**FAQ Number** 07-0035 **FAQ Revision** 1

**FAQ Title** **Bus Duct Counting Guidance for High Energy Arcing Faults**

Plant: Harris
Date: January 21, 2009
Contact: David Miskiewicz
Phone: 919.546.7588
Email: David.Miskiewicz@pgnmail.com

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**Purpose of FAQ:**
Clarification/enhancement of Ignition Source counting guidance for High Energy Arcing Faults (HEAF) in NUREG/CR-6850, supporting NFPA-805 Fire PRA applications.

**Is this Interpretation of guidance?** Yes / No

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

**Details:**

**NEI 04-02 guidance needing interpretation (include section, paragraph, and line numbers as applicable):**

New attachment on interpretation issues

**Circumstances requiring guidance interpretation or new guidance:**

Pilot discussions and benchmarking of NUREG/CR-6850 for Task 6, Fire Ignition Frequency, has shown inconsistency in the treatment of High Energy Arcing Faults (Bin 16). There is a need to resolve these issues to prevent future rework and to reduce burden associated with uncertainty treatment. This topic has impact on the NFPA-805 pilots, nonpilots and other users of NUREG/CR-6850.

The guidance provided in NUREG/CR-6850 for Task 6, Fire Ignition Frequency (Section 6.5.6, Bin 16), states:

Bin 16 – High-Energy Arcing Faults (Plant-Wide Components): High-energy arcing faults are associated with switchgear and load centers. Switchyard transformers and isolation phase buses are not part of this bin. For this bin, similar to electrical cabinets, the vertical segments of the switchgear and load centers should be counted. Additionally, to cover potential explosive failure of oil filled transformers (those transformers that are associated with 4.16 or 6.9kV switchgear and lower voltage load centers) may be included in vertical segment counts of the switchgear.

The current guidance is silent regarding the treatment of bus duct. Preliminary discussions between the user community and the NUREG authors indicate that some specific guidance is needed to assure more consistent treatment of bus duct.

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

N/A

**Potentially relevant existing FAQ numbers:**

This guidance is specific to the characterization of bus duct for Bin 16 HEAF determination. The characterization and counting of electrical cabinets for Bin 16 determination is addressed by FAQ 06-0017.

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**Response Section:**

**Proposed resolution of FAQ and the basis for the proposal:**

See attached

**Basis:**

See attached

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

NA

## Background

FAQ 07-0035 requests clarification regarding the treatment of high energy arc faults specific to bus duct failures. Appendix M of the consensus methodology document (NUREG/CR-6850, EPRI TR-1011989) provides guidance for the treatment of high energy arc faults in switchgear and load centers, but does not cover the treatment of bus duct fires. Further, while the document mentions bus ducts as a potential source of high energy arc fault events, no fire event frequency or treatment guidance is provided. The original question as provided to the team for response is attached.

It should be noted that, in developing guidance for fire ignition sources, the absence of guidance on the treatment of bus duct arc faults and fires was an unintended oversight on the part of the report authors and should not be taken to indicate that such fires need not be treated. This FAQ response corrects this inadvertent omission and provides the required guidance for the treatment of bus duct arc fault fires.

## Resolution Approach

The team has reviewed the EPRI fire event database used in the development of NURE/CR-6850, EPRI 1011989 and identified several events involving bus ducts arc fault failures. This event set was supplemented by a set of additional NPP fire events identified by the NRC staff as potentially relevant to the bus duct arc fault question. All of the identified events were reviewed for relevance to the topic of this FAQ and a final set of fire events to be used in calculating fire frequency was identified (see further discussion below). In addition, a public meeting was held (August 2007, ADAMS ML072560081) to discuss the team's preliminary insights, and to gain additional input from stakeholders. The proposed resolution is based on, and consistent with, all of the input received from these resources.

## Technical Resolution

*Intended scope of the bus duct analysis*

The guidance provided here applies to any electrical power distribution bus associated with the equipment already identified in Appendix M of the guidance document as subject to high energy arc fault (HEAF) failures and fires. That is, the guidance applies to power distribution buses associated with switchgear, load centers, and motor control centers of 440V or greater. The guidance also applies to bus ducts associated with turbine generator output (the iso-phase bus), unit main, auxiliary and start-up transformers, and the unit emergency generators and their associated power transformers.

*Classification of bus ducts by type*

A review of bus duct physical configurations as typically used in power plant applications has resulted in a recommended practice that would first classify each bus duct as falling into one (and only one) of the following four general categories:

- **Category 1: Non-segmented or continuous bus ducts:** A bus duct where the bus bar associated with each power phase is comprised of single length of metal bar connecting two end-devices (e.g., terminating within a cabinet or at a specific piece of electrical equipment) with no intermediate junctions, transitions, or terminations along the length of the bus bars. Typically, the bus bars are wholly contained within a grounded metal enclosure that runs the full length of the distance between the termination points.
  - Non-segmented bus ducts tend to be comparatively short (on the order of no more than 12 feet in length) due to practical limits on the length of a single segment of bus bar.
  - Examples:
    - A bus duct connecting a station service transformer to the associated switchgear cabinets where the transformer and switchgear are located in close proximity within a common fire area.
    - A bus duct connecting two separate banks of load cabinets located in close proximity (e.g., across an intermediate access walkway) and fed from a common power source.

- **Category 2: Segmented bus ducts:** A bus duct where the bus bars are made up of multiple sections bolted together at regular intervals (transition points). Here, the bus bars are contained within open ended sections of metal covers that are bolted together to form a continuous grounded enclosure running the full distance between termination points. Segmented bus ducts are able to accommodate tap connections to supply multiple equipment termination points.
  - Segmented bus ducts tend to be longer in comparison to the non-segmented bus ducts. Segmented bus ducts are used in cases where the required lengths and/or geometries make the use of non-segmented bus ducts impractical.
  - The length of each segment may vary depending on supplier and installation details.
  - Segmented bus ducts tend to connect end devices that are remote from each other.
  - Example: A segmented bus duct might be used to connect an oil-filled transformer located in an outdoor area to equipment (e.g., switchgear) located inside the plant buildings.

- **Category 3: Cable ducts:** A power conductor configuration that provides a function like a bus duct but uses a length of insulated electrical cable in lieu of metal bus bars. Cable ducts may be routed in a variety of ways, not necessarily within continuous runs of metal enclosures.

- Cable ducts can be as long as, or longer than, a segmented bus duct because there is no practical limit to the length of cable that can be obtained and installed.
- Cable ducts may be used in application conditions similar to either a segmented or non-segmented bus duct.

- **Category 4: Iso-phase bus ducts: A** bus duct where the bus bars for each phase are separately enclosed in their own protective housing. The use of iso-phase buses is generally limited to the bus work connecting the main generator to the main transformer.

*Selection of bus duct fire scenarios*

A review of the experience base for all types of bus ducts revealed one common characteristic; namely, that all of the identified bus duct arc fault events occurred either at the termination point of the duct or at a transition point along the length of a segmented bus duct.

With the exception of the iso-phase bus ducts (category 4), in those events occurring at the termination point, all had been included in the "high energy arc fault (switchgear and load centers)" or "catastrophic failure (transformers)" event sets for the end devices as fire ignition sources. Hence, these events are already accounted for in the methodology and are treated as originating in the end device. Because non-segmented bus ducts (category 1) and cable ducts (category 3) have no transition points other than the terminations at the end device, no treatment of bus duct faults/fires independent from the treatment of fires for the end devices is required. That is, arc faults for these two categories of bus ducts, 1&4, are inherently included in the treatment of the end device, and no further treatment is needed.

A review of available data indicates that events associated with iso-phase bus ducts (category 4) also manifest themselves at the termination points (i.e., the main generator or main transformer) but these events had <u>not</u> been included in the associated end device frequencies. The potential effects of the iso-phase faults also appear unique in comparison to the end device (transformer or exciter) fires as recommended in the existing guidance. Hence, some additional treatment for iso-phase bus duct faults occurring at the termination points is needed.

For segmented bus ducts (category 2), a number of the identified fire events were manifested at bus transition points (a point where two segments of the bus duct are bolted together) rather than at the bus termination points. These events were generally attributed to loose bolted connections, to failed insulators, or to the accumulation of dirt/debris/contaminants in the bus duct. The key, however, is that the effects of the fault are manifested at transition points along the bus duct length. Fire scenarios for segmented bus ducts should, therefore, be postulated to occur at duct transition points (i.e., bolted connections). An alternate treatment is provided if the transition points cannot be easily identified based on external inspection.

**<u>Ignition Source Counting Guidance</u>**

*Counting guidance: iso-phase bus ducts*

For iso-phase bus ducts, there should generally be one iso-phase bus per unit (an iso-phase bus includes all three phases). If there is more than one iso-phase bus, simply count the total number of iso-phase buses per unit. For individual fire scenarios, the plant-wide frequency is applied (i.e., partitioned) equally to each end of each iso-phase duct counted. The plant-wide fire frequency and zone of influence are discussed below.

*Counting guidance: segmented bus ducts*

The analyst will need to choose between one of two recommended practices for counting segmented bus ducts as a fire ignition source. The choice will be dependent on whether or not the transition points can be identified based on an external visual inspection of the bus duct.

- **Counting approach 1:** If the transition points along the length of the segmented bus duct can be identified by external visual inspection, or based on plant electrical construction drawings, then count the total number of transition points. Note that transition point counting *excludes* the bus end termination points which are considered a part of the end device for fire frequency purposes. Transition points may be identifiable based on visual observation or review of design drawings. Transition points for the bus bars may, or may not, correspond to junctions in the outer ducting that surrounds the bus bars. It is not intended that the protective duct be removed to identify transition points. However, industry feedback indicates that the joints or junctions in the outer ducting surrounding a bus duct cannot be assumed to correspond to junctions in the bus bars themselves without confirmation. A representative sample of plant applications should be inspected to ensure that the internal bus bar transition points and external duct junctions do in fact align with each other. Once the total count of transition points has been obtained, the plant-wide fire frequency is then partitioned to a specific location based on the number of transition points in the location of interest divided by the total number of transition points for the entire plant.

- **Counting approach 2:** If the transition points *cannot* be identified based on external visual inspection, or by plant electrical construction drawings, then the partitioning of fire frequency to a specific fire scenario is based on apportioning of the fire frequency equally along the length of the bus duct. Hence, the analysis must estimate the total length of segmented bus duct present in the plant under analysis. A “per linear foot” fire frequency can then be estimated by dividing the plant-wide fire frequency by the total length of segmented bus duct in the plant.

- That is, the fire frequency for a given fire scenario would be based on the ratio of the length of duct for which identified targets fall within the bus duct arc fault zone of influence (see discussion below for a definition of the zone of influence) to the total length of bus duct in the plant. A lower limit to the assumed fire frequency for any given fire scenario is also applied. That is, if the length of bus duct for which the identified target(s) fall within the zone of influence is less than 12 linear feet, then a minimum length of 12 feet should be assumed. This lower bound based on the assumption that, lacking specific information on segment lengths, a nominal segment length of 12 feet should be assumed. Any single scenario is then assigned a fire frequency equivalent to that associated with one bus bar segment 12 feet in length (i.e., equivalent to one nominal transition point).

Once the count and partitioning values are known, the next step is to develop fire scenarios for analysis. The development of fire scenarios is again expected to follow one of two potential approaches as outlined in the following discussions.

The analyst should be aware that the second of these two approaches introduces a degree of uncertainty into the analysis. As noted above, arc faults generally occur at the transition points. When the actual location of the transition points is not known, the approach assumes that a fault might occur at any point along the duct length. Hence, fire scenarios might be developed for locations where there is, in actuality, no junction point. By the same token, the approach partitions fire frequency equally along the length of the bus duct whereas in reality faults would be more frequent at the actual (but unknown) transition points. It is recommended that in assessing analysis results, these observations be treated as a part of the uncertainty and sensitivity analyses, and that the analysis be refined for cases where risk-significant fire scenarios develop (i.e., by examining the bus duct to determine if any transition points are actually present in the segment of bus duct associated with a significant scenario). This is discussed further below.

**Anticipated analysis approach for segmented bus ducts**

*Approach for known transition points:*

If the transition points for the bus ducts are known, then the approach to analysis would focus on the development of scenarios at those known locations. Note that even when transition points are not known generally, certain locations will represent known transition points based on geometric factors. For example, if a horizontal duct changes direction (i.e., makes a flat or vertical turn) or changes elevation (e.g., a step), that geometric transition would represent a transition point for that bus duct.

For known transition points, the analysis should look for fire PRA targets (i.e., fire PRA equipment and cables) within the zone of influence (described below) and postulate scenarios accordingly.

*Approach when transition points are not identifiable*

In the case where transition points are not in known locations, the approach to analysis is similar but begins by assuming that a fault might occur at any point along the length of the bus duct. In this case, the analyst should trace the path of bus ducts through the plant and identify potential fire PRA targets within the bus-duct arc fault zone of influence (see definition below) at any point along the duct length. The development of fire scenarios would then depend on the relative length of bus duct for which an identified target set lies within the bus duct zone of influence.

- Analysis Approach 1: Potential fire PRA targets are located within the zone of influence for a significant length of duct (greater than the nominal assumed segment length of 12 feet): In this case, an estimate of the scenario fire frequency can be based on the plant-wide fire frequency times the ratio of the length of duct (e.g., linear feet) for which scenario targets lie within the zone of influence to the total length of segmented bus duct in the plant.

- Analysis Approach 2: A target set is identified but lies within the zone of influence for a limited portion of bus duct (i.e., less than the nominal assumed segment length of 12 feet): In this case, an initial analysis should assume that a fault occurs within that segment of the bus duct for which fire PRA targets might be impacted, however, long it might be. The fire frequency assigned to the scenario is the minimum fire frequency value calculated based on a minimum 12 foot length of duct.

Note that in either approach, the analysis can always be refined by examining the bus duct to determine if one or more transition points actually lie within the applicable bus duct segment. If no transition points are identified within that particular duct section, then a fault scenario need not be postulated and the scenario “goes away.” If one or more transition points are identified within a particular duct section, then the analysis can be refined based on the known locations (i.e., both the fire frequency and the impacted target set may be refined once transition points are identified).

**Fire frequency and frequency partitioning**

The team has reviewed all of the identified “candidate” fire events. Tables 1 and 2 list the events used to estimate the frequencies for segmented bus ducts and for iso-phase ducts, respectively. The events listed were identified based on a review of the events in EPRI’s Fire Event Data Base (FEDB) and on a similar review of events identified in various NRC documents (information notices, inspection reports, LERs, and staff reports) as provided by the NRR staff. Each event that included a bus duct was reviewed to determine (1) if the event meets the general criteria associated with a "potentially challenging event" consistent with the treatment of other fire ignition sources and (2) if the event was indeed uniquely associated with a bus duct arc fault and consequential fire rather than some other fire ignition source bin.

**Table 1: Segmented Bus Duct Fire Events Used in Frequency Calculations**

| FEDB Incident No: | Event Date | Description |
|---|---|---|
| 195 | 4/15/80 | Fire involved a supply bus located in a switchgear room. |
| 218 | 8/20/80 | A short occurred on the bus work from the RAT to buses 1-1 and 1-2. This caused a reactor trip and turbine trip. Damage to equipment was limited to a 10 foot section of the bus-bar. In addition insulation between the insulated bus bar supports experienced some cracking due to the force of the fault. Several non-safety related cables located in a cable tray adjacent to the bus experienced insulation failure as a result of this event. (NOTE: Information in FEDB has been supplemented with information provided in LER 88-001-00.) |
| 575 | 3/19/87 | A fault in a 6.9 kV feeder line to the in house buses of unit auxiliary transformer resulted in a fire and explosion outside the building. |
| 678 | 3/2/88 | A section of the bus bar running from the mat to the bus switchgear was badly damaged due to insulation failure and a subsequent fault. During normal operations, a combination of insulation failure, debris accumulation, and possibly water resulted in an electrical fault in a main (4000 AMP) power bed bus bar. Degradation of the electric power feed resulted in a reactor trip. The fault was detected by a phase inbalance (differential current) alarm in the main control room and by reports of smoke in the turbine building basement. The fire brigade was called out. Deenergizing of the bus ended the fire. In addition to damage to the effected bus, several non-safety related cables located in a cable tray adjacent to the bus experienced insulation failure. |
| 922 | 7/10/87 | Insulation on a 4160 V bus bar failed. This condition resulted in a phase to ground fault which caused extensive damage to the bus bar and a fire. Upon investigation, the equipment operator noticed smoke and fire coming from the vicinity of the electrical Bus Bar located on the eastern end of the 606' elevation of the Turbine Building. The bus fire terminated once the transformer was deenergized. A smaller fire was extinguished by the equipment operator when rags and rubber goods on a maintenance cart ignited by the falling aluminum slag. |

| FEDB Incident No: | Event Date | Description |
|---|---|---|
| 2426 | 5/15/00 | An electrical fault occurred on the 12kV bus bars from UAT to nonvital switchgear resulting in a fire in the nonvital switchgear room. The fault continued to be fed for 4-8 seconds by the decay of the main generator electrical field during generator coast down contributing to catastrophic failure of the bus bars. Security officers reported a fire at UAT 1-1 and operators notified the fire brigade. The fire brigade arrived at the switchgear room and determined that the fire was internal to the switchgear room and not associated with UAT 1-1. Given the large amount of smoke, the Fire Brigade Captain requested offsite fire brigade support. The fire brigade extinguished a small fire in the 12 kV bus duct with a carbon dioxide extinguisher within 17 minutes of arriving at the switchgear room. Post-event inspection revealed that the center 12kV bus bar was missing for approximately 1 yard, with the two exterior bus bars missing for approximately 6 and 9 inches. The bottom and top of the bus duct was melted for several feet, along with sections of the duct work on the perpendicular 12 kV bus sections at the tee connection. In addition, the fire had burned an approximate 1 foot square hole in the bottom a second 4 kV bus duct 4 inches above the 12 kV bus duct. Although the 4 kV bus bars and duct were covered with black soot, the only conductor damage was a small piece of metal missing from the center bus bar and one outer bus bar, which the inspectors considered to be indicative of a single phase-to-phase fault. The floor beneath the fault contained a large slag pile, and a great deal of metal had splattered on the face of 12 kV nonvital Switchgear D and E. However, no missiles penetrated the switchgear, and they remained energized throughout the event. Later inspection revealed no internal damage. Smoke patterns on the cabinet doors indicate that plastic components on the cabinet faces (e.g., gauge faces, identifier tags, indicator lamp housings) ignited and burned during the event. |
| Not in FEDB | 5/18/83 | Startup bus failed because of a phase B to phase C fault, which propagated to ground. Further investigation revealed several degraded areas in the bus insulation at the support blocks. (See NRC Information Notice 89-64 for information on this event.) |

## Table 2: Iso-Phase Bus Duct Fire Events Used in Frequency Calculations

| FEDB Incident No: | Event Date | Description |
|---|---|---|
| 792 | 7/15/1988 | Arcing and fire was observed at 22kV iso-phase bus duct due to damaged ground straps and a deteriorated gasket between the cover and the duct. |
| 929 | 10/9/1989 | Multiple ground faults caused by aluminum debris in an iso-phase bus duct started a chain of events that led to three separate fires: (1) an oil fire in the 'B' main power transformer, (2) a hydrogen fire under the main generator, and (3) a small oil fire in the generator housing. In addition to site fire brigade, off-site fire departments were contacted to assist. |

| FEDB Incident No: | Event Date | Description |
|---|---|---|
| Not in FEDB | 6/18/2004 | An electrical fault in the one phase of the iso-phase bus lead to a fire near the main transformer at Vermont Yankee.[1] The fire also involved oil leaking from a flange on the main transformer itself and resulted in severe damage to the low voltage bushing box on top of the Main Transformer, to the Generator PT Cabinet in the Turbine Building, and to the iso-phase bus duct itself. |

The resulting set of relevant and potentially challenging events includes 7 events for segmented bus ducts and 3 events for iso-phase bus ducts. Note that, because of its significance, the June 18, 2004 Vermont Yankee iso-phase fire event is included in the frequency calculations. All other frequencies were based on events prior to December 31, 2000. The iso-phase event set, therefore, extends beyond the period covered by the FEDB; hence, the number of plant reactor years was adjusted to reflect plant operations through mid June 2004 for the iso-phase bus duct case only. Also, it was verified that no other iso-phase bus fires have been reported between January 1, 2001 and mid June 2004. The resulting plant-wide fire event frequency for segmented bus duct arc fault failures and iso-phase bus duct fires is characterized by the frequency distributions presented in Table 3.

Note that in calculating fire frequencies, the number of plant reactor years is based on the entire U.S. fleet of light water reactors. That is, it has been assumed that all of the existing plants contribute to the bus duct fire frequency for both segmented and iso-phase events.

**Table 3: Iso-Phase and Segmented Bus Duct Fire Frequency Distributions**

| Frequency Bin | # of Events | Total Reactor Years | 5th percentile | 50th percentile | 95th percentile | Mean | Variance |
|---|---|---|---|---|---|---|---|
| Segmented Bus Duct | 7 | 2618 | 3.45E-05 | 8.51E-04 | 1.07E-02 | 3.27E-03 | 2.03E-02 |
| Iso-Phase Bus Duct | 3 | 2054 | 3.29E-05 | 6.79E-04 | 5.40E-03 | 1.85E-03 | 0.0801 |

Partitioning of these fire frequencies to specific locations for the segmented bus ducts should be performed in accordance with the counting guidance provided above. That is, each transition point will be assumed to have an equal fraction of the total plant-wide fire frequency.

For the iso-phase bus, partitioning should assume that the likelihood of a fire is equal for each end of the bus (i.e., half of the frequency goes to the transformer end and half to the

[1] Reference: Licensee Event Report (LER) 50-064-2004-003-01, Revision 1, June 14, 2005.

generator end) and that the initial fault is equally likely to occur in any one of the three phases (i.e., the fault initiates in one of the three phases, not all three concurrently).

## Estimating the Initial Fault Zone of Influence

*Zone of influence for segmented (non-iso-phase) bus duct fires*

The zone of influence for a segmented bus duct arc fault fire is considered unique from that assumed for electrical cabinets. The experience base illustrates that the bus duct events generally involved a pool of molten conductor and possibly burning insulation materials that forms within and then burns through the lower surface of the bus duct enclosure itself. This material spills out of the bus duct, may form a molten pool of metal on the floor or objects below, may splatter onto other nearby surfaces, and may ignite any combustible or flammable materials contacted. The recommended zone of influence is intended to reflect this experience base.

For reference, one well documented event considered prototypical of a bus duct fire occurred at Diablo Canyon on May 15, 2000[2]. Figures 1 and 2 provide photographs taken after this event (as provided in the cited inspection report - see footnote). Note the damage visible to the face panels on cabinets located below and to the side of the fault point. The photos show clear evidence (soot traces) that the surface-mounted components (e.g., the dial indicators, labels, switches, etc.) ignited and burned. Individual points of charring on the panel face are taken as indicative of impinging molten metal droplets. The exterior surfaces of cabinets on both sides of the access walkway directly below the primary faulting point were damaged. The fire did not extend to the interior of these cabinets. Surface damage occurred on cabinets on both sides of the aisle-way directly below the fault point, and extended to three adjacent panels on each side of the aisle.

Based on the observed behavior, the recommended zone of influence for a segmented bus duct fire is as follows:

- Assume that the effects of the bus duct fault will be manifested at a transition point (the fault point). Recall that failures at end point terminations are captured under the end point equipment.
- The following zone of influence is assumed to originate from a point at the center of the bus duct at the assumed transition point location.
- Assume that molten metal material will be ejected from the bottom of the bus duct below the fault point and will spread downward encompassing the shape and volume of a right circular cone whose sides are at an angle of 15° from the vertical axis (a total enclosed solid angle of 30°).

[2] References: (1) U.S. NRC Information Notice 2000-14, "Non-Vital Bus Fault Leads to Fire and Loss of Offsite Power", 9/27/2000 and (2) U.S. NRC Diablo Canyon Inspection Report No. 50-275/00-09; 50-323/00-09, July 31, 2000.

- The cone will expand (height allowing) to a maximum diameter of 20 feet. Beyond this point, the burning materials will fall straight downward in a cylindrical shape. Note that the maximum expansion zone for the cone (20 foot diameter) corresponds to a distance 37 feet below the point of origin.
- Assume that any exposed combustible or flammable materials within this cone-shaped zone of influence will be ignited. Combustible/flammable materials will not be considered exposed if they are protected by a fire-rated raceway wrap, conduit, or solid steel panels. Specific examples of the recommended treatment of exposed versus non-exposed materials are as follows:
    - The solid metal side panels of a cabinet *will* prevent ignition of the combustible/flammable materials inside the cabinet.
    - For cabinets with a solid steel top where all cable or conduit penetrations are sealed (e.g., consistent with the guidance provided in NUREG/CR-6850, EPRI TR 1011989, Chapter 11, with respect to the propagation of fires out of an electrical panel), molten material deposited on top of the cabinet *will not* burn through the panel top[3].
    - For cabinets with a ventilated top or unsealed cable or conduit penetrations, molten material deposited on top of the panel *will* penetrate into the panel and ignite the contents if the openings are within the zone of influence.
    - Open ventilation sections on cabinet side panels that are made up of an open mesh or screen section *will* allow the penetration of molten material into the cabinet if the openings are within the zone of influence.
    - For cabinet side panels or doors that include louvered ventilation openings where the louvers point downwards to the outside of the panel, molten material deposited on the surface of such panels *will not* penetrate into the cabinet.
    - Cables in open-top cable trays *will* be ignited if they are within the zone of influence.
    - Cables in conduit *will not* be ignited by molten materials deposited on the outer conduit surface if the open ends of the conduit are located outside the zone of influence.
    - Cables in trays that are equipped with un-ventilated steel covers *will not* be ignited by molten metals falling from above (see footnote 2).
    - Cables in trays that are equipped with aluminum covers of any kind, or with ventilated steel covers, *will* be ignited by molten metals falling from above.
    - The first solid surface encountered by the material ejected from the bus duct will truncate the zone of influence along that line of travel (examples include: where the zone of influence intersects the floor, a sealed cabinet

[3] Note that, relative to this particular point of guidance, it is the judgment of the authors that even the minimum thickness of a typical steel cabinet top panel as employed in practice by manufacturers will be sufficient to prevent burn-through of the molten material ejected from a bus duct. The guidance specifically excludes credit for aluminum panels.

top, or a cable tray with a solid metal cover, it does not extend through that surface to other targets or flammable material beyond).

- Damage and ignition within the initial zone of influence occurs at time zero (concurrent with the initial fault) but the ensuing fire can be assumed to develop over time from a point ignition origin (e.g., a cable tray should be assumed to ignite at one point, not over its entire exposed length).
- Subsequent analysis of fire development, fire detection, and fire suppression response follow the same practices as applied to high energy arc faults for switchgear and load centers. In particular, the manual fire brigade response curve applicable to high energy arc faults for switchgear also applies to bus duct faults.

Figure 1: Photograph of the point on the bus duct where the arcing fault at Diablo Canyon was manifested (the fault point). Note that the tops of the cabinets to the left and right (the cabinets to the left are shown in figure 2) are visible in the lower corners of this photograph.

Figure 2: Photograph of the surface damage and burning observed for the more heavily impacted cabinets on one side of the aisle-way below the fault point (the cabinets to the left as seen in Figure 1).

*Zone of influence for iso-phase duct fires*

For the iso-phase bus duct fires, it is recommended that the zone of influence should assume damage to any component or cable that would normally be considered vulnerable to fire damage (i.e., excluding items such as water-filled piping that would not normally be considered vulnerable to fire damage) located within a sphere centered on the fault point and measuring 5 feet in radius. Any flammable or combustible material within this same zone of influence should be assumed to ignite. The recommended zone of influence is intended to cover both the initial fault effect and the potential burning of hydrogen gas[4] that may be released at low pressure from the bus casing upon rupture. An enduring fire (i.e., lasting beyond the initial fault) should be assumed consistent with the nature of any flammable or combustible materials present within the zone of influence and potential fire spread beyond the zone of influence.

For the case of fires occurring as the main transformer termination points, the potential for involvement of the main transformer (and its oil) should be considered. In particular, the electrical lines will each penetrate the casing of the transformer and this could allow the fire to spread to the transformer itself. Failure of the electrical penetration seals (e.g.,

[4] Iso-phase bus ducts are generally filled with hydrogen gas at low pressure to enhance both cooling and electrical isolation. Upon rupture the hydrogen gas will leak from the duct, but neither a jet fire nor an explosion are anticipated due to the initial rupture.

melting of a rubber boot) could also create a path for oil leakage outside the transformer as was observed in the Vermont Yankee event.

The analysis should also consider the potential for involvement of additional hydrogen gas beyond that which will leak from the casing as a result of the initial fault. That is, the configuration of, and potential failure in, the hydrogen purge/fill system should be evaluated to determine if additional leakage of hydrogen gas is plausible. This assessment will require consideration of case-specific storage, piping and valve arrangements.