March 2001

PRA Technology and Regulatory Perspectives (P-111) Syllabus

This course is intended to provide the PRA background required for reactor inspectors. The terminal objectives for the course are to provide:

- practical understanding of basic PRA concepts and terminology,
- practical experience using PRA information and results to improve accomplishment of inspection program requirements,
- understanding of PRA strengths and limitations,
- relationship between PRA and the reactor significance determination process,
- understanding of how PRA information may be integrated with traditional engineering analyses and assessments.

The course is divided into two parts. The first week of the course presents basic PRA concepts and terminology in a lecture format, supplemented with student exercises, some using actual plant PRAs, and required reading of agency PRA policy and guidance documents. This portion of the course includes a closed-book exam at the beginning of the second week. The second part of the course is a series of integrated workshops that build upon the material presented in the first part of the course. The second part culminates with an open-book exam at the end of the second week.

<u>Syllabus of topics</u>

<u>Week 1</u>

Module A - Introduction to PRA and its Use at the NRC
Objectives:

- Define risk
- List the basic questions answered by PRA
- Generally describe NRC's quantitative health objectives and subsidiary numerical goals
- Describe the reasons for and expected outcomes of the NRC Policy Statement on uses of PRA
- List major elements of the PRA Implementation Plan
- List three general ways for inspectors to potentially use PRA
- List two areas explicitly precluded from PRA application
- Identify two general ways PRA is affecting design basis
- Provide examples of the strengths and limitations of PRA
- Discuss the ways in which the limitations of PRA are addressed
- Pictorially illustrate NRC's framework for incorporating PRA into facility regulation

Module B - Traditional Engineering Analysis and PRA
Objectives:

- Describe the traditional engineering approach to controlling risk
- Compare and contrast this approach with that used in PRA

- Give examples of how defense-in-depth is included in the design per the traditional approach, and how PRA measures the level of protection provided by the design

Module C - Overview of PRA Process
Objectives:
- Describe the major steps in the PRA process
- Describe the outputs of each of the "Levels" of PRA
- Describe why probabilistic models are used
- Give examples of disciplines required to perform a PRA
- Give examples of where deterministic inputs are used by the PRA process

Module D - Accident Sequence Initiating Events
Objectives:
- Describe the relationship between initiating event identification and other PRA related tasks.
- List information sources used to identify initiating events.
- Describe how initiating events are grouped and quantified.
- Draw comparisons between PRA "initiators" and traditional "plant challenges" in a safety analysis report (SAR).

Module E - Accident Sequence Analysis Using Event Trees
Objectives:
- Describe the purposes of event tree analysis
- Describe techniques and notations employed in event tree construction
- Describe the relationship between event tree construction and deterministically-identified success criteria
- Compare PRA accident sequences (as depicted by the event trees) and the traditional SAR design basis accidents

Module F - Systems Analysis Using Fault Trees
Objectives:
- List the purposes of fault tree analysis.
- Define the terminology, notation, and symbology used in fault tree analysis.
- Interpret the results of fault tree reduction.
- Define and correctly apply the definition of "minimal cutsets".

Module G – Equipment Failure Modes and Data Sources for Parameter Estimation
Objectives:
- List the failure modes typically modeled in PRA and how parameter values for these failure modes are estimated
- Define what is meant by "generic data" and list common sources
- List limitations associated with plant-specific data
- Explain qualitatively what Bayesian updating accomplishes

Module H - Common-Cause Failures
Objectives:
- Define several types of dependent failures and how they are modeled
- Give examples of dependent and common cause failures
- Describe the importance of modeling common cause failures in PRAs

Module I - Human Reliability Analysis
Objectives:

- Explain the role of HRA within the overall context of PRA
- Describe common error classification schemes used in HRA
- Describe how human interactions are incorporated into system models
- Identify strengths and limitations of HRA

Module J - Accident Sequence Quantification
Objectives:

- Explain how the various aspects of accident sequence quantification are accomplished.
- Describe the differences in the various approaches used for accident sequence quantification.
- List the major steps in accident sequence quantification, including approximations that are used.
- Describe the relationship between minimal cutsets and accident sequences (for LET and SET models).
- Given minimal cutsets of varying order (number of basic events), list the defense-in-depth features associated with each which are presumed to fail to get to core damage.

Module K - External Events
Objectives:

- Define external events and differentiate them from the broader class of common cause events
- List several of the more significant external vents, including those analyzed in the IPEEEs
- List the objectives of the IPEEE and the acceptable approaches for seismic events and fires
- Explain the ways in which external events may be evaluated and how this evaluation is related to the overall PRA task flow

Module L - Level 2 and 3 PRA
Objectives:

- Describe the general purpose of Level 2 and 3 analyses
- List typical types of consequences from a Level 3 PRA

Module M - Shutdown Risk
Objectives:

- Describe how shutdown modes can be risk-significant
- Describe why PRA must treat separate modes of operation during shutdown
- Discuss the risk-importance of systems available to maintain plant safety functions and the effect of equipment outages on shutdown risk

Module N - Importance Measures
Objectives:

- Identify and define (both mathematically and in words) 3 types of quantitative importance measures
- Discuss how importance measures are influenced by the value of the associated basic event, the values of other basic events, and modeling assumptions
- Explain why use of importance measures is considered valid for Maintenance Rule applications (i.e., binning SSCs into risk and non-risk categories)

Module O – Uncertainty
Objectives:

- List the types of uncertainty and their sources
- Describe how uncertainty is accounted for in PRA and in traditional engineering analysis
- Explain the meaning of the area, between two given frequency or probability values, under a probability distribution function representing CDF, LERF, or a basic event probability

Module P - Plant-Specific, Risk-Informed Applications
Objectives:

- Describe the objectives of the PRA Policy Plan and the scope of the Implementation Plan for the various NRC offices affected
- List the major elements of the decision logic used to review submittals containing changes to the current licensing basis and the role of the new draft Reg. Guides and SRPs in this process, including the numerical decision criteria related to CDF and LERF

<u>Week 2</u>

Module Q - Configuration Risk Management
Objectives:

- Explain why base case or nominal PRA results cannot be used for maintenance planning
- Explain what is meant by "configuration risk management," and how it is related to risk-based regulation
- Evaluate "risk" profiles quantitatively

Module R - Maintenance Rule Implementation
Objectives:

- Explain the purposes of the Maintenance Rule and identify areas in which PRA can support the rule's implementation
- Explain how performance goals/criteria are established using the "EPRI Method"

Module S – Reactor Safety SDP Principles
Objectives:

- Describe how initiating event (IE) frequency influences SDP result and how inspection finding could increase likelihood of IE
- Describe how remaining mitigation capability is estimated for a multi-train system (per Table 3) and why result is different for a system with two or more <u>diverse</u> trains
- Describe why SDP cannot assess significance of component with degraded reliability (component not completely failed)
- Describe mathematical meaning of estimated likelihood rating and remaining mitigation capability rating
- Describe conceptually how SDP result is considered a change in annualized CDF and why this risk metric was chosen

- Describe intended benefit of using SDP to foster better understanding and communication of probabilistic analyses and influential assumptions of specific analyses
- Describe how CCDP for an event differs from CCDP for degraded plant condition existing for specified period of time
- Perform Phase 1 screening analysis for findings related to fire protection
- List and describe steps in Phase 2 analysis for findings related to fire protection
- Describe basis for shutdown risk phase 1 checklist in IMC 0609
- Describe difference between Type A and Type B findings related to containment integrity

Closed-Book Exam

Integrated Workshop #1 - Inspection Planning
Integrated Workshop #2 - Assessment of the Significance of Inspection Findings
Integrated Workshop #3 – SDP Evaluation of Fire Protection Findings

Open-Book Exam

DAILY REQUIRED READING ASSIGNMENTS FOR P-111

Note: The instructor will allow 30 minutes at the beginning of each day (7:30am - 8:00am) and 30-45 minutes at the end (~3:45pm - 4:30pm) for students to perform the reading assignments and IPE "lookups" assigned at the end of each days' lecture material. Use the beginning of the next class (starting at 8:00am) to ask any questions about the previously assigned reading.

Week 1

Day 1

~~Module A - Introduction to PRA and its Use at the NRC~~
~~Module B - Traditional Engineering Analysis and PRA~~
Module C - Overview of PRA Process

Required Reading:

1) Review PRA Final Policy Statement
   Section III - Deterministic and Probabilistic Approaches to Regulation (pp. 18-21)
2) ACRS Letter dated April 11, 1997 "Risk-Based Regulatory Acceptance Criteria for Plant-Specific Application of Safety Goals"
3) NRR memorandum, SUBJ: Use of IPEs for Regulatory Decision-Making, dated 10/3/95
4) IMC 0609, App. A, pp. A1-1 through A1-4.
5) Part 9900 Inspection Guidance
   Operability - Section 6.9
   Resolution of Degraded and Non-conforming Conditions - Section 4.5.3

Optional (Background) Reading:

1) PRA Final Policy Statement, all sections
2) NUREG 1560 pp. 14-4 to 14-5

Day 2

Module D - Accident Sequence Initiating Events
Module E - Accident Sequence Analysis Using Event Trees
Module F - System Analysis Using Fault Trees

Required Reading:

1) IMC 0609, App. A, pp. A1-5 through A1-14
2) EGM 97-11 "Consideration of Risk in Enforcement Actions"
3) NUREG 1560 - Chapter 2 Tables (e.g., 2.1, 2.2, 2.3) applicable to the student's chosen plant

Optional (Background) Reading:

NUREG 1560 - Sections 14.3.1, 14.3.2, 14.3.3 (pp. 14-6 to 14-22)

Day 3

Module G - Estimation of Equipment Reliability and Unavailability
Module H - Estimation of Common-Cause Failure Probabilities

Module I - Human Reliability Analysis

Required Reading:

1) ACRS Letter dated D910719 "The Consistent Use of PRA"
2) IMC 0609, App. A, pp. A1-15 through A1-23.
3) NUREG 1560 - Chapter 5 Tables (e.g., 5.1, 5.2, 5.3, 5.4) applicable to the student's chosen plant)

Optional (Background) Reading: NUREG 1560 Sections 14.3.4, 14.3.5 (pp. 14-23 to 14-31)

<u>Day 4</u>
Module J - Accident Sequence Quantification
Module K - External Events
Module L - Level 2 and 3 PRA
Module M - Shutdown Risk

Required Reading:

1) IMC 0609, App. A, pp. A1-24 through A1-27
2) NUREG 1560 Chapter 3 and 4 Tables applicable to the student's chosen plant

Optional (Background) Reading: NUREG 1560 Sections 14.3.6 (pp. 14-32 to 14-35)

<u>Day 5</u>
Module N - Importance Measures
Module O - Uncertainty
Module P - Plant-Specific, Risk-Informed Applications

Required Reading:

1) Reread NRC Final PRA Policy Statement, Section III.B. "Uncertainties and Limitations of Deterministic and Probabilistic Approaches"
2) ACRS Letter dated Dec 16, 1997 "Treatment of Uncertainties versus Point Values in the PRA-related Decision-making Process"
3) IMC 0609, Apps. F, G, and H.
4) 10CFR50.65 "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants"

<u>Week 2</u>

<u>Day 6</u>
Module Q - Configuration Risk Management
Module R - Maintenance Rule Implementation
Module S – Reactor Safety SDP Principles

Reading: Review for closed-book exam

Day 7
Closed-Book Exam (9:00am - 10:15am)
Integrated Workshop #1 - Inspection Planning

Reading: None - students are encouraged to use IPEs, NUREG 1560, and the Maintenance Rule Guidebook to formulate a list of questions for discussion with licensee PRA analysts for a plant of their choosing. Students may begin drafting a risk-informed inspection plan (optional).

Day 8
Integrated Workshop #2 - Assessing the Significance of Inspection Findings

Reading: None - students are encouraged to use IPEs, NUREG 1560, and Maintenance Rule Guidebook to formulate a list of questions for discussion with licensee PRA analysts for a plant of their choosing. Students may begin drafting a risk-informed inspection plan (optional).

Day 9
Integrated Workshop #3 - SDP Evaluation of Fire Protection Findings

Day 10
Open-Book Exam (9:00am - 12:00noon)

Module S

Reactor Safety SDP Principles

Reactor Safety SDP Principles

- Purpose
  - Describe the PRA basis behind SDP Tables 1 - 3 in App. A to IMC 0609
  - Describe how these tables are used in the SDP
  - Describe how SDP is consistent with PRA principles and practices

1. I.E Freq * Duration = IE likelihood
2. Remaining Mitigation
3. IE likelihood * Remaining Mitigation = Significance (ΔCCDP)

ΔCCDP = ΔCDF ave overlying

Know SDP colors for ΔCDF
Red > 10^{-4}/yr
Yellow 10^{-5} – 10^{-4}/yr
White 10^{-6} – 10^{-5}
Green < 10^{-6}/yr

Objectives

- Upon completion of this module, students should be able to

  as IE goes ↑, sig ↑

  - Describe how initiating event (IE) frequency influences SDP result and how inspection finding could increase likelihood of IE

    Can adjust IE freq ↑ if degraded condition identified that can increase IE freq.

  - Describe how remaining mitigation capability is estimated for a multi-train system (<u>per Table 3</u>) and why result is different for a system with two or more <u>diverse</u> trains

    needs to account for CCF.

    assumes independent failures.

Objectives (cont.)

- Upon completion of this module, students should be able to
  - Describe why SDP cannot assess significance of component with degraded reliability (component not completely failed)
  - Describe mathematical meaning of estimated likelihood rating and remaining mitigation capability rating

Est likelihood rating = 1/freq * Duration

Mitigation capability rating = $-\log_{10} \sum Pr(CD|IE$ [illegible]$)$

0 ⇒ No mitigation capability [illegible] CD occurs

Objectives (cont.)

- Upon completion of this module, students should be able to
  - Describe conceptually how SDP result is considered a change in annualized CDF and why this risk metric was chosen
  - Describe intended benefit of using SDP to foster better understanding and communication of probabilistic analyses and influential assumptions of specific analyses
  - Describe how CCDP for an event differs from CCDP for degraded plant condition existing for specified period of time

Objectives (cont.)

- Upon completion of this module, students should be able to
  - Perform Phase 1 screening analysis for findings related to fire protection
  - List and describe steps in Phase 2 analysis for findings related to fire protection
  - Describe basis for shutdown risk Phase 1 checklist in IMC 0609 5 Safety Functions from NUMARC Guide. 91-06
  - Describe difference between Type A (Impact CDF & LERF) and Type B (Don't impact CDF) findings related to containment integrity

Outline of Topics

- PRA Bases for SDP Tables 1 -3 in App. A of IMC 0609
- Using SDP to determine risk significance of inspection findings (SDP Phase 2)
- Phase 1 screening analysis of fire protection findings

Table 1 - Estimated Likelihood for Initiating Event Occurrence During Degraded Period

- PRA uses constant (time-independent) frequencies for various initiating events
- Each core damage sequence starts with initiating event
- CDF for sequence is frequency of initiating event multiplied by probability of failure of mitigating systems and/or operator responses, given initiating event
- Probability of initiating event occurring between t_1 and t_2 is approximately

$$\Pr(IE\ between\ t_1\ and\ t_2) \approx \lambda_{IE}(t_2 - t_1)$$

Table 1 (cont.)

- Rows in Table 1 correspond to different frequency ranges for IEs
  - Most frequent IEs at top, least frequent at bottom
- Columns in Table 1 correspond to duration of degraded condition
  - > 30 days, 3 -30 days, < 3 days
- Estimated likelihood rating is product of IE frequency and condition duration
  - Upper end of frequency range used
  - 1 year used if duration > 30 days
  - 0.1 year used if duration between 3 and 30 days
  - 0.01 year used if duration < 3 days

Table 1 (cont.)

Row	Approx. Freq.	Example IE	Estimated Likelihood Rating		
I	$10^{0} - 10^{-1}$	Turbine trip Loss of PCS	10^{0}/yr*1 yr = 1 (A)	10^{0}/yr*0.1 yr = 10^{-1} (B)	10^{0}/yr*0.01 yr = 10^{-2} (C)
II	$10^{-1} - 10^{-2}$	LOSP SLOCA (BWR)	10^{-1}/yr*1 yr = 10^{-1} (B)	10^{-1}/yr*0.1 yr = 10^{-2} (C)	10^{-1}/yr*0.01 yr = 10^{-3} (D)
III	$10^{-2} - 10^{-3}$	SGTR RCP seal failure Stuck-open PORV	10^{-2}/yr*1 yr = 10^{-2} (C)	10^{-2}/yr*0.1 yr = 10^{-3} (D)	10^{-2}/yr*0.01 yr = 10^{-4} (E)
IV	$10^{-3} - 10^{-4}$	SLOCA (pipe break) MLOCA	10^{-3}/yr*1 yr = 10^{-3} (D)	10^{-3}/yr*0.1 yr = 10^{-4} (E)	10^{-3}/yr*0.01 yr = 10^{-5} (F)
V	$10^{-4} - 10^{-5}$	LLOCA ATWS (BWR)	10^{-4}/yr*1 yr = 10^{-4} (E)	10^{-4}/yr*0.1 yr = 10^{-5} (F)	10^{-4}/yr*0.01 yr = 10^{-6} (G)
VI	$< 10^{-5}$	ATWS (PWR) ISLOCA Vessel rupture	10^{-5}/yr*1 yr = 10^{-5} (F)	10^{-5}/yr*0.1 yr = 10^{-6} (G)	10^{-5}/yr*0.01 yr = 10^{-7} (H)
Duration of Degraded Condition			> 30 days	3 –30 days	< 3 days

Summary of Estimated Initiating Event Likelihood

- Result from Table 1 represents <u>probability</u> of having IE occur during degraded condition
- Numerically (including uncertainty)
  - A ↔ 10^{0} to 10^{-1}
  - B ↔ 10^{-1} to 10^{-2}
  - C ↔ 10^{-2} to 10^{-3}
  - D ↔ 10^{-3} to 10^{-4}
  - E ↔ 10^{-4} to 10^{-5}
  - F ↔ 10^{-5} to 10^{-6}
  - G ↔ 10^{-6} to 10^{-7}
  - H ↔ $\leq 10^{-7}$

Summary of Estimated Initiating Event Likelihood (cont.)

- Note uncertainty in IE frequencies shown in Table 1 (order of magnitude in each row)
  - SDP intended to be conservative, uses upper end of each row's frequency band
- IE frequency will impact final risk significance, can adjust upward (subjectively) if degraded condition can increase IE frequency (cf. IMC 0609, p. A1-21 for example)

Analysis of Remaining Mitigation Capability (IMC 0609 Table 2)

- Mitigation capability rating is $-\log_{10}$[Pr(core damage|IE occurs during degraded condition)]
  - Rating of 0 means no mitigation capability available, so core damage is certain, given the IE occurs
  - Rating of 6 means Pr(core damage|IE) is one in a million (10^{-6})

Analysis of Remaining Mitigation Capability (IMC 0609 Table 2) (cont.)

- Table 3 assigns probabilities of failure to different means of mitigation, based on past PRA experience
  - One train: 10^{-2}
  - Multi-train system: 10^{-3} (this is the probability of CCF, assumed independent of number of trains)
  - Recovery of failed train: 10^{-1}
  - Operator action under high stress: 10^{-1}

Analysis of Remaining Mitigation Capability (IMC 0609 Table 2) (cont.)

- "+" in Table 2 means either option specified can be used, therefore failure of mitigation means failure of all options, so probabilities are multiplied
  - Example: "1 train + 1 multi-train system + recovery of failed train"
    - Probability that mitigation fails is $(10^{-2})((10^{-3})(10^{-1}) = 10^{-6}$, so rating is 6
    - Note assumption that mitigation options are independent, allowing probabilities to be multiplied

Determination of Final Risk Significance (IMC 0609 Table 2)

- Colors in Table 2 correspond to colors used for Performance Indicators (PIs)
- Risk significance of each sequence determined by multiplying probability of IE by probability of mitigation failure
  - Example: Initiating event likelihood is “C,”, remaining mitigation capability rating is “3”
    - Final significance is $(10^{-2})(10^{-3}) = 10^{-5}$, which is designated as “White” in Table 2

Determination of Final Risk Significance (IMC 0609 Table 2) (cont.)

- Note that result of SDP is a probability: the probability of core damage, given a degraded condition of specified duration, and given the occurrence of an IE during that condition
  - Called conditional core damage probability (CCDP)
- Problems with using CCDP as risk metric
  - PI program uses ΔCDF, as does R.G. 1.174
  - NRC has no criteria for using CCDP

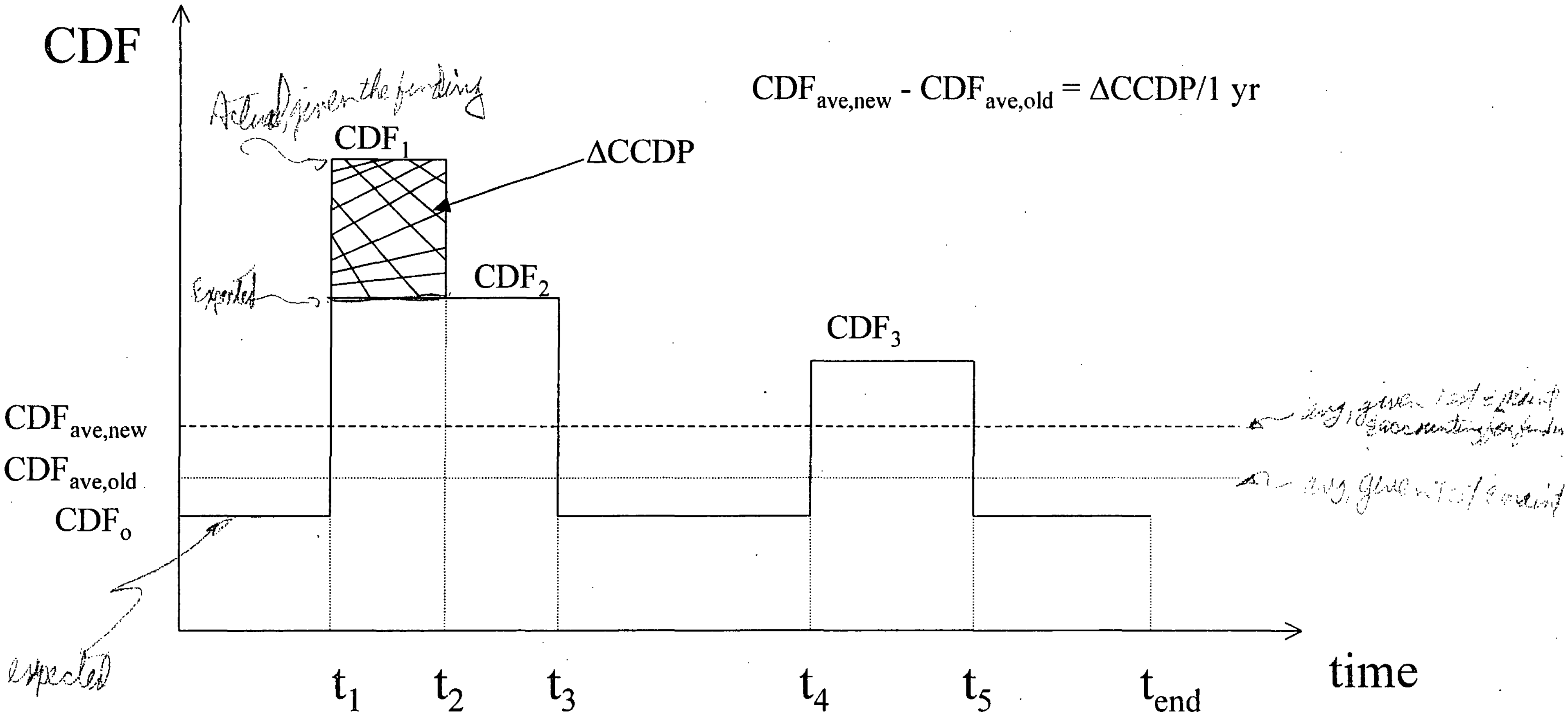
Determination of Final Risk Significance (IMC 0609 Table 2) (cont.)

- SDP estimates risk significance of licensee performance problems
  - Does not include equipment out of service for test or maintenance, unless related specifically to performance problem
  - Therefore, final result is increase in CCDP, or incremental CCDP, caused by the performance problem (see following graph for illustration)
  - It turns out (see algebra following graph) that, numerically, the incremental CCDP is equal to the increase in the time-weighted average CDF, if the averaging is done for a period of one year
    - So result from SDP can be compared to color criteria for PIs

Determination of Final Risk Significance (IMC 0609 Table 2) (cont.)

- What the colors in Table 2 mean in terms of increase in annual time-averaged CDF
  - Red: increase is > 10^{-4}/yr
  - Yellow: increase is between 10^{-5}/yr and 10^{-4}/yr
  - White: increase is between 10^{-6}/yr and 10^{-5}/yr
  - Green: increase is $\leq 10^{-6}$/yr

Illustrative CDF Profile



Algebra for CDF Profile (optional)

$$CDF_{ave,old} = \frac{CDF_o(t_1 + t_4 - t_3 + t_{end} - t_5)}{t_{end}} + \frac{CDF_2(t_3 - t_1)}{t_{end}} + \frac{CDF_3(t_5 - t_4)}{t_{end}}$$

$$CDF_{ave,new} = \frac{CDF_o(t_1 + t_4 - t_3 + t_{end} - t_5)}{t_{end}} + \frac{CDF_1(t_2 - t_1)}{t_{end}} + \frac{CDF_2(t_3 - t_2)}{t_{end}} + \frac{CDF_3(t_5 - t_4)}{t_{end}}$$

Algebra for CDF Profile (cont.)

$$CDF_{ave,new} - CDF_{ave,old} = \frac{CDF_1 t_2 - CDF_1 t_1 + CDF_2 t_3 - CDF_2 t_2 - CDF_2 t_3 + CDF_2 t_1}{t_{end}}$$

$$= \frac{CDF_1(t_2 - t_1) - CDF_2(t_2 - t_1)}{t_{end}} = \frac{(CDF_1 - CDF_2)(t_2 - t_1)}{t_{end}} = \frac{\Delta CCDP}{t_{end}}$$

Algebra for CDF Profile (cont.)

- If t_{end} = 1 yr, then we have (numerically) ΔCDF_{ave} = ΔCCDP, as claimed

Notes on use of Tables

- Cannot assess impact of degraded equipment reliability
  - Process analyzes significance of complete failure only (cf. IMC 0609, p. A1-15)
- SDP set up to analyze conditions that exist for a period of time
  - Initiating events result in CCDP "spike," which cannot be analyzed in this manner (cf. IMC 0609, pp. A-1, A1-26, A1-27)

SDP for External Initiators

- SDP treats only fires and floods (internal and external), because licensee performance cannot impact frequency of other external events, such as earthquakes and severe weather
- External events treated in separate PRA analysis (see External Events Module)
  - IPEEE did not require PRA for external events
  - If PRA performed, separate accident sequences generated that start with fire, flood, etc.
  - Core damage requires external IE and failure of one or more systems and/or operator actions

SDP for External Initiators (cont.)

- SDP Phase 1 screens findings for events that increase likelihood of external IEs
  - Such events are analyzed by risk analyst in Phase 3 (not covered by Phase 2 SDP)
- Inspector may be able to identify external event sequences for analysis in Phase 3, using IPEEE or other licensee analysis
- If finding affects fire barrier or fire suppression feature, Appendix F is used by inspector for Phase 1 screening analysis

Evaluating Fire Protection Findings

- Inspectors use App. F to IMC 0609 to perform Phase 1 screening of findings
  - May also be involved in Phase 2 analysis
  - Phase 3 analysis performed by SRAs and fire protection engineers

Evaluating Fire Protection Findings (cont.)

- Three elements of defense in depth related to fire protection
  - Prevent fires from starting (initiating event frequency)
  - Rapidly detect and suppress fires that occur (probability of damage)
  - Protect equipment needed to safely shut down the plant (probability of damage)

Phase 1 Screening of Fire Protection Findings

- Screening to see which fire protection findings are potentially risk significant
- No CDF calculations necessary
- Step 1 identifies findings that impact at least one defense-in-depth element
  - These are most likely to be risk-significant

Step 1 Uses Figure 4-1 from App. F

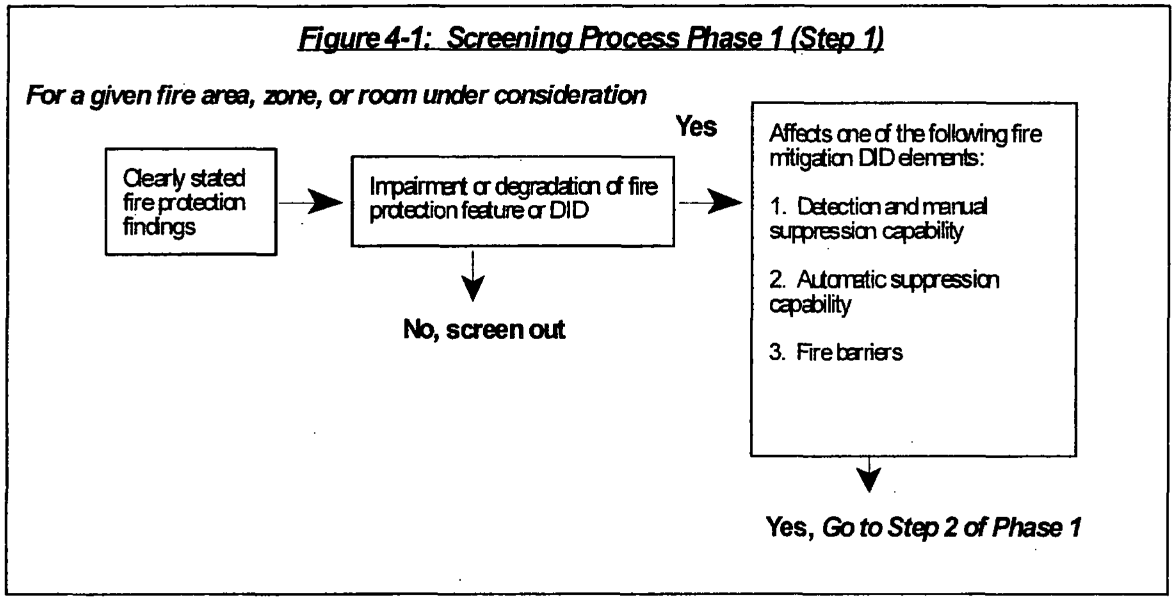


Figure 4-1: Screening Process Phase 1 (Step 1)

Phase 1, Step 2 Evaluates Safety Importance of Unscreened Elements

- Determine the fire area, zone, or room of concern
- Determine the method and equipment used to achieve and maintain safe shutdown in this area after the fire
  - Four possible arrangements given in Figures 4-2 through 4-5 in App. F
- Determine the fire protection scheme used to protect safe shutdown equipment
- Perform screening evaluation per criteria in App. F
  - Will be illustrated during workshop in second week

Summary of Phase 1 Analysis

- Have evaluated fire protection findings to identify those with potential risk significance
  - Unscreened findings evaluated in more detail in Phase 2 (quantitative)
- Screened findings are passed to the licensee for corrective action

Outline of Phase 2 Analysis

- Group fire protection and post-fire safe shutdown findings
- Define relevant fire scenarios
- Evaluate findings qualitatively
- Assign quantitative values
- Determine fire ignition frequency (IF)
- Calculate fire mitigation frequency (FMF)

Outline of Phase 2 Analysis (cont.)

- Adjust FMF for duration of degradation and account for remaining safe-shutdown capability
- Evaluate impact of compensatory measures
- Evaluate impact of spurious equipment actuations
- Will illustrate major steps in Phase 2 analysis during workshop in week two

SDP for Containment Integrity

- IMC 0609 contains draft guidance (App. H), still being evaluated by NRR
- Significance criteria for ΔLERF are order of magnitude less than for ΔCDF
  - Red: increase > 10^{-5}/yr
  - Yellow: increase between 10^{-6}/yr and 10^{-5}/yr
  - White: increase between 10^{-7}/yr and 10^{-6}/yr
  - Green: increase ≤ 10^{-7}/yr
- Finding that is "Green" for ΔCDF could by "White" for ΔLERF

SDP for Containment Integrity (cont.)

- Only some core damage sequences have significant LERF potential
  - ISLOCA
  - SGTR
  - Sequences where reactor vessel fails at high pressure
- Bear in mind that a "large early release" is one likely to cause acute fatalities offsite
  - Well in excess of 10 CFR 100 release

SDP for Containment Integrity (cont.)

- SDP considers two types of findings, Type A and Type B
- Type A findings
  - Findings that affect CDF; CDF SDP performed
  - LERF considerations may adjust final risk significance
  - Use Appendix H, Table 2
- Type B findings
  - Findings that do not affect CDF; CDF SDP not performed
  - Appendix H, Table 3 gives results based on ΔLERF
    - Baseline CDF assumed to produce Table 3
      - PWRs: 10^{-4}/yr
      - BWRs: 10^{-5}/yr

SDP for Shutdown Conditions

- Monitors five safety functions defined in NUMARC 91-06
  - Core decay heat removal
  - RCS inventory control
  - Power availability
  - Containment control'
  - Reactivity control

SDP for Shutdown Conditions (cont.)

- Phase 1 checklists are specific to plant operating state, as requirements vary among states, and states are not of equal risk significance
- Items screening to Phase 2 require more detailed analysis

P-111 INTEGRATED WORKSHOP #2

THE RISK SIGNIFICANCE OF FINDINGS & EVENTS

Objective: The student will learn how PRA information can be used to provide insight into the risk significance of specific inspection findings or operational events. This includes Phase 2 analysis using the Significance Determination Process (SDP).

Method: Students will be given the North Anna SDP Notebook and material from the North Anna IPE Submittal to be used as an illustration of PRA information for carrying out this workshop. Only portions of the submittal useful for performing the workshop will be provided to the students in order to avoid ineffectual time looking through a large volume of material. Completion of this workshop should be expected to take approximately ½ day and will be given at the end of the P-111 course after all course modules have been presented.

Materials:
1) Example of an operational event and related inspection finding
2) North Anna SDP Notebook
3) Summary of Major Findings from the IPE
4) Functional failure summary information from the IPE
5) List of Initiating Events from the IPE
6) Success Criteria information from the IPE
7) Event tree information from the IPE
8) Plant design and Safety Injection System information from the IPE
9) Core damage (and dominant cut sets) results information from the IPE
10) Risk importance information from the IPE
11) List of basic events and descriptions

Instructions: By using the material provided and answering the questions in this workshop, arrive at a tentative conclusion regarding the risk-significance of the operational event and related inspection finding based on the SDP and on the PRA information provided. The conclusion ought to be considered "tentative" because in a real situation, there may be other information not provided, which could alter the conclusion reached.

Example Operational Event / Inspection Finding:

[Note: This example is based on an actual operational event and inspection finding at a power plant similar to North Anna. The facts related to the actual event have been altered somewhat for purposes of the class workshop. Nevertheless, similarity between this fictitious event and the actual event provides "realism" toward meeting the objective of this workshop.

During a test of the auxiliary feedwater system (AFW) with the plant at power (Mode 1), an operator noticed that the manual discharge valve for the turbine-driven pump, valve 1-FW-278 (refer to the simplified AFW flow diagram in Module F), is locked closed. It is required to be locked open when the plant is at power. This misalignment has existed for 48 days and violates the Technical Specification Limiting Condition of Operation of 72 hours. With the system in this condition, no flow would be available from the turbine-driven AFW pump to any of the steam generators. Upon review of the event, the NRC determined that the misalignment occurred during performance of an AFW valve operability test. The misalignment was discovered when an operator noticed the valve stem position and questioned whether the valve was in the correct position.

Questions:

(These initial questions examine how the SDP evaluates the risk significance of the finding.)

1. Use the SDP Phase 1 screening worksheet to evaluate this finding. Explain in detail why Phase 2 analysis is or is not necessary. *See 0609 Phase 1 wksht* *Gets Phase 2*
2. Assume that Phase 2 analysis is required and use the SDP Worksheets in the North Anna SDP Notebook to evaluate the risk significance of this condition.
3. What is the overall "color" for this finding?
4. Which accident sequence dominates this result?
5. List any assumptions you made in doing the Phase 2 analysis and be prepared to defend these assumptions before a mock Significance Evaluation Review Panel (SERP).

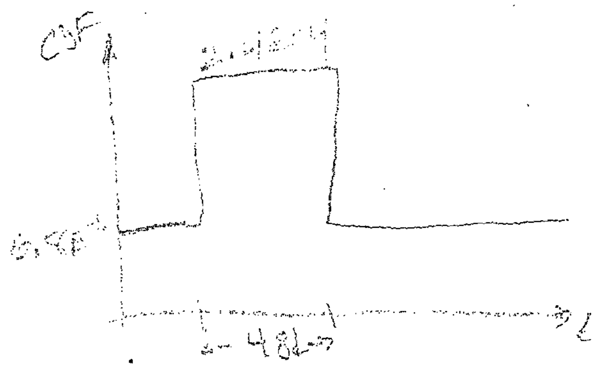
(The following questions explore how the PRA results could be used to evaluate the risk significance of this finding.)

1. Looking in the PRA,
   a) Is the equipment of interest and the function(s) that equipment performs "captured" in the PRA for the North Anna IPE?
   b) If so, where in the materials provided did you find the relevant information?

   a) Yes b) See T1A event tree
2. Based on the modeling in the PRA,
   a) What types of failures (e.g., independent, common cause, human error, hardware failure, support system failures…) or other reasons for unavailability (e.g., test or maintenance outage) did the PRA include in considering the inoperability of the turbine-driven AFW train? *See AFW fault tree AF1 15 16 etc.*
3. Which event tree sequences correspond to the dominant sequence you found in the Phase 2 SDP above? Note: Level 2 information may be included in the Level 1 event trees; any sequences that lead to core uncovery can be considered core damage sequences for this question. *SDP sequence gets mapped into several PRA sequences that are in T1a L+B...*
4. Using the dominant sequence cut sets, along with the table of basic event probabilities, estimate the change in CDF for this sequence. With what "color" does this change in CDF correspond? Note: if you found more than one PRA sequence that corresponded with the dominant SDP sequence, use the sequence with the highest frequency to answer this question.

5. Use the importance measure information to estimate the overall impact of this condition on CDF. How does this compare with what you calculated in the question above?

RAW for AFW FS = 3.48
so CDF ↑ at least 3.48 factor when TDAFW OOS



old avg CDF = 6.8E-6/yr

$$\text{new avg CDF} = \frac{(2.4E\text{-}4\,yr^{-1})(48\,d) + (6.8E\text{-}6\,yr^{-1})(365-48\,d)}{365}$$

$= 9.1E\text{-}5\,yr^{-1}$

$\Delta CDF_{avg} = 2.2E\text{-}5\,yr^{-1}$

P-111 INTEGRATED WORKSHOP #2

THE RISK SIGNIFICANCE OF FINDINGS & EVENTS

Objective: The student will learn how PRA information can be used to provide insight into the risk significance of specific inspection findings or operational events. This includes Phase 2 analysis using the Significance Determination Process (SDP).

Method: Students will be given the North Anna SDP Notebook and material from the North Anna IPE Submittal to be used as an illustration of PRA information for carrying out this workshop. Only portions of the submittal useful for performing the workshop will be provided to the students in order to avoid ineffectual time looking through a large volume of material. Completion of this workshop should be expected to take approximately ½ day and will be given at the end of the P-111 course after all course modules have been presented.

Materials:

1) Example of an operational event and related inspection finding
2) North Anna SDP Notebook
3) Summary of Major Findings from the IPE
4) Functional failure summary information from the IPE
5) List of Initiating Events from the IPE
6) Success Criteria information from the IPE
7) Event tree information from the IPE
8) Plant design and Safety Injection System information from the IPE
9) Core damage (and dominant cut sets) results information from the IPE
10) Risk importance information from the IPE
11) List of basic events and descriptions

Instructions: By using the material provided and answering the questions in this workshop, arrive at a tentative conclusion regarding the risk-significance of the operational event and related inspection finding based on the SDP and on the PRA information provided. The conclusion ought to be considered "tentative" because in a real situation, there may be other information not provided, which could alter the conclusion reached.

Example Operational Event / Inspection Finding:

[Note: This example is based on an actual operational event and inspection finding at a power plant similar to North Anna. The facts related to the actual event have been altered somewhat for purposes of the class workshop. Nevertheless, similarity between this fictitious event and the actual event provides "realism" toward meeting the objective of this workshop.

During a test of the auxiliary feedwater system (AFW) with the plant at power (Mode 1), an operator noticed that the manual discharge valve for the turbine-driven pump, valve 1-FW-278 (refer to the simplified AFW flow diagram in Module F), is locked closed. It is required to be locked open when the plant is at power. This misalignment has existed for 48 days and violates the Technical Specification Limiting Condition of Operation of 72 hours. With the system in this condition, no flow would be available from the turbine-driven AFW pump to any of the steam generators. Upon review of the event, the NRC determined that the misalignment occurred during performance of an AFW valve operability test. The misalignment was discovered when an operator noticed the valve stem position and questioned whether the valve was in the correct position.

Questions:

(These initial questions examine how the SDP evaluates the risk significance of the finding.)

1. Use the SDP Phase 1 screening worksheet to evaluate this finding. Explain in detail why Phase 2 analysis is or is not necessary.

Answer

Refer to the SDP Phase 1 Screening Worksheets in Appendix A to IMC 0609. The finding affects core decay heat removal, a mitigating system cornerstone. It does not represent complete loss of a safety function of a system, but it does represent loss of a safety function of a single train for a time longer than that allowed by Tech. Specs., so Phase 2 analysis is required.

2. Assume that Phase 2 analysis is required and use the SDP Worksheets in the North Anna SDP Notebook to evaluate the risk significance of this condition.

Answer

See the attached sheets.

3. What is the overall "color" for this finding?

Answer

The overall "color" is White.

4. Which accident sequence dominates this result?

Answer

LOOP sequence 10 (LOOP*EAC*TDAFW*REC2) dominates the results. The risk-significance rating of this sequence is White (B4).

5. List any assumptions you made in doing the Phase 2 analysis and be prepared to defend these assumptions before a mock Significance Evaluation Review Panel (SERP).

Answer

Recovery of the TDAFW is assumed to not be possible. This seems reasonable for a screening analysis of a station blackout sequence. The major contributor to operator recovery is ability to diagnose the condition. Core uncovery for this sequence would take place in about an hour, leaving somewhere between 30 minutes and one hour for the

operators to make the diagnosis and restore the train to service. Operator stress would be high under conditions of station blackout with multiple equipment failures. A Phase 3 analysis would examine these assumptions in detail, and would evaluate available procedural guidance, training, valve location and labeling, etc.

(The following questions explore how the PRA results could be used to evaluate the risk significance of this finding.)

1. Looking in the PRA,
   a) Is the equipment of interest and the function(s) that equipment performs "captured" in the PRA for the North Anna IPE?
   b) If so, where in the materials provided did you find the relevant information?

Answer

Yes, the turbine-driven AFW pump is modeled in the PRA. It is modeled at the system level in the Station Blackout event tree, and component level failure modes appear in the AFW fault tree (refer to Module F for this fault tree).

2. Based on the modeling in the PRA,
   a) What types of failures (e.g., independent, common cause, human error, hardware failure, support system failures...) or other reasons for unavailability (e.g., test or maintenance outage) did the PRA include in considering the inoperability of the turbine-driven AFW train?

Answer

Failure modes modeled are failure to start, failure to run, and test and maintenance unavailability.

3. Which event tree sequences correspond to the dominant sequence you found in the Phase 2 SDP above? Note: Level 2 information may be included in the Level 1 event trees; any sequences that lead to core uncovery can be considered core damage sequences for this question.

Answer

Sequences 46 and 51 (T1AP046 and T1AP051) on the Station Blackout event tree correspond to LOOP*EAC*TDAFW*REC2 from the SDP Notebook. There are two sequences, because Level 2 considerations were included in the Level 1 event trees.

4. Using the dominant sequence cut sets, along with the table of basic event probabilities, estimate the change in CDF for this sequence. With what "color" does this change in CDF correspond? Note: if you found more than one PRA sequence

that corresponded with the dominant SDP sequence, use the sequence with the highest frequency to answer this question.

Answer

Sequence T1AP051 has the higher frequency, so use these cut sets. The cut sets are listed on p. B-175 of the North Anna IPE information. Note that the frequency of 2.99E-06 comes from 401 cut sets, of which only the top 23 are shown. The sum of the top 23 frequencies is 2.3E-06. The new cut set frequencies are found by dividing the old frequency by the probability of the affected TDAFW event. In cut set 1, this event is 1FWTRB-FS-1FWP2, with a probability of 0.0185, obtained from the listing of basic events in the IPE. Doing this for each of the 23 cut sets listed gives a new sequence frequency of 9.6E-05. The new time-average CDF is given by

$$\mathrm{CDF}_{\mathrm{ave,new}} = \frac{(9.6\mathrm{E}-05)(48)+(2.3\mathrm{E}-06)(365-48)}{365} = 1.5\mathrm{E}-5/\mathrm{yr}$$

The delta is 1.5E-5 – 2.3E-6 = 1.2E-5/yr, corresponding to “Yellow.”

5. Use the importance measure information to estimate the overall impact of this condition on CDF. How does this compare with what you calculated in the question above?

Answer

The risk achievement worth of basic event 1FWTRB-FS-1FWP2 is 3.48. Multiplying this value by the internal events point estimate CDF of 6.8E-05 gives a new CDF of 2.4E-04. This new CDF exists for 48 days, so the new time-average CDF is given, as above, by

$$\mathrm{CDF}_{\mathrm{ave,new}} = \frac{(2.4\mathrm{E}-4)(48)+(6.8\mathrm{E}-5)(365-48)}{365} = 9.1\mathrm{E}-5/\mathrm{yr}$$

This is between 1E-5 and 1E-4/yr, so the significance is Yellow.

Note that the SDP significance is White because the SDP requires the ΔCCDP to be 1E-4 before Yellow is assigned. So here is an example of where a more detailed analysis might increase the risk significance.

P-111 INTEGRATED WORKSHOP #3

SDP EVALUATION OF FIRE PROTECTION FINDINGS

Objective: The student will learn how to use Appendix F to IMC 0609 to perform Phase 1 and Phase 2 evaluation of fire protection findings.

Method: Students will be given material from the North Anna SDP Notebook to be used for carrying out this workshop. Completion of this workshop should be expected to take approximately ½ day and will be given at the end of the P-111 course after all course modules have been presented.

Materials:
1) Example of an operational event and related inspection finding
2) IMC 0609
3) North Anna SDP Notebook

Instructions: By using the material provided and answering the questions in this workshop, arrive at a tentative conclusion regarding the risk-significance of the operational event and related inspection finding based solely on the information provided. The conclusion ought to be considered "tentative" because in a real situation, there may be other information not provided, which could alter the conclusion reached.

Example Operational Event / Inspection Finding:

[Note: This example is based on an actual operational event and inspection finding at a power plant other than North Anna. The facts related to the actual event have been altered somewhat for purposes of the class workshop. Nevertheless, similarity between this fictitious event and the actual event provides "realism" toward meeting the objective of this workshop.

Inadequate CO_2 Flooding Capacity in Emergency Switchgear Room

The 4160 Vac Emergency Switchgear Room contains both divisions of emergency ac power. The two divisions are separated from one another by a radiant energy shield wall. There are safe shutdown cables located in the room overhead. One train of these cables is protected by a one-hour fire barrier. One train in the affected area is recoverable by operator action if these cables are not damaged by the fire. The room is protected by a auto ~~manually~~ actuated CO_2 flooding system, which was designed in accordance with Standard 12 of the National Fire Protection Association. This standard requires that, for a deep-seated fire, the system maintain 50% CO_2 concentration in the room for at least 20 minutes. According to the licensee's FSAR, the system should be capable of 2 full discharges into the room, equating to about 10 tons of CO_2. According to the licensee's IPEEE, the frequency of large switchgear room fires is about 0.01/yr.

Findings:

1. The licensee has reported that the CO_2 flooding system does not meet the FSAR design requirements. The tanks hold 10 tons of CO_2, but the weekly surveillance only requires that the tanks be 50% full.

2. The one-hour fire barrier protecting the SSD cable train in the room overhead was inspected by the NRC and found to be degraded, such that in several locations the actual rating would be less than ten minutes.

3. A fire brigade drill was observed by the NRC and the brigade performed satisfactorily.

Questions – Phase 1 Screening

1. Which fire protection defense-in-depth elements are affected by the findings?

   Suppression & barriers.

2. Which Figure from App. F is appropriate for Step 2?

   Fig 4-2

3. Explain why the findings are screened from further analysis or if Phase 2 analysis is appropriate. Scheme 2

   1 hr barrier affected → 50% Phase 2 between redundant SSD trains

   CO_2 probably has enough CO_2

Phase 2 Analysis

1. Describe a credible fire scenario for analysis. Which event tree in the SDP Notebook will be most appropriate for analysis? Fire in 1 side w/ failure of CO_2 causes failure of redundant cables in 1 hr barrier & failure of both train fire brigade fail.

LOOP

2. Decide upon and be ready to defend qualitative degradation ratings for the CO_2 flooding system, the one-hour fire barrier, and fire brigade effectiveness. Does dependency need to be addressed?

3. Calculate the fire mitigation frequency (FMF). FMF = IF + FB + MS + AS + CC

   FMF = -2 + 0 + -1 + -1.25 + 0 → -4.25 → 1 per 10^4 - 10^5

4. Find the initiating event likelihood rating.

   Exposure time 73 d → E

5. Using the appropriate sequence results from the North Anna SDP Notebook, find the integrated risk significance (color) of these findings. Is Phase 3 analysis required?

   White

P-111 INTEGRATED WORKSHOP #3

SDP EVALUATION OF FIRE PROTECTION FINDINGS

Objective: The student will learn how to use Appendix F to IMC 0609 to perform Phase 1 and Phase 2 evaluation of fire protection findings.

Method: Students will be given material from the North Anna SDP Notebook to be used for carrying out this workshop. Completion of this workshop should be expected to take approximately ½ day and will be given at the end of the P-111 course after all course modules have been presented.

Materials:
1) Example of an operational event and related inspection finding
2) IMC 0609
3) North Anna SDP Notebook

Instructions: By using the material provided and answering the questions in this workshop, arrive at a tentative conclusion regarding the risk-significance of the operational event and related inspection finding based solely on the information provided. The conclusion ought to be considered "tentative" because in a real situation, there may be other information not provided, which could alter the conclusion reached.

Example Operational Event / Inspection Finding:

[Note: This example is based on an actual operational event and inspection finding at a power plant other than North Anna. The facts related to the actual event have been altered somewhat for purposes of the class workshop. Nevertheless, similarity between this fictitious event and the actual event provides "realism" toward meeting the objective of this workshop.

Inadequate CO_2 Flooding Capacity in Emergency Switchgear Room

The 4160 Vac Emergency Switchgear Room contains both divisions of emergency ac power. The two divisions are separated from one another by a radiant energy shield wall. There are safe shutdown cables located in the room overhead. Train B of these cables is protected by a one-hour fire barrier. The room is protected by an automatically actuated CO_2 flooding system, which was designed in accordance with Standard 12 of the National Fire Protection Association. This standard requires that, for a deep-seated fire, the system maintain 50% CO_2 concentration in the room for at least 20 minutes. According to the licensee's FSAR, the system should be capable of 2 full discharges into the room, equating to about 10 tons of CO_2. According to the licensee's IPEEE, the frequency of large switchgear room fires is about 0.01/yr.

Findings:

1. The licensee has reported that the CO_2 flooding system does not meet the FSAR design requirements. The tanks hold 10 tons of CO_2, but the weekly surveillance only requires that the tanks be 50% full. This condition has existed for at least six months.

2. The one-hour fire barrier protecting the SSD cable train in the room overhead was inspected by the NRC and found to be degraded, such that in several locations the actual rating would be less than ten minutes.

3. A fire brigade drill was observed by the NRC and the brigade performed satisfactorily.

Questions – Phase 1 Screening

1. Which fire protection defense-in-depth elements are affected by the findings?

Ans. The CO2 flooding system and the one-hour fire barrier protecting the SSD cables in the overhead.

2. Which Figure from App. F is appropriate for Step 2?

Ans. Figure 4-2, since equipment in the affected area would have to be used for recovery. Figure 4-3 is appropriate for recovery actions taken outside the affected area, such as from an alternate shutdown panel.

3. Explain why the findings are screened from further analysis or if Phase 2 analysis is appropriate.

Ans. Phase 2 analysis is appropriate because both suppression and barriers are affected by the findings.

Phase 2 Analysis

1. Describe a credible fire scenario for analysis. Which event tree in the SDP Notebook will be most appropriate for analysis? Note: for purposes of this workshop only, do not consider propagation of the fire beyond the emergency switchgear room.

Ans. The cabinets contain large circuit breakers and relays, along with cooling fans and associated control circuits. A fire could start in one of these components and spread throughout the cabinet and to other cabinets and panels in the room. The large amount of cabling in the room provides a fuel source for a sustained fire. This fire can eventually spread to the SSD cables in the overhead. Assume that this fire results in a loss-of-offsite-power transient with a loss of emergency ac power. The LOOP event tree is the one most impacted by the findings. If the one-hour barrier protecting a SSD cable train fails, then the only way to prevent core damage is to recover offsite ac power. If the cables are not

damaged, then the operators may be able to prevent core damage by recovering a train of emergency ac power.

2. Decide upon and be ready to defend qualitative degradation ratings for the CO_2 flooding system, the one-hour fire barrier, and fire brigade effectiveness. Does dependency need to be addressed?

Ans. The CO2 flooding system is not completely impaired by the reduced capacity of the tanks, so high degradation seems too conservative. On the other hand, the degradation in system capacity is significant, so medium degradation will be assigned. For the one-hour fire barrier, the actual rating is less than 20% of the design rating, so high degradation is assigned. For fire brigade effectiveness, assign low degradation. No dependency needs to be addressed according to the guidance in Appendix F.

3. Calculate the fire mitigation frequency (FMF).

Ans. The IF is 0.01/yr (from the IPEEE), so FMF = $\log_{10}$(IF) + FB + AS + MS + CC = -2 +0 + (-0.75) + (-0.5) = -3.25.

4. Find the initiating event likelihood rating.

Ans. This condition has lasted more than 30 days and the frequency is 1 per 10^3 to 10^4 years, so the rating is D.

5. Using the appropriate sequence results from the North Anna SDP Notebook, find the integrated risk significance (color) of these findings. Make sure to state and defend any assumptions you make. Is Phase 3 analysis required?

Ans. The impacted sequences in Table 2.6 of the North Anna SDP Notebook are those sequences where emergency ac (EAC) has failed and is not recovered, that is, sequences 8 and 10. We examine each sequence in turn below.

In sequence 8, a credit of 2 is given for recovery of ac power within 5 hours, for a total of 2, making this sequence White, assuming that recovery is credible. If recovery is not credible, the sequence becomes Red.

In sequence 10, the credit is 2 for TDAFW plus 1 for recovery of ac power within 2 hours, for a total of 3, making this sequence Green (next to White), again assuming that recovery is credible. If recovery is not credible, the sequence becomes Red, because the TDAFW battery will deplete in a matter of hours, and core damage will ensue in the long term unless ac power is restored.

The final result, assuming recovery is credible, is one White sequence and one Green sequence lying next to White. So the overall risk significance of these findings from the Phase 2 analysis is White. Therefore, further Phase 3 analysis may be required to refine

these results. If recovery is not credible, the risk significance is Red, and Phase 3 analysis is required.