Attachment 5

Characterizing Non-Simple Fire Ignition Sources

Self-Ignited Cable Fires

The procedure for characterization of self-ignited cable fires is as follows:

- Determine if self-ignited cable fires are plausible

  Self-ignited cable fires are considered plausible only for thermoplastic or non-qualified thermoset cables. Self-ignited cable fires will be assumed to be implausible for Thermoset cables rated as low flame spread per the IEEE-383 standard. If self-ignited cable fires are not plausible, they will not be considered in the Fire Protection SDP analysis (no self-ignited cable fire scenarios need to be developed).

  This approach assumes proper current limiting provisions (fuses and/or breakers) are provided for all cables. If this assumption is not applicable, additional guidance should be sought from the Regional or Headquarters fire protection staff.

- Determine if self-ignited cable fires should be included in risk calculations

  The frequency of a self-ignited cable fire occurring in a specific location is low, even if such fires are plausible. In most fire areas, fire risk will be dominated by fires involving other fixed fire ignitions sources, in large part because such fires are simply far more frequent. Hence, a defensible estimate of fire risk change can often be calculated without explicitly analyzing the self-ignited cable fire scenarios.

  Self-ignited cable fire scenarios should only be analyzed when there is a specific set of post-fire safe shutdown cable damage targets that is not threatened by any fixed fire ignition source. This could occur under the following conditions:

  " The fire area being analyzed contains no fixed ignition sources (e.g., a cable tunnel or cable spreading room with nothing but cables in it), <u>or</u>
  " All of the fixed ignition sources that might have threatened the target cables were screened out in Step 2.3, <u>or</u>
  " None of the fixed ignition sources is close enough to the target cables to cause ignition/damage.

  Include specific analysis of self-ignited cable fires if and only if one or more of the above conditions is met. If none of the above conditions are met, do not analyze self-ignited cable fire scenarios.

- Choose a critical ignition zone

  A self-ignited cable fire will begin in a specific location - the ignition point. Many ignition points are possible, and the importance of any given ignition point is case-specific. The importance of a given ignition point is driven by its proximity to thermal damage targets (other cables of risk importance). Locations where a fire might lead to critical damage (loss of a risk-important thermal damage target set) are referred to as critical ignition points.

In some cases, a fairly specific location may be the critical ignition point:

- The critical thermal damage target set might be two cables located in separate cable trays that cross at a particular location. In this case, ignition points near the crossing point would likely be the most risk-significant.

Often, a combination of critical ignition points may form a critical zone:

- If the location of risk-important damage targets are poorly characterized, it may be assumed that a fire in almost any location could lead to critical damage.

- If the critical cables are all located in a specific cable tray, any ignition point that could threaten that tray, including an ignition within the target tray, is a potential critical ignition point.

In effect, the collection of critical ignition points becomes a critical ignition zone. This zone must be defined for the fire area being analyzed.

- Calculate the critical ignition zone weighting factor

A weighting factor is used to characterize the likelihood that the fire will start within the critical ignition zone as compared to all other possible locations. The weighting factor is based on the linear feet of cable tray within the critical ignition zone versus the total linear feet of cable trays in the fire area.

WF = (linear feet of trays in critical ignition zone)/(total linear feet of trays in fire area)

The Weighting Factor (WF) is applied as a multiplier on the fire area fire frequency for self-ignited cable fires.

- Fire characterization assumptions

Following ignition, the subsequent fire spread among the exposed cable trays is treated using the general rules for fire spread within a stack of cable trays (see Attachment 3).

Once a cable tray has ignited, including the tray in which the fire is assumed to start, all cables in that tray are assumed to be fire damaged (no additional time delay).

If a specific heat release rate is needed for a given case, the initial self-ignited cable fire can be treated as using a 70kW fire intensity. This allows the self-ignited fire to map into the matrix of fire characteristics for simple fire ignition sources. As the fire spreads, fire intensity increases based on the surface area of the burning cable trays. A fire heat release rate of 400 kW/m^2 of burning cable tray is assumed.

<u>Energetic Electrical Arcing Faults Leading to Fires</u>

Both switchgear and load centers (440V and above) are subject to a unique failure mode and, as a result, unique fire characteristics. In particular, these types of high energy electrical distribution and switching panels are subject to electrical arcing failures. This failure mode leads to the rapid release of electrical energy in the form of heat, vaporized copper, and mechanical force. Faults of this type are also commonly referred to as high energy, energetic, or explosive electrical equipment faults or fires.

The arcing or energetic fault scenario is <u>in addition</u> to the possibility of a general or thermal fire in these same components. That is, switchgear and load centers as subject to two types of fires, a general electrical cabinet fire and the arcing fault fire. The fire frequency, fire characteristics, and manual suppression curve are unique for each fire type. In dealing with postulated switchgear and load center fires, both fire types should be considered. This particular sections describes only the arcing fault fires.

The arcing fault failure is initiated in a specific electrical cabinet chosen to represent the fire scenario of interest. The fault is initiated as the result of electrical arcing either between one phase and ground, or phase to phase. The fault typically occurs on the input side of the equipment (i.e., in the electrical sense, that side of the component where power feeds into the device rather than the output side of the device). Fire growth and damage for the arcing fault fire is characterized by the following features/assumptions.

- The initial arcing fault will cause destructive failure of the faulting device.
    - This failure is non-recoverable.

- The next upstream over-current protection device in the power feed circuit leading to the initially faulting device will trip open causing the loss of all components fed by that electrical bus.

- The release of copper plasma and/or mechanical shock will cause the next directly adjoining/adjacent switchgear or load center elements within the same cabinet bank and in all directions (above, below, to the sides) to trip open.
    - If the first adjoining cabinet section is essentially empty, then the next adjoining cabinet section will be assumed to trip open (e.g., the central sections of a switchgear bank often include a cross-tie cabinet section that is essentially empty).

- The cabinet or cabinet section in which the initial arcing fault occurs will be blown open by the initial energy release.

- The subsequent (or enduring) cabinet fire will continue to burn consistent with the a “small electrical fire” using the 98th percentile fire intensity (i.e., 200 kW) and a severity factor of 1.0.
    - For arcing fault scenarios, the 75th percentile small electrical fire will not be considered.

- Any unprotected cables that drop into the top of the panel in an open air-drop configuration will ignite.

  - Cables in conduit or in a fire wrap are considered protected in this context.
  - Armored cables with an exposed plastic covering are considered unprotected in this context.

- Any unprotected cables in the first overhead cable tray will be ignited concurrent with the initial arcing fault provided that this first tray is within five feet vertical distance of the top of the cabinet. The cable tray fire will propagate to additional trays consistent with the general guidance provided for the treatment of cable tray fires elsewhere in this document assuming that the time to ignition of the first tray is zero rather than the normal five minutes (see "*Rules for Development of Cable Tray Fire Scenario*" under Task 2.5.1).
  - Applies to any cable tray located directly above the panel.
  - Applies to any cable tray above the aisle-way directly in front of, or behind, the faulting cabinet provided some part of that tray is within 12" horizontally of the cabinet's front or rear face panel.
  - Cables in conduit or in a fire wrap are considered protected in this context.
  - Armored cables with an exposed plastic covering are considered unprotected in this context.

- Any vulnerable component or movable/functional structural element located within three feet horizontally of either the front or rear panels/doors, and at or below the top, of the faulting cabinet section will suffer physical damage and failure.
  - This will include mobile/functional structural elements such as fire dampers and fire doors.
  - This will include potentially vulnerable electrical or electro-mechanical components such as cables, transformers, ventilation fans, other cabinets, etc.
  - This will exclude fixed structural elements such as walls, floors, ceilings, and intact penetration seals.
  - This will exclude large components and purely mechanical components such as large pumps, valves, major piping, fire sprinkler piping, or other large piping (1" diameter or greater).
  - This may include small oil feed lines, instrument air piping, or other small piping (less than 1" diameter).

- Exposed cables, or other exposed flammable or combustible materials transient fuel materials located within this same region will be ignited.
  - Exposed flammable materials would include a vertical cable riser
  - Cabinets or transformers are not
  - Transients might be
  - Vertical riser that is wrapped or covered is not
  - Materials within a second closed panel will not be ignited even if within this distance.

Adjusting Transient Fire Source Characteristics

If a finding against the administrative controls program involves the identification of inappropriate material types or quantities within a fire area, the characteristics of the transient fire ignition source are adjusted to reflect the as-found condition.

Determine if the fire intensity should be adjusted:

The fire intensity table for simple fire ignition sources includes values for typical transient fuel packages of the type that are routinely encountered in the plant. These fire characteristics bound transient fire sources with the following characteristics:

- A single plastic or metal trash can of up to 55 gallons size loaded with general waste materials such as paper, packing materials, etc.
- Up to three small office-size trash cans with general waste (e.g., on the order of 2-4 gallons each, typically either plastic or fiberglass construction).
- A single wooden pallet.
- A single small packing crate (no more than 24" cube).
- A plastic bucket of up to 7 gallons in size (e.g., a used paint bucket) with cleaning materials (e.g., rags, brushes, no more than a pint of cleaning solvents).
- One or two plastic trash bags containing general waste materials.
- A quart of flammable solvents that remains in the container).
- A gallon of combustible liquids that remains in the container (e.g., paint, oil).
- An open grease bucket up to one gallon.
- A spill of combustible or flammable liquids that is no larger than 3 feet in diameter (7 feet square surface area).
- A single collection bin for protective clothing (e.g., at a step-off / dress-out area).

If the as-found conditions exceed the above examples, the fire intensity should be increased to reflect the as-found conditions.

For most cases, it will be sufficient to increase the fire intensity values by one level of intensity using the fire intensity table for simple fire sources. This means that the anticipated (75^{th} percentile) fire is increased from 70 to 200 kW, and the high confidence (98^{th} percentile) fire is increased from 200 to 650 KW).

If, in the judgement of the analyst, the as-found conditions still may not be bounded by use of these modified values, it is recommended that additional guidance be sought from either the Regional or Headquarters fire protection staff.

Weighting Factors for Transient Fires

A weighting factor may be applied to reflect the likelihood that a transient fire will occur in one specific location versus all the other plausible locations in the fire area where a fire might occur. When applied, the transient fire frequency for the fire area is multiplied by the weighting factor to estimate the fire scenario fire frequency. That is, the weighting factor reduces the transient fire frequency for the entire fire area to that for the specific fire scenario in the specific location.

- If the inspection observed transient fuels in a specific location, and the transient fire scenario being analyzed places the fire in essentially the same location, then NO weighting factor is applied. The full transient fire frequency can be applied to fires located where actual transient fuel material were located in practice.

An arbitrary location may also be chosen for development of a transient fire scenario. In general, the transient fire is positioned so as to optimize the damage potential. In this case, a weighting factor is applied based on the relative floor area represented by the critical floor area versus the total floor area for plausible locations that transient fuel might be located:

- Determine where in the fire area transient fuel materials might be either temporarily or permanently stored.
    - Exclude normal pathways, designated clear spaces (e.g., in front of electrical distribution panels), or areas that are not accessible.
    - Include locations that might not be intended for the storage of such materials, but might see temporary storage based on convenience (e.g., materials might be pushed under a cable tray to get them “out of the way”).
    - Estimate the total floor space where temporary or permanent storage of transient fuel material is considered plausible (the “plausible” floor area).

- The critical floor area is a subset of the “plausible” floor area.
    - Identify the potential damage targets and potential fire spread paths required for a transient fuel fire to reach those damage targets.
    - Use the ball-and-column diagrams to determine if a transient fire could actually cause damage or initiate the required fire spread if placed in various locations within the “plausible” floor area.
    - Estimate the total floor area where fire spread/damage is possible (the “critical” floor area).

- The weighting factor is the “critical” floor area divided by the “plausible” floor area:

$WF_{transients}$ = (critical floor area - ft^2) / (plausible floor area - ft^2)

- In most cases, choose one location to conservatively represent all transient fuel fires. The location is chosen to minimize the fire growth and damage time.
    - If the fire area contains two or more unique target sets that are spatially separated, additional locations and additional transient fire scenarios may be analyzed. Each scenario should be assigned its own weighting factor using the above method.
    - When summed, the weighting factor for all transient fire scenarios should not add to more than 1.0 (in most cases the sum will be less than 1.0).

Hot Work Fires

For hot work fires, it will be assumed that the hot work leads to ignition of either transient combustibles, exposed cables, or insulation materials depending on the specific situation. Transient combustibles could include flammable materials used in conjunction with the hot work itself (e.g., plastic sheeting or non-fire retardant scaffold materials).

- If the hot work is assumed to ignite transients, treat the subsequent fire like any other transient fuel fire. As-found conditions may be reflected in fire characterization.
- If the hot work is assumed to ignite exposed cables, treat the subsequent fire like a self-ignited cable fire.
- If the hot work fire is assumed to ignite insulation materials, seek additional guidance from Regional or Headquarters fire protection staff.

<u>Weighting Factors for Hot Work Fires</u>

A weighting factor may be applied to hot work fires.

- Determine if there is a designated location or locations within the fire area where hot work activities are performed, or if a location can be identified where hot work will be undertaken in the vast majority of cases.
    - If such a location exists, then hot work fires should generally be postulated to occur in the area of this location (e.g., within reach of sparks from the hot work)
    - If only one hot work fire scenario is developed, the weighting factor is 1.0 (in effect, no weighting factor is applied).
    - If more than one hot work fire scenario are developed, each scenario is assigned a corresponding fraction of the total fire frequency (if three scenarios are developed, each scenario uses a weighting factor of 1/3).

- If hot work activities appear equally likely in several locations, use an approach similar to that discussed for transient fires:
    - Identify the “plausible” hot work fire locations.
    - Identify “critical” locations for a hot work initiated fire using the appropriate ball and column diagram, or the rules for cable tray fire spread.
    - Calculate a weighting factor based on the relative size of the floor space in the “critical” versus “plausible” locations.

<u>Liquid Fuel Spill Fires</u>

A liquid fuel spill fire could involve oil, motor fuels, flammable solvents, or any other combustible or flammable liquid used or stored in the plant.

Additional guidance will be required to complete the Phase 2 assessment for such fires. Guidance from either Regional or Headquarters fire protection staff should be sought in the treatment of these fires. General guidance for the analysis of these cases is provided below.

- Determine spill volume:

  The spill volume sets the fuel loading. Spill volume for the expected (75th percentile) and high confidence (98th percentile) fire intensity values will be established as follows:

    - The expected spill volume is release of 10% of the contained oil, and
    - The high confidence spill volume is 100% of the contained oil.

These assumptions may be modified to suit a specific application based on inspector judgement.

- Determine spill size:

  A second critical factor in a liquid fuel pool fire is the surface area of the burning pool. The surface area may be bounded either by physical constraints or based on fuel spill depth:

  - Fuel spread will be contained by physical features such as walls, curbs, and berms if present.
  - When a spill in not confined by physical features, the liquid will spread until some limiting fuel depth is reached. The limiting depth is dependent on the fuel type (primarily by the materials viscosity). The pool surface area is then set to match the total fuel volume.

- Determine fire intensity:

  Simple modeling correlations are available to predict the fire intensity for a burning pool fire based on the material properties and the spill size.

Severe Fires Involving the Main Turbine Generator Set

For inspections involving the turbine building, a need to address severe fires involving the main turbine generator set may arise. In this case, additional guidance will be needed to completed the Phase 2 analysis. Guidance from either Regional or Headquarters fire protection staff should be sought in the treatment of these fires.

This particular case reflects world-wide plant fire experience (see NUREG/CR-6738 for a more complete discussion of these events). Several fires have been observed where a catastrophic failure of the main turbine generator set (e.g., a blade ejection event) has led to a large spill of turbine generator lube oil and/or hydrogen gas. Such fires are uniquely challenging. In at least one case, structural collapse of the turbine building was been observed within about 15 minutes of the initial failure.

Hydrogen Fires

Hydrogen fires may occur as the result of leakage from hydrogen tanks, hydrogen piping, and/or near a bearing/seal surface that contains hydrogen within process equipment (e.g., the turbine generator set or hydrogen recombiners).

If for a given fire area, hydrogen fires might be a significant factor in the risk quantification, additional guidance will be needed to completed the Phase 2 analysis. Guidance from either Regional or Headquarters fire protection staff should be sought in the treatment of these fires.