DAY 1 - Transition Examples

Transitioning From Appendix R to NFPA 805: Overview of Change Evaluation Process

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September 19-22, 2004

Fire Protection Program

- 10 CFR Part 50.48(c)(3)(i) [2004]
  - A licensee may maintain a fire protection (FP) program that complies with NFPA 805 as an alternative to [Appendix R or its equivalent].
- NFPA 805 (2001)
  - Performance Based Standard for FP of LWRs
- NEI 04-02 (2004)
  - Guidance for Implementing Risk-informed Performance Based FP Program Under 10 CFR 50.48(c)

NFPA 805

- Section 4.2.4, Performance-Based Approach
  - Two performance-based alternatives to deterministic approach (Section 4.2.3) to specify fire protection systems and features to meet nuclear safety performance criteria (Section 1.5.1)
    - Subsection 4.2.4.1 – Fire Modeling
    - Subsection 4.2.4.2 – Fire Risk Evaluation
      - Probabilistic safety assessment for fire-induced core damage and large early release (Section 2.4.3)

NFPA 805
(Continued)

- Section 2.4.4, Plant Change Evaluation
  - Plant change evaluation to ensure change to fire protection program element is acceptable
    - Risk acceptance criteria based on core damage and large early release frequencies
      - Evaluation of cumulative changes
    - Maintaining of philosophy of defense-in-depth
      - Deterministic approach satisfactory
    - Maintaining of sufficient safety margins
      - Deterministic approach satisfactory

NEI 04-02

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- Section 5.3, Plant Change Process
  - If deterministic criteria (NFPA 805, Section 4.2.3) are met along with defense-in-depth and safety margin requirements, plant change can be completed without further analysis
  - Otherwise, assess plant change via one or both of the following pathways
    - Fire Modeling
    - Risk Assessment

NEI 04-02
(Continued)

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- Section 5.3
  - 5.3.1, Overall change evaluation process
    - All pathways
  - 5.3.2, Acceptance criteria
    - Quantitative risk, based on RG 1.174
    - Defense in depth, based on NEI 00-01
    - Safety margins
      - Fire modeling, plant system performance, probabilistic safety assessment logic model, and miscellaneous
    - Uncertainties, based on RG 1.174

Change Evaluation Process

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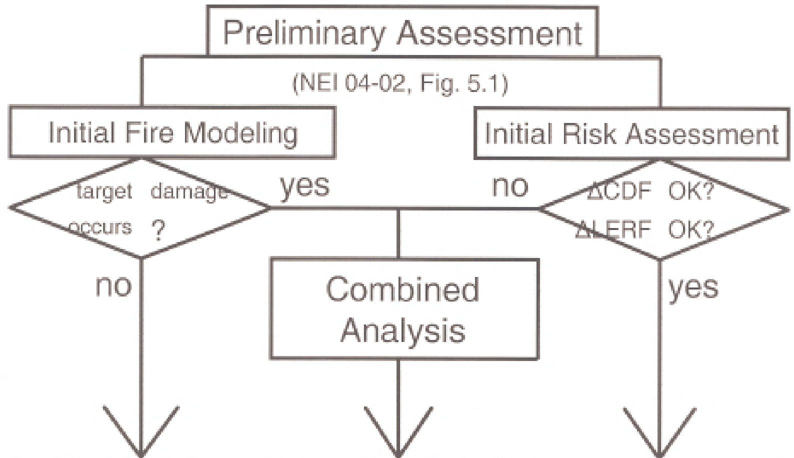

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Fire Modeling Path

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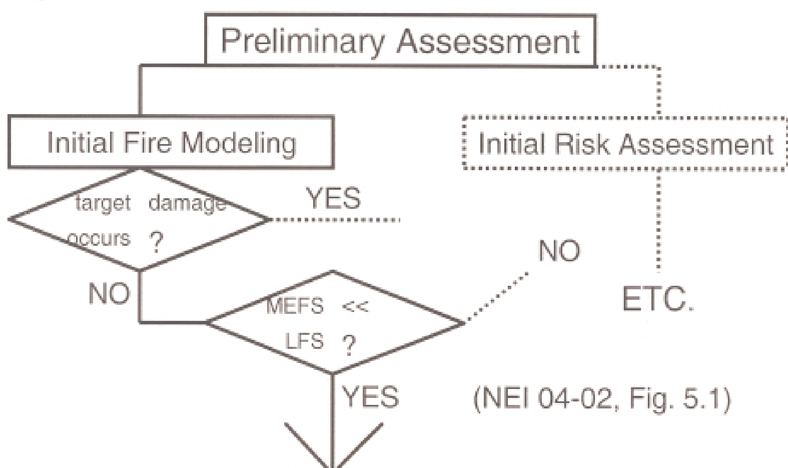

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Fire Modeling Path

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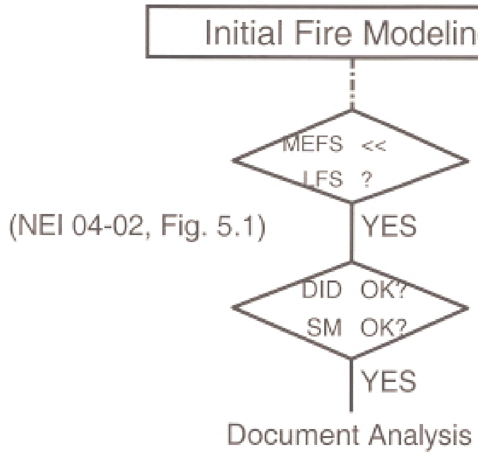

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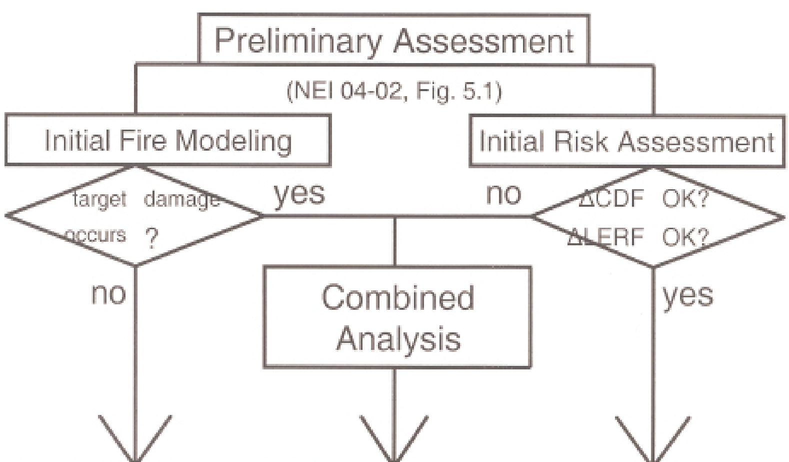
Change Evaluation Process



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Risk Assessment Path

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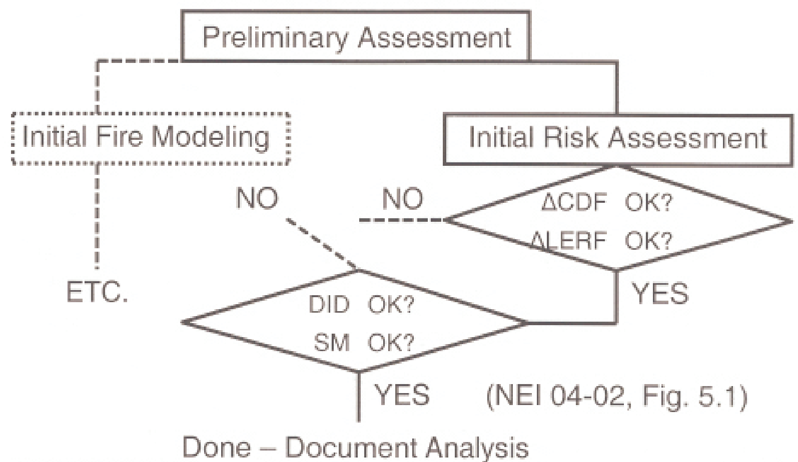

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Change Evaluation Process

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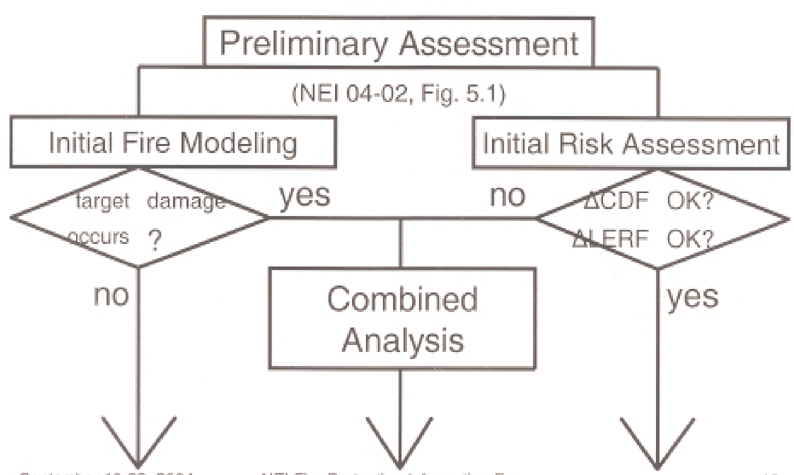

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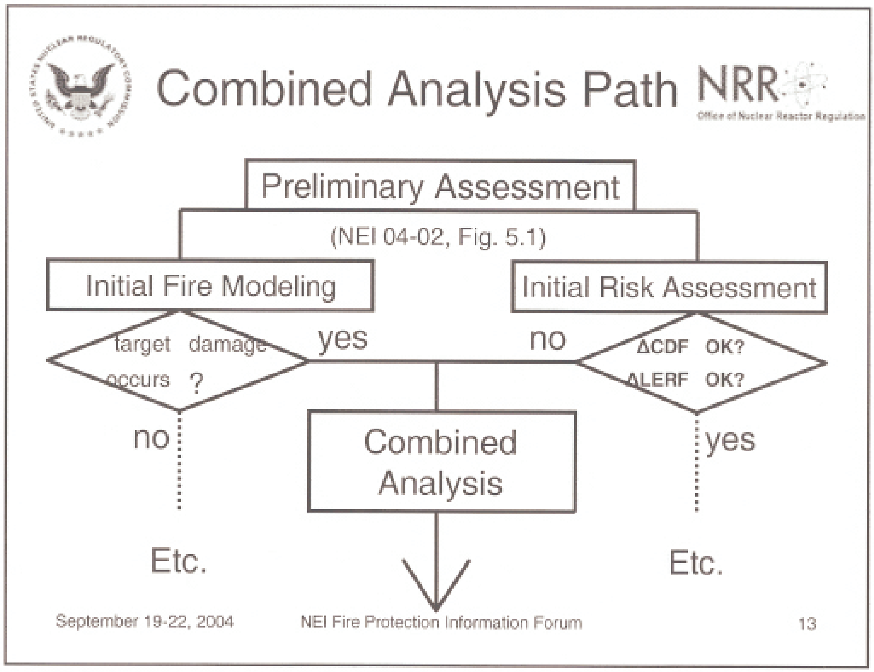
Combined Analysis Path
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Preliminary Assessment
(NEI 04-02, Fig. 5.1)
Initial Fire Modeling
Initial Risk Assessment
target damage occurs ?
yes
no
ΔCDF OK?
ΔLERF OK?
no
Combined Analysis
yes
Etc.
Etc.
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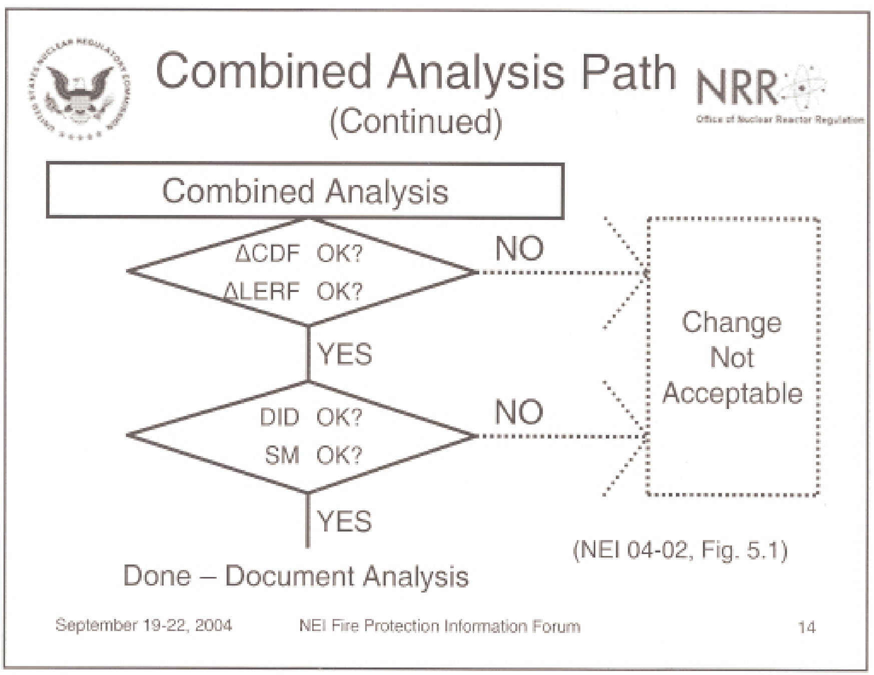
Combined Analysis Path
(Continued)
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Combined Analysis
ΔCDF OK?
ΔLERF OK?
NO
YES
DID OK?
SM OK?
NO
Change Not Acceptable
YES
Done – Document Analysis
(NEI 04-02, Fig. 5.1)
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Plant Change Evaluation Examples

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- Three artificial examples, solely to illustrate plant change evaluation process
  - Fire Modeling Pathway
    - Transient combustibles
  - Risk Assessment Pathway
    - Manual suppression
  - Combined Analysis Pathway
    - Train free of fire damage

Transitioning From Appendix R to NFPA 805: Fire Modeling Pathway

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TRANSITIONING FROM APPENDIX R TO NFPA 805: FIRE MODELING PATHWAY

Illustrative method for NFPA 805 transition (Section 4.2.4.1) via transient combustibles example

Two Redundant Trains

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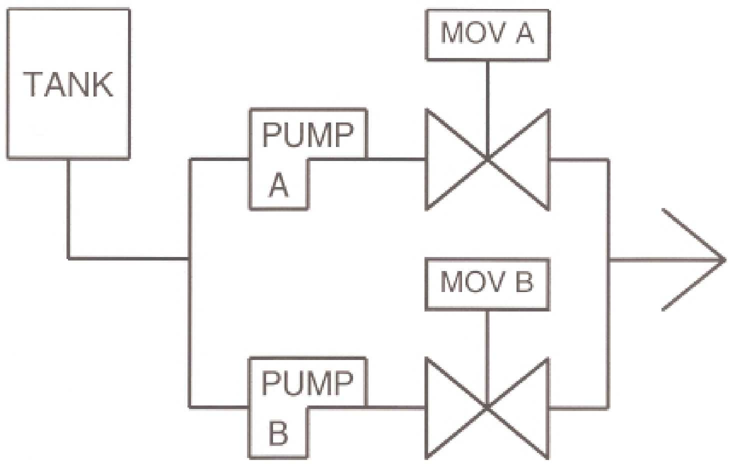

"'Pinch Point" Schematic

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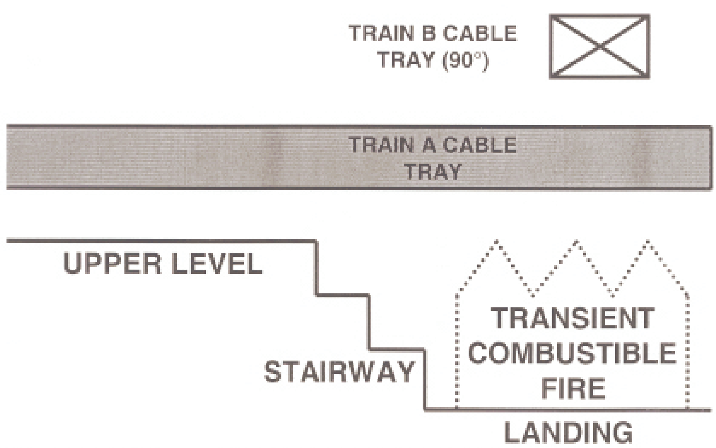

Appendix R

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- III.G.2 Fire Area
  - Train B cables "protected" by non-compliant 3-hr fire barrier
    - Train A and B cables are vertically co-located only above landing ("pinch point")
    - No fire detector or suppression system in landing area
  - Landing area was not originally identified as separate from overall, larger fire area containing cables for both trains

Identify Fire Sources

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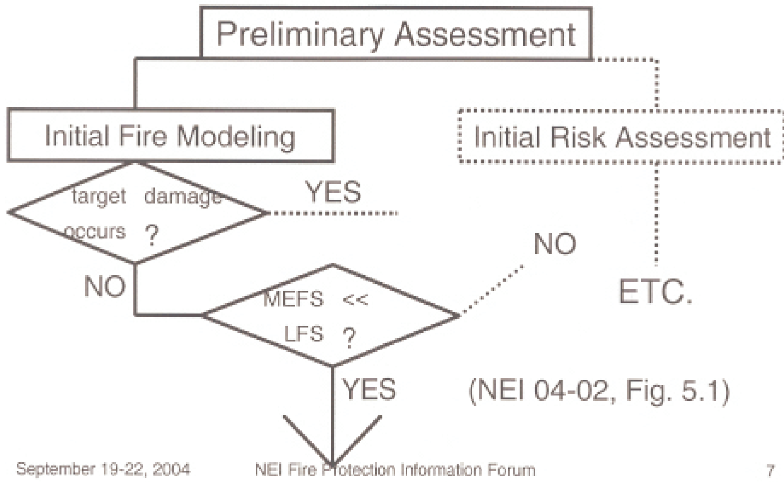
- No permanent combustibles in landing area
  - Cables for both Trains A and B are thermoset and IEEE-383 "qualified"
    - Self-ignition not a concern
    - Damage threshold = 625°F
  - Transient combustibles could be located on the landing beneath both cable trays
    - Amount based on combustible loading limits

Change Evaluation Process



(NEI 04-02, Fig. 5.1)

Maximum Expected Fire Scenario (MEFS)

- NFPA 805, Section 1.6.39
  - MEFS represents "the most challenging [fire] that could <u>reasonably be anticipated</u> for the occupancy type and conditions in the space"
- Define "target set"
  - Lower of two cable trays above landing
    - If lower ignites, upper can be ignited by lower

“”Pinch Point” Schematic

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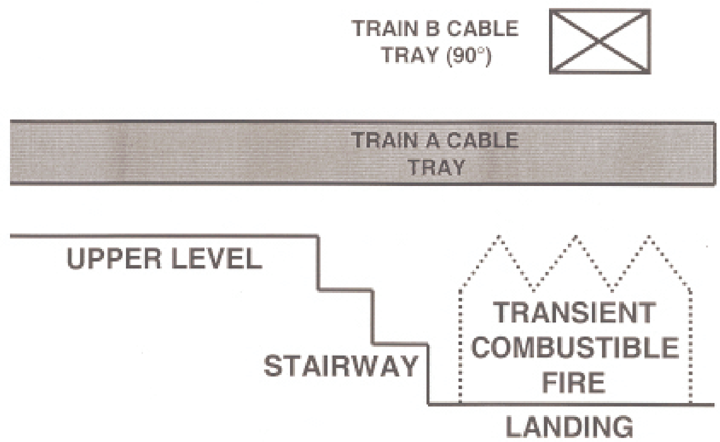

MEFS (continued)

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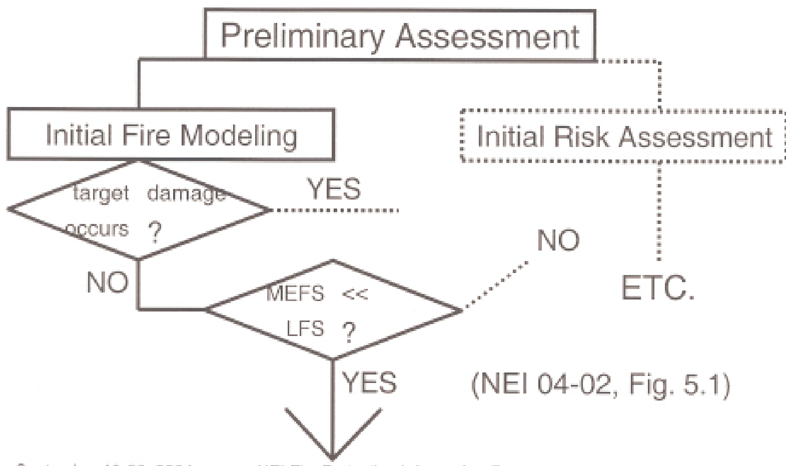
- Perform CFAST fire model for transient combustible fire at the landing
  - Assume transients based on combustible loading limits (Fire Protection Program)
    - Representative transient fire → peak heat release rate = 332 kW with fire duration = 10 min
    - CFAST smoke layer environment with corner thermal plume at target elevation
    - Maximum exposure temperature = 270°F << threshold of 625°F → *NO TARGET DAMAGE!*

Change Evaluation Process



(NEI 04-02, Fig. 5.1)

Limiting Fire Scenario (LFS)

- NFPA 805, Section 1.6.37
  - LFS is scenario where "one or more of the inputs to the fire modeling calculation (e.g., heat release rate …) are varied to the point that the performance criterion is not met"
  - Intent is to determine if <u>reasonable margin</u> exists between MEFS conditions and failure threshold, i.e., is MEFS << LFS?

LFS (continued)

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- LFS is one where threshold ignition temperature of 625°F is reached
  - Heat release rate would have to be at least four times greater than 332 kW from MEFS
    - For representative transient fire, combustible mass would have to be nearly 10 times larger
      - May be physically (if not procedurally) impossible to locate this large a mass of transient combustibles on the landing
    - LFS requirements (heat release rate, combustible loading) are >> MEFS requirements
      - Essentially satisfies safety margin criteria

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Evaluation Process

(Continued)

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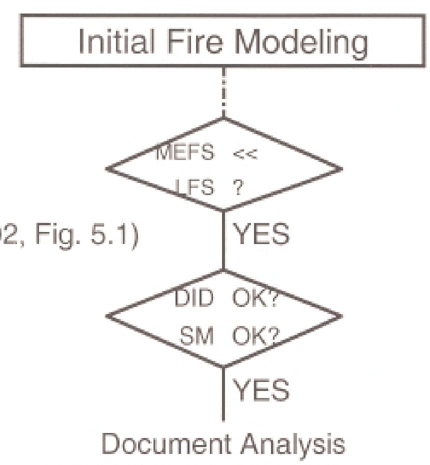

(NEI 04-02, Fig. 5.1)

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Adequate DID and SM

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- NFPA 805 also requires that adequate defense-in-depth (DID) and sufficient safety margin (SM) be maintained
  - Typically, DID is evaluated qualitatively based on objectives for Fire Protection Program in 10 CFR Part 50, Appendix R, Section II.A
    - Prevent fires from starting
    - Rapidly detect, control, and extinguish fires that do occur
    - Provide protection for structures, systems, and components (SSCs) important to safety so that a fire that is not promptly extinguished will not prevent plant safe shutdown (SSD)

DID and SM
(Continued)

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- Non-compliant 3-hr fire barrier for Train B cables
  - No challenge to fire ignition or rapid detection, control, and extinguishment
  - Challenges protection for SSCs important to SSD when exposed to non-extinguished fire
    - Challenge shown to be negligible via Fire Modeling (MEFS << LFS)
- Both DID and SM criteria are satisfied

Summary

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- Example for transient combustibles chosen to illustrate transition to NFPA 805 via Change Evaluation Process pathway for <u>initial fire modeling</u>
  - MEFS does not damage target set, AND
  - Reasonable margin exists between MEFS conditions and failure threshold, i.e., MEFS << LFS
    - Qualitative DID and SM criteria

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Transitioning From Appendix R to NFPA 805: Risk Assessment Pathway

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TRANSITIONING FROM APPENDIX R TO NFPA 805: RISK ASSESSMENT PATHWAY

Illustrative method for NFPA 805 transition (Section 4.2.4.2) via manual suppression example

Appendix R

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- 10 CFR Part 50, Appendix R, Paragraph III.G.2
  - Except as provided for in paragraph G.3 …, one of the following means of ensuring that one of the redundant trains is free of fire damage shall be provided [non-inerted containment]
    - Separation … by a fire barrier having a 3-hour rating
    - Separation … by a horizontal distance of more than 20 feet with no intervening combustible or fire hazards ... [with] fire detectors and an automatic fire suppression system
    - Enclosure … in a fire barrier having a 1-hour rating ... [with] fire detectors and an automatic fire suppression system

Appendix R (continued)

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- 10 CFR Part 50, Appendix R, Paragraph III.G.3
  - Alternative or dedicated shutdown capability … in the area … under consideration should be provided
    - Where the protection of systems whose function is required for hot shutdown does not satisfy the requirement of paragraph G.2 of this section; or
    - Where redundant trains of systems required for hot shutdown located in the same fire area may be subject to damage from fire suppression activities or from the rupture or inadvertent operation of fire suppression systems
  - In addition, fire detection and a fixed fire suppression system shall be installed

Cable Spreading Room

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- Appendix R licensee has cable spreading room (CSR) protected by non-compliant fixed gaseous suppression system
  - Cables for numerous redundant trains are present
  - Compensatory measures temporarily in place
- Compliance alternatives
  - "Deterministic" – upgrade current or install new suppression system (expensive), or file exemption
  - "Risk-informed, performance-based" – NFPA 805

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Change Evaluation Process

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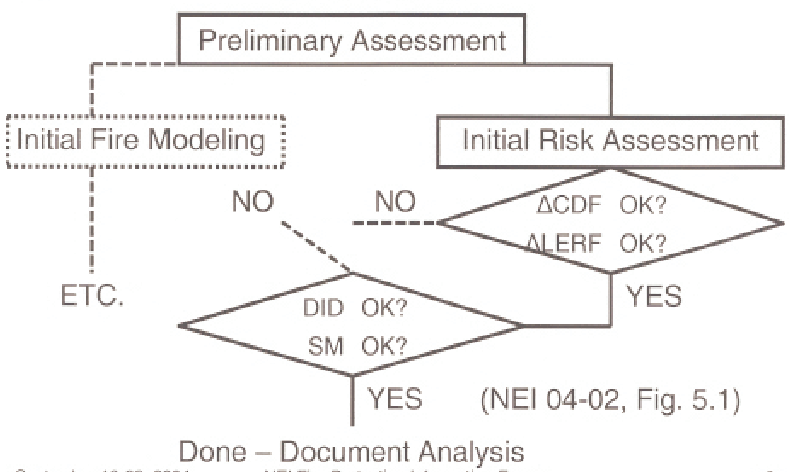

(NEI 04-02, Fig. 5.1)

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Appendix R → NFPA 805

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- Preliminary assessment via initial fire modeling or initial risk assessment
- "An example approach for acceptance criteria for changes in risk from a plant change can be found in Regulatory Guide [RG] 1.174" (NFPA 805)
  - RG 1.174 and NFPA 805 also require that adequate defense-in-depth (DID) and sufficient safety margin (SM) be maintained

Initial Risk Assessment

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- Fire frequency, CSR (λ) = 0.003/yr
- Probability of non-suppression (P_{NS})
  - System maloperates (0.05) + suppressing agent is ineffective (0.05) ≈ 0.1
- Probability of cable failures (P_{CF}) = 0.1
- Conditional core damage probability (CCDP) = 0.1 (alternative shutdown)
  - All of above are "mean" values

Risk Assessment (Cont.) NRR

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- Δ Core damage frequency (CDF)
  - $\lambda * P_{NS} * P_{CF} *$ CCDP = 3E-6/yr ("mean")
  - "Mean" ΔCDF does not satisfy RG 1.174 quantitatively (i.e.,< 1E-6/yr)
  - Alternatives
    - Upgrade current or install new suppression system
      - Satisfy "deterministic" requirements (Appendix R, III.G.3)
    - Credit highly reliable automatic detection and manual suppression by plant fire brigade
      - Re-evaluate ΔCDF

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Risk Assessment (Cont.) NRR

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- Credit highly reliable automatic detection and manual suppression by plant fire brigade
  - Probability of non-suppression, manual (P_{NS}) = 0.01
- From before
  - Fire frequency, CSR (λ) = 0.003/yr
  - Probability of cable failures (P_{CF}) = 0.1
  - Conditional core damage probability (CCDP) = 0.1 (alternative shutdown)
- "Mean" ΔCDF now = 3E-7/yr
  - Satisfies RG 1.174 quantitatively (i.e., < 1E-6/yr)

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Risk Assessment (Cont.)

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- RG 1.174 also requires that adequate DID and sufficient SM be maintained
  - Typically, this is evaluated qualitatively
    - Nonetheless, a quantitative estimate on the upper bound ΔCDF can suggest whether additional DID or SM is needed

Change Evaluation Process

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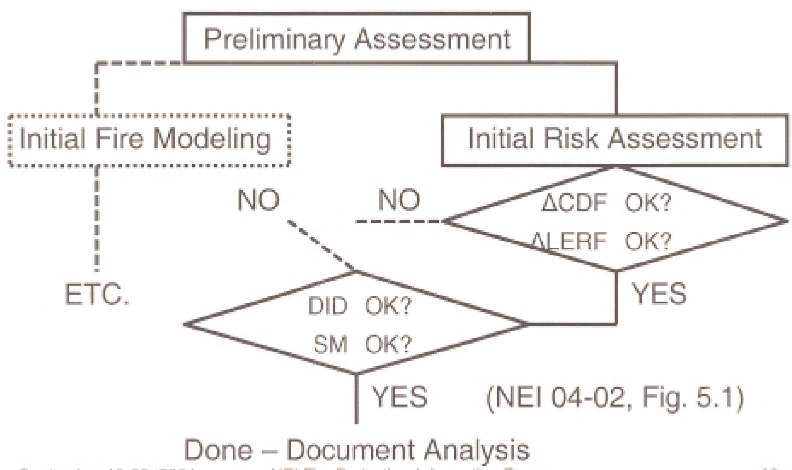

(NEI 04-02, Fig. 5.1)

Risk Assessment
(Continued)

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- Assume λ, P_{NS}, P_{CF} and CCDP are lognormal variables with large error factors (EFs) of 10 each → total compound EF on ΔCDF < exp $\{(4[\ln 10]^2)^{0.5}\} \approx 100$, implying an upper bound ≈ 6E-7/yr (i.e., 100 * median, not mean [≠ 100 * 3E-7/yr])
  - Even this upper bound satisfies the RG 1.174 criterion of 1E-6/yr, suggesting adequate DID and SM
  - RG 1.174 ΔLERF requirements follow parallel thought process (omitted in example)

Summary

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- Example for manual suppression under Appendix R, Paragraph III.G.3, chosen to illustrate transition to NFPA 805 via Change Evaluation Process pathway for initial risk assessment
  - RG 1.174 quantitative (ΔCDF [and ΔLERF]) and qualitative (DID and SM, with quantitative representation) criteria are satisfied

Transitioning From Appendix R to NFPA 805: Combined Analysis Pathway

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TRANSITIONING FROM APPENDIX R TO NFPA 805: COMBINED ANALYSIS PATHWAY

Illustrative method for NFPA 805 transition (Section 4.2.4) via train free of fire damage example

Flow Diversion - MOV

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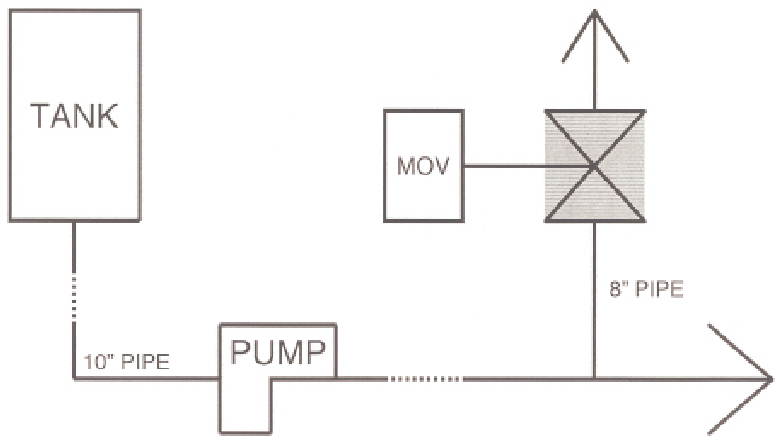

Train Free of Fire Damage

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- Normally de-energized conductor for normally-closed MOV in flow diversion path located in same cable (and cable tray) with other energized conductors
  - Spurious energizing of MOV control cable due to fire-induced "hot short" with an energized conductor could open MOV → flow diversion
    - MOV and its cable are within train that needs to be free of fire damage

Change Evaluation Process

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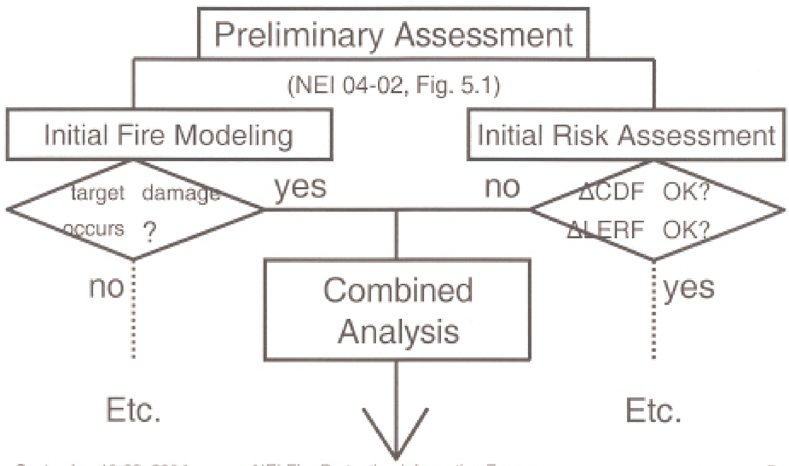

Initial Fire Modeling

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- Maximum Expected Fire Scenario (MEFS)
  - Most challenging fire that can reasonably be expected to occur → "realistic and conservative" (NFPA 805, Section 1.6.39)
  - Assume thermoplastic cables subject to MEFS with exposure temperature = 550°F
    - Thermoplastic control cables subject to fire damage at > 400°F → "target damage" can occur
      - Possible "hot shorting" of MOV control circuit with another de-energized conductor in same or adjacent cable

Initial Risk Assessment

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- Fire frequency (λ) = 0.01/yr
- Probability of non-suppression (P_{NS}) = 0.05
- Probability of cable failure (P_{CF})
  - At 550°F, thermoplastic cable fails in 7 min
  - Assume fixed halon suppression system, if effective, extinguishes fire in 1 min
    - P_{CF} (6-min "damage" margin) = 0.25

Risk Assessment
(Continued)

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- Probability of spurious actuation (P_{SA})
  - Thermoplastic, intra/inter-cable = 0.6
- Conditional core damage probability (CCDP) = 0.05
- Δ Core damage frequency (CDF) = product of all of above = 4E-6/yr > 1E-6/yr
  - All of above are "mean" values

Combined Analysis

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- Two pathways
  - Initial fire modeling → target damage occurs? YES (550°F > 400°F)
  - Initial risk assessment → ΔCDF (ΔLERF) ok? NO (4E-6/yr > 1E-6/yr)
- When neither pathway succeeds, perform Combined Analysis
  - More detailed modeling of fire effects may lower ΔCDF (ΔLERF)

Change Evaluation Process

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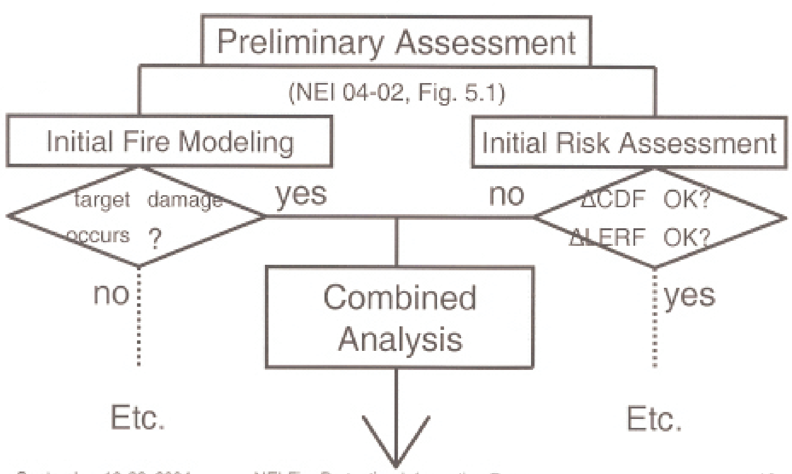

Evaluation Process

(Continued)

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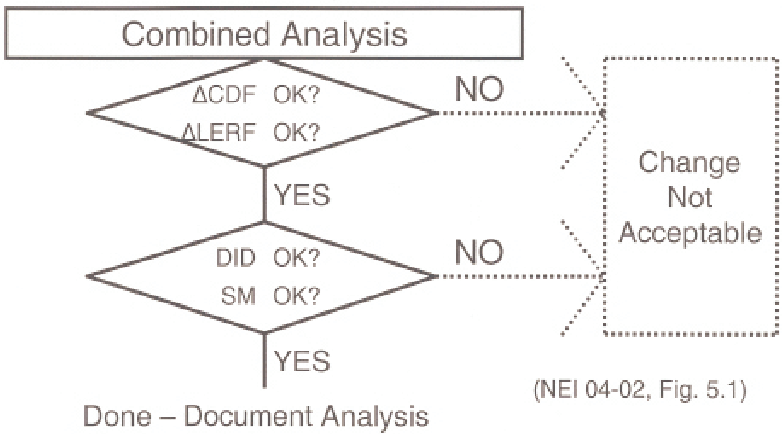

(NEI 04-02, Fig. 5.1)

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Combined Analysis

(Continued)

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- ΔCDF (4E-6/yr) assumed zonal $\lambda = 0.01$/yr
  - More detailed modeling of fire scenario indicates "severity factor" (likelihood that MEFS actually damages target cable) = 0.1
    - Also, fire cannot damage all components in zone, leaving available some previously assumed to be lost → CCDP reduced by factor of 2
  - ΔCDF = (0.1/2) x 4E-6/yr = 2E-7/yr < 1E-6/yr
    - (Similar approach for ΔLERF, omitted in example)

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Evaluation Process
(Continued)

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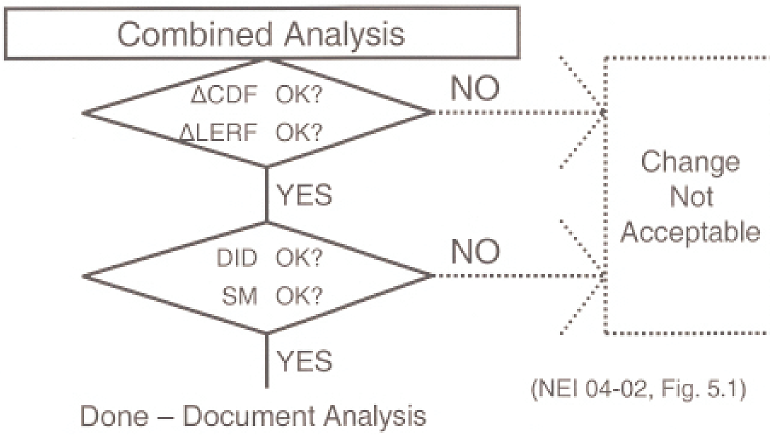

(NEI 04-02, Fig. 5.1)

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Adequate DID and SM

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- Although typically qualitative, a quantitative estimate on the upper bound ΔCDF can suggest whether additional DID or SM is needed
  - Assume λ, P_{NS}, P_{CF} and CCDP are lognormal variables with large EFs of 10 each
    - Total compound EF on ΔCDF = $\exp\{(4[\ln 10]^2)^{0.5}\} \approx 100$, implying an upper bound ≈ 4E-7/yr < 1E-6/yr
  - DID and SM criteria, in addition to ΔCDF and ΔLERF (omitted in example) are satisfied

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Summary

- Example for train free of fire damage chosen to illustrate transition to NFPA 805 via Change Evaluation Process pathway for <u>combined analysis</u>
  - Initial fire modeling indicates that target damage occurs, AND
  - Initial risk assessment indicates ΔCDF or ΔLERF > RG 1.174 acceptance threshold