Module III – Fire Analysis

Task 6 – Fire Ignition Frequency

Joint EPRI/NRC-RES Fire PRA Workshop

August 21-25, 2017

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

Fire Ignition Frequencies
Purpose of Task 6 per NUREG/CR-6850 / EPRI 1011989

- Task 6 establishes fire source ignition frequencies
  - How often do we expect to see a particular type of fire or a fire in a particular location?
- Just for reference – what sort of numbers are we talking about?
  - Plant-wide frequency for <u>all</u> fire sources is *roughly**

    0.2 fire events per year (or 2.0E-1/yr)

  - That is *roughly** one fire somewhere in the plant every 5 years
  - Most of these fires are small, quickly suppressed, and cause no damage beyond the ignition source
  - We are still interested in these events because we'll ask the risk question:

    "What would happen if a similar fire occurs that is not quickly suppressed and/or in a critical location more sensitive to fire damage?"

*Emphasis on *roughly* - *t*his is an illustrative discussion only. The actual plant wide fire frequency depends on which source you use. The original 6850/1011989 value was 2.89E-1/ry. We'll talk about these topics as we continue…

Corresponding PRA Standard Element

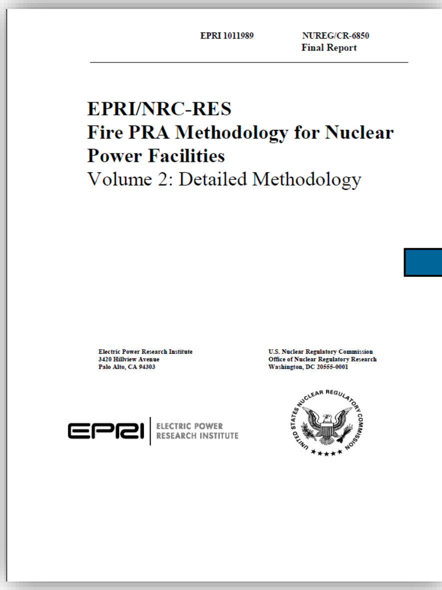
- Task 6 maps to element IGN – Ignition Frequency
  - IGN Objectives (per the PRA Standard):
    - Establish the plant wide frequency of fires of various types on a generic basis for NPPs
    - Tailor the generic fire frequency values to reflect a particular plant
    - Apportion fire frequencies to specific physical analysis units, and/or fire scenarios

IGN HLRs (per the PRA Standard)

- HLR IGN-A: The Fire PRA shall develop fire ignition frequencies for every physical analysis unit that has not been qualitatively screened (10 SRs)

- HLR IGN-B: The fire PRA shall document the fire frequency estimation in a manner that facilitates Fire PRA applications, upgrades, and peer review (5 SRs)

Fire Ignition Frequency Evolution



EPRI 1011989 NUREG/CR-6850
Final Report

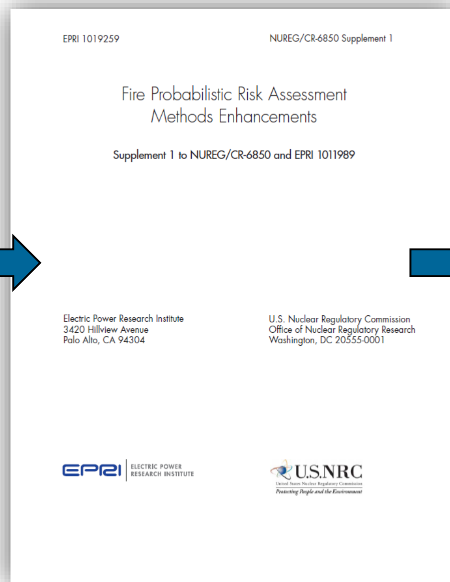
EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 2: Detailed Methodology

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94303

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

NUREG/CR-6850 and EPRI 1011989

Original methodology and frequencies



EPRI 1019259 NUREG/CR-6850 Supplement 1

Fire Probabilistic Risk Assessment Methods Enhancements

Supplement 1 to NUREG/CR-6850 and EPRI 1011989

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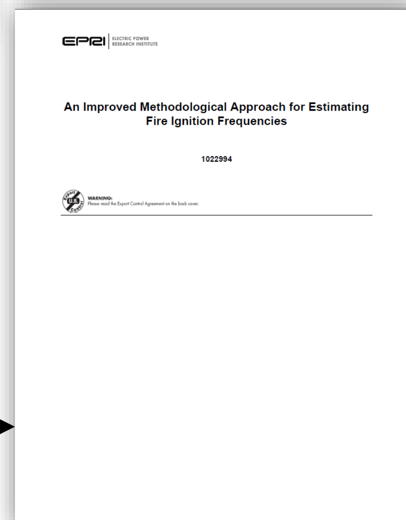
NUREG/CR-6850 S. 1 and EPRI 1019259

Updated counting guidance and updated frequencies from FAQ process

The Updated Fire Events Database: Description of Content and Fire Event Classification Guidance

2013 TECHNICAL REPORT

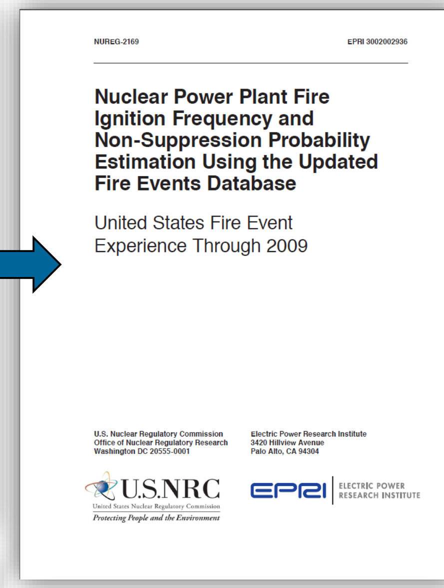


An Improved Methodological Approach for Estimating Fire Ignition Frequencies

1022994

EPRI 1022994 and EPRI 1025284

Improved fire frequency calculation methodology and fire event collection and classification through 2009.



NUREG-2169 EPRI 3002002936

Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database

United States Fire Event Experience Through 2009

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington DC 20555-0001

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304

NUREG-2169 and EPRI 3002002936

Updated methodology with additional decade of data event data. Most recent fire frequencies for at-power and LPSD.

Summary of Available Reference Material

- ***NUREG/CR-6850 / EPRI 1011989***
  - Overall methodology
  - General bin descriptions
- ***Supplement 1***
  - Chapter 3: *Ignition source counting guidance for electrical cabinets* **FAQ 06-0016**
  - Chapter 4: *Ignition source counting guidance for high-energy arcing faults (HEAFS)* **FAQ 06-0017**
  - Chapter 5: *Ignition source counting guidance for main control board (MCB)* **FAQ 06-0018**
  - Chapter 6: *Miscellaneous fire ignition frequency binning issues* **FAQ 07-0031**
  - Chapter 7: *Bus duct (counting) guidance for high energy arcing faults* **FAQ 07-0035**
  - Chapter 10: *Fire ignition frequency* **FAQ 08-0048**
- ***NUREG-2169 / EPRI 3002002936***
  - Updated fire ignition frequencies through 2009
- ***Recent FAQs***
  - **FAQ 12-0064** *Hot work/transient fire frequency: influencing factors*
  - **FAQ 14-0008** *Main control board treatment (counting)*

Fire Ignition Frequencies
High level summary

- General approach
  - Fire event data
  - Sources of data
  - Types of ignition sources
- Task 6 procedure
  - Step by step
  - Counting example

Fire Ignition Frequencies
A note on terminology

- We have noted that different documents use different terms for the physical plant partitions used in fire PRA
  - NUREG/CR-6850 / 1011989 refers to "fire compartments"
  - The standard refers to "physical analysis units" or PAUs
- This makes <u>no difference</u> to Task 6 fire frequency analysis
  - You are developing fire ignition frequencies for whatever set of fire locations you have defined
  - Whether you call it a fire area, fire compartment or PAU does not really matter – it is what is in that location that counts
    - The total frequency for any location is simply the sum of the frequencies for the ignition sources present in that location
  - Once you get to the scenario level (individual fire sources or fire source groups) the differences are totally irrelevant
    - You are estimating fire frequency for a very specific ignition source

Fire Ignition Frequencies
General approach

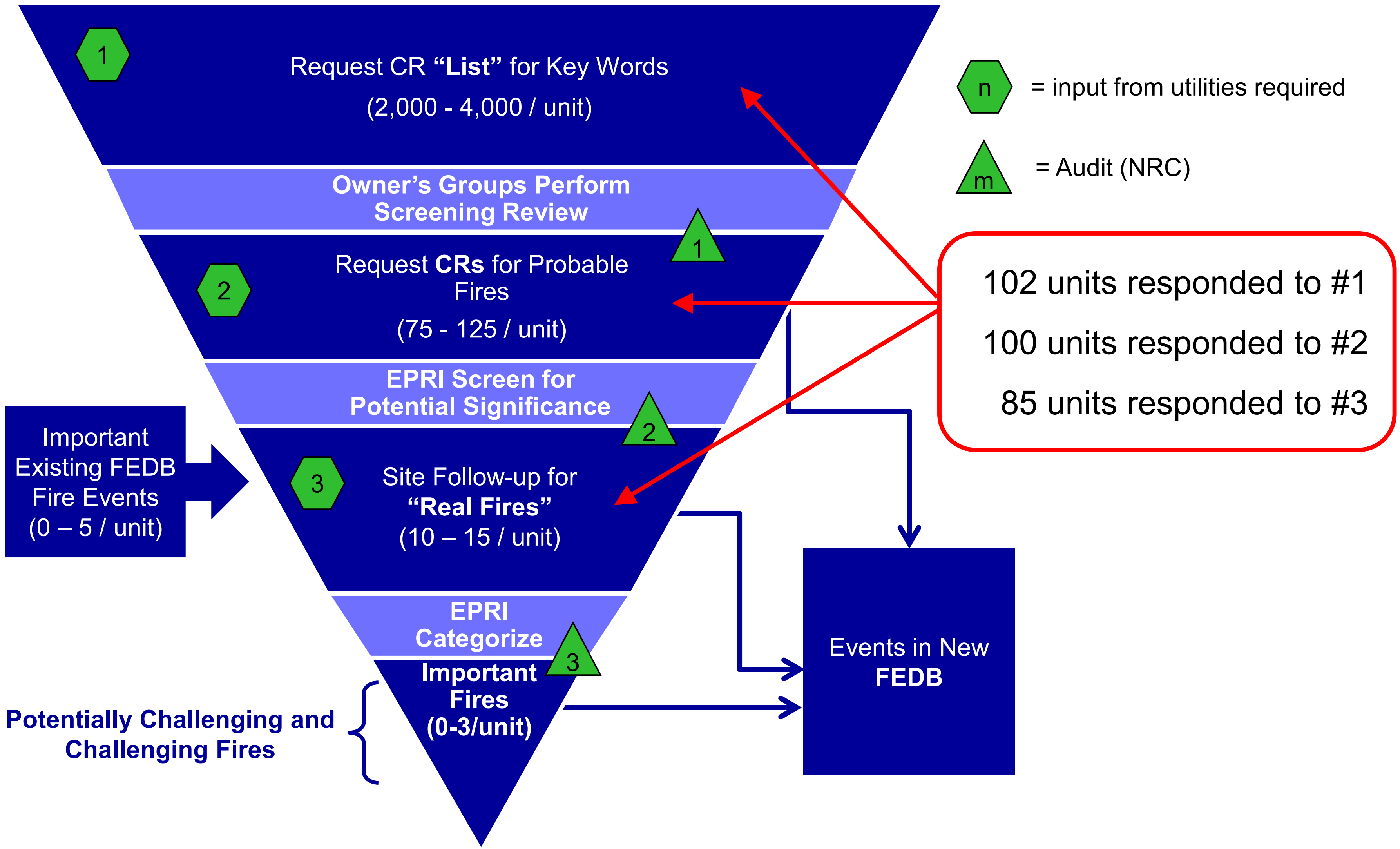
- The generic fire frequencies are based on the collective experience of the US nuclear power industry
  - EPRI Fire Event Database (FEDB) included data from 1968 through December 2000 including over 1400 records
  - EPRI published the Updated Fire Events Database in 2013 extending the collective experience through 2009 (approximately 2000 records)
- Although the database quality and supporting information has advanced in the Updated FEDB, there are still some limitations
  - Inconsistent reporting practices – reporting has been largely voluntary
  - Uneven data collection – different folks at different times have added data using different sources and bases
  - Completeness of event descriptions – reports tend to focus more on plant response to event than the details of fire
- Industry data collection through INPO can help enhance future data collection efforts through a standardized reporting process

Fire Ignition Frequencies
Fire Event Data

- In the end each event is “binned” considering four primary factors
  - Was it a *risk-relevant* fire (potentially challenging or greater)?
  - What was the fire source?
  - How was the fire put out?
  - How long did the fire last?
- The historical fire event set is used to estimate generic fire frequencies
  - Generic frequencies are in events/reactor-year
  - Numbers are for one unit (i.e., frequency plant-wide for a single plant unit)
- Event sources (* indicated as primary source for Updated FEDB)
  - Mandatory reporting to NRC*
    - Licensee event reports (LERs)
    - Event notifications (ENs)
  - Comprehensive NRC records search
  - Voluntary reporting to industry sources
    - Nuclear Energy Insurance Limited (NEIL) and American Nuclear Insurers (ANI)
  - Ad-hoc additions based on specific PRA studies
    - IPEEE analysis during early to mid 1990s
  - Plant fire reports*
- Individual follow up for key events or for events requiring additional information

Corresponding PRA Standard SRs: IGN-A1, IGN-A5, & IGN-A10

Fire Events Database Screening



Fire Ignition Frequencies
Event Data Analysis

- EPRI 1025284 contains extracted fire event information including:
  - Fire ID: A unique identifier for record
  - Event Date: Date of fire event
  - Disposition: Describes classification of fire either:
    - challenging
    - potentially challenging
    - not challenging
    - undetermined (NC-PC)
    - undetermined (PC-CH)
    - not evaluated
  - Five reports are available each with different attributes including:
    - fire summary
    - fire attributes
    - fire severity evaluation
    - fire timeline
    - plant response

Fire Ignition Frequencies
Event Data Analysis

- **Fire Summary**
  - Event description / review comments
  - Outside PA? Y or N
  - Plant area / Building
  - System / Component / Component Group
  - Voltage (and current if available) or horsepower (and rating)
- **Fire Attributes**
  - Fire cause
  - Combustible
  - Fire type
  - Observed smoke, temperature
  - Extent of damage
- **Fire Severity**
  - Automatic determination of fire events based on severity algorithm
  - Standard override (if disagreed with algorithm classification)
- **Fire Timeline**
  - Time at ignition, discovery, report, brigade response, fire control, extinction, and scene release
  - Detection method and performance
  - Suppression method and performance
- **Plant Response**
  - Mode and power level pre and post fire
  - Power effect

Fire Ignition Frequencies
Event Data Analysis

- For each event, information was reviewed and the following were established

<u>Raw info from event reports:</u>

- Fire event date
- Plant type (i.e., PWR vs. BWR)
- Plant status (operating mode)
- Fire location
- Fire cause
- Initiating equipment and combustibles
- Detection and suppression information
- Severity related information
- Event description (narrative)

<u>Derived info from event analysis:</u>

- Potentially challenging?
- Fire location
- Ignition source type
- Plant operating mode
- High energy arc fault (Y/N)
- Detection and suppression data
  - Who put fire out?
  - Fixed system performance
  - Prompt suppression (Y/N)
  - Assign to one suppression curve
  - Fire duration

Not all events in the database are risk-relevant Identification of the events that "count" to risk

- Challenging (CH) fires that had an observable and substantive effect on environment outside the ignition source
- Potentially challenging (PC) fires are those that could have grown or caused damage under foreseeable alternate circumstances
  - May be potentially challenging even if no damage occurred
  - Ask: what could happen given the same sort of fire in a different location, failures of fire protection defense in depth, or delays in successful intervention?
- Non-challenging (NC) fires that did not cause or would not have caused adjacent objects or components to become damaged regardless or location for essentially any amount of time. These fires are not counted in frequency
  - Not a location of interest to PRA (e.g., parking lot fires, off-site fires…)
  - Occurred during plant construction
  - Case specific rules such as:
    - Hot work fires suppressed by a fire watch using a single extinguisher
    - "Smoked" component reports (e.g., a "burned out relay" with no suppression needed, no signs of damage beyond that one failed component)
- Some event records we simply could not tell (Undetermined (U PC-CH or U NC-PC)

Fire Ignition Frequencies
Counting the fire events

- For EPRI 3002002936 / NUREG-2169 frequencies:
  - Challenging, potentially challenging, and undetermined (PC-CH) fires count as one event each
  - Undetermined (NC-PC) fire events count as 0.5 events
- For original and supplement 1 frequencies:
  - Potentially challenging events count as one event each
  - Weighted the unknowns to get final event count, so
    - We assume that resolution of all unknowns would yield the same split between PC and NC as we got for those events we could resolve
    - If we had 100 raw events in a bin…
    - We classify 30 as non-challenging…
    - We classify 40 as potentially challenging…
    - The other 30 were unknown…
    - Each unknown event would be weighed based on ratio of PC to total resolved: $W = [40 \div (40+30)] = 4/7$
    - So for this example our total event count would be:

      $57.1 = [40 + 30 \times W)]$

Fire Ignition Frequencies Assumptions

- The model developed for estimating fire ignition frequencies is based on the following assumptions
  - The generic frequencies are fire events per reactor year per operating unit
  - Frequencies remain constant over time
  - Each fire event is assigned to an Ignition Source Bin and frequencies are calculated for each bin
    - See Table 6-1, Bins 1-37 (electrical cabinets, motors, pumps)
  - Total unit-wide ignition frequency for each ignition source bin is the same for all units in the US fleet
    - Unit A at Plant X has the same plant-wide frequency of electrical cabinet fires as Unit B Plant Y
  - Within a plant, the ignition frequency is the same for each individual member of a given ignition source bin
    - At Unit A of Plant X, each individual electrical cabinet is assigned the same fire frequency (frequency of cabinet A = frequency in cabinet B)

Fire Ignition Frequencies
Available data

- There are now three sources of fire ignition frequency data
  - NUREG/CR-6850 and EPRI 1011989 (2005)
    - Original fire PRA methodology data for fire ignition frequencies through 2000
  - EPRI 1016737 / Supplement 1 / FAQ 08-0048 (2008)
    - Update of original fire ignition frequencies that considered potential industry trends (i.e., towards reduced fire frequencies)
    - EPRI / industry proposed that some ignition source bin frequencies have decreased based on analysis of post 1990s data
    - This set weights the more recent data (1991 forward) more heavily
  - EPRI 3002002936 / NUREG-2169 (2014)
    - Included additional decade of fire event data (through 2009)
    - Improved methodology / different calculations for sparse versus medium or dense event sets

Fire Ignition Frequencies
Generic data sources – NUREG/CR-6850 & Supplement 1

- NUREG/CR-6850
  - Included data from 1965-2000 time period
    - Event details are limited and typically uninformative on fire attributes
    - Consider events prior to the implementation of Appendix R fire protection programs
- FAQ 08-0048 / Supplement 1 / EPRI 1016735 frequencies
  - Review of data set (1965-2000) supported reduced frequencies for most ignition source bins post 1990
  - If using this set, review the NRC staff position on FAQ 08-0048 (ML092190457)
    - The fire PRA and plant change evaluations must evaluate sensitivity of the risk and delta-risk results to change in fire frequency values (i.e., difference in results using original versus revised values)
    - Identify cases where the results sensitivity evaluation indicates a change in risk significance based on values used
      - e.g., what is acceptable with the new frequencies might not be acceptable with the original frequencies
    - For these cases the licensee must consider measures to provide additional defense-in-depth
  - FAQ likely to be rescinded for use in risk-informed applications

Fire Ignition Frequencies
Generic data sources – NUREG-2169

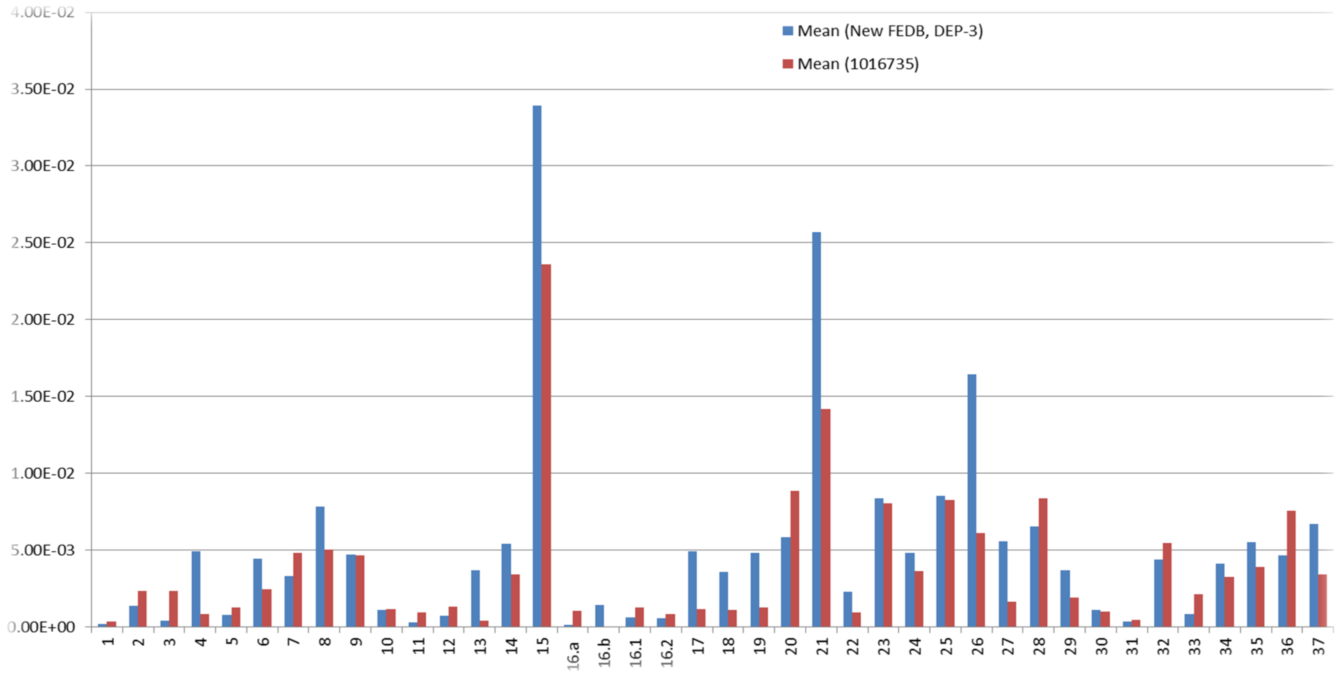
- NUREG-2169 / EPRI 3002002936
  - Published in December 2014
  - Included additional ten years of US fire event experience
  - Implemented methodology changes per EPRI 1022994
  - Split data into three time periods
    - 1968-1990 – used to develop prior
    - 1990-1999 – used as update period for sparse bins (20 year update)
    - 2000-2009 – used as update period for medium and dense bins (10 year update)
  - Fire event density determined by 2000-2009 time period
    - Sparse bins (< 2.5 events)
    - Medium or dense bins ($\geq$ 2.5 events)

Fire Ignition Frequencies
Generic data sources – NUREG-2169

Bin	Location	Ignition Source	Power Modes	FPRA Counts		
				1968–1989	1990–1999	2000–2009
14	Plant-Wide Components	Electric motors	AA	6.5	4	4.5
15	Plant-Wide Components	Electrical cabinets (non-HEAF)	AA	64.5	29.5	25.5
16.a	Plant-Wide Components	HEAF for low-voltage electrical cabinets (480–1000 V)	AA	0.5	0	0
16.b	Plant-Wide Components	HEAF for medium-voltage electrical cabinets (>1000 V)	AA	1	2.5	2
16.1	Plant-Wide Components	HEAF for segmented bus ducts	AA	5	0	2
16.2	Plant-Wide Components	HEAF for iso-phase bus ducts	AA	2	0	1
17	Plant-Wide Components	Hydrogen tanks	AA	3	1	4
18	Plant-Wide Components	Junction boxes	AA	2	1	3
19	Plant-Wide Components	Miscellaneous hydrogen fires	AA	4.5	0	4
20	Plant-Wide Components	Off-gas/H_2 recombiner (BWR)	BP	22.5	2.5	0
21	Plant-Wide Components	Pumps	AA	32.5	14	23

Fire Ignition Frequencies
Comparison of generic data sources

- Total sum of all bins
  - NUREG/CR-6850 EPRI 1011989 2.89E-01
  - EPRI 1016735 1.50E-01
  - Updated FEDB 2.10E-01



Fire Ignition Frequencies
A note on nomenclature

- Fire frequency = $\boldsymbol{\lambda}$ = (fire ignition events) / (specified time period)
  - Time period of interest is either a reactor year (ry) or calendar year (cy)
  - We generally work on an ry basis (more on this a bit later)
- You will see subscripts that designate location and/or source type
  - λ_{MCR} = fire frequency for the *main control room*…
  - $\lambda_{HW,J}$ = fire frequency for *hot work* in *location " J "* …
  - Be careful because subscripts are context driven
- We can estimate frequency at many levels of detail
  - The entire plant (e.g., the generic tables in 6850/1011989…)
  - A building
  - A PAU
  - Ultimately we often want frequency for a specific *fire ignition source* in a *specific location*

Fire Ignition Frequency
Ignition source binning differences

- Caution – fire ignition source bin numbers and frequency basis for ***electrical cabinet HEAFs*** vary among the frequency data sets

	Mapping of electrical cabinet HEAFs by source document		
Fire source binning basis:	NUREG/CR-6850 / EPRI 1011989 (based on event set 1965-2000)	Supplement 1 / FAQ 08-0048 and EPRI 1016735 (heavily weighted 1990s data)	NUREG-2169 / EPRI 3002002936 (sparse event set with 20 year update and legacy data used for prior)
One bin for all cabinet HEAF	Bin 16	Bin 15.2	Not available
Split bins for cabinet HEAF based on voltage level	Bins 16.a and 16.b (Supp.1 Chapter 4)	Not available	Bins 16.a and 16.b

Fire Ignition Frequency
Ignition source binning differences

- Caution – there are two sets of frequency values for bus ducts

	Mapping of electrical bus duct HEAF frequency sets by source document		
Fire source binning basis:	NUREG/CR-6850 / EPRI 1011989 (based on event set 1965-2000)	Supplement 1 / FAQ 08-0048 and EPRI 1016735 (heavily weighted 1990s data)	NUREG-2169 / EPRI 3002002936 (sparse event set with 20 year update and legacy data used for prior)
Bus Duct HEAFs	FAQ 07-0035 (Supp. 1 Ch. 7) No bin numbers provided	Bins 16.1 and 16.2	Bins 16.1 and 16.2

Fire Ignition Frequencies
General approach

- Start with pre-calculated unit-level generic fire ignition frequencies (λ_{IS})
- These are given for roughly 40 ignition source bins, for example:
  - Bin 21: general pump fires = 2.72E-02/ry
    - About 1 fire every 37 years…
  - Bin 15: general fires in electrical cabinets = 3.0E-2/ry
    - About 1 fire every 100 years…
  - Bin 37: transient fuel fires in the turbine building = 6.71E-03/ry
    - About 1 fire every 150 years…
  - Bin 4: main control board (MCB) fires = 4.91E-3/ry
    - About 1 fire every 205 years…
  - Bin 1: battery fires = 1.96E-4/ry
    - About 1 fire every 5000 years…

Fire Ignition Frequencies
General approach

- We then distribute *(partition or apportion)* the unit-level frequency to suit needs of a scenario analysis
  - Again, to a building, room, PAU, or to individual members of the ignition source bin
- Some bins are partitioned by population, others by location
  - Fixed ignition sources we generally count and apportion based on local population versus plant-wide population
    - How many are “here” versus total in the “plant”
    - Exceptions: cables and junction boxes (more later)
  - Non-fixed ignition sources are apportioned by location
    - Hot work and transients
    - Qualitative weighting factor method
- We will cover details of both approaches

Fire Ignition Frequencies
General approach

- The fire frequency for a location (e.g., a PAU) or for a scenario is the simple sum of the fire frequencies for each ignition source present in the location or that contributes to the scenario:

$$\lambda_J = \sum_{i=1}^{n} \lambda_{ISi} W_{J,ISi}$$

Where:

λ_J : Fire frequency for location J

n : Total number of unique ignition sources in location/scenario J

λ_{ISi} : Plant-wide fire frequency for ignition source bin "i" (IS_i)

$W_{J,ISi}$: Ignition source weighting factor for IS_i in location/scenario J

- Corresponding PRA Standard SR: IGN-A7

Fire Ignition Frequencies
General approach

- There is a second weighting factor to consider for some cases:

$$\lambda_J = \sum_{i=1}^{n} \lambda_{ISi} \cdot W_{J,ISi} \cdot W_L$$

- W_L is a location weighting factor used only for shared locations at multi-unit sites under specific conditions
  - Common applications: turbine building and main control room
    - There may be others…
  - For shared locations, you may need to double (or triple) the fire frequency to reflect contributions from multiple plant units
- We will cover this under Step 7

Fire Ignition Frequencies

- What are some examples of NPP fire ignition sources?

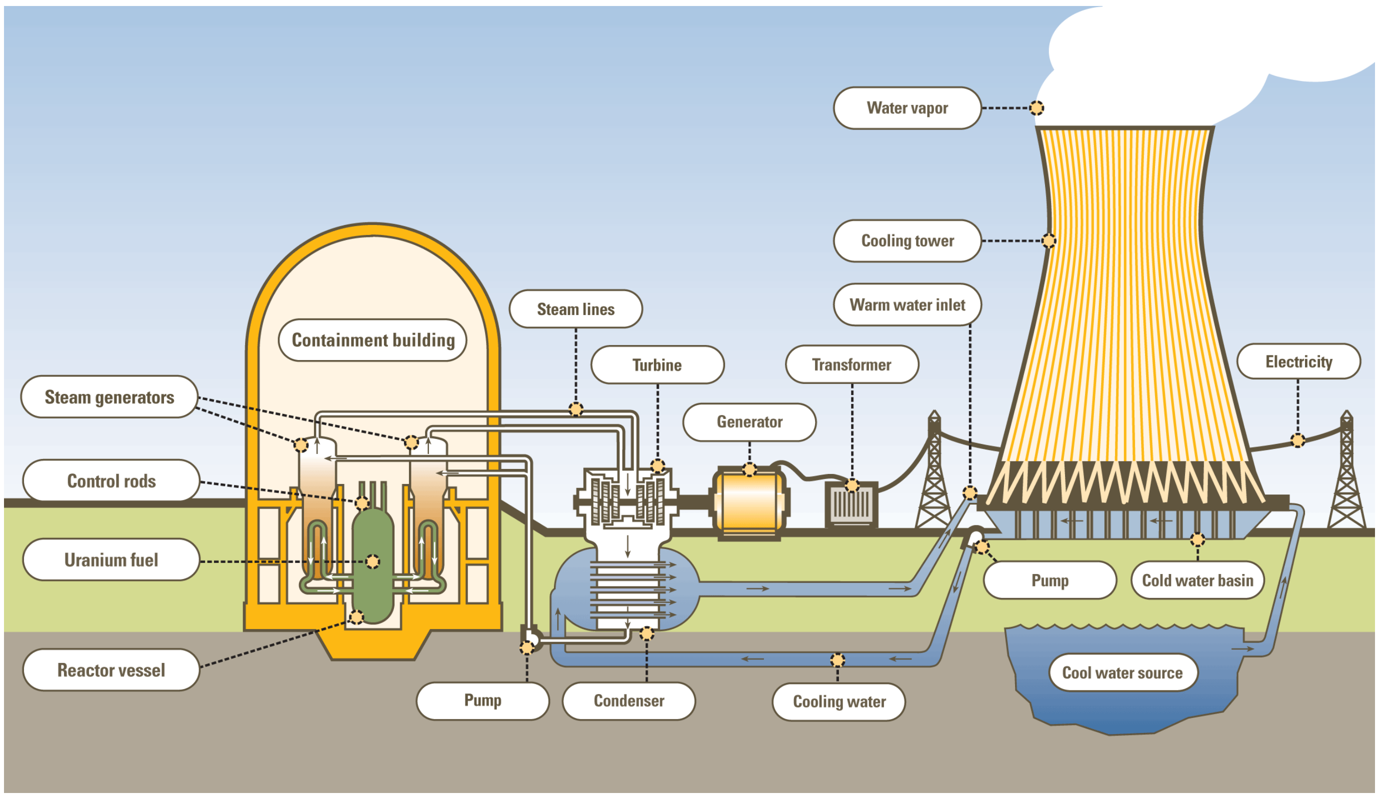


Photo from: http://newenergyandfuel.com/wp-content/uploads/2013/01/Nuclear-Plant-Block-Diagram.gif

Fixed Fire Ignition Sources

- Batteries
- Reactor Coolant Pumps
- Main Control Board
- Diesel Generators
- Air Compressors
- Battery Chargers
- Dryers
- Electric Motors
- Electrical Cabinets
- High Energy Arcing Faults
- Hydrogen Tanks
- Misc. Hydrogen Fires
- Off-gas/H^2 Recombiners
- Pumps
- RPS MG Sets
- Transformers
- Ventilation Subsystems
- Yard Transformers
- Boilers
- Main Feedwater Pumps
- Turbine Generator Excitor
- Turbine Generator Hydrogen
- Turbine Generator Oil

Fire Ignition Frequency
Non-countable sources

- PWR Containment
  - Transients and Hotwork
- Reactor / Control / Auxiliary Building
  - Cables fires caused by welding and cutting
  - Transient fires caused by welding and cutting
  - Transients
- Turbine Building
  - Cables fires caused by welding and cutting
  - Transient fires caused by welding and cutting
  - Transients
- Plant-Wide Locations
  - Cables fires caused by welding and cutting
  - Transient fires caused by welding and cutting
  - Transients
- All Locations
  - Self ignited cables fires
  - Junction boxes

Fire Ignition Frequencies
Plant Level Ignition Source Bins (Table 6-1)

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Generator Room	Diesel Generators	All	2.1E-02	0.16	0.84	0	0	0	0
11	Plant-Wide [illegible]	Cable fires caused by [illegible]tting	Power	2.0E-03	0	0	0	1.0	0	0
[illegible]	[illegible] Components	[illegible]	All	4.6E-03	1.0	0	0	0	0	0
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0	0	0	0	0	
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Frequency Bin

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement or EPRI 3002002936 / NUREG-2169.

Fire Ignition Frequencies
Plant Level Ignition Source Bins

Table 6-1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type: Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diese Room				0.16	0.84	0	0	0	0
11	Plant- Comp				0	0	0	1.0	0	0
14	Plant- Comp				1.0	0	0	0	0	0
15	Plant- Comp				1.0	0	0	0	0	0
20	Plant- Comp				0	0	0	0	1.0	0
27	Trans				1.0	0	0	0	0	
32	Turbir				0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

ID	Location
1	Battery Room
2	Containment (PWR)
4	Control Room
8	Diesel Generator Room

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

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Fire Ignition Frequencies
Plant Level Ignition Source Bins

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ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Ge Room									
11	Plant-Wid Compone									
14	Plant-Wid Compone									
15	Plant-Wid Compone									
20	Plant-Wid Compone									
27	Transform									
32	Turbine B									

1. See Appendix M
2. See Section 6.5.6 below for a definition.

ID	Location	Ignition Source (Equipment Type)
1	Battery Room	Batteries
2	Containment (PWR)	Reactor Coolant Pumps
4	Control Room	Main Control Boards
8	Diesel Generator Room	Diesel Generators

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

Fire Ignition Frequencies
Plant Level Ignition Source Bins

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
			Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
Batteries	All	7.5E-04	1.0	0	0	0	0	0
Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
Main Control Board	All	2.5E-03	1.0	0	0	0	0	0

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

Fire Ignition Frequencies
Plant Level Ignition Source Bins

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
16	Plant-Wide Components	High Energy Arcing Faults[1]	All	1.5E-03	0	0	0	0	0	1.0
17	Plant-Wide Components	Hydrogen Tanks	All	1.7E-03	0	0	0	0	1.0	0
18	Plant-Wide Components	Junction Boxes	All	1.9E-03	1.0	0	0	0	0	0
19	Plant-Wide Components	Misc. Hydrogen Fires	All	2.5E-03	0	0	0	0	1.0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
21	Plant-Wide Components	Pumps	All	2.1E-02	0.54	0.46	0	0	0	0
22	Plant-Wide Components	RPS MG Sets	Power	1.6E-03	1.0	0	0	0	0	0
23a	Plant-Wide Components	Transformers (Oil filled)	All	9.9E-03	0	1.0	0	0	0	0
23b	Plant-Wide Components	Transformers (Dry)			1.0	0	0	0	0	0
24	Plant-Wide Components	Transient fires caused by welding and cutting	Power	4.9E-03	0	0	0	1.0	0	0

Fire Ignition Frequencies
About the mode column…

- For each plant, two time periods were established based on operating mode:
  - Power operations (including low-power) – total years spent in power operation since initial commercial operation or ***reactor years (ry or rx yr)***
  - Shutdown operations – total time since initial commercial operation spent in non-power operating modes
- Some frequency bins cover all modes of operation, some only cover power operations (including low-power)
- Both sets represent ignition frequencies *per mode-year*
  - Some are simply power-modes-only and some are applicable to all modes
- Applied to at-power fire PRA the generic frequencies (in all references) are all ***per ry***

Fire Ignition Frequencies
And what about the standard…

- IGN-A5 says (same for all CC's):

  "… INCLUDE in the fire frequency calculation the plant availability, such that the frequencies are weighted by the fraction of time the plant is at-power."

- This means that to meet IGN-A5, convert the generic frequencies:

  FROM per reactor year (ry) TO *per calendar year* (cy)

- You do that by multiplying the generic frequencies by the *plant-specific* average annual availability factor
  - These are typically in excess of 90% for most plants today
- The risk results you get will then be *per cy* numbers (instead of per ry)
- Why? Creates common basis for estimating total plant risk numbers that include the contribution from all sources including shutdown operations

Fire Ignition Frequencies
Task 6 procedure

Task 6 develops location and item specific fire frequency values for each fire frequency bin using an 8-step process:

- Step 1. Mapping plant ignition sources to generic sources,
- Step 2. Plant fire event data collection and review,
- Step 3. Plant specific updates of generic ignition frequencies,
- Step 4. Mapping plant-specific locations to generic locations,
- Step 5. Location weighting factors,
- Step 6. Fixed fire ignition source counts,
- Step 7. Ignition source weighting factors, and
- Step 8. Ignition source and compartment (PAU) fire frequency evaluation.

- Relevant PRA Standard Supporting Requirement: IGN-A7

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- In practice, Steps 1 and 6 are done together so we'll cover them together here
  - Step 1 is ignition source mapping
  - Step 6 is fixed ignition source counting
- Both are done by visual inspection
- In short, the process is:
  - Perform a *thorough* walkdown of the plant (preferably with tablet in hand)
  - Identify any and all potential fire ignitions sources
  - Map each source to one of the 37 ignition source bins
  - And, oh by the way…, count them (Step 6)
  - Keep a list with name, bin assignment, and location as you go
  - If you want to get fancy, link the list to photos
- Now for the long version…

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- In step 1 <u>everything</u> in the plant that is capable of starting a fire should be mapped to one of the 37 pre-defined ignition source bins.
- Nominally covers <u>all</u> locations within the global analysis boundary, but…
- EXCLUDE locations that screen out qualitatively
  - Qualitative screening is Task 4 which is covered in Module 1
  - Locations with no *fire PRA equipment or cables* and no *plant trip initiators* don't require quantitative analysis – they screen out on a qualitative basis
    - Parking lots, office buildings, warehouses, security access buildings,…
  - The fire frequency classification excluded fire events in these types of locations
    - Classified as non-challenging based on *location not of interest to fire PRA*
  - For consistency <u>*do not apportion*</u> any fire frequency to such locations
    - That means we don't count ignition sources in those locations and
    - Exclude them from the transient and hot work location sets as well (more later…)

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- Steps 1 & 6 specifically focus on fixed equipment, but watch for transients and hot work activities as well
  - There are several location based bins for transients and hot work
  - You don't "count" these as sources per-se, but you do have to characterize likelihood and, for transients, the type expected in each plant location
  - Make note of what you see and where you see it
  - We will talk about the weighting factor approach later but you must use judgment to assign relative weighting factors to each PAU
  - Insights gained during the plant walkdown can help this process
  - Again, more on this later…

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

If an ignition source does not map directly to one of the 37 available bins you have two options:

- You may be able to match to an existing bin even if fit is not perfect
  - Look for a bin with similar characteristics *relative to fire likelihood*
    - e.g., a motor-driven widget may map to motors if the widget part is not significant
  - Provide explanation for why you think fit is OK, again, *relative to frequency*
- Create a new bin for the item, but then you need a fire frequency
  - A plant-specific history of fires may be enough to establish frequency
    - Caution: a history of no fires at one plant probably won't be enough by itself
  - Relevant experience at other plants may help
  - Fire history in other industries may be used… with caution
  - You will be on the hook to quantify and justify your frequency assumptions
- One example we ran into: a gas-fired emergency generator unit

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- For each of the 37 ignition source bins there is corresponding description and counting guidance
- We'll highlight a few bins, but for the others refer to the report:
  - **Bin 1 – Batteries (Battery Room):** Each bank of interconnected sets of batteries located in one place should be counted as one battery set. Cells may not be counted individually.
  - **Bin 4 – Main Control Board (Control Room):** A control room typically consists of one or two (depending on the number of units) main control boards as the central element of the room. The control room may also include plant computers, other electrical cabinets containing plant relays, and instrumentation circuits, a kitchen type area, desks, bookshelves, and etc. Aside from the main control board, the ignition source weighting factors of the remaining ignition sources of the control room should be based on the approach specific to each ignition source.
    - **FAQ 06-018 (Supplement 1)** – clarification of MCB definition (horseshoe or equivalent)
      - There is a one-to-one correspondence between Appendix L and Bin 4
      - All other electrical cabinets in MCR should be counted with Bin 15
    - **FAQ 14-008** – updates the definition to include the rear side of the MCB

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- Counting guidance examples continued:
  - **Bin 15 – Electrical Cabinets (Plant-Wide Components):** Electrical cabinets represent such items as switchgears, motor control centers, DC distribution panels, relay cabinets, control and switch panels (excluding panels that are part of machinery), fire protection panels, etc. …The following rules should be used for counting electrical cabinets:
    - Simple wall-mounted panels housing less than four switches may be excluded from the counting process (these become junction boxes…)
    - ***Well-sealed*** electrical cabinets that have robustly secured doors (and/or access panels) and that house only circuits below 440V should be excluded from the counting process
    - Free-standing electrical cabinets should be counted by their ***vertical segments***

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- Counting guidance examples continued:
  - **FAQ 06-0016 (Supplement 1)** – Provides updated counting guidance for electrical cabinets
  - Clarifies guidance on counting electrical cabinets and for treating "outlier" cabinets
    - Cabinet counting guidance gets applied to a wide range of cabinet sizes
    - Ignition frequency is more a function cabinet contents than cabinet size
    - A basis is needed to address outlier conditions
  - Each user should establish criteria for identifying outliers and a basis for counting them
  - Examples of possible rule-set approaches:
    - Establish a nominal 'standard' or reference cabinet size
    - Consider cabinet internals relative to a defined 'standard' or reference configuration

Fire Ignition Frequencies

Steps 1&6 –FAQ 06-0016 Counting Example

- An analyst defines a ‘standard’ cabinet as nominally 4’ long and 3’ deep and an outlier is any cabinet with any horizontal dimension greater than 8’

6’ long cabinet,

no partitions

Cabinet is not an outlier –
Count = 1

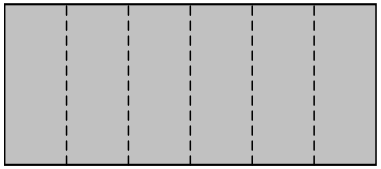
4’ long cabinet,

no internal partitions

Cabinet is same as standard –
Count = 1

Larger cabinet with

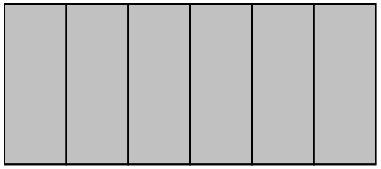
non-solid internal partitions



Internal dividers are not solid –
Count = 6

Larger cabinet with

solid internal partitions



Internal dividers are solid –
Count = 6

Fire Ignition Frequencies
Steps 1&6 –FAQ 06-0016 Counting Example (continued)

- How to count using example rule set…

**Three independent cabinets –
Count = 3**

12 ft wide, 3 ft deep

**Panel is an outlier, using a 4' standard cabinet –
Count = 3**

9 ft wide, 6 ft deep

Cabinet is an outlier, no evaluation of contents, based on reference cabinet – Count = 3 due to variation from the standard length and depth

**9 ft wide, 6 ft deep
walk through cabinet**

The counts should depend on the cable termination load and devices in the panel by comparing it with a reference cabinet.

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- Some specific exclusions for certain bins
  - **Bin 14 – Electric motors**: exclude small motors of 5 hp or less and *totally enclosed* motors.
  - **Bin 21 – Pumps**: exclude small sampling pumps, and other pumps of 5 hp or less
  - **Bin 23 – Transformers**: exclude dry transformers of 45 KVA or less
  - **Bin 26 – Ventilation subsystems**: exclude small subsystems powered by motors of 5 hp or less (consistent with electric motors Bin 14)
- **FAQ 07-0031 (Supplement 1)** provides clarification and extension beyond 6850 / 1011989 that are reflected in the bullets above

Fire Ignition Frequencies
Steps 1&6 – FAQ 06-0017

- Ignition source counting guidance for high energy arcing faults (HEAFs) in electrical switching equipment
  - Issue: Originally all HEAF events were lumped in one ignition source bin (16) that were applied across all voltages 440V or greater. However, cabinet voltage should impact fire frequency
  - Resolution: **FAQ 06-0017 Supplement 1** splits Bin 16 into 2 parts:
    - **16.a Low-voltage panels (440 to 1,000V)** – 1.52 E-04/ry (mean)
    - **16.b Medium-voltage panels (> 1000V)** – 2.13E-03/ry (mean)
  - This treatment carries forward for Supplement 1 & new fire ignition frequencies in EPRI 3002002936 / NUREG-2169
  - Counting method remains unchanged (i.e., vertical sections)

Fire Ignition Frequencies
Steps 1&6 – FAQ 07-0035

- Guidance for counting HEAFs in bus ducts
  - Issue: NUREG/CR-6850 / 1011989 was silent on this topic
  - Resolution: **FAQ 07-0035 Supplement 1**
    - Acknowledge the potential for such events (e.g., Diablo Canyon 5/2000)
    - Provides plant wide frequency and counting/partitioning guidance
    - Provides zone of influence and scenario development guidance
    - Two categories of bus duct are defined:
      - 16.1 Segmented Bus Duct
      - 16.2 Iso-Phase Bus Duct
    - Bins 16.1 and 16.2 in Supplement 1 Chapter 10 and new frequencies NUREG-2169 / EPRI 3002002936
      - Beware the bin numbering issue – not 16a/16b…
      - FAQ 07-0035 did not list bin number with frequencies

Fire Ignition Frequencies
Steps 1&6 – Mapping and Counting Ignition Sources

- Counting guidance examples continued:
  - Some things we don't count at all, we use a relative weighting factor based on location characteristics (more on this later):
    - Hot work and transients
      - Qualitative relative weighting factor by location
    - Cables
      - We will use a relative mass/volume weighting factor
    - Junction boxes
      - We apportion to a location using cable factors

Fire Ignition Frequencies
FAQ 12-0064

- This FAQ is unique and you should download a copy
  - NRC ADAMS Accession Number: ML12346A488
- Impacts some of the fire frequency mapping guidance
  - Clarification of mapping of plant-specific locations to generic locations
  - Modifies / expands the transient and hot work weighting factor methods
- Presented in the form of Chapter 6 redline / strikeout revisions
  - This format is unique for Fire PRA FAQs, but necessary because the changes impact many parts of Chapter 6
- We will cover this in more detail, but in general
  - Clarification of where the *Location = "Plant Wide Components*" bin apply
    - Short version: "everywhere else…" not "everywhere"
  - Revised (slightly expanded) ranking factors for hot work and transients

Fire Ignition Frequencies FAQ 12-0064

- FAQ clarifies the intent of the *"location = plant-wide components"* bin
  - These bins do not apportion to *every* location throughout the plant
  - They are apportioned only to locations / components not explicitly covered by another *corresponding* ignition source bin
- Example 1:
  - There are transient fire bins for the Turbine Building (37), Containment (3), and for the Control/Aux/Reactor building complex (7)
  - Bin 25 is the corresponding "plant-wide components-transients" bin
  - Bin 25 applied to the ***rest of the plant***, i.e. all locations ***except*** those mapped to bins 3,7 or 37
- Example 2:
  - Main feedwater pumps have their own bin (32), so…
  - "Plant-wide components – pumps" bin 21 excludes the MFW pumps
  - Same goes for reactor coolant pumps (bin 2)

Fire Ignition Frequencies
FAQ 12-0064

- Other cases that also overlap:
  - Main control board (bin 4) vs. electrical cabinets (bin 15)
  - Battery chargers (bin 10) vs. electrical cabinets (bin 15)
  - Specific yard transformer (bins 27-29) vs. general transformers bin (23a/b)
  - The various location-based hot work fire bins
- Bottom line: In general only one bin contributes to the frequency of:
  - Any given location for location-based bins (hot work and transients)
  - Any given fixed fire ignition source
  - Exceptions:
    - Some ignition source bins have multiple fire types that are reflected as split fractions in the table – one bin, multiple fire types
    - Electrical cabinets have general thermal fires and high energy arc faults (HEAF)
      - These were bins 15 and 16 originally,
      - but were re-named in FAQ 48 as 15.1 and 15.2
      - And finally in NUREG-2169 as 15 and 16.a and 16.b (see slide 24…)

Fire Ignition Frequencies
Steps 1 & 6 – Concluding remarks

- At the end of the step 1/6 you will have:
  - Been on several plant walkdowns
  - Identified all fixed ignition sources and:
    - Mapped each to a location
    - Mapped each to the generic fire ignition source bins
    - Created a new bin if you found something truly unique
    - Counted them
  - Hopefully, you also made some observations on transients and hot work

Fire Ignition Frequencies
Steps 1 & 6 – Concluding remarks

- Some hints:
  - Every ignition source needs some sort of identifier so you can track them through the analysis
  - Document so that you, or someone else, can tell what was counted and what name or identifier was assigned to each item – photos may be helpful
  - Also document what was excluded from the count and why
  - Counting is mainly about being consistent in application

Fire Ignition Frequencies
Step 2 – Plant Fire Event Data Collection

- The generic fire frequencies are just that – generic
- If the plant under analysis has some "unusual" fire experience, then that should be reflected by updating the fire frequencies
- What constitutes "unusual" is a matter of judgment
  - Every plant in the country has had some fires even though they may not have had "reportable" fires
  - The question really is whether or not the plant's experience is consistent with the rest of industry, example:
    - FAQ 07-0035 found roughly a dozen high energy arc faults in bus ducts, but…
    - Six had occurred at the same plant over the course of three years
    - That constitutes "unusual" experience…
  - Note that it is not unusual for a plant to have experienced no fires in a given ignition source bin
    - We have roughly 40 total bins and given plant-wide total fire frequency or 2E-1/ry, we would only expect about 6-10 fires over a nominal 40 year lifetime

Fire Ignition Frequencies
Step 2 – Plant Fire Event Data Collection

- Common practice is to perform a Bayesian update of the generic fire frequencies to reflect plant-specific fire experience
- You need to gather plant-specific fire event data to establish plant-specific fire ignition frequencies
  - Gather and review plant reports relating to fire events over some reasonable time period
    - 10-15 years minimum, more if possible
    - Look at the screening criteria and think about your event experience in the same context – are they risk relevant or not?
      - Screening criteria
        - NUREG/CR-6850 EPRI 1011989 Appendix C “*Potentially challenging screening criteria”*
        - EPRI 1025284, updated challenging and potentially challenging criteria
  - First question to ask is “are plant specific fire ignition frequencies warranted?”
    - Plant has experienced a repeated set of similar events
    - Events that cannot be mapped to a bin
    - Unusual fire occurrence patterns
  - May be selective in which plant specific frequency bins are updated
    - Not an all or nothing situation

Fire Ignition Frequencies
Step 3 – Calculate Plant Specific Frequencies *(λ_{IS})*

- The Bayesian update approach is the accepted method used to estimate plant-specific fire ignition frequencies
  - PRA standard endorses/requires Bayesian methods in the SRs related to formal data analysis
    - You'll find this in the Internal Events section (Part 2) rather than the fire section (Part 4)
    - Look for the "DA" technical element
  - Generic frequency uncertainty distributions are used as the prior, plant specific data is used to do update
- Note that this approach does raise possible double-counting issue since same events identified in update may already be in the FEDB
  - Generally not considered a significant issue, but be aware…

- Corresponding PRA Standard SRs: IGN-A4, IGN-A6, and IGN-A10

Fire Ignition Frequencies
Steps 2 & 3 – Illustrative example

- The following events have taken place at the unit under analysis over the past 10 years of plant operation:
  - Event 1: Fire in MCC-A because breakers were not properly engaging the bus bars.
  - Event 2: Fire in 125VAC-A panel. The fire was extinguished when 4kV bus-A was de-energized from the control room. Fire resulted from arcing of supply lead to one of the fittings connecting to a controller to the bus.
- Both fires can be included in the frequency analysis
- Both events would map to "Electrical Cabinets – non HEAF"
  - Per NUREG/CR-6850 / 1011989 and EPRI 3002002936 / NUREG-2169 this is bin 15
  - EPRI 1019259 (Supplement 1 to NUREG/CR-6850) calls this bin 15.1
- 2 electrical cabinet fires in 10 years is high compared to generic frequency so an update would be appropriate
- Given 2 fires in 10 years Baysian update would increase mean fire frequency from 0.024/ry to 0.084/ry

Fire Ignition Frequencies
Step 4 – Mapping Plant-Specific Locations

- Not a major step, but plant-specific locations should be mapped to the locations defined by the ignition source bins
  - Several ignition source bins are explicitly location based, especially hot work and transients
  - You will need to define what constitutes the following “locations” for the plant being analyzed:
    - Battery rooms
    - Turbine building
    - Control/auxiliary/reactor buildings
    - Control room
    - Containment
    - Transformer yard
    - Everywhere else…
  - Names often don’t match exactly – you have to match based on function

Fire Ignition Frequencies
Step 5 – Location Weighting Factor (W_L)

- Recall our fire frequency equation from earlier:

$$\lambda_J = \sum_{i=1}^{n} \lambda_{IS,i} \cdot W_{J,ISi} \cdot W_L$$

- W_L is a weighting factor that only applied to multi-unit sites
  - W_L = number of units that share locations at the site
  - If W_L = 1, it has no effect at all and we simply drop it
- Takes a bit of common sense to apply, and how you use it depends a lot on what scope of the analysis is (i.e., one unit only versus all site units) and on the specific scenarios
  - Don't just dive in and multiply all the frequencies by 2 because you are at a dual unit site
  - Use of W_L depends on how you are doing the analysis…

Fire Ignition Frequencies
Step 5 – Location Weighting Factor (W_L)

- Examples where $W_L > 1$ applies even if we are analyzing one unit:
  - Main control room abandonment:
    - Two units share one control room but we are only analyzing Unit 1
    - The likelihood of fire leading to MCR abandonment for Unit 1 must consider uncontrolled fires in Unit 2 MCR equipment
    - It is all the same space, but each unit has it's own "stuff"
    - That means nominal fire frequency doubles ($W_L = 2$)
  - Catastrophic turbine generator fires in a shared turbine hall
    - Same sort of issue – fires in sister unit may impact unit under analysis
  - General shared equipment areas – e.g., pump room with pumps for both units
    - This one is a bit tricky – done carefully you can use W_L
    - Alternative is to count only the one unit under analysis and use Step 7 approach – simply add the extra pumps to local count (but not plant-wide count) even though they are sister unit equipment (example coming up…)

Fire Ignition Frequencies
Step 5 – Location Weighting Factor (W_L)

- W_L works best when we are analyzing all units of a multi-unit site
- Example: We are working a two-unit site and analyzing both units
  - We can use (W_L = 2) which effectively doubles the base frequencies for all ignition source bins
  - Then we can simply identify and count ignition sources for both units and partition using Step 7 (next up…)
  - In terms of fire frequency, this eliminates the need to worry about what equipment goes with which unit
    - A cabinet is a cabinet…
- One caution:
  - This works well when units are essentially the same and have shared areas
  - Not good when units are very different styles of plant
    - e.g., a BWR and PWR happen to share a site
  - Not recommended when each unit is stand-alone (no shared locations)

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Again, recall our frequency equation:

$$\lambda_J = \sum_{i=1}^{n} \lambda_{IS,i} \cdot W_{J,ISi} \cdot W_L$$

- $W_{J,IS}$ = weighting factor for ignition sources in a given scenario
  - For fixed ignition sources it is calculated based on the *local* versus *plant-wide* population ratio for each type of fixed ignition source in the scenario
  - For transient and hot work, there is a qualitative approach that weights locations relative to each other
  - We calculate one or more weighting factors for each fire scenario we analyze
    - Generally one per ignition source bin represented in the scenario
  - Corresponding PRA standard SRs: IGN-A7 & IGN-A9

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

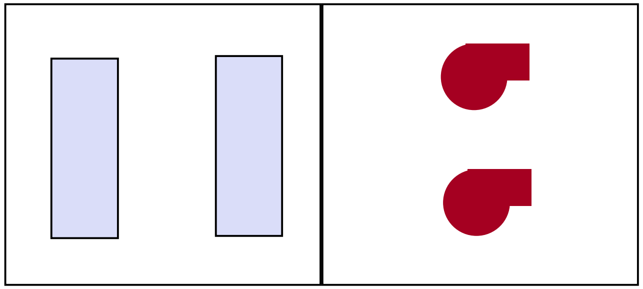
- Scenarios can involve anything from a building to a single piece of equipment – whatever sources contribute to the fire scenario
  - Example 1:
    - At an early stage we postulate room-wide burn-out screening scenarios
    - We would include all of the ignition sources in the room
    - We calculate an ignition source weighting factor for each unique ignition source bin represented in the room
    - Scenario fire frequency is sum of all these contributing fire sources
  - Example 2:
    - Scenario is a bank of electrical cabinets threatening overhead cables
    - All the cabinets have the same fire characteristics and same potential to damage the cables
    - We'll only need one location weighting factor to represent the bank of cabinets since all are members of the same ignition source bin (15)

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- The general process for **fixed ignition sources**:
  - We start from the total number of relevant items in each bin ***plant-wide***
    - Recall that we counted these in step 6
    - Caution: be consistent relative to W_L if you are at a shared site…
  - We count the ignition sources that contribute to the scenario of interest
  - The scenario-specific ignition source weighting factor is then the simple ratio of the *local* count to the *plant-wide* count
  - Example: estimate the fire frequency for PAU J:
    - PAU J contains 2 pumps assigned to Bin 21
    - We counted 50 Bin 21 pumps plant-wide
    - $W_{J,21}$ = 2/50 = 0.04
    - λ_{21} = 2.7E-2/ry (from 3002002936 / NUREG-2169)
    - $\lambda_{J,21}$ = 0.04 × 2.7E-2/ry = 1.08E-3/ry
    - Repeat for each ignition source bin represented in PAU J…

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Single unit plant



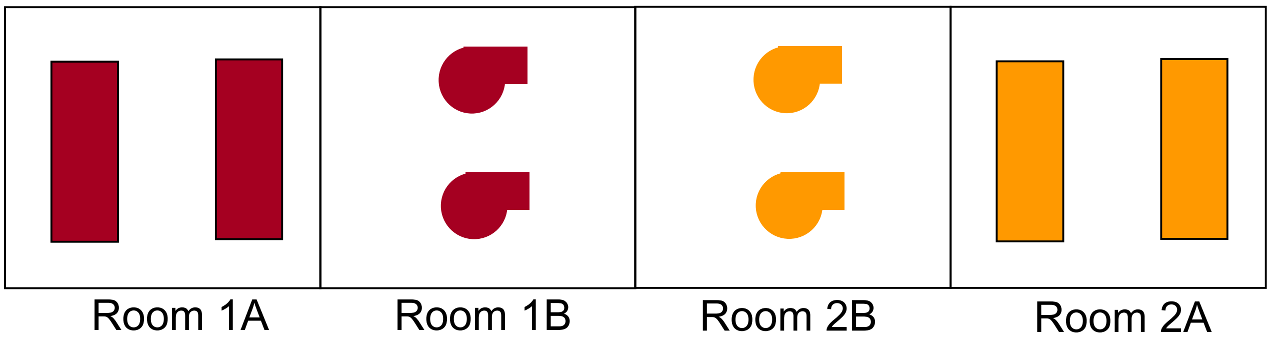
Count	Room 1A	Room 1B	Total
Elec. Cab.	2		2
Pump		2	2

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{2} \cdot 1$$

$$\lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Two units, two units in scope

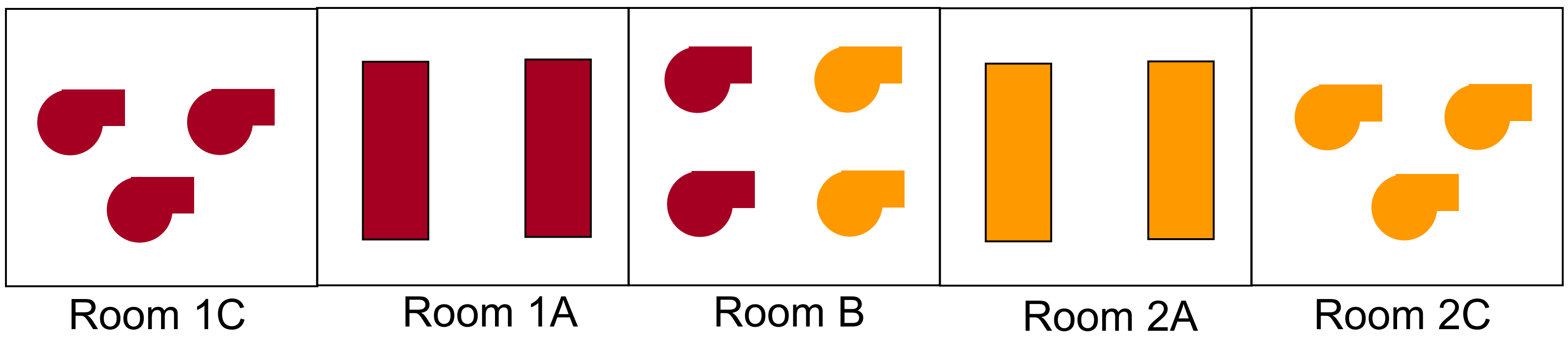


Count	1A	1B	2A	2B	Total
Elec. Cab.	2		2		4
Pump		2		2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 2 \qquad \lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp-1B} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Two Units, Two Units in scope, shared room



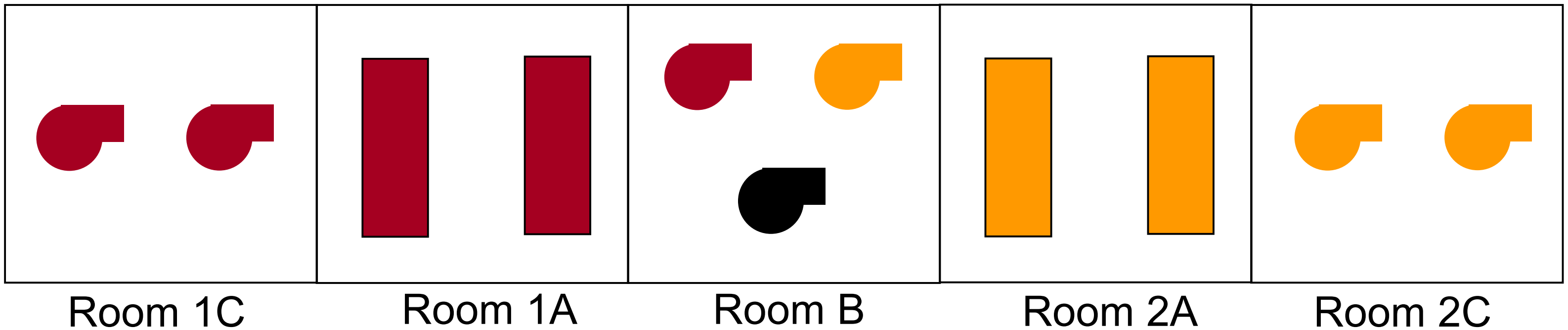
Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		3		3	4	10

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{10} \cdot 2$$

$$\lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 4$$

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Two units, two units in scope, shared room, swing pump

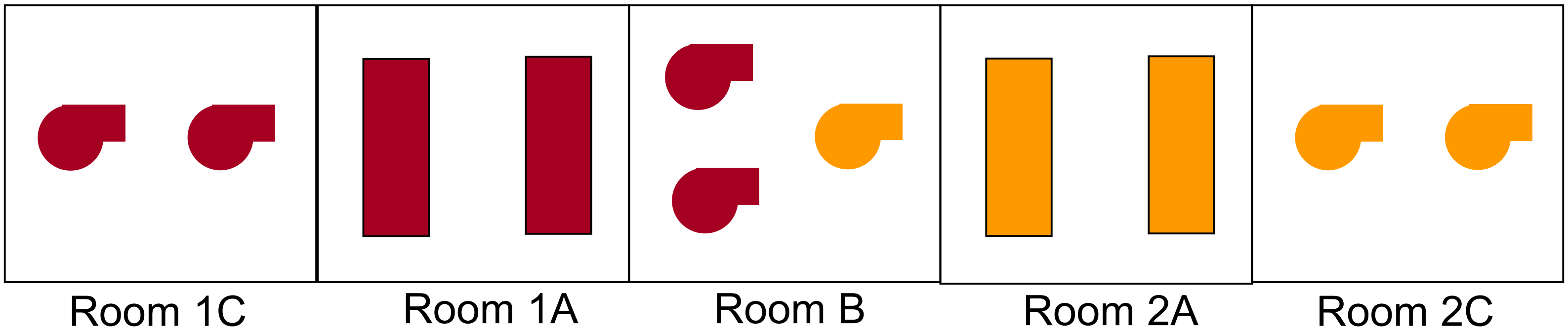


Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		2		2	3	7

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{7} \cdot 2 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Two units, one unit in scope, shared room



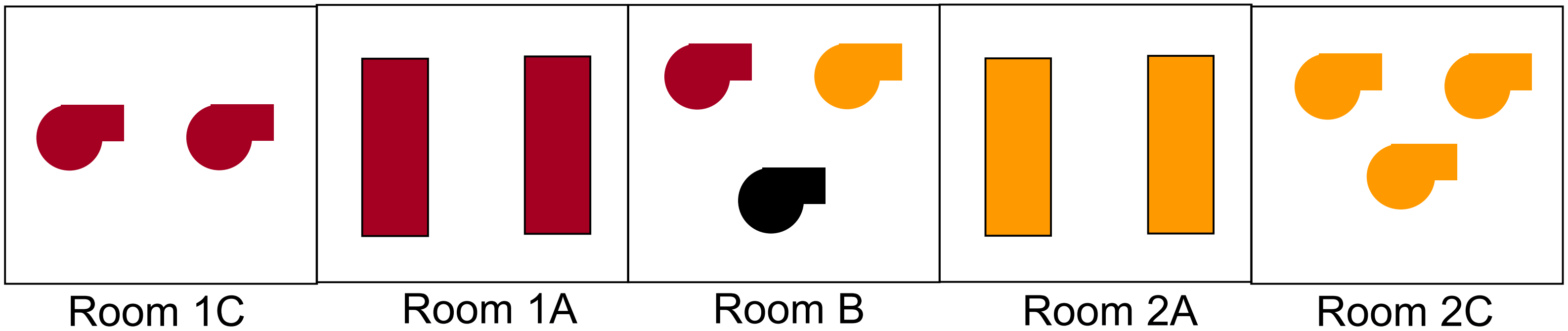
Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 1$$

$$\lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequencies
Step 7 – Ignition source weighting factors ($W_{J,IS}$)

- Two units, one in scope, shared room, swing pump



Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			1.5	3.5

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{3.5} \cdot 1$$

$$\lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients and hot work fires

- There is a new FAQ out that modifies the approach for non-fixed ignition sources
  - Transient fires
  - Transient fires caused by hot work
  - Cable fires caused by hot work
- Reference is **FAQ 12-0064** (ML12346A488)
  - Issued January 2013
- We will present the methods *as modified by this FAQ*
  - The set of ranking factor values has been expanded
  - Fractional values now allow more credit for very strict administrative controls in a location
    - Application of the fractional values generally requires a review of plant records to verify that controls have not been violated

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients and hot work fires

- All three fire types are handled in a similar manner, but factors will vary
- General approach:
  - The PAUs that make up the location "set" (L) for each of the transient and hot work bins are defined (see slide 32…)
  - The PAUs that make up a location set are assigned a numerical ranking value based on certain characteristics (covered shortly…)
  - The PAUs within a set are ranked *relative to each other*
  - The ranking values for all PAUs in the set are summed to get a total for the set (this becomes the normalizing factor for the set)
  - The fraction of the fire frequency assigned to a given location (J) is calculated based on ratio of ranking for location to set total:

$$W_{IS,J,L} = \text{(rank for the location J) / (total for all locations in the set L)}$$

Fire Ignition Frequencies
Step 7: $W_{IS,J,L}$ – Transients

- Transient fire bins are **3, 7, 25** and **37**
- General transients covers all the fires that didn't fit in the other frequency bins and that were not associated with hot work
  - Trash
  - Liquids not actually inside a component (e.g. oil, solvents…)
  - Portable heaters
  - Portable lighting
  - Stored materials
  - Staged materials and associated packing materials
  - Scaffolding
  - Temporary computers or instruments
  - Rad protection dress-up areas
  - Temporary structures inside plant…

Fire Ignition Frequencies
Step 7: $W_{IS,J,L}$ – Transients

- Transient fire frequencies are apportioned based on qualitatively estimated ranking level for three factors:
  - General electro/mechanical **maintenance**
    - Excludes hot work
  - **Occupancy** level and traffic density
    - Implication is that people bring stuff with them
  - **Storage** (temporary and permanent)
    - Combustible and flammable materials
    - Includes liquids
    - Staging area

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients

- There are five ranking levels that applied to all three ranking factors:
  - **No (0)** - Can be used only for those PAUs where transients are precluded by design
    - Administrative restrictions do not qualify for a ‘0’ ranking*
  - **Very low (0.3)** – applies only to locations with the strictest levels of administrative control - strict prohibitions in force and verified effective (no violations)
  - **Low (1)** – Reflects minimal level of the factor
  - **Medium (3)** – Reflects average level of the factor
  - **High (10)** – Reflects the higher-than-average level of the factor

- … plus one rating level that applied to general maintenance factor only:
  - **Very high (50)** – Reflects the significantly higher-than-average level of the factor (only for “maintenance” influencing factor).

* Corresponding PRA Standard SR: IGN-A9

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients – Table 6-3 (FAQ 12-0064)

Table 6-3
Summary Description of Transient Fire Influencing Factors

Influencing Factor	Ranking value	Where Applicable
General Electro-Mechanical (E/M) Maintenance (excluding hot work)	**No (0)**	General electro-mechanical maintenance activities during power operation are precluded by design and/or operation (see discussion in Section 6.5.7.2).
	Very Low (0.3)	A "0.3" rating may be applied only to locations meeting the strictest of access controls, that are largely devoid of equipment, and that contain no equipment subject to frequent maintenance. This rating may be applied provided that (1) access to the location is strictly controlled (see discussion above), and (2) the location contains no plant equipment or components other than cables, fire detectors, junction boxes and other minor plant support equipment such as normal and emergency lighting, access control panels, plant paging or communications equipment, alarms or alarm panels, and security monitoring or support equipment. In general, the presence of any piece of equipment that was

■ ■ ■

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients – Table 6-3 (FAQ 12-0064)

...

Table 6-3 Summary Description of Transient Fire Influencing Factors		
Influencing Factor	**Ranking value**	**Where Applicable**
		counted as a fire ignition source during Step 6 would preclude assignment of "very low" for this factor. Conversely, it cannot be assumed that the lack of countable fire ignition sources implies that the very low ranking factor applies. If equipment items are present that may require maintenance but do not meet the counting criteria (e.g., smaller pumps, motors or ventilation subsystems) then the very low ranking factor would not apply. Application of this ranking value requires verification that no violations of the controls associated with transient combustibles and activities have occurred over a reasonable prior time period (i.e., five years). This rating may not be applied to the MCR but may be applied to a cable spreading room (CSR) devoid of other equipment, and cable vault and tunnel areas meeting the criteria. Other plant locations may also be assigned the "very low" (0.3) ranking factor provided all of the defined criteria are met.

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients

- A ranking value for each factor is assigned to each PAU

$$Ranking_{J,L} \rightarrow \{ n_{genmaint,J,L} , n_{occup,J,L} , n_{storage,J,L} \}$$

- The total for the room is the simple sum of the three assigned values:

$$N_{GT,J,L} = (n_{genmaint,J,L} + n_{occup,J,L} + n_{storage,J,L})$$

- The total for the location set is the sum of the values for each PAU:

$$N_{GT,L} = \Sigma N_{GT,J,L} \quad \textit{(summed over J, for all PAUs included in location set L)}$$

- The PAU_J general transients weighting factor is the ratio of these two values:

$$W_{GT,J,L} = N_{GT,J,L} \ / \ N_{GT,L}$$

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients caused by hot work

- This is for bins **3, 6, 24,** and **36**
- Process is similar but there is only <u>one</u> ranking factor:
  - Hot work maintenance activities - welding and cutting
- Ranking values for $N_{WC,J,L}$ are:
  - **No (0)** - Can be used only for those PAUs where hot work is precluded by design
    - <u>Administrative restrictions do not qualify for a ‘0’ ranking</u> *
  - **Extremely low (0.1)** – only allowed in MCR (requires verification)
  - **Very low (0.3)** – only applies two places:
    - Cable spreading room (CSR) (required verification)
    - MCR if it did not qualify for 0.1 ranking
  - **Low (1)** – Reflects minimal level hot work
  - **Medium (3)** – Reflects average level of hot work
  - **High (10)** – Reflects the higher-than-average level of hot work
  - **Very high (50)** – Reflects the significantly higher-than-average level of hot work

*See IGN-A8 – assign an ignition frequency greater than zero to every PAU (CC-I/II) or PAU and risk relevant ignition source (CC-III)

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients caused by hot work

Influencing Factor	Ranking value	Where Applicable
Hot work	**No (0)**	Hot work activities during power operation are precluded by design and/or operation (see discussion in Section 6.5.7.2).
	Extremely Low (0.1)	This specialized Hot Work factor of 0.1 may be applied to the MCR provided plant procedures prohibit hot work in the MCR during power operations. Application requires that a review of plant records be performed and the review confirms that no violations of, or exceptions to, the MCR hot work restrictions while at power have been recorded over some reasonable prior time period (i.e., five years).
	Very Low (0.3)	May be applied to the CSR and to cable vault and tunnel areas provided that (1) access to the location is strictly controlled (see discussion above), (2) the location contains no plant equipment or components other than cables, fire detectors, and junction boxes, (3) hot work during power operations is prohibited by plant procedures, and (4) a review of plant records is performed and confirms that no violations of those plant procedures have been recorded over some reasonable prior time period (i.e., five years). This 0.3 ranking may also be applied to the MCR if the previous conditions for an extremely low ranking of 0.1 are not satisfied.

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Transients caused by hot work

- Each PAU (J) within a location set (L) gets a hot work ranking factor:

$$\text{PAU weighting factor -> } N_{WC,J,L}$$

- Normalizing factor for the location set (L) as a whole:

$N_{WC,L} = \Sigma N_{WC,J,L}$ *(summed over J, for all PAUs included in location set L)*

- The PAU_J “transients caused by welding and cutting” weighting factor is the ratio of the PAU to the location set:

$$W_{GT,J,L} = N_{WC,J,L} \;/\; N_{WC,L}$$

Fire Ignition Frequencies
Step 7 - $W_{IS,J,L}$ – Cables fires caused by hot work

- Cable fires caused by hot work is similar, but adds a factor based on the relative cable mass/volume in each PAU (J) of the location set (L)

  $W_{cable,J,L}$ = Ratio of cable load in PAU (J) over the total cable load for all members of location set (L)

  – Check your fire hazards analysis (FHA combustible fuel loads)
- Use the hot work weighting factors you already have ($N_{WC,J,L}$)
- The normalizing factor is:

$$N_{HWCF,L} = \sum W_{cable,J,L} \times N_{WC,J,L}$$ (sum over all PAUs in the location set)

- The weighting factor for PAU J is:

$$W_{HWCF,J,L} = [\, W_{cable,J,L} \times N_{WC,J,L} \,] \,/\, N_{HWCF,L}$$

Fire Ignition Frequencies
Step 7 – Final notes on weighting factors

- Weighting factors are always relative ***within each frequency bin / location set***
  - Each ignition source bin where we apply weighting factors defines a location set
  - *DO NOT* weigh across bins, *DO NOT* weight across location sets:
    - For transients in the turbine building (Bin 37), weigh locations in the turbine building against each other
    - For transients in the Aux/Control/Reactor building complex (Bin 7), weigh locations in that complex against each other
    - Do NOT compare the turbine building to the control building. That comparison is built into the base frequencies

Fire Ignition Frequencies
Step 7 – Final notes on weighting factors

- A ranking of **3** is considered Normal/Average/Typical
  - Decide what is "typical" for the location set overall – just the one set
  - Define that condition as "3" in your ranking scheme
  - Everything else is up or down from the typical condition
  - You **do not** need to average the rankings for a set and show the average is 3…
- The method is designed to reflect real differences in the likelihood of these kinds of fires in different locations
  - You need to exercise the full range of ranking values to take full advantage of the method
  - Otherwise, frequency for each bin will be distributed evenly to each PAU

Fire Ignition Frequencies
Step 8 – Fire Frequency Evaluation

- The fire frequency (generic or plant-specific) for each ignition source, $\lambda_{IS,J}$, can now be calculated using the data quantified in the preceding steps

$$\lambda_{J,L} = \underbrace{\Sigma\, \lambda_{IS}\, W_L\, W_{IS,J,L}}_{\text{summed over all ignition sources}}$$

Where:

$\lambda_{J,L}$: Fire frequency associated with PAU J at location L

λ_{IS}: Plant level fire ignition frequency associated with ignition source IS

W_L: Location weighting factor

$W_{IS,J,L}$: Ignition source weighting factor

Corresponding PRA Standard: IGN-A7

Fire Ignition Frequencies
Concluding remarks

- Fire ignition frequency evaluation (Task 6) uses a mix of plant specific and generic information to establish the ignition frequencies for specific fire compartments or PAUs and from that for specific fire scenarios.
  - Generic fire ignition frequencies based on industry experience
  - Elaborate data analysis method
  - Frequencies binned by equipment type
  - Methodology to apportion frequencies according to relative characteristics of each fire compartment or PAU

Mapping HLRs & SRs for the IGN Technical Element to NUREG/CR-6850 / EPRI 1011989

Technical element	HLR	SR	6850 sections	Comments
IGN	A	The Fire PRA shall develop fire ignition frequencies for every physical analysis unit that has not been qualitatively screened.		
		1	Appendix C	The generic frequencies have been modified in EPRI 1019259 to reflect changes in fire event frequency trends. The methodology used in that study is also consistent with this SR.
		2	6.5.1	
		3	n/a	Using engineering judgment to establish a frequency is not addressed in 6850/1011989.
		4	6.5.2, 6.5.3	
		5	6.5.3 and Appendix C	The generic frequencies of EPRI 1019259 are also consistent with this SR.
		6	6.5.3	
		7	6.5.1, 6.5.4, 6.5.5, 6.5.6, 6.5.7	
		8	n/a	Although it is effectively implied in Section 6.5.7.2, this SR is not explicitly discussed in 6850/1011989.
		9	6.5.7	Inherent in transient weighting factor ranking approach
		10	6.5.3, Appendix C	Generic frequencies consistent with this SR
	B	The Fire PRA shall document the fire frequency estimation in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	n/a	Documentation is covered in minimal detail in 6850/1011989
		2	n/a	
		3	n/a	
		4	n/a	
		5	n/a	

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