset	11 kW/m^2	330°C		

*Assume bulk of cable insulation within the cable tray is ignited and contributes to the heat release rate as a secondary combustible for room heating (e.g. hot gas layer temperature calculations) calculations when any of these thresholds are reached or exceeded. Below these criteria, ignition is assumed to be localized and is not contributing to the overall heat release rate within the compartment."

In R.2

Replace: "If trays are stacked, calculate the flame height, plume temperature, and heat flux at the height of the above tray. Assume ignition of the above tray if it is immersed in flames, or the plume temperature or heat flux are higher than the levels required for ignition."

With: "If trays are stacked, calculate the flame height, plume temperature, and heat flux at the height of the above tray. Assume cable tray ignition and fire propagation if it is immersed in flames, or the plume temperature or heat flux are higher than the levels required for cable tray ignition."

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<u>In R.4.1.1</u>

For the material properties for PVC cables,

Replace: T_{ig} = 218˚C

With: T_{ig} = 205˚C for the purposes of flame spread calculations within one cable tray (i.e., no propagation through different cable trays). See Table 8-2 or H-1 for criteria on full cable tray ignition.

For the material properties for XPE cables are:

Replace: T_{ig} = 330˚C

With: T_{ig} = 330˚C for the purposes of flame spread calculations within one cable tray (i.e., no propagation through different cable trays). See Table 8-2 or H-1 for criteria on full cable tray ignition.

<u>In Table R-2</u>

For Ignition temperature[C]

Replace: 330

With: 330. See Table 8-2 or H-1 for criteria on full cable tray ignition. .

<u>In Table R-3</u>

For Ignition temperature[C]

Replace: 205

With: 205. See Table 8-2 or H-1 for criteria on full cable tray ignition.

<u>In R.4.2.2</u>

Replace: "Exposure source to first tray: tray ignites at time to damage/ignition using the plume temperature correlation"

With: "Exposure source to first tray: cables are damaged or ignited at time to damage using the plume temperature correlation. Cable tray ignition for propagation up the stack at flame immersion or the plume temperature or heat flux are higher than the levels required for cable tray ignition."

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