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APPROPRIATE FIRE SCENARIOS AND SPRINKLER SYSTEM RELIABILITY FOR FIRE ENGINEERED DESIGNS

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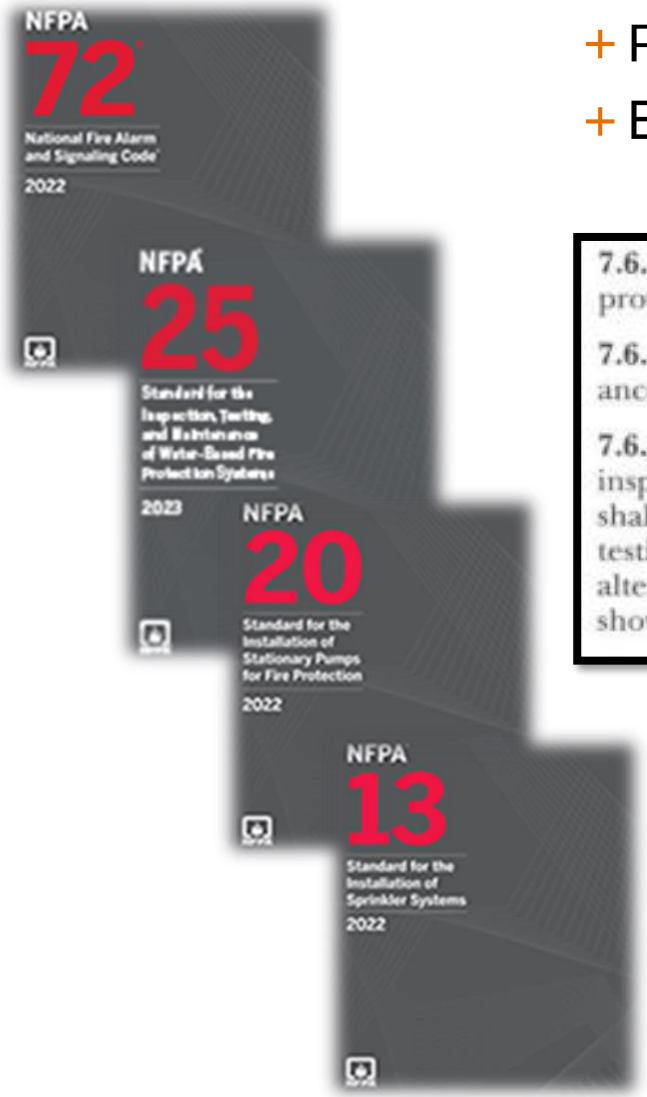
Objectives

This presentation covers

- Key practical definitions for
  - Reliability
  - Availability
- Factors influencing reliability and availability
- Generic reliability values
- Performance based approaches for inspection, testing and maintenance (ITM)

Reliability… Its Managed Daily!



+ Prescriptive requirements
+ Example… NFPA 72

7.6.4 Periodic inspection and testing documentation shall be provided in accordance with 14.6.2 through 14.6.4.

7.6.5 Impairment documentation shall be provided in accordance with Section 10.21.

7.6.6 Record of Inspection and Testing. The record of all inspections, testing, and maintena
shall be documented using either t
testing forms, Figure 7.8.2(g) thro
alternative record that includes all
shown in Figure 7.8.2(g) through F

14.2.2 Performance.

14.2.2.1 Performance Verification. To ensure operational integrity, the system shall have an inspection, testing, and maintenance program.

14.2.2.1.1 Inspection, testing, and maintenance programs shall satisfy the requirements of this Code and conform to the equipment manufacturer's published instructions.

14.2.2.1.2* Inspection, testing, and maintenance programs shall verify correct operation of the system.

14.2.2.2 Impairments. Where an automatic function of a fire alarm or signaling system is taken out of service for testing and a manual means or other compensatory measures are unavailable, the system or portion thereof is impaired and shall comply with the requirements of Section 10.21 until the automatic function is restored.

14.2.2.3 Deficiencies.

14.2.2.3.1 System deficiencies shall be corrected.

10.21* Impairments.

10.21.1 The system owner or the
tative shall be notified when a
impaired. Impairments to systems
events.

10.21.2 A record of the impairm
the system owner or the owner's d
period of 1 year from the date the

Reliability… Its Managed Daily!

- Performance-Based/Risk-Informed requirements
- Example: NFPA 551, Standard for the Review of Fire Risk Assessments

5.1.4.5 Assessment of Reliability, Availability, and Efficacy.

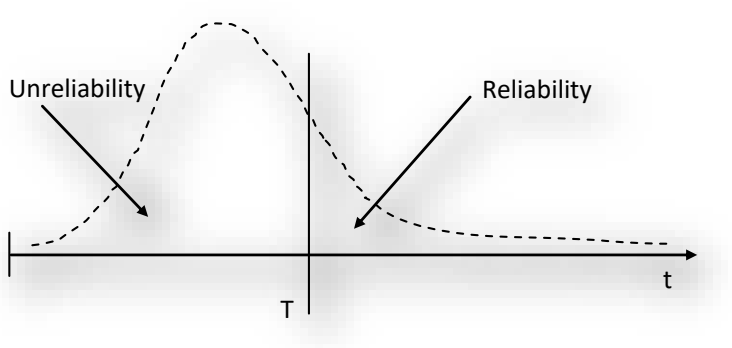
5.1.4.5.1 Methods of analysis should address reliability, availability, and efficacy of fire protection and other key systems as part of the FRA. These elements are necessary to evaluate the likelihood of the mitigation strategies' success.

5.1.4.5.2* The effectiveness of fire protection equipment, features, programs, and procedures changes over time. The FRA should consider how these changes can affect risk.

Reliability: Text Book Definition

- Reliability, R(t), is a probability of an item functioning AFTER time T (mission time)
- The fundamentals of reliability analysis
  - found in probability and statistical theory,
  - in the physical characterization of the failure mechanisms.
- Focus on the statistical methods for analyzing reliability
  - time is considered an aggregate agent of failure
- Time to failure is the random variable

$$R(t) = \int_{T}^{\infty} f(t)dt = 1 - \int_{0}^{T} f(t)dt$$



Reliability: Technical Areas

- Non-Repairable components
  - e.g., sprinkler heads
- Repairable components
  - e.g., fire pump
- Human reliability
  - e.g., errors during inspection/testing
- **System reliability: Integrates all elements**
  - **(e.g., fire pumps + piping + sprinkler heads + main power + backup power + operator…)**

Reliability Analysis

Follows the same "standard" process for an engineering analysis

+ Define system boundaries
+ Conduct failure analysis
+ Collect reliability data
+ Select modeling method or technique
+ Quantification
+ Documentation

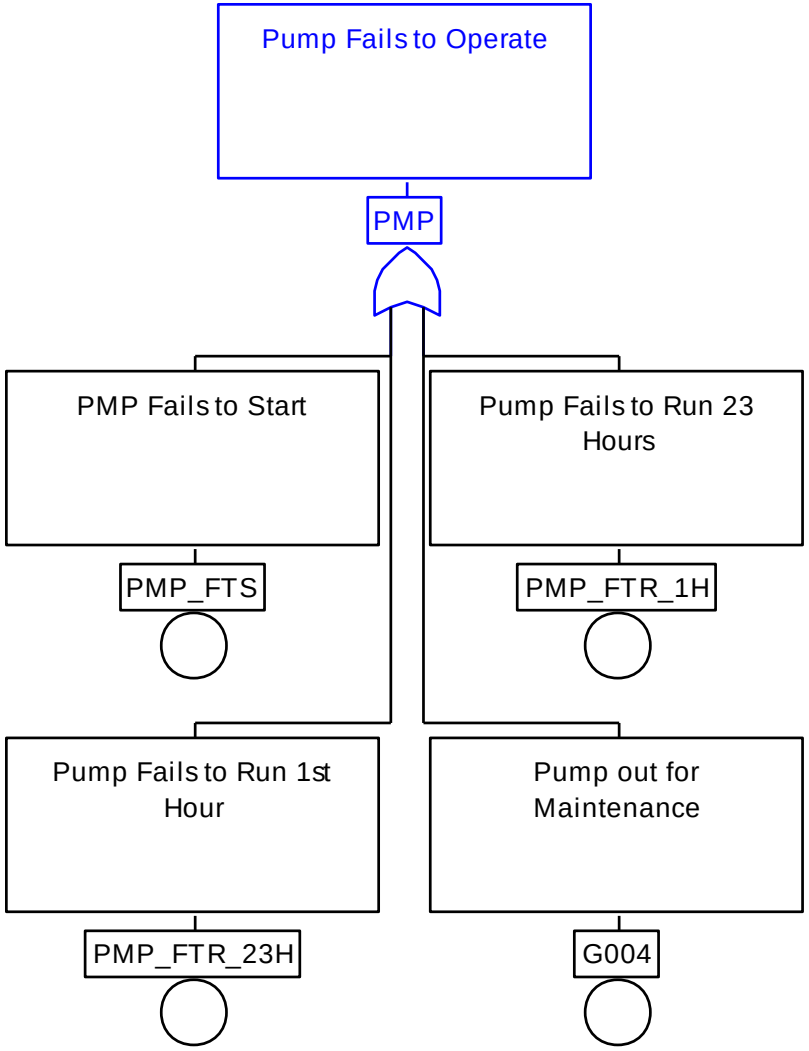
Availability: Text Book Definition

- Availability (A) is the probability that an item will be operational at a predefined time T.
  - Reliability is a probability of an item functioning AFTER time T
  - Availability refers to the probability of the item being operational AT time T
- Unavailability (U) is the complement
- The parameter d is the fraction of time the item is “down” (i.e., not in service)
- The parameter u is the fraction of time the item is “up” (i.e., in service)

$$A = \frac{u}{u + d}$$

$$U = \frac{d}{u + d} = 1 - A$$

Reliability VS Availability: Conceptual Example



- + Reliability
  - − Captures random failures
  - − Captures different types of failure modes
  - − Use reliability data, Example:
    - Equipment fails to start
    - Equipment fails to run in the first hour
    - Equipment fails to run in 23 hours
- + Availability
  - − Also based on data
  - − Captures maintenance
  - − Equipment out of service time

Reliability VS Availability: Conceptual Example

- Another way of understanding the interactions between availability and reliability is through a “state model” (e.g., Markov)
- Percentage of time in each state
  - Availability is the percentage of time in the operational state

- Therefore, managing availability includes:
  - Reducing failures (random equipment failure, human errors, etc.)
  - Reducing time locked-out time
  - Reducing down/repair times

Human Reliability

- Used for modeling human failure events (Example: Manual activation of a system)
- Calculates “human error probabilities”
- Mostly based on complexity of the task and time margin
- Should consider other human factor elements

Complexity

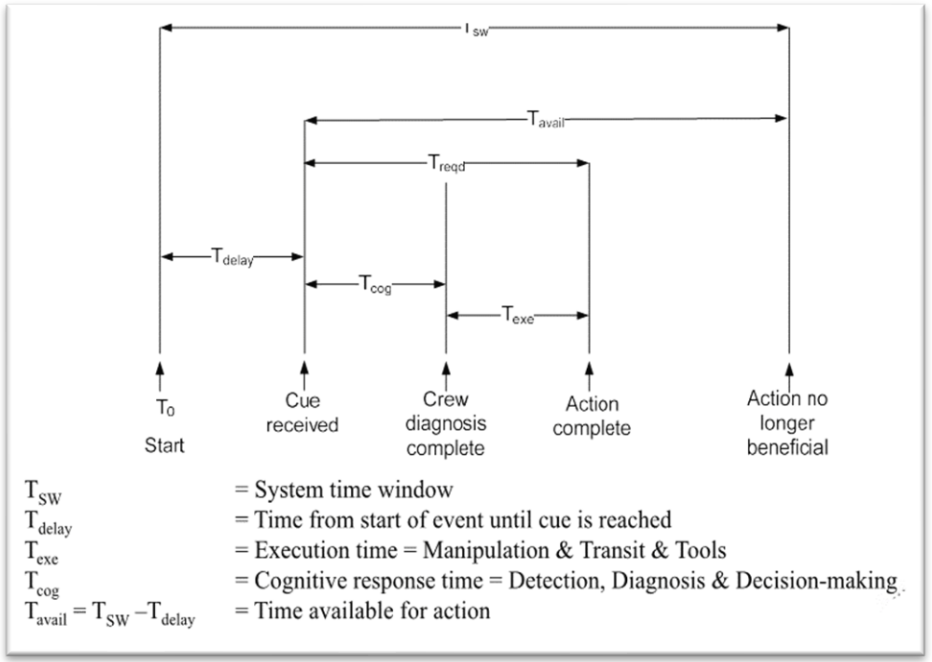
Multiple crew members in multiple locations performing steps

Multiple crew members performing steps in same location

Multiple step action

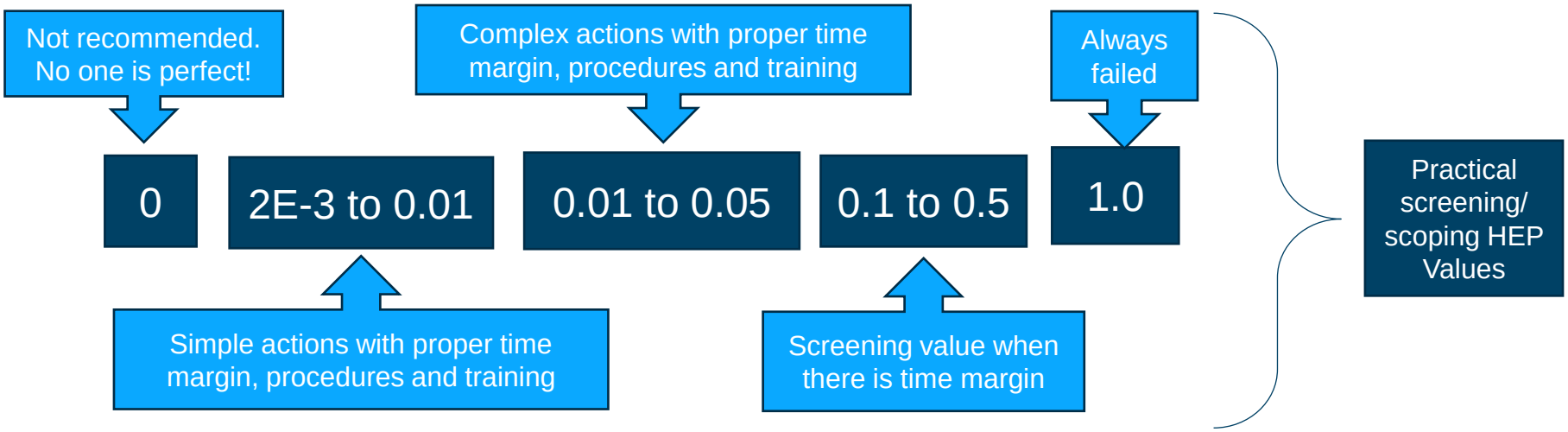
Single/Simple step action

Time



Human Reliability

Representative Screening/Scoping Human Error Probabilities (HEPs from NUREG 1921, Ex Control Room Actions)



- Treat these as representative “screening/scoping” level values
- Increase or decrease the value depending on specific situations:
  - Environment, human/machine interface, fitness, communications, availability of special tools, cues/alarms, staff, training, good procedures, etc.
- “Ex Control Room” suggest activities where personnel may need to travel to a specific location to perform the action.
- A full human reliability assessment requires:
  - Qualitative evaluation: Is the action feasible?
  - Quantitative evaluation: How reliable is a “feasible” action

But We Are Fire Protection Engineers…

Do We need "Availability" Calculations?

- In the deterministic world we use codes/standards with prescriptive requirements for inspection/testing/maintenance
  - NO, we don't need calculations, we manage the "availability" of the systems
  - Mostly comply with standard requirements/manufacturers recommendations
- In the performance based/risk informed world
  - MAYBE
    - Developing a risk assessment
    - Relaxation of deterministic requirements
- If you need calculations
  - Should understand qualitatively all the factors affecting "availability"
  - Best to find a reliability engineer
  - **Reliability data will be challenging (but should not be as standards require routing ITM)**

Generic Values

Are there easy generic values that I can use?

- Short/Simple answer is…. "Yes", but
  - Is the generic data representing your system?
  - Will the authority having jurisdiction accept the value?

- These systems are routinely inspected and tested
  - Reliability data should exist
  - Good data collection and maintenance will capture fire modes in time (e.g., aging effects)

- In performance based/risk informed applications
  - Generic values need to be justified
  - May require sensitivity/uncertainty analysis

Examples of Generic Values

For Automatic Sprinklers

- In 2021 NFPA published key findings on the United States experience with sprinklers. This summary notes that from 2015 to 2019:
  - When sprinklers were present and the fire was large enough to active them, sprinklers operated 92% of the time.
  - This value is repetitive of a combined sprinkler reliability and availability of 0.92.

Generic Reliability + Availability Values for Automatic Sprinklers[#]

Residential	Educational	Manufacturing	Warehouse	Eating or Drinking
0.94	0.84	0.91	0.86	0.88

- Is this applicable to any scenario?
  - A practical way to answer this question is through “code compliance”.
  - A code compliant system represents accepted “risk” by society. Its failure probability and unavailability should be low… but not zero.

Examples of Generic Values

- The most recently published studies have reported that where sprinklers could have been expected to have operated, the reliability was found to be greater than 99% (Melin 2018, Parsons 2018.)
- This high level of reliability is a product of several factors, including:
    1. Use of system components that are Listed / Approved to a recognized standard by a 3rd party certification body (e.g., UL199 for sprinklers)
    2. System components installed in accordance with manufacturer's instructions
    3. System designed and installed in accordance with a recognized standard
- For new systems everything should be compliant on day one
- Planned maintenance is an essential element. Must be in place to ensure that reliability continues to be above 99% over the lifetime of a system.
- **Remember AVAILABILITY! Remember SYSTEM RELIABILITY!**

Can we relax the prescriptive ITM requirements?

- Short/Simple answer is…. "Yes",
- There are reliability models that can suggest performance based ITM intervals
- A performance criteria is needed
  - e.g., maintain the reliability of the system at a value of "#".
- Preferably, reliability data for the system will be collected and maintained over time to support the modeling
  - Tracking of failures and failure modes in time
  - Clear and consistent documentation of inspection and testing results
- Start with prescriptive requirements
  - Develop data
  - Based on the data, update ITM intervals
- Needs approval from authority having jurisdiction

In Summary!

Let's Revisit the Text of a Different Standard!

+ Standard for fire risk assessment in nuclear power facilities
+ Captures Availability, Outlier Behavior, Facility Specific Data, System Effectiveness

FSS-D7 [Notes (5)–(7)]	In crediting fire detection and suppression systems, USE generic estimates of total system unavailability provided that *(a)* the credited system is installed and maintained in accordance with applicable codes and standards, *and* *(b)* the credited system is in a fully operable state during plant operation	In crediting fire detection and suppression systems, USE generic estimates of total system unavailability provided that *(a)* the credited system is installed and maintained in accordance with applicable codes and standards *(b)* the credited system is in a fully operable state during plant operation, *and* **(c) the system has not experienced outlier behavior relative to system unavailability**	In crediting fire detection and suppression systems, USE **plant-specific information, where available, to quantify total unavailability factors.**
FSS-D8 [Note (8)]	INCLUDE an assessment of fire detection and suppression systems effectiveness in the context of each fire scenario analyzed.		

In Summary!

- Start with code compliance
  - Design for the hazard
  - Monitor for hazards over time
  - ITM program
- Collect and maintain reliability data
- Apply performance-based ITM
  - Establish reliability goals
  - Develop a reliability model
  - Discuss with the authority having jurisdiction

