Module 5B – Phase 2 details continued

Steps 2.5-2.9

Step 2.5 – Fire growth and damage scenarios and 2nd check on SSD

- In this step the process of defining specific fire scenarios continues
  - Fire growth and damage scenarios are defined for each combination of a fire ignition source and FDS that we are retaining
- This step includes identification of scenario specific target sets
- Once fire growth and damage scenarios are defined, we re-assess survival of the designated safe shutdown path in context of each fire ignition source

Step 2.5 – Targets and Target sets

- We need to identify targets by both location and function
  - We want to know where important targets are with as much accuracy as possible
  - Don't start routing cables, but use information made available by licensee
- We are going to group individual targets into target sets
  - Sets correspond to fire ignition source/FDS combination

Step 2.5 – target sets (cont.)

- We would like to know what function is lost given failure of each target
  - If possible, tie specific targets to specific functions
- As a minimum it is sufficient to know what functions are lost given loss of the entire target set
  - In practice, this is how we use information
  - The greater level of detail is still good information to record as available

Step 2.5 – Target sets

- If location information is lacking or uncertain, targets are placed in worst plausible location
  - Lacking any other information, assume all target cables are in the tray right above the source
- Some rules of thumb may be applied
  - Power cables tend to be routed in upper trays
  - Control cables are often in lower or mid-level trays
  - Instrument cables usually in the lowest trays
- When uncertain, err towards conservatism, but use available information

Task 2.5.1 – Fire growth and damage scenarios

- Define fire growth and damage scenarios for each combination of an unscreened fire source and FDS
  - Define the fire ignition source
  - Define the applicable path for fire growth at each applicable FDS
  - Define the associated target set

Defining FDS1 Scenarios

Start with a fire ignition source and ask yourself:

- Q: Was this fire ignition source retained based on targets within the zone of influence?
  - If yes then we may have an FDS1 scenario to consider
- Or Q: Was this fire ignition source retained based only on potential for hot gas layer damage (not plume/radiant damage)?
  - If yes, then there will be no FDS1 for that source – might still have FDS2 or FDS3

Defining FDS1 scenarios

- FDS1 involves localized damage near the fire source
- Focus especially on vertical fire spread/damage
- Define logical path of fire spread if one exists
  - Allow fire to grow vertically (i.e. through a stack of cable trays or up a vertical cable riser)
  - Do not postulate substantial horizontal spread – that is for FDS2
- Note: we will cover specifics on cable fire spread rules in Module 6

Defining FDS1 scenarios

- FDS1 Target set can include any of the following:
  - Targets within zone of influence for radiant heating
    - The ball in the ball and column
  - Targets above the fire source
    - Targets within the column in the ball and column
    - Targets within the range of upward fire spread
      - e.g., Lowest tray in a stack may be within zone of influence, but target may be a tray ignited due to additional fire spread
  - Unprotected cables and components
  - Cable and components "protected" by a highly degraded localized fire barrier system
    - e.g. a non-functional or missing cable wrap

Defining FDS2 fire scenarios

Start with a fire ignition source:

- Define fire spread path if needed
  - If fire source alone is enough to cause damaging hot gas layer, then fire spread is moot – just worry about the source
  - If fire ignition source is not enough to cause hot gas layer damage without fire spreading, then you must postulate a path of fire spread
    - This time we allow for more extensive horizontal fire spread
    - Define the fire spread path
    - Define in particular, maximum extent of fire possible

Defining FDS2 scenarios (cont.)

- Define the fire damage target set
  - FDS2 involves widespread damage within the fire area
  - Look for HGL potential and timing
    - If HGL not reasonable or simply takes too long to be risk important (high likelihood of suppression), then FDS2 target set may be limited by extent of direct fire spread
    - If HGL is possible in reasonable time, any and all exposed cables and components anywhere in the room may be damaged
  - Note: anything damaged in the corresponding FDS1 scenario for the same fire source (if you developed one) is also included in the FDS2 target set

Defining FDS2 scenarios (cont.)

- Cables protected by a moderately degraded localized cable or component fire barrier element are also damaged in FDS2
  - These targets will likely drive the overall damage time
- Cables and components protected by a one-hour fire barrier wrap may be damaged in FDS2 even if wrap is not degraded
  - Recall - we did not credit a one-hour wrap alone in Step 2.1 as meeting independence criteria!
  - Any scenario that requires one hour is likely to be relatively low risk, so a "scoping" calculation may be appropriate:
    - Check product of manual non-suppression probability at one hour and refined fire frequency
  - If non-degraded automatic fire suppression system is present, don't chase these scenarios – they will be low risk
- Don't try to fail a non-degraded three hour wrap

Defining FDS3 fire scenarios

- The FDS3 scenarios depend a bit on what your finding is – two cases:
  - Finding is not fire confinement
  - Finding is fire confinement

FDS3 – Fire is not fire confinement

- The inspected area is always the exposing fire area, an adjacent area is the exposed area
- For this case, something in the fire area that you are inspecting is degraded, but it is not the fire area boundaries
- In developing FDS3 scenarios, we are presuming that a fire in the inspected compartment might be more likely to spread to an adjacent compartment
  - i.e., it might go unsuppressed for a longer time than one would normally expect

If you Step 2.2 didn't drop FDS3 you must have found:

- A somewhat weak barrier to at least one adjacent fire area
- Questionable or non-existent fixed suppression capability in exposing compartment
- Unique and exposed targets in at least one adjoining room
- The potential for fire that can directly challenge the fire barrier

It's not hard to develop a fire scenario out of that situation!

FDS3 – Finding is fire confinement

- In this case you have a degraded fire barrier between two fire areas
- Fire spreading through the degraded barrier IS the scenario
- Fire might go in either direction, so you may have two scenarios
  - Hopefully the screening question would eliminate fire in one direction or the other
  - e.g., if one fire area has a non-degraded fire sprinkler system, that should not be the exposing fire compartment

For both cases: Defining the FDS3 scenarios

- Focus only on fire getting through the barrier(s) that did not meet the screening rules
  - The degraded barrier or the one that didn't give at least 2 hours
  - If endurance rating is greater than 20 minutes, but less than 2 hours, your targets in the exposed room should be right near the barrier
  - If it's less than 20 minutes or barrier is degraded, could be anywhere
- Focus on the fire ignition sources that could challenge the fire barrier
  - High hazard
  - Near barrier
  - Direct path for fire spread through the barrier

Defining FDS3 scenarios (cont.)

- Again start with a fire ignition source
  - Pick the worst one an let it represent the whole set
  - You want one that can spread fire or fire effects into the adjacent area
    - If you applied the screening rules in step 2.2 correctly, then you should have verified at least one such source existed
- Characterize the conditions that lead to fire spread into the adjacent fire area
  - Fire spread along cable trays that penetrate the barrier is typical
  - If you have a high hazard fire source (e.g., oil-filled transformer or other large oil source), it could be a hot gas layer impacting both fire areas

Defining the FDS3 Scenarios

- Target set should be pretty obvious
- Minimum set:
  - Everything within reach of your fire source (zone of influence)
  - Everything in the path of fire spread
  - The unique targets in the exposed fire area
- Maximum:
  - Everything in both fire areas
- Use your judgment, pick a target set

Task 2.5.2 – Plant damage state

- For each fire growth and damage scenario determine what failure of the target set means in the context of plant safe shutdown response
  - What functions/systems are lost
  - What is the nature of the failure
    - loss of function, spurious operation, operable but with loss of indication….
  - What is function/system state given failure
    - System may be running
    - Valve may be open or closed…
- Recall – it is enough to know this answer for the set as a whole, but nice if you can tie functions to specific targets

Plant Damage State (cont.)

- Also define what survives
  - What functions/systems can be credited for safe shutdown
  - Assume systems are lost unless it can be verified with reasonable confidence that the system will survive
- Identify any manual actions needed to support safe shutdown
  - Focus on actions outside the main control room or complex actions within the main control room

Task 2.5.3 – Re-check SSD path

- In this task the independence of the designated SSD path is re-assessed based on the specific plant damage states
  - Plant damage state will define whether or not the SSD path is available – no more rules/questions needed
- You look at the worst case target set for each fire ignition source
  - If the SSD path survives in this worst case, the CCDP from Step 2.1 can be applied to all scenarios for that fire ignition source

Step 2.5.4 – Screening check

- In this Step, the SSD path is credited, or not credited, on a fire ignition source specific basis
  - The CCDP for each ignition source is either 1.0 or $CCDP_{2.1}$ depending on results of 2.5.3
- If the SSD path is lost for at least one fire scenario for each fire ignition source, then this step is skipped
  - You can only improve screening result if you are going to credit the SSD path for at least one fire ignition source
- If you decided earlier that $CCDP_{2.1}$ applied in general, then there is no benefit to be gained

Screening check:

$$\Delta CDF_{2.5} = DF \times \sum \{(F_{source})_i \times (CCDP_{2.1})_i\}$$

- Sum over all fire ignition sources (i=1 to n)

Table A1.8 - Phase 2, Screening Step 5 Quantitative Screening Criteria		
Assigned Finding Category (from Step 1.1):	**$\Delta CDF_{2.5}$ screening value**	
	Moderate Degradation	**High Degradation**
Fire Prevention and Administrative Controls	N/A	1E-6
Fixed Fire Protection Systems	1E-5	
Fire Confinement	1E-5[1]	
Localized Cable or Component Protection	1E-5[1]	
Post-fire SSD	1E-6	

[1] This entry applies to both 'Moderate A' and 'Moderate B' findings against a fire barrier.

Step 2.6: Damage time

- Analyze the fire growth and damage time for each fire scenario
- Separate “rules” for FDS1, 2, and 3
  - Task 2.6.1 – FDS1
  - Task 2.6.2 – FDS2
  - Task 2.6.3 – FDS3
- FDS1 and FDS2 require use of Fire Dynamics tools (plume, radiant, hot gas layer)
- Fire spread rules also apply

Task 2.6.1: FDS1

- If all elements of the target set are within the zone of influence then plume/radiant heating is enough – don't need fire spread
  - Calculate plume temperature or radiant flux level at target location
  - Pick damage time off the lookup table
- If target tray is outside the zone of influence, fire spread upwards through the cable tray stack is needed
  - Use the cable tray fire growth rules
  - Details in Attachment 3

Fire spread in a tray stack:

- If the first tray is within zone of influence it can be ignited and fire will spread
- Fire spreads according to the following rules:
  - Time to ignition of first tray: use plume temperature at height of tray and time to damage/ignition table
    - Call this t_1
    - Note: Early versions of guidance say use five minutes but this was an error and has been corrected in latest version
  - Second tray 4 minutes later (elapsed time t_1 + 4 min.)
  - Third tray 3 minutes later (elapsed time t_1 + 7 min.)
  - Fourth tray 2 minutes later (elapsed time t_1 + 9 min.)
  - Fifth tray 1 minute later (elapsed time t_1 + 10 min.)
  - Higher trays 1 minute later (elapsed time t_1 + 11 min.)
- Cables fail when the tray ignites

Task 2.6.2 – FDS2 damage time

- Begin with the corresponding FDS1 damage time if there is one for the fire ignition source
  - FDS2 can't be any faster
- Then you need to go after the hot gas layer, and consider time to damage for degraded raceway fire barriers

FDS2 damage time (cont.)

- Targets with no barrier protection are damaged based on exposure temperature and time to damage table
- If FDS2 target sets include cables or components within a moderately degraded local fire barrier system, add in the remaining performance time given the degradation to get total damage time

HGL Damage

Check the HGL temperature for the fire ignition source alone (using FDT) – if this is enough:

- If HGL temperature reaches the damage threshold in less than 30 minutes, then ignition source alone is enough to cause damage
  - You may have checked this during screening back in Step 2.4
- First check HGL temperature at 10 minutes
  - If this value exceeds the damage threshold, record the value, use the lookup table to get damage time at this temperature
  - Total damage time is 10 minutes plus time from lookup table
- If HGL temperature reaches damage threshold in greater than 10 minutes:
  - Damage time is time to reach damage threshold plus damage time from lookup table at the threshold temperature (e.g., 28 minutes)

HGL Damage (2)

If fire spread to cables is needed to get a damaging HGL process requires use of both FDT and the Cable Tray Fire Spread spreadsheets:

- FDT HGL tool: Determine HRR needed to get a damaging HGL in the room of interest
  - Input room parameters (dimensions, ventilation)
  - Adjust HRR for the fire
  - Look at HGL temperature at 10 minutes
  - Compare to damage threshold temperature
  - Iterate until HGL temperature equals or exceeds damage

HGL Damage (3)

- Fire ignition source contributes to total HRR, so we subtract that out from required HRR
  - The HRR difference needs to come from the cables
- Have to figure out time for fire to spread far enough to create a fire this big:
  - Cable trays are assumed to burn at 400 kW/m^2
  - We can calculate square feet of tray required to get fire size needed
  - Determine if there are enough trays in the area to get a fire this big
    - If no, then the FDS2 scenario is not credible
    - If yes, need to estimate time for fire to grow this far using cable tray fire spread rules
    - Spreadsheet provided for this case

HGL Damage (4)

- If there are enough trays, use the Cable Tray spreadsheet:
  - Calculate time to ignition of first tray
    - Using plume temperature at tray and damage time lookup table (as in a FDS1 scenario)
  - Spreadsheet Input: total HRR needed, ignition source HRR, time to ignition of first tray, characteristics of cable trays
  - Manipulate "time of interest" until damaging HGL is indicated
- That puts us at the damage threshold
  - Assume pre-heating of the exposed cables during time of fire growth so no additional time to damage
  - Time to develop damaging HGL is take as time to damage exposed cables for fire propagation scenarios
  - Fire barrier wrapped cables get additional time – ½ nominal fire barrier rating (after applying penalty for any degradation)

HGL Damage (5)

- Don't try to get too fine an answer:
  - HRR steps of 50 kW
  - Time steps of integer minutes

Task 2.6.3: FDS3 Scenarios

- If you have a highly degraded fire barrier as the finding, combine the two areas and treat just like FDS2
  - Inter-area barrier gets no credit
  - Credit only one fire suppression system if more than one exist (i.e. you might have had some coverage in both rooms

Task 2.6.3 – FDS3 (cont.)

- If you have a moderate degraded barrier or a finding that is not fire confinement
  - Use one scenario to estimate time for direct fire spread to and through the fire barrier
    - Estimate time for fire to spread to the barrier
  - Use one scenario (same or other) to try to get a damaging hot gas layer
    - Use FDS2 approach to estimate time to reach a damaging hot gas layer in the exposing fire area
  - Pick the shorter time from these two cases to represent all FDS3 fires
    - This is the fire growth time

Task 2.6.3 – FDS3 (cont.)

- Moderate degradation fire confinement or non-confinement finding (cont.)
  - Add in the fire endurance time allowed for the degraded barrier (e.g., 65% or 35% of nominal if barrier is degraded or full credit if not)
  - If targets in exposed fire area have raceway fire barrier protection, add in the fire endurance rating of this protection

Total fire damage time = (fire growth time) + (endurance of degraded barrier) + (endurance of raceway barriers is present in exposed compartment)

Step 2.7 – PNS analysis

- This step estimates the probability that suppression fails in the time available before our target set is damaged
- Credit is given to both fixed fire suppression and manual fire suppression
- For the fire brigade, we also need the detection time
  - Detection activates the human response including the fire fighting response

Task 2.7.1 – Fire detection time

Detection time is a race – shortest time wins:

- Fixed fire detection is estimated using FDT spreadsheet
- Other means of detection
  - Continuous fire watch – $t_{detection} = 0$
  - Roving fire watch – $t_{detection}$ = ½ repeat time
  - General plant personnel:
    - $t_{detection}$ = 5 minutes if continuously manned
    - $t_{detection}$ = 15 if not manned
  - Maximum detection time is 15 minutes

Task 2.7.2 – Fixed fire suppression

- Activation of a fixed fire suppression system that is considered effective against the fire ignition source is assumed to end the fire scenario
  - Inspector decides on effectiveness
  - Timing needs to be determined
- Skip this task is no fixed suppression of installed system is highly degraded

Fixed suppression (cont)

- Use the fire detector tool in FDT to estimate actuation time
  - Sprinkler head is just a fancy heat detector
- Watch for cross-zoned actuation logic
  - Common for auto gas systems and deluge
  - Need to ensure both zones actuate so analyze the detector that is farthest from the fire source
- Add discharge delay time for gaseous systems
  - Minimum of 30 seconds, 1-2 minutes is typical

Fixed suppression (cont)

- If the suppression system is moderately degraded:
  - If issue is head spacing – model as found
  - If some subset of discharge heads are degraded then assume nearest head won't work, second closest head is modeled
  - If system does not provide adequate coverage to some fire ignition sources, credit only for those source that are covered

Fixed suppression (cont)

- If fixed system is manually actuated
  - Estimate the fire brigade response time
  - If fire brigade members have full decision making authority to actuate system, allow additional 2 minutes for assessment and decision making process
  - If fire brigade must get authorization (e.g., from MCR, shift supervisor, plant manager) you must assess the time required for such authorization
  - Don't forget delay time for gaseous system discharge applies even when manually actuated

Task 2.7.1 – PNS_{fixed}

- Now that you have a time to actuation and a time to damage the two are weighed to assess the value of PNS_{fixed}
  - Take the difference:
    - t_{damage} - t_{supp_fixed}
  - Refer to lookup table for PNS
- Point is that both values have uncertainty
  - If difference is small, we don't allow as much credit as when difference is large

The PNS_{fixed} lookup table

Probability of Non-suppression for Fixed Fire Suppression Systems Based on the Absolute Difference Between Damage Time and Suppression Time	
Time Delta: (t_{Damage} - $t_{Suppress}$)	**PNS_{Fixed}**
Negative Time up to 1 Minute	1.0
> 1 Minute to 2 Minutes	.95
> 2 Minutes to 4 Minutes	.80
> 4 Minutes to 6 Minutes	.5
> 6 Minutes to 8 Minutes	.25
> 8 Minutes to 10 Minutes	.1
> 10 Minutes	0.0

Task 2.7.2 – Manual suppression

- Manual suppression is based on fire duration curves
  - Analysis of historical event
  - Based on total fire duration so we don't do brigade response time – built into curves
- Several curves for various fire ignition sources
  - Pick the curve that fits you ignition source
  - Example: If fire spreads from a panel to cable trays, the ignition source was the panel, use the electrical fire curve

Manual suppression

- "Curves" are available in three forms
  - Graphical
  - Lookup table
  - Equation:

$$PNS_{manual} = \exp[-\lambda \times t]$$

  - Values of constant are in lookup table

Task 2.7.4: Final combined PNS

For water-based systems:

$$PNS_{scenario} = (0.98 \times PNS_{fixed\text{-}scenario}) + (0.02 \times PNS_{manual\text{-}scenario})$$

For Gaseous systems:

$$PNS_{scenario} = (0.95 \times PNS_{fixed\text{-}scenario}) + (0.05 \times PNS_{manual\text{-}scenario})$$

** $PNS_{scenario} \geq PNS_{manual\text{-}scenario}$

And the Degraded Gaseous system – inadequate soak time case

$$PNS_{scenario} = 0.95 \times (1 - PNS_{fixed}) \times PNS_{gas\_manual}$$

$$+ [(0.95 \times PNS_{fixed}) + 0.05] \times PNS_{manual}$$

Step 2.7.5 – screening check

- We now have scenario specific PNS
- Combine with duration factor, scenario specific frequency, scenario specific credit for SSD path to get new screening result
- Screen to green if change in CDF is less than 1E-6

Step 2.8 – SSD / CCDP analysis

- I won't go into detail
  - Task 2.8.1 – select plant initiating event worksheet
  - Task 2.8.2 – identify credited systems and functions
  - Task 2.8.3 – identify ex-control room actions
  - Task 2.8.4 – assess failure probability for manual actions
  - Task 2.8.5 – assess CCDP

Step 2.9 – final quantification

- In this step you take all your best information that now includes a specific CCDP for each individual scenario
- Run them through the risk equation
- Sum scenarios
- Assign a preliminary color