Module 2: Concepts and Terminology

Concepts and Terminology

- Objectives:
  - Outline the basic quantification process used in fire risk analysis
  - Define the factors that go into quantification
  - Define key terms
  - Along the way, I’ll point out some “red flag” issues

Why?

- Why spend time here? Why not jump right into the SDP process?
  - The new SDP structure is the same as that used in a general fire PRA
    - If you understand this basis, life will be much easier
  - Lots of unique terminology
    - Meanings need to be clear
  - Allows us to look at the technical quantification process separate from the SDP regulatory decision making process

Risk

- Risk combines the likelihood that something undesirable will happen with the severity of resulting consequences
- In context of NRC mission, risk is most correctly measured based on potential public health consequence:
  - Atomic energy act empowers NRC to establish and enforce standards governing the commercial use of nuclear materials and facilities as "the Commission may deem necessary or desirable in order to protect health and safety and minimize danger to life or property."
- That implies risk measures such as LERF and latent cancer
- Primary measure of fire risk is Core Damage Frequency (CDF)
  - CDF is a surrogate for public health consequence risk
  - We won't do fire-induced LERF for fire protection SDP

How we estimate CDF

- We calculate CDF using four basic factors:
  - Fire Frequency (F)
  - Severity Factor (SF)
  - Probability of Non-Suppression (PNS)
  - Conditional Core Damage Probability (CCDP)

- Note that SF is often folded in as a part of 'F' or 'PNS' depending on analyst preference – we'll call it out explicitly

How we estimate fire risk (cont.)

- For one fire scenario:

  $CDF_i = F_i * SF_i * PNS_i * CCDP_i$

- We do as many fire scenarios as we need to, add them up (carefully), and that is our risk estimate
- We can roll-up risk values at different levels:
  - One fire scenario
  - One fire ignition source – multiple scenarios
  - One fire area – multiple ignition sources
  - One building – multiple fire areas
  - Entire unit
  - Entire plant site

How we estimate fire risk (cont.)

- SDP focuses on fire area roll-up
  - Question: what is the risk impact of a specific performance deficiency?
  - Deficiency is assumed to be tied to one or two fire areas
  - We estimate risk for the impacted area(s)
- Remember that some issues cut across fire areas – examples:
  - Post-fire manual actions
  - Manual fire brigade
  - Circuit analysis issues
- We don't do the cross-cutting issues (yet)
  - You have to tie your finding to one or more fire areas
  - No guidance for picking areas for a cross-cutting issue

Fire Frequency (F):

- Definition: The likelihood that a fire will occur during some time period
  - Time period is generally 12 months of at-power reactor operations
    - one reactor year (ry)
- Calculated based on past experience
  - A bunch of statistics that we won't go into
  - Database we use contains nearly 1500 reported "fires"
    - EPRI Fire Event Database updated through 2002
  - Industry average capacity factors are factored in
- General units of measure:
  - fires / ry

Pop quiz – Who is this?

Fire Frequency (cont.)

- You often hear that not all events reported as a fire hold the potential to challenge nuclear safety – TRUE!
  - We took care of this for you
  - Events were "screened out" if there was no potential for a safety challenge
  - The values provided for SDP should not be adjusted beyond the instructions provided – leave that to Phase 3
  - In the end, we retain about ½ of the fire "events" as potentially challenging
    - Actual percentage retained depends on nature of fire source

Event screening

- Sounds easy, but you can really cause problems if you're not careful
- Important to maintain independence
  - Other steps in analysis take credit for things you might be "counting" when you screen the events
  - Basic assumptions tend to flow from the "event set" you choose as representing your fire frequency
- Be skeptical when someone argues that particular events are not relevant to fire risk
  - They may be right, but their basis for rejecting an event cannot align with another factor credited elsewhere

Fire Frequency (cont.)

- Statistics give us the frequency of a fire somewhere, or involving something, in the plant
  - May be a for a location or fire ignition source
  - We assume this number is the same for all plants
- What we want is the frequency for a fire involving a specific ignition source in a specific location
  - For most cases, component based fire frequencies do this directly – e.g., you get frequency for one motor
  - In some cases we apply a partitioning factor to reflect a critical location out of all possible locations
    - Area ratio factors – e.g., transients, welding
    - Linear feet ratio factors – e.g., cable trays, control room panels

If we need a room fire frequency

- We can use a generic fire area fire frequency based on average industry experience for similar fire areas
  - SDP through step 2.3

OR

- We can add up the contribution from all the individual sources in that particular fire area
  - SDP beginning with Step 2.4
- Don't expect to get the same answer either way
  - For SDP, the generic values are intended to be slightly conservative – especially in Phase 1
  - This won't be a universal truth, but differences should not be significant

Grouping fire ignition sources

- You can group some individual ignitions sources, and treat the group rather than each individual
  - Common example is electrical cabinets/panels
  - Want all member of the group to be “the same”
    - fire characteristics, proximity to targets for ignition and damage
- Frequency for the group is the sum of the frequency of each individual member
  - If 10 panels, fire frequency = 10 times frequency for a single panel
- More on grouping later

Severity Factor (SF)

- General Definition: A value between 0 and 1 reflecting the fraction of all fires that are considered threatening in the context of a specific fire scenario

Severity Factors (cont.)

- SDP approach ties SF to fire intensity
  - Current PRA practice, but not same as typical IPEEE
- Why:
  - Burn an electrical panel 10 times, and you'll probably get 11 different burn profiles
  - That reflects fact that fire intensity profile is inherently uncertain
    - All things being equal, still some fires will remain small, some will get big
  - If it takes a big fire to cause problems (and it usually does) we reflect this through the severity factor

Severity Factors (cont.)

- SDP Definition: SF = the fraction of fires big enough to cause damage to at least one potential target and/or spread fire to secondary combustibles
  - We calculate "big enough" on a case-specific basis
    - How big is the fire (HRR)
    - How close are the targets
  - We use two HRR values for each fire ignition source
    - Lower HRR represents 90% of all fires – SF = 0.9
    - Larger HRR represents worst 10% of fires – SF = 0.1
  - In effect we split each fire ignition source into two possible fires – one big and one not so big
  - If only the larger HRR leads to spread/damage, we end up with a net severity factor – SF = 0.1

Illustration of SF Concept:

- Even looking at a single fire ignition source, not all fires will be the same some will be big, some not so big
- Fire Intensity or heat release rate (HRR) is not a point value!
- We treat this characteristic (peak HRR) as uncertain; i.e., as a distribution

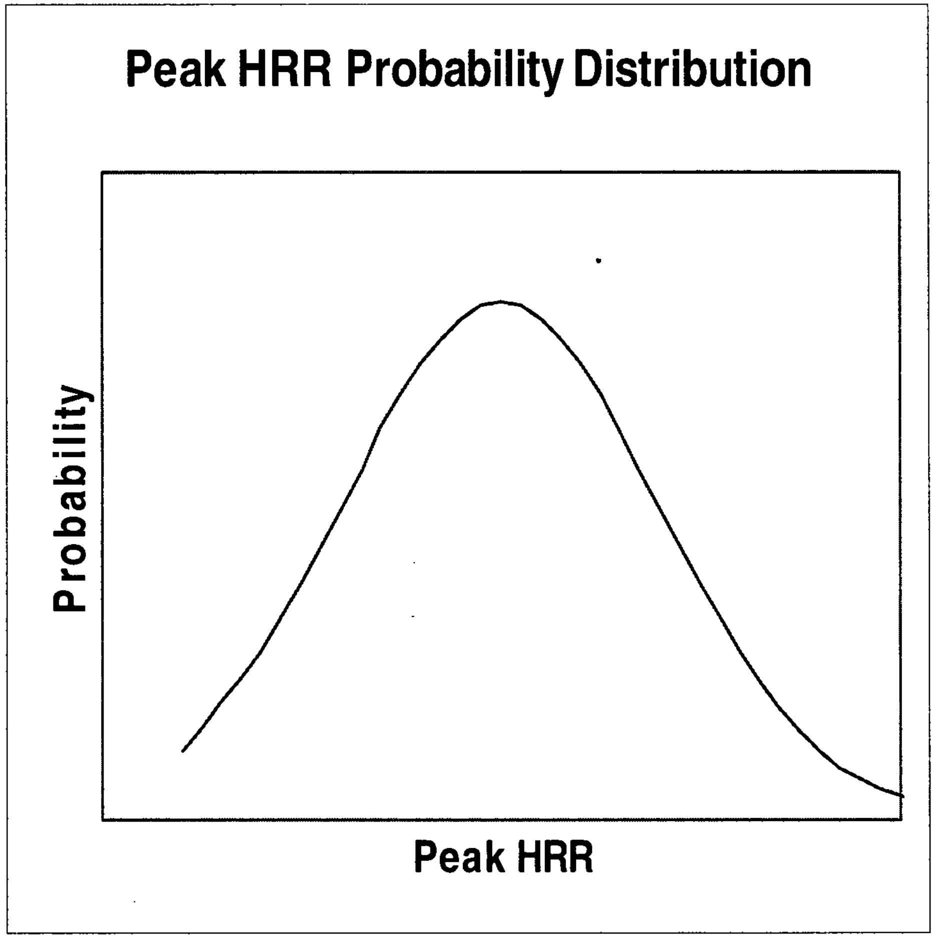


Illustration of SF Concept (cont):

- We look for the smallest fire leading to fire damage and/or spread
- Fires that large or larger are the "risky" ones
- We tie SF to the fraction of fires that large or larger

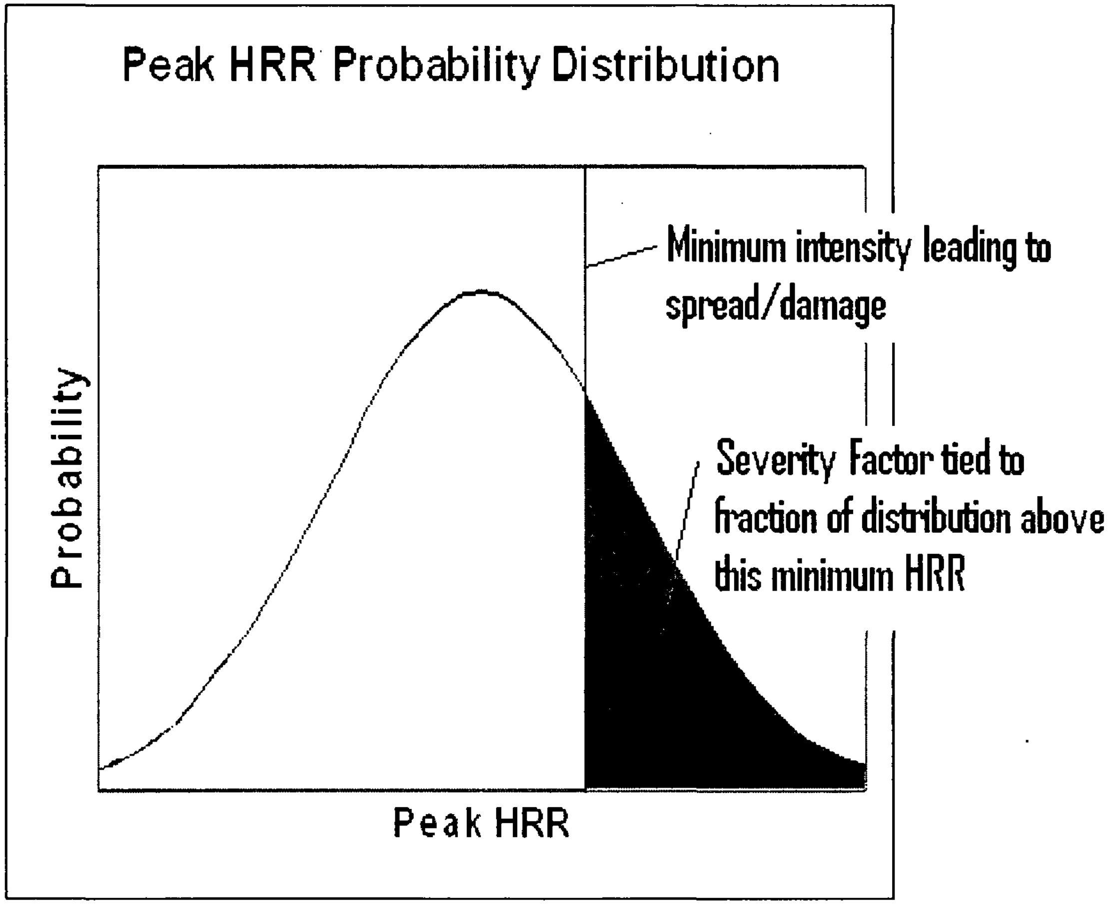
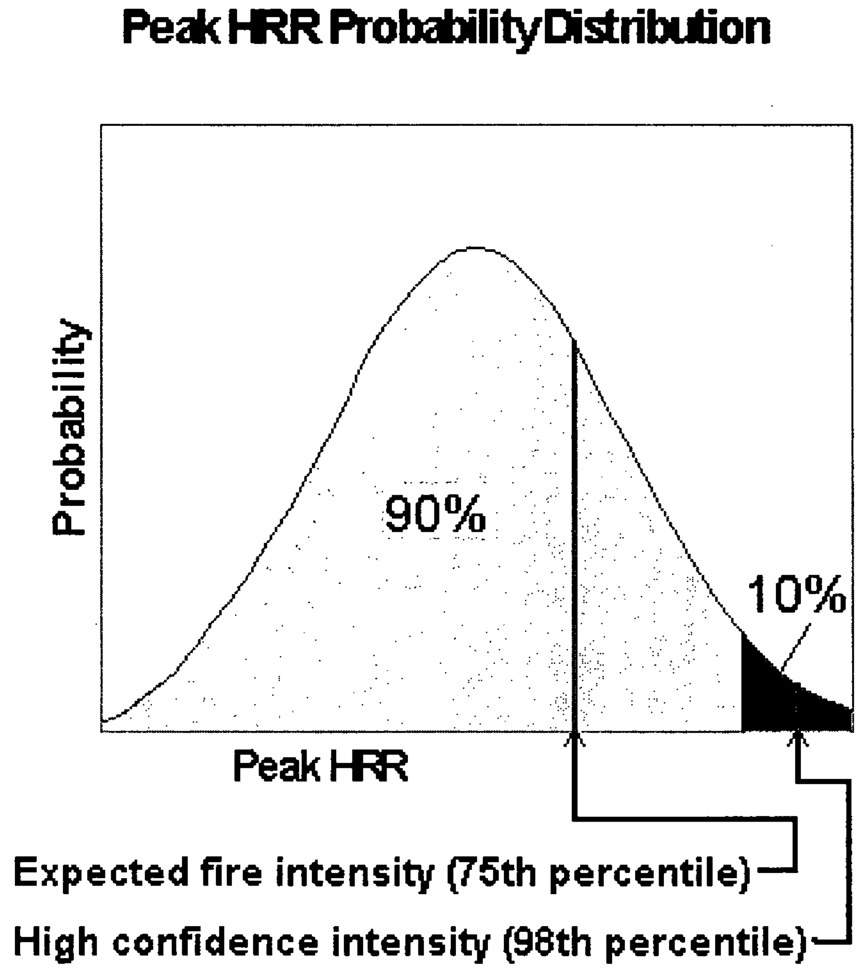


Illustration of SF Concept - SDP

- For SDP we use a simplified version
- Two fire HRR values for each fire ignition source
  - Expected value represents 90% of fires
  - High confidence value represents 10% of fire



SDP approach – quick review

- SDP using simplified version of same approach
  - Two fire intensity (HRR) values used represent the full distribution for each fire ignition source
    - 'Expected' and 'High Confidence' <u>or</u> 50% and 95% <u>or</u> 75% and 98%
    - Words/numbers not important – it's the concept that counts
    - Assigned SF of 0.9 and 0.1 respectively
  - You assess the spread/damage potential for these two HRR values
  - The final risk results combine these two cases using SF as, in effect, a weighting factor
  - Net severity factor depends on whether each intensity value causes damage

Severity factors (cont.)

- How we got to SDP HRR values
  - Discrete HRR values were suggested based on Requantification Study
  - Review and discussion by SDP fire scenario team including NRC and Industry reps. – an expert panel
  - Final values ultimately accepted for SDP
  - Some adjustments made in Requantification Study approach to reflect SDP team/panel input

Severity Factor – Red Flag Issue

- One of the most widely and easily abused aspects of fire PRA
  - You can quote me – that's my professional view
  - Some cases of abusive application were seen in the IPEEEs, so take care when someone cites those to you
- You'll see severity factors crediting:
  - Prompt suppression, self-extinguished fires, fires that caused no trip, fires that did not spread, fires that did not damage secondary components, fires in non-vital areas, and … the kitchen sink

Severity Factors (summary)

- Before you buy, remember the three “D”’s of PRA:
  - Dependency, dependency, dependency
  - The same factors may be accounted for elsewhere in the PRA – either implicitly or explicitly
  - When you see the use of one (or heaven forbid more than one) severity factor in quantification you have to ask if they are double counting somewhere

Probability of Non-Suppression

- Definition: PNS - The conditional probability that, *given the fire*, the fire will not be suppressed prior to the failure of a specific set of damage targets
  - Key 1: Specific to a particular fire ignition source scenario
    - May be a grouped set of fire ignition sources
  - Key 2: Specific to a particular targets set
  - PNS reflects the probability that given the fire, these targets will fail

Target Set

- A collection of components and/or cables that are <u>assumed</u> to be threatened give the postulated fire
  - This could be anything from one cable to everything in the fire area

Target Sets (cont.)

- The target set either survives or fails as a whole
  - If you need to break down a target set, you really need to define more than one target set
- Target sets can be progressive if needed – one set represents expansion of another smaller set:
    - Target Set 1 = {item 1}
    - Target Set 2 = {items 1,2,3} …
    - Helpful if two trains are threatened but separated (for example)
- Different fire ignition sources may have the same target set(s) or different target set(s)

Target Sets (cont.)

- For any one fire ignition source:
  - Most often one target set is enough
  - You may define a series of expanding target sets reflecting growth and spread of the fire
  - Don't go overboard – one, two, or at most three, should handle most situations

Target Sets (cont.)

We'll come back to this a bit later, but…

- Poor cable routing data actually makes this step easier
  - If you don't know where specific cables are, you basically have to assume the worst
- Good cable routing data can actually complicate the choice
  - You may be tempted to define many target sets as each tray becomes involved – don't – keep it simple

Back to PNS…

- PNS is a 'probabilistic' horse race: time to damage versus time to suppression
- Time to damage depends on:
  - How close targets are to the fire
  - Target failure threshold
  - How big the fire is
  - Possibly: How quickly fire spreads
- The plant's chances of putting the fire out within this time depends on:
  - What sort of fixed fire suppression capability is available
  - Timing of manual fire response (e.g., the brigade)

Time to Damage

- We can predict time to damage in three steps:
  - Set the damage threshold
    - Usually cables
    - Thermoset or thermoplastic
  - Predict the exposure conditions
    - Plume, direct radiant heating, or hot gas layer
    - Estimate temperature or heat flux at target location using Fire Dynamics Tool (FDT)
  - Convert exposure condition to damage time
    - SDP uses a look-up tables

Cables insulation/jacket types

- Thermoplastic
  - Melt if heated, solidify if cooled,
  - Drip and burn as a liquid pool
  - More wimpy
  - Examples:
    - Polyethylene (PE)
    - Polyvinylchloride (PVC)
- Thermoset
  - Don't melt
  - Burn/char in place if heated enough
  - More macho
  - Examples:
    - Cross-linked polyethylene (XLPE or XPE)
    - Ethylene-Propylene rubber (EPR)

Damage Thresholds

Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables

Cable Type: Thermoplastic	(Metric)	(English)
Radiant Heating:	6 kW/m^2	0.5 $BTU/ft^2 s$
Temperature:	205°C	400°F

Cable type: Thermoset	(Metric)	(English)
Radiant heating:	11 kW/m^2	1.0 $BTU/ft^2 s$
Temperature:	330°C	625°F

Damage Time (example*)

*check for updated damage time tables

Failure Time-Temperature Relationship for Thermoset Cables

Exposure Temperature		Time to Failure (minutes)
°C	°F	
330	625	28
350	660	13
370	700	9
390	735	7
410	770	5
430	805	4
450	840	3
470	880	2
490 (or greater)	915 (or greater)	1

Automatic suppression time

- We can predict the time to actuation for an automatic suppression system using a simple spreadsheet tool
  - e.g., a sprinkler head looks just like a heat detector
  - Fire Dynamics Tool (FDT) from NRR
- That give us a number
  - x:x minutes:seconds

PNS and auto suppression

- We don't want to do a straight yes/no comparison between damage time and suppression time – this can be very misleading
  - Damage time = 10 min
  - Suppression time = 9 min, 30 sec.
  - Nominally suppression wins, but what is your confidence in this answer
    - is it really yes/no or fail/no fail
  - We look at the margin between damage time and suppression time

Probability table

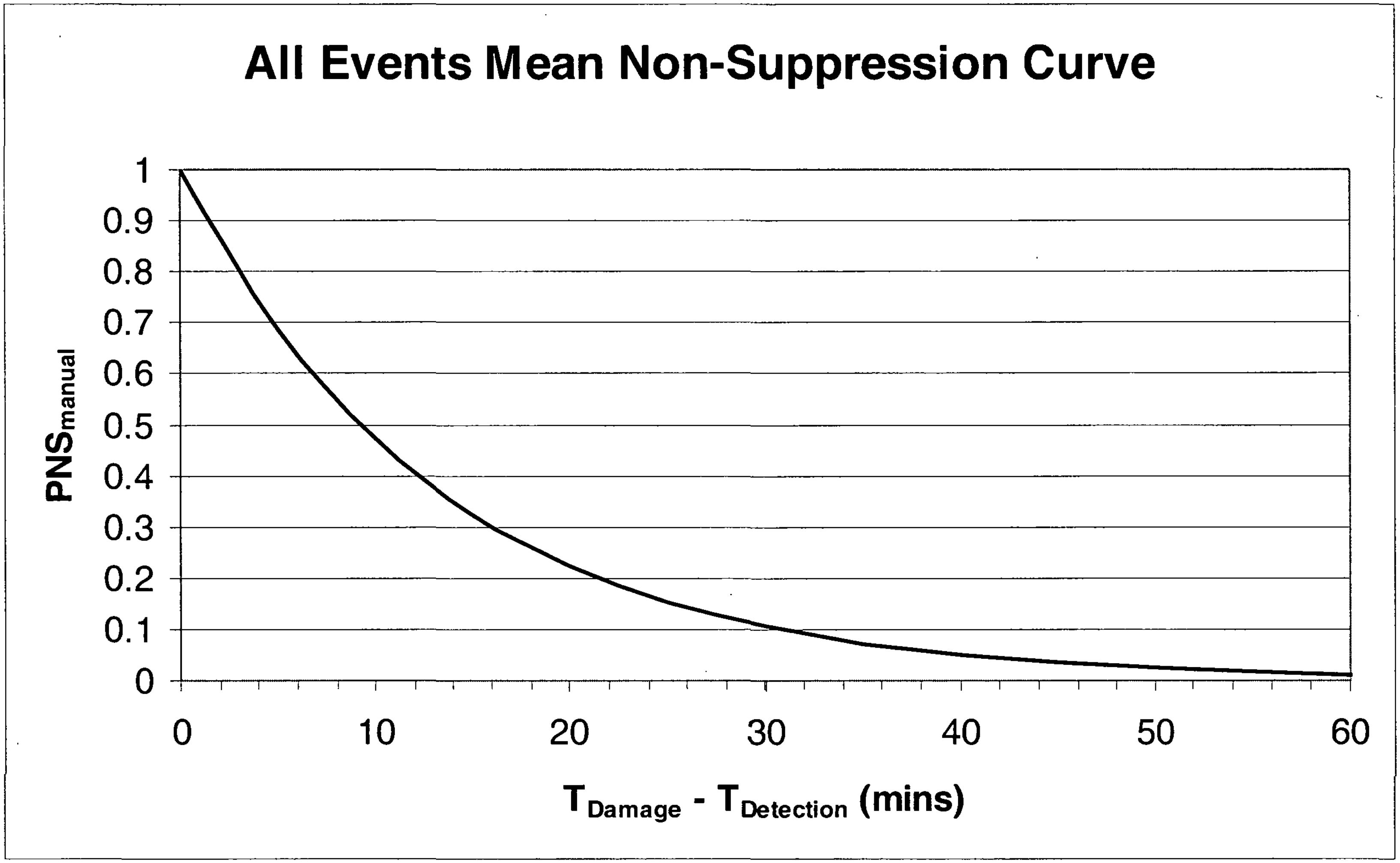
Probability of Non-suppression for Fixed Fire Suppression Systems Based on the Absolute Difference Between Damage Time and Suppression Time

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

PNS and Manual Suppression

- PNS for Manual suppression relies on historical fire duration curves
  - The vast majority of fires are manually suppressed
  - We get fire duration data for enough of the reported fires to develop a fire duration curve
- Pick the appropriate duration curve
- Calculate $(t_{damage} - t_{detection})$
  - Remember that detection triggers manual response, but damage time measured from time of ignition ($t = 0$)
- Pick off PNS_{manual}
  - Values also available in a lookup table

Duration curve example:



Auto vs. Manual

- If auto is present, we assume it will be primary suppression means
- If auto fails, manual is always the backup
  - We assume that a water based automatic suppression system will fail on demand 2% of the time
  - Gaseous systems – 5%
- If no auto system, then manual is all there is

Manual fixed systems

- Fixed fire suppression systems that have no automatic actuation mechanism – human action is required
- No hard/fast rule possible – use following:
  - Estimate detection time
  - Estimate physical response time
  - Review decision criteria and estimate decision making time
    - nominal value is 2 minutes
    - increase if circumstances warrant
  - Actuation time is sum of these three

Combining manual/auto

- Again, if fixed system is present, it is assumed first line of defense
- Auto systems don't always work:
  - Water based system ~2% failure on demand
  - Gaseous systems ~5% failure on demand
- Nominally reflects both reliability and availability
- Manual is always available as a backup

Combining manual/auto (cont.)

For Water-based systems:

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

For Dry-pipe and Gaseous systems:

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

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

Special consideration for degraded gaseous system

- If a gaseous suppression system cannot maintain adequate concentration for a sufficient time to assure fire extinguishment, then manual fire fighting <u>must</u> do the final mop-up
  - The gaseous system cannot put out the fire, but does buy the fire brigade some additional response time
  - We assume that the fire will be held in check during the time that the fire suppressant concentration is maintained at design level
  - Upon dissipation of suppressant fire will re-flash – we assume it will pick up right where it left off

Degraded gaseous systems (cont.)

- To get PNS_{fixed} we need to compare damage time to a suppression time-line with the following elements:
  - Actuation time for gaseous system (manual or automatic as normally analyzed)
  - The probability table that reflects our confidence that system actuation is timely compared to fire damage time
  - Hold time / soak time for design concentration that system can deliver
  - Manual response following loss of concentration

Degraded gaseous system PNS analysis approach

First we calculate a PNS for manual response as if gaseous system was not in place (or was to fail):

- Select the appropriate fire duration curve
- Estimate fire detection time in the usual manner
  - Assume a valid actuation signal on gaseous system will trigger a fire detection signal as well
- Calculate t_{damage}-$t_{detection}$
- Estimate PNS_{manual} in the usual manner

Degraded gaseous approach (cont.)

Next we look at timeliness of the system discharge:

- Estimate discharge/actuation time ($t_{suppress}$) as you would for any fixed system
  - Could be automatic or manual actuation of fixed system
- Calculate the time margin ("Time Delta") between the actuation time and fire damage time in the normal manner
  - Time Delta = (t_{damage} - $t_{suppress}$)
- Use the general PNS_{fixed} probability table (pg. 9-7) to assess our confidence that suppression system actuation is timely in comparison to the estimated fire damage time.

Degraded gaseous approach (cont.)

Based on PNS_{fixed} we decide if we will be crediting the gaseous system at all:

- If the PNS_{fixed} value assigned is 1.0, then the gaseous system will not be credited.
  - Use $PNS_{scenario} = PNS_{manual}$
  - Analysis is complete.
- If the PNS_{fixed} value is less than 1.0, then the gaseous system will be credited.
  - Continue this analysis to estimate $PNS_{scenario}$.

Degraded gaseous approach (cont.)

Now we do the case where the system buys some added time for fire brigade response:

- Calculate a modified fire damage time as follows:

  $t_{damage\_new} = t_{damage} + t_{maintain\_gas}$

  where $t_{maintain\_gas}$ is the time suppressant concentration can be maintained.

- Calculate modified time available for manual suppression:

  $[t_{damage\_new} - t_{detection}]$

- Estimate PNS_{gas_manual} in the manner normally applied to PNS_{manual}
  - Use the fire duration curve with the modified time available

Degraded gaseous approach (cont.)

To get final $PNS_{scenario}$ we now need to combine three cases:

- Case 1: Suppression system works (0.95 - no random failure), the actuation is timely (1- PNS_{fixed}), and fire brigade responds with extra time available (PNS_{gas_manual})
- Case 2: Suppression system works (95% - no random failure), but discharge of the fire suppression system is not timely (PNS_{fixed}), manual brigade must respond within original fire damage time (no extra time available – PNS_{manual})
- Case 3: Gaseous suppression system suffers random failure on demand (0.05), fire brigade must respond within the originally estimated fire damage time (PNS_{manual})

Degraded gaseous approach (cont.)

- And the final equation is…

$$PNS_{scenario} = 0.95 \times (1 - PNS_{fixed}) \times PNS_{gas\_manual} + [(0.95 \times PNS_{fixed}) + 0.05] \times PNS_{manual}$$

- Verify that ($PNS_{scenario} \geq PNS_{manual}$)
  - As in other cases, the manual brigade response given the original fire damage time the minimum credit given to fire suppression for any scenario
  - If ($PNS_{scenario} < PNS_{manual}$) reset ($PNS_{scenario} = PNS_{manual}$)

Conditional Core Damage Probability (CCDP)

- Definition: The conditional probability that, *given fire-induced loss of a target set*, safe shutdown efforts will fail to achieve a safe and stable state thus resulting in some core damage
  - Safe and stable generally means hot shutdown
  - Risk analyses don't generally look at ability to achieve cold shutdown

CCDP (cont.)

- CCDP is calculated using a post-fire safe shutdown plant response model
  - Screening estimates may only credit the designated post-fire safe shutdown path
  - For more detail, we use a broader plant response model that may credit components and systems beyond Appendix R
  - SDP uses the plant notebooks

CCDP (cont.)

- We won't go into depth on this topic, but some high level rules:
  - To credit a system or function, you must have reasonable assurance that it will not be damaged by the fire - your judgment counts
  - We do credit manual actions – guidance is provided – but complex sets of actions will likely get little credit in Phase 2
  - Spurious operations may be a part of CCDP calculation – you may need help here

That's pretty much it.

$$CDF_i = F_i * SF_i * PNS_i * CCDP_i$$

Of course, the devil's in the details…