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August 26, 2016

Mr. William M. Dean
Director, Office of Nuclear Reactor Regulation
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Transmittal of NEI 16-06, "Crediting Mitigating Strategies in Risk-Informed Decision Making," Revision 0, For Information Only

Project Number: 689

References:

1. Nuclear Energy Institute, "White Paper – Qualitative Assessment for Crediting Portable Equipment in Risk-Informed Decision Making," ADAMS Accession No. ML16138A018.
2. Nuclear Energy Institute, "White Paper – Streamlined Approach for Crediting Portable Equipment in Risk-Informed Decision Making," ADAMS Accession No. ML16138A017
3. Letter from William M. Dean to Mr. Anthony Pietrangelo dated August 9, 2016, ADAMS Accession No. ML16167A034

Dear Mr. Dean:

The purpose of this letter is to provide NEI 16-06, Revision 0, "Crediting Mitigating Strategies in Risk-Informed Decision Making," for NRC staff's information.

Previously, NEI submitted two white papers (Reference 1 and 2) to the staff providing initial guidance on establishing the estimated safety benefit of portable equipment and mitigating strategies in various risk-informed decision making processes. NRC's comments were provided through multiple public meetings and those comments were addressed through the issuance of the finalized white papers. NEI 16-06 incorporates the guidance from those two white papers and provides additional guidance and examples on modeling portable equipment and mitigating strategies in plant-specific Probabilistic Risk Assessments (PRAs).

D046
NRR

Original
TRENT WERTZ
Matthew Humberstone
10/11/2016

I want to express my appreciation of the staff's efforts in support of reviewing the NEI white papers. As you note in your August 9, 2016 letter (Reference 3), "the white papers provide appropriate high-level guidance to licensees on a process to seek credit in various RIDM processes..." Additionally, the timeliness of making this guidance available for industry use is important since, as you note in your letter, "the NRC is already allowing credit for mitigating strategies equipment on an ad-hoc basis for certain applications" and that "the white papers will help guide licensees to perform more consistent assessments and provide the NRC pertinent information when seeking credit."

The purpose of this letter is to provide the NEI 16-06 guidance document for staff information. This document utilizes established industry methods and practices currently used in licensee PRAs in support of numerous regulatory applications. The PRA modeling portion of the guidance was developed to meet the ASME/ANS PRA Standard that has been endorsed by NRC through Regulatory Guide 1.200 Revision 2. Therefore, NEI does not plan to submit NEI 16-06 for formal NRC review or endorsement.

It is our intent to refine NEI 16-06 in the future through the incorporation of operating experience and data related to the use and reliability of portable equipment and human actions. We look forward to including the perspectives of NRC staff in this regard. If you have any questions about this information, please contact Thomas Zachariah at (202) 739-8058; txz@nei.org.

Sincerely,

Anthony R. Pietrangelo

Attachment

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Risk Informed Steering Committee
NRC Document Control Desk

NEI 16-06 [Rev 0]

Crediting Mitigating Strategies in Risk-Informed Decision Making

August 2016

NEI 16-06 [Rev 0]

Nuclear Energy Institute

Crediting Mitigating Strategies in Risk-Informed Decision Making

August 2016

Nuclear Energy Institute, 1201 F Street N. W., Suite 1100, Washington D.C. (202.739.8000)

ACKNOWLEDGMENTS

This report was prepared by the FLEX in Risk-Informed Decision Making (FRIDM) Task Force under the oversight of the industry Risk Informed Steering Committee (RISC) and would not have been possible without valuable input from many individuals including:

- Don Vanover (Jensen Hughes)
- John Weglian (Electric Power Research Institute)
- Bill Webster (Dominion)
- Thomas Zachariah (Nuclear Energy Institute)
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- Dick Haessler (Westinghouse Electric Company)
- Ricardo Davis-Zapata (Duke Energy)
- Mike Powell (Arizona Public Service)
- Randy Bunt (Southern Nuclear Company)
- Young Jo (Southern Nuclear Company)

REVISION TABLE

Revision	Description of Changes	Date Modified	Responsible Person
0	Initial Issuance	August 2016	T. Zachariah

TABLE OF CONTENTS

CREDITING MITIGATING STRATEGIES IN RISK-INFORMED DECISION MAKING

1 PURPOSE

The purpose of this document is to provide guidance on the treatment of plant mitigating strategies in risk-informed decision making. These mitigating strategies employ plant responses which utilize portable equipment to restore or maintain various safety functions during beyond design basis conditions and the loss of permanently installed plant equipment. Examples of these strategies include but are not limited to the FLEX and Extensive Damage Management Guidelines (EDMG)/B.5.b strategies implemented for compliance with NRC Order EA-02-026 and 10 CFR 50.54(hh)(2) as well as with NRC Order EA-12-049 and 10 CFR 50.155.

Typically, traditional risk-informed decision making processes, such as ones that apply probabilistic risk assessments (PRA), have only evaluated permanently installed plant equipment. However, it is anticipated with the increased use of portable equipment at sites to enhance defense-in-depth capabilities, that there will be a substantial risk benefit to plants. The intent of this guidance is to provide an approach to determine what attributes of these strategies should be assessed and how to address any unique considerations in determining the safety benefit within the risk-informed decision making process. It is not the intent of this guidance to provide decision making criteria for any specific risk informed application or to determine when specific approaches are appropriate for use. These determinations would be on a case-by-case basis and would require an evaluation using existing industry and regulatory guidance or practices.

2 BACKGROUND

To meet certain regulations, the nuclear industry developed mitigating strategies and procured portable equipment in support of regulations and orders following the terrorist attacks on September 11, 2001 and the beyond design basis earthquake and subsequent tsunami that led to the Fukushima accident in March 2011. These strategies and equipment provide an additional layer of defense in depth to add flexibility and diversity to permanently installed plant equipment.

2.1 FLEX STRATEGIES

Under the NRC order EA-12-049, plants have implemented or have planned to implement a series of strategies called FLEX with a goal of establishing an indefinite coping capability to prevent core damage, ensure containment function is not jeopardized and spent fuel pool cooling is retained for events which cause an extended loss of ac power (ELAP) to the site and a simultaneous loss of normal access to the ultimate heat sink (LUHS). These mitigating strategies utilize on-site permanent equipment, pre or permanently staged equipment, and portable equipment. Therefore, during events which cause an ELAP to the station's emergency buses (assuming no additional failures or events, such as a loss of coolant accident), the strategies can be implemented to prevent core damage.

The industry guidance document for the implementation of FLEX is NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide" (Reference 1). NEI 12-06 focused on developing strategies based on an ELAP and an LUHS caused by a beyond-design-basis external event (BDBEE). An ELAP assumes a loss of off-site power, emergency diesel generators and any alternate ac source but not the loss of ac power to buses fed by station batteries through inverters. However, plants could also use the equipment and similar strategies to increase defense-in-depth for other plant events and conditions. NEI 12-06 identified the following elements in the FLEX concept:

- **Portable equipment that provides means of obtaining power and water to maintain or restore key safety functions for all reactors at a site.** This could include equipment such as portable pumps, generators, batteries and battery chargers, compressors, hoses, couplings, tools, debris clearing equipment, temporary flood protection equipment and other supporting equipment or tools.
- **Reasonable staging and protection of portable equipment from BDBEEs applicable to a site**. The equipment used for FLEX would be staged and reasonably protected from applicable site-specific severe external events to provide reasonable assurance that N sets of FLEX equipment will remain deployable following such an event.
- **Procedures and guidance to implement FLEX strategies.** FLEX Support Guidelines (FSG), to the extent possible, will provide pre-planned FLEX strategies for accomplishing specific tasks in support of Emergency Operating Procedures (EOP) and Abnormal Operating Procedures (AOP) functions to improve the capability to cope with beyond-design-basis external events.

- **Programmatic controls that assure the continued viability and reliability of the FLEX strategies.** These controls would establish standards for quality, maintenance, testing of FLEX equipment, configuration management, and periodic training of personnel.

Considerations of availability and reliability, adequate time margin to implement, clear and effective command and control, and environmental factors were taken into account when these strategies were developed for the specific conditions identified in EA-12-049. These same considerations can be credited or further established for additional scenarios and applications. This document provides licensees guidance to utilize applicable information, analysis, and documentation developed for FLEX strategies in establishing credit in risk-informed decision making.

2.2 OTHER MITIGATING STRATEGIES

Under the NRC Order EA-02-026 (Section B.5.b), and 10 CFR 50.54 (hh) (2), plants have implemented a series of mitigating strategies known as "B.5.b." Further industry guidance was developed in NEI 06-12, Revision 3, "B.5.b Phase 2 & 3 Submittal Guideline" (Reference 2), where more specific details of these mitigating strategies are discussed. Due to the security related nature of these strategies, the operating scope and capability of these mitigating strategies will not be discussed in this guidance.

The NRC published a Regulatory Issue Summary (RIS) 2008-15 where the staff allowed licensees to credit use of B.5.b mitigating strategies in licensing actions and in the significance determination process (SDP). Since regulatory activities rely on realistic assessments of the change to reflect the as-built, as-operated plant, it was determined that crediting these strategies in PRA to the extent necessary would provide useful insights. Therefore, it was recognized that these strategies would improve safety and reduce plant risk. An important aspect of crediting this equipment, both portable and permanent, used in these strategies is that the licensee would have to demonstrate the appropriate level of reliability and availability. Though the RIS does not state what program must be used to demonstrate reliability and availability, performance monitoring programs (e.g. Maintenance Rule Program or B.5.b specific monitoring program) can be used to meet this requirement. Additionally to credit this equipment in a PRA, a human reliability analysis would have to be performed, procedural guidance developed, and plant personnel trained to show an acceptable probability of success in equipment mobilization and operation.

Similarly multiple references provide guidance on shutdown defense-in-depth, and describe contingency plans, which can include portable equipment, to ensure availability of key safety functions. The primary references are NUMARC 91-06, "Guidelines for Industry Actions to Assess Shutdown Management" (Reference 3), EPRI TR 1008501, "Outage Configuration Risk Management Consistency Study Final Report" (Reference 4), EPRI TR 1013501, "Qualitative Risk Assessment Methods for Shutdown Risk Management" (Reference 5), and INPO 06-008, "Guidelines for the Conduct of Outages at Nuclear Power Plants" (Reference 6). It has become common practice for utilities to rent commercial grade equipment to enhance defense in depth and reduce risk during plant shutdown operations. In some cases this equipment has been purchased by the utility. The temporary modification process or modifications to operating procedures along with the 10 CFR 50.59 process, have been used to ensure the equipment is capable of performing a key safety function or support function. The licensee must demonstrate

the appropriate level of reliability and availability in order to credit this equipment for this purpose. Additionally to credit this equipment in a PRA, a human reliability analysis would have to be performed, procedural guidance developed, and plant personnel trained to show an acceptable probability of success in equipment mobilization and operation.

Other examples for the use of portable equipment can be found in support of Notice of Enforcement Discretion and Exigent Technical Specification requests. This equipment has typically been used for defense in depth compensatory actions where qualitative credit has been given. However, there are examples of where compensatory actions have been quantitatively analyzed through bounding assessments and/or specific modeling in PRAs. These assessments utilized many of the insights and techniques described in the previous paragraphs along with those described in this guidance and associated examples.

2.3 Risk Informed Decision Making

Regulatory Guide (RG) 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" (Reference 7), describes the five principles of risk-informed decision making.

1. The proposed change meets the current regulations unless it is explicitly related to a requested exemption.
2. The proposed change is consistent with a defense-in-depth philosophy.
3. The proposed change maintains sufficient safety margins.
4. When proposed changes result in an increase in core damage frequency (CDF) or risk, the increases should be small and consistent with the intent of the NRC's Safety Goal Policy Statement (Reference 8).
5. The impact of the proposed change should be monitored using performance measurement strategies.

Depending on the application, this report provides guidance to help support the use of portable equipment and related mitigating strategies to address principles 2, 3, and 4. This report does not specifically address principles 1 and 5 of the risk-informed decision making process.

3 APPLICABILITY OF GUIDANCE

This guidance provides a suitable approach in crediting the use of portable equipment associated with various plant mitigating strategies in risk-informed decision making. Many of the examples in this guidance describe the use of FLEX-specific portable equipment and strategies. However, the approach described can be applied to other portable equipment independent of the strategies they were originally designed to support. In general, mitigating strategies are supported by various types of equipment and the applicability of this guidance varies with their primary function, location, and normal configuration. Equipment used to support mitigating strategies may include the following:

- **Permanently Installed Plant Equipment** – Equipment permanently installed in the plant with a primary function associated with traditional plant operations outside of their role in the mitigating strategies. This guidance document is not directly applicable, because traditional processes apply to this type of equipment.
- **On-site Portable Equipment** – Equipment on or near the owner controlled area which may need to be mobilized and connected to plant systems where their primary functions are to support the mitigating strategies. This guidance document is directly applicable and focused on this type of equipment.
- **Permanently Staged Portable Equipment** – Equipment that is permanently staged to reduce installation time, but its primary function is to support mitigating strategies. The licensee should determine if the nature of the specific equipment being addressed is similar to permanently-installed plant equipment or to portable equipment. If the determination is that the equipment is similar to portable equipment, then the considerations in this guidance are applicable.
- **Off-site Portable Equipment** – Equipment almost identical to the on-site portable equipment but housed remotely at locations such as national response centers or other plant sites. This guidance is directly applicable to this type of equipment but it is recognized that crediting this equipment is likely to only be applicable in scenarios with much longer mission times and may not be readily creditable in most qualitative assessments. Licensees should demonstrate that credited off-site portable equipment would clearly be available on-site within the mission time of the scenario.

4 OVERVIEW OF APPROACH

This guidance document outlines a three tiered approach to evaluating the safety benefits of the use of portable equipment in risk-informed decision making. These tiers include:

Tier	Assessment	Description
1	Qualitative Assessment	This assessment evaluates the key considerations that need to be addressed. In this tier, the licensee should collect the necessary information to produce the foundation of the overall approach to credit mitigating strategies. This assessment can be used to inform the other tiers of this approach or can be used to inform a risk-informed decision making process where a quantified model is not required.
2	Semi-Quantitative Streamlined Assessment	This assessment applies a decision tree process to the qualitative considerations identified in the previous tier to estimate the risk benefit of a mitigating strategy. This assessment can be used on its own to inform risk-informed decision making processes where a RG 1.200 PRA is not required. This assessment can also be used to inform Tier 3 by identifying which mitigating strategies provide a substantial level of risk benefit.
3	Full Probabilistic Risk Assessment	This assessment seeks to fully quantify the risk impact of mitigating strategies using a RG 1.200-compliant PRA model by implementing the qualitative considerations identified in Tier 1, and incorporating insights from Tier 2 as applicable.

5 QUALITATIVE ASSESSMENT

This section identifies the key, unique considerations in making a determination of the benefits of mitigating strategies and associated portable equipment. These considerations are similar to considerations that would be addressed in evaluating permanently-installed plant equipment, as described in Section 3. However, permanently-installed plant equipment necessary for the success of mitigating strategies is not explicitly addressed since existing industry and regulatory guidance is determined to be sufficient. Using these considerations, licensees can develop the necessary information to create a qualitative risk assessment or build the foundation of more quantitative assessments discussed later in this document.

A qualitative risk assessment that properly evaluates the following considerations (below and in Figure 5-1) can demonstrate that these mitigating strategies and associated portable equipment can be used to further improve safety margin in a variety of scenarios.

- Overall feasibility and applicability for use in identified scenario(s)
- Availability of equipment
- Reliability of equipment
- Ability to deploy equipment
- Adequacy of time margin
- Adequacy of procedures for diagnosis and execution
- Adequacy of training
- Adequacy of staffing and communications
- Effects of any potential environmental conditions

However, it should first be determined whether the use of a qualitative risk assessment is acceptable for the specific risk-informed decision making process (e.g. Shutdown Risk Assessment, Online Configuration Risk Management, and Notice of Enforcement Discretion (NOED)) being evaluated. Typically, a qualitative assessment is not the only aspect of the decision making process being taken into account to make a final decision. Other aspects of the process should be evaluated to determine if a qualitative assessment could potentially affect the outcome of the final decision.

The following sections provide guidance on what information should be reviewed, evaluated and discussed to address each of the elements above. Examples are provided only to illustrate where this type of information could be found for certain mitigating strategies. An example of a qualitative risk assessment is provided in Appendix A.

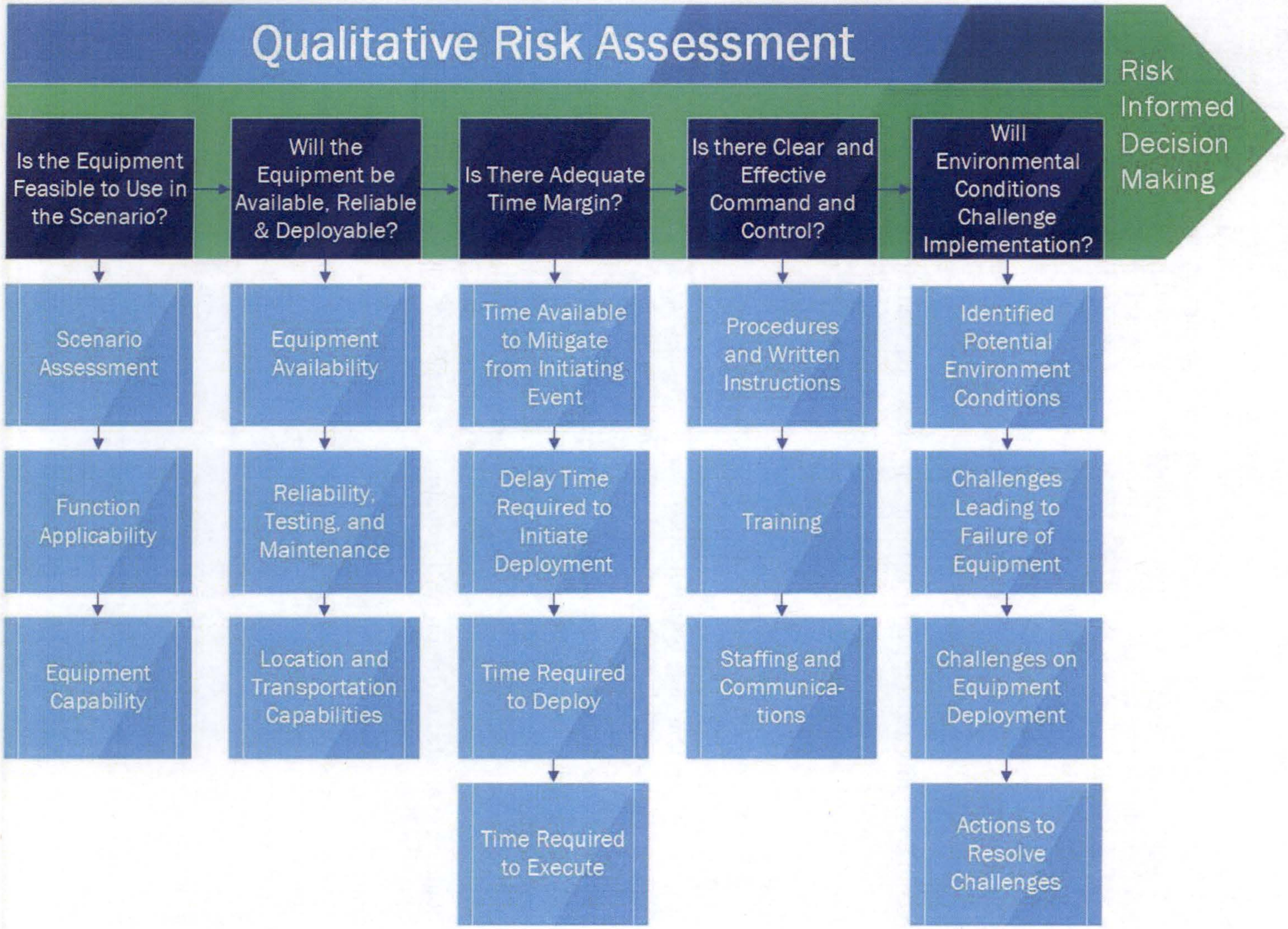

Figure 5-1: Considerations for a Qualitative Risk Assessment of Mitigating Strategies

5.1 INITIAL FEASIBILITY ASSESSMENT

The purpose of the feasibility assessment is to collect the necessary information to perform the qualitative assessment and make an initial determination if mitigating strategies could be used to support the identified scenarios. This initial assessment:

- Identifies the potential scenarios
- Evaluates adequacy of the mitigating strategy to support the success criteria for the scenarios
- Identifies the necessary equipment to successfully implement the mitigating strategy
- Determines if the operators would be directed to implement the equipment after diagnosing the scenario
- Evaluates the capability of using the portable equipment given its capacity and the conditions of the systems in which it needs to interact

The feasibility assessment allows the licensee to evaluate necessary considerations at a high level to establish whether or not a detailed assessment is warranted. Based on the conclusions of this assessment, the licensee may identify important changes (e.g. pre-deployment of equipment or revised written instructions) that need to be implemented prior to the appropriate level of credit being established.

5.1.1 Scenario Assessment

The first step in a feasibility assessment is to identify the accident scenarios the portable equipment can be used for (e.g. SBO, loss of heat sink, loss of inventory). The intent of the scenario assessment is to determine whether the use of the portable equipment is feasible for the given scenario. This determination should include the following:

- Whether the overall timeline of the scenario supports the deployment and installation of the portable equipment to meet the success criteria
- Identification of all equipment, including permanently installed plant equipment, needed to implement the mitigating strategies and meet the success criteria of the scenario
- Whether operators would know to use the portable equipment for the given scenario
- Whether there are written instructions that would drive the use of the portable equipment in the given scenarios
- Whether the process of deploying and installing the portable equipment has been demonstrated and/or validated

5.1.2 Function Applicability

The purpose of this step is to determine which functions are desired to be credited in the qualitative assessment. For example, scenarios with the following functions may be mitigated using portable equipment:

- Restoration/maintenance of dc or vital ac systems to restore instrumentation and dc functions
    - Example: Portable 480V generator sets can be used to provide power to identified electronic loads such as vital instrumentation, battery chargers, etc.
- Restoration/maintenance of core cooling
    - Example: A portable pump can be used to makeup to the reactor coolant system (RCS) to provide the water volume necessary to support natural circulation.
- Restoration of RCS inventory and reactivity control
    - Example: The RCS reactivity and inventory control can be achieved initially by the discharge of the Safety Injection Tanks/Accumulators as a result of RCS depressurization and then a portable pump can be used to provide borated makeup from site tanks to the RCS.
- Maintenance of containment function
    - Example: Portable equipment can be used to assist containment venting and/or closure of containment openings.
- Restoration of Spent Fuel Pool (SFP) makeup
    - Example: A portable pump can be deployed at pre-designated external locations to supply water to the SFP. This pump provides inventory makeup sufficient for SFP leakages and/or boil-off.

When using FLEX-specific portable equipment, the licensees should review the details of the FLEX program appropriately for use in this assessment. The use of other portable equipment to support mitigating strategies may need a similar evaluation to determine if use is appropriate.

5.1.3 Equipment Capability

Once the equipment is determined to be able to support the function, the capabilities of that equipment should be evaluated against the success criteria of the scenario. The first step of this evaluation is to determine if the equipment has the capability to meet the success criteria of the scenario. To do this, an understanding of the specific equipment that has been procured and its relevant performance specifications is needed. The following is a list of considerations:

- Pump performance and capability (e.g. flow/pressure)
- Flow path capability and compatibility (e.g. hose/pipe capacity and rating, adequate lengths, connections, valves, environmental rating)
- Generator performance capability (e.g. voltage)

- Generator cable capability (e.g. rating, adequate lengths, connections, grounding, environmental rating)
- Electrical breaker capability
- Air compressor performance capability
- Equipment fuel and re-fueling capability

The next step of this evaluation includes the following considerations.

- Evaluate the conditions of the system being supported to determine whether they are within the capabilities of the equipment being used.
    - Are the conditions within the design capabilities of any support components such as hoses, piping, or valve connections?
    - If conditions are outside of design parameters, is there any basis (e.g., design margin) to support the use for these conditions?
- Determine and evaluate the connection points and routing paths to connect the equipment into the system being supported.
- Evaluate system considerations (e.g. valve alignments, backpressure)
- Evaluate the suction sources (e.g. tank levels/capacity, water quality, need for strainers)
- Evaluate the level of instrumentation and control needed to ensure the functionality of the equipment.

Plants developed the FLEX equipment and documented performance capability in accordance with NEI 12-06, Sections 11.2 and 11.3. For this qualitative assessment, the specific capability should be documented or referenced from the site's program documents as applicable. Other equipment may need further evaluation to determine if use is appropriate.

5.2 Availability and Reliability

The availability and reliability of equipment should be considered to determine if credit can be taken for the scenario being evaluated in the applicable risk-informed decision making process. In addition, the capability to deploy the equipment should be accounted for as a part of the qualitative assessment.

5.2.1 Equipment Availability

The qualitative discussion should consider the availability of the equipment for the function and scenario needed. Competing functions should be considered. As an example, the use of a piece of equipment for one function may preclude its use for another function.

NEI 12-06 requires that FLEX equipment be administratively tracked when unavailable and compensatory measures should be taken for equipment unavailability that does not

meet certain requirements (NEI 12-06, Section 11.5). As an example, the program may require that the site has N+1 sets of equipment, where N is the number of units on site (NEI 12-06, Section 3.2). If the additional (+1) set is unavailable for 90 days, the equipment must be returned to service or other compensatory actions are required. The qualitative assessment can credit the existing controls, or, if necessary, additional controls can be established if appropriate for the needed function. Equipment pre-staging can be used to ensure availability.

The installed FLEX connections provide a level of flexibility and diversity by requiring that each function have a primary connection/capability and an alternate connection/capability (NEI 12-06, Section 3.2). The qualitative assessment can include this diversity as appropriate when discussing the additional defense in depth being provided by the FLEX equipment. The qualitative assessment should demonstrate that equipment and connections are available when needed. The existing requirements of the FLEX program can be referenced for FLEX equipment being credited as applicable. Other equipment and connections may need further evaluation to determine an acceptable level of availability.

5.2.2 Reliability, Testing and Maintenance

A discussion of the relevant reliability information of the equipment should be evaluated and discussed in the qualitative assessment. The following should be evaluated for relevant information or it should be determined if additional/supplemental performance testing is warranted:

- Manufacturer testing and reliability information
- Generic industry information and operating experience
- Plant specific operating experience and/or testing and maintenance program

NEI 12-06 requires key FLEX equipment to be subject to maintenance and testing guidance provided in INPO AP 913, "Equipment Reliability Process" (Reference 9), and EPRI 3002000623, "Nuclear Maintenance Applications Center: Preventive Maintenance Basis for FLEX Equipment – Project Overview Report" (Reference 10). The FLEX program established for each site can be used as a reference for reliability of the equipment as applicable. Other equipment may need further evaluation to determine an acceptable level of reliability.

5.2.3 Location and Transportation Capability

The location and storage of equipment must be considered including the deployment capabilities. Support equipment (e.g. for hauling or debris removal) should be available after the event, if required. Pre-deployment or pre-staging may be credited to ensure equipment is at the proper location to meet the time line established for the scenario.

The FLEX program considered deployment of equipment for the applicable evaluated external hazards (seismic, flooding, wind, cold and hot temperatures) which can be used as a reference to justify the use in a given scenario. Other equipment may need further evaluation to determine deployment requirements.

5.3 TIME AVAILABILITY AND MARGIN

The availability of time margin to complete necessary actions is an important consideration in the qualitative risk assessment of the mitigating strategies equipment. To support this effort, a timeline of the necessary actions should be constructed, and adequate time margin should be demonstrated to provide confidence in meeting the success criteria. A bounding timeline can be utilized when multiple scenarios are being evaluated. The individual elements comprising the timeline are shown in Figure 5-1 and discussed below.

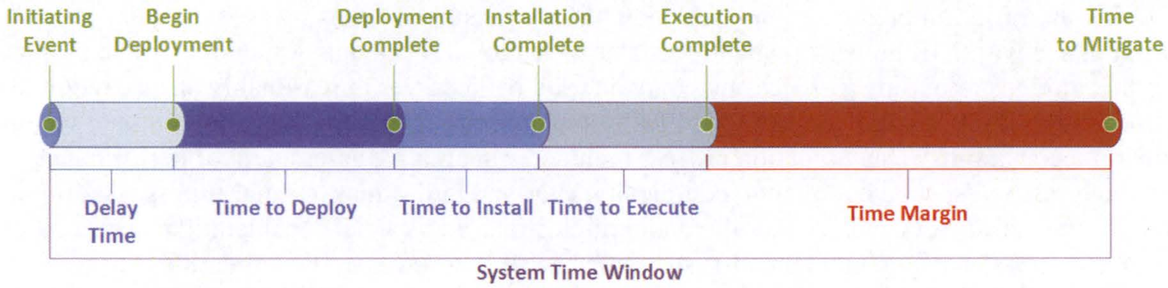

Figure 5-2: Structure of a Timeline for Mitigating Strategies Actions

The scenario first needs to be evaluated to determine the following:

- Time of Initiating Event – This is when the initiating event occurs to begin the scenario. (e.g. Reactor Trip, Loss of Offsite Power (LOOP), Turbine Trip, Loss of Feedwater)
- Time to Mitigate – This is the endpoint of the timeline where mitigation must begin to restore or maintain the function in order to ensure the success criteria is met.
- System Time Window (T_{sw}) – The time available between the Time of Initiating Event and the Time to Mitigate. This is the overall time window where actions to implement a mitigating strategy will be evaluated.

Next, the following elements of the timeline need to be identified:

Delay Time (T_{delay}) – This is the duration of time it takes to diagnose the situation and begin the deployment of the mitigating strategies equipment, measured from the Time of Initiating Event. This includes the time for operators to receive enough indication, evaluate the written instructions, and take any necessary preparatory actions to begin the deployment actions.

- Time to Deploy (T_{deploy}) – This is the duration of time needed to fully deploy the equipment so it is ready to be installed. This includes the time associated with getting the equipment out of the storage area and transporting the equipment to the appropriate location (T_{trans}), as well as clearing any debris from the route (T_{debris}). Actions for pre-deployment may be considered to adjust the timeline.
- Time to Install ($T_{install}$)– This is the duration of time to complete necessary steps in aligning connections such as hoses and power cables.

- Time to Execute (T_{exe}) – This is the duration of time necessary to complete the steps to start equipment and begin restoration or continuation of the function provided by the equipment.

Finally, the Time Margin should be assessed:

- Time Margin – This is the difference between the Time to Mitigate and the execution completion time.

During the FLEX implementation, validation of time sensitive actions was required in accordance with NEI guidance which was later added to NEI 12-06 as Appendix E. The purpose of this guide is to outline a process that may be used by licensees to reasonably ensure required tasks, manual actions and decisions for FLEX strategies are feasible and can be executed within the time constraints. The validation process included a qualitative assessment of performance shaping factors (special equipment, complexity, cues and indications, special fitness issues, environmental factors and accessibility, communications and special considerations, procedures, training, stress, staffing, and human-system interfaces). The site specific validation documentation should be used as a reference for time considerations if applicable for crediting FLEX equipment. Other mitigating strategies or new scenarios not previously assessed may need further evaluation to determine adequate time margin.

5.4 Command and Control

The credit for use of mitigating strategies is dependent on the quality of knowledge of when and how to use the portable equipment in a given scenario. Therefore, associated procedures, written instructions, training and availability of the implementation staff are very important to provide confidence that the appropriate mitigation or prevention activities will be successful.

5.4.1 Procedures and Written Instructions

Relevant procedures should be reviewed to confirm that operators will have clear directions and cues to implement the equipment successfully. It should be noted that there could be different procedures for different types of scenarios for the same equipment. For portable equipment it is recognized that not all instructions will be contained within plant procedures, however other written instructions may be implemented to deliver the same level of clarity. Though not explicitly called procedures, these instructions should be reviewed, evaluated and credited based on their clarity and effectiveness.

FSGs were developed during implementation of the FLEX program. In general, the command and control was retained within the EOPs. The EOPs direct the implementation of the FSGs to complete steps required for the mitigating function associated with the specific conditions that necessitated entry into the FSGs. The site specific development and procedural structure can be referenced and reviewed to ensure the operating staff has sufficient information to implement the strategy being credited. Additionally, operation placards for FLEX equipment were developed and standardized across the industry to ensure adequate instruction is available for operation of the portable equipment and can be referenced in the assessment. Written instructions for other equipment or mitigating strategies may need further evaluation to determine adequacy.

5.4.2 Training

Training programs should be evaluated to determine how well operators are aware of equipment capabilities, the location of the equipment, and actions necessary to deploy, align and operate the equipment. For portable equipment it is recognized that not all training will be part of accredited programs, however other training may be performed to provide a similar level of proficiency. The quality, effectiveness, and frequency of training programs and operator exercises should be evaluated to understand the knowledge base of the personnel required to perform the necessary actions to implement the credited mitigating strategies.

For example, NEI 12-06 required FLEX training to be provided to key personnel relied upon to implement the procedures and guidelines for responding to a beyond design basis event. Utility training programs have been revised to ensure personnel proficiency in utilizing FSGs and associated Beyond Design Basis (BDB) equipment for the mitigation of BDBEE is adequate and maintained. These programs and controls have been developed and implemented in accordance with the elements of the Systems Approach to Training (SAT) Process defined in 10 CFR 55.4 (Reference 11).

Initial training has been provided and continued training has been established for appropriate site personnel on BDB response strategies and implementing guidelines. Personnel assigned to direct the execution of the FLEX strategies have received the necessary training to ensure familiarity with the associated tasks, available job aids, instructions, and mitigating strategy time constraints. Training for other mitigating strategies may need further evaluation for adequacy. Just-in-time training may be required for emergent conditions or infrequent or complex evolutions.

5.4.3 Staffing and Communications

The availability of the staffing required to implement the mitigating strategies needs to be evaluated given the specific scenario being assessed. Sites with multiple units should consider whether the scenario affects all units. Pre-deployment of equipment or additional staffing (e.g. staffing during an outage) should be considered. Communication required to implement the mitigating strategies needs to be considered including the availability of necessary communications equipment.

Staffing studies in accordance with NEI 12-01, "Guideline for Assessing Beyond Design Basis Accident Response Staffing and Communication" (Reference 12), were performed and referenced in the site-specific FLEX program. Minimum administrative staffing was verified to be sufficient to execute the FLEX strategies for all units on site. FLEX strategies required consideration for communications (NEI 12-06, NEI 12-01). Staffing and communication for other mitigating strategies may need further evaluation for adequacy.

5.5 Environmental Challenges

This assessment should evaluate whether the environmental conditions hinder the deployment, timing, or implementation of the equipment being assessed. This consideration also identifies any actions to address these conditions. In general, these conditions are driven by the initiating

event of the scenario and are specific to that hazard. For this evaluation the potential environmental conditions given the hazard should be identified. These conditions could include the failure of buildings and structures, or generation of debris that could obstruct access to areas. The location of equipment and the building that houses it should be assessed to determine if these conditions could impact the availability of the equipment. The route necessary to deploy the equipment to the required location should also be evaluated for impacts. Potential methods of recovery should be evaluated such as alternate paths, pre-deployment, or removal of debris. The following are examples of hazards and how they could potentially challenge the implementation of mitigating strategies equipment:

Table 5-1: Potential Challenges of Some Example External Hazards

Hazard	Potential Challenges
Internal Fire	• Direct failure of equipment • Fires could block equipment routing and limit or delay access to areas
Internal Flooding	• Direct failure of equipment • Flooded areas could block equipment routing and limit or delay access to areas
Seismic	• Direct failure of equipment • Failure of buildings and structures that house equipment • Debris could block equipment routing and limit or delay access to areas
External Flooding	• Direct failure of equipment • Failure of buildings and structures that house equipment • Flood level could prevent access to equipment • Debris could block equipment routing and limit or delay access to areas

Hazard	Potential Challenges
High Winds and associated missiles	• Direct failure of equipment • Failure of buildings and structures that house equipment • Debris could block equipment routing and limit or delay access to areas
Extreme Temperatures	• Direct failure of equipment • Habitability of areas required for operator actions • Snow or ice could block equipment routing and limit or delay access to areas

Once potential challenges are identified, actions that can be taken to resolve challenges should be evaluated. This evaluation should demonstrate adequate likelihood of successful implementation in the scenario such that it can be credited in the assessment. These environmental conditions and associated actions should be taken into consideration for impact on other elements of this assessment such as the time margin evaluation, command and control, and transportation capabilities.

In accordance with NEI 12-06, Section 4, the housing, deployment and installation of FLEX equipment was required to be evaluated against a number of external events. The evaluations identified actions and requirements that ensured a higher likelihood of successful implementation of FLEX equipment and strategies. These elements should be considered and referenced in the assessment as applicable. Housing, deployment and installation for other mitigating strategies equipment may need further evaluation. Pre-deployment or pre-staging of equipment needs to consider the potential environmental impacts at their staging location.

6 SEMI-QUANTITATIVE STREAMLINED ASSESSMENT

The purpose of the semi-quantitative streamlined assessment is to establish a reasonably conservative method of estimating the risk benefit from mitigating strategies using a decision tree approach. This assessment utilizes the same considerations identified in the qualitative assessment and a set of representative estimates to re-quantify existing plant specific PRA results. Figure 6-1 illustrates the high level approach using the following steps:

1) Identify specific scenarios (i.e., cutsets or accident sequences) in the plant specific PRA results that could benefit from the implementation of a mitigating strategy.

2) Determine if a potential reduction in the CDF and Large Early Release Frequency (LERF) results using the mitigating strategies provides sufficient benefit to warrant the performance of the assessment.

3) Perform the steps of the qualitative assessment described in Section 5.

4) Apply the decision tree approach to develop a representative multiplier value of the overall failure of the mitigating strategy for the applicable scenarios.

5) Re-quantify CDF/LERF results using the multiplier for the applicable scenarios.

6) Use results in the risk-informed decision making process:

    a. If the intent is to only utilize a semi-quantitative assessment for the risk-informed decision making process, document the basis for the credit and influence on the decision, OR

    b. If looking to model mitigating strategies in the PRA, use results to identify which scenarios and strategies were of the highest benefit and model using Tier 3 guidance.

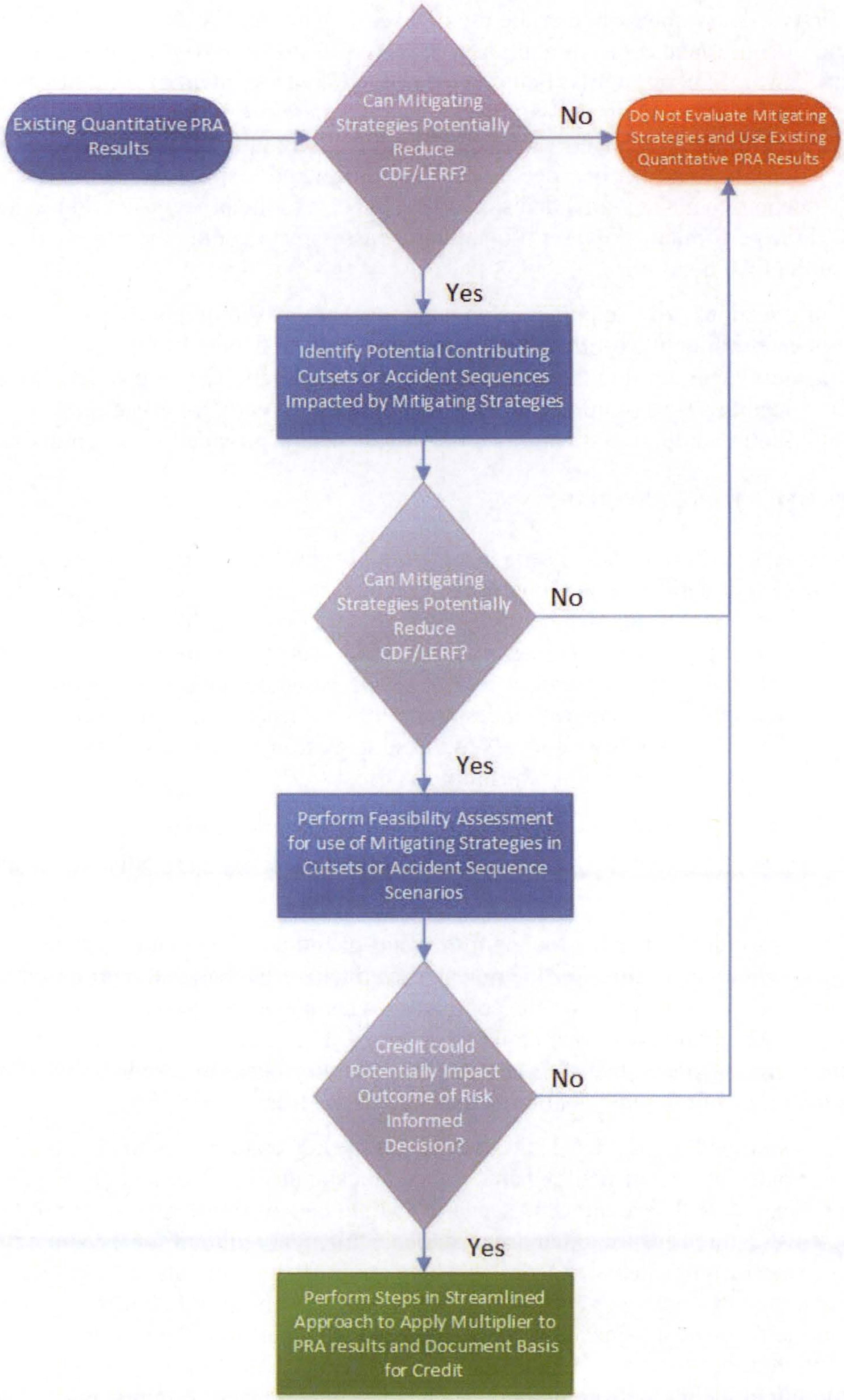

Figure 6-1: Process Overview of the Semi-Quantitative Streamlined Approach

It should first be determined whether the use of a semi-quantitative assessment is acceptable for the specific risk-informed decision making process (e.g. Shutdown Risk Assessment, Online Risk Management, SDP or NOED) being evaluated. It is not the intent of the assessment in this section to meet the PRA requirements of RG 1.200 and therefore is not intended to be implemented in areas where a RG 1.200-compliant PRA is required. Typically, an estimate of the change in risk is not the only aspect of the risk-informed decision making process being taking into account to make a final decision. Other aspects of the process should be evaluated to determine if the performance of a semi-quantitative assessment could potentially affect the outcome of the final decision.

The following sections provide guidance on what information should be reviewed, evaluated and discussed in determining the estimated quantification of the risk benefit from mitigating strategies without incorporating the strategies into the PRA model. Examples are provided only to illustrate where this type of information could be found for certain mitigating strategies. An example of a semi-quantitative streamlined risk assessment is provided in Appendix B.

6.1 Identification of Scenarios

The results (i.e., cutsets or accident sequences) of the licensee's existing PRA are to be reviewed in this approach to identify which scenarios should be evaluated. The cutsets or accident sequences assessed for this approach may get different treatment in this process due to the initiating event or additional failures, as applicable. For example, a fire-induced LOOP may be treated differently than a severe weather-related LOOP based on timing and environmental factors. These cutsets or accident sequences represent the scenarios that are used in the process. For example, the key elements for success of the strategy from the review of the cutsets and/or sequences could be determined to be the ability to use:

- Two portable backup generators to provide prolonged dc availability, and
- One portable pump to provide Reactor Pressure Vessel (RPV) or suppression pool makeup.

These elements would then be the focus for the semi-quantitative evaluation. Once the appropriate boundary conditions for the potential credit are established, the proposed semi-quantitative approach would rely on the completion a simple decision tree (Figure 6-2) to determine the numerical benefit that could be obtained. The intent is to provide a means to obtain an estimate of the calculated CDF/LERF reduction that may occur in certain applications of PRA models using many of the same qualitative considerations from Section 5.

In the process outlined in Figure 6-1, the focus is on the key contributors to the decision. Once the key contributors are identified, the analysts can look at any validation studies and related procedural direction to determine what scenarios would benefit from credit of the mitigating strategies. This requires ensuring that any installed equipment required for the strategy has not failed in the scenarios of interest. Scenarios where credit for the mitigating strategies is feasible can be determined by reviewing cutsets and/or accident sequences and identifying those that would have the permanently-installed equipment available, but could benefit from implementation of mitigating strategies to avoid core damage. Ancillary actions required for implementation of the portable equipment, such as opening doors or establishing alternate ventilation systems for long term room cooling, must also be deemed feasible as part of the

assessment. Their failure probabilities, however, are implicitly included in the bounding approach provided in the next sections.

6.2 Decision Tree Summary

The streamlined decision tree for crediting portable equipment in risk-informed decisions is shown in Figure 6-2.

The nominal failure value for crediting the mitigating strategy in applicable scenarios starts at 0.1. As described in Section 6.3, this is a well-established value for feasible actions that are deemed likely to succeed under nominal conditions. This is the entry condition for the decision tree.

As described in Section 6.4, depending on the available time margin for deploying and implementing the portable equipment, the first branches of the decision tree in the Time Margin node are based on whether inadequate, nominal or expansive time margin exists for crediting the mitigating strategies in the scenarios of interest.

Time Margin (TM) Branch Descriptions

Inadequate	Time Margin Negative (Fail strategy)
Nominal	Time Margin < 100% (Retain nominal value)
Expansive	Time Margin >= 100% (Reduce nominal value by factor of 2)

As described in Section 6.5, the Command and Control node of the decision tree is a Yes or No determination (i.e., either functional or impaired) and either leads to a pass-through to assess environmental factors and equipment availability issues in the last two nodes of the decision tree, or it leads to guaranteed failure of the action.

Command and Control (CC) Branch Descriptions

Impaired	Command and Control Impaired (Fail strategy)
Functional	Command and Control Functional (Retain nominal value)

As described in Section 6.6, the Environmental Factors node of the decision tree is used based on whether the equipment and staff are capable of operating in the scenarios in which credit for the strategy is desired. There are three possible outcomes:

1) it is deemed that nominal environmental conditions exist,
2) it is deemed that adverse environmental conditions exist that will challenge deployment but will not preclude deployment, or
3) it is deemed that the environmental factors will preclude deployment or other conditions exist to make the portable equipment unavailable for deployment.

Environmental Factor (EF) Branch Descriptions

Nominal	Environmental Factors Nominal (Retain nominal value)
Adverse	Environmental Factors Adverse (Increase nominal value by factor of 2)
Precludes	Environmental Factors Preclude Deployment (Fail Strategy)

As described in Section 6.7, the Equipment Availability node of the decision tree applies a 0.05 or 0.1 additional term to the overall credit for deploying the mitigating strategy depending on whether N or N+1 (or more) portable equipment is determined to be available and how much time margin is available for the scenarios of interest. A conservative value of 0.1 is assigned when only N trains are available. When N+1 trains of equipment are available and could be used based on the time margin analysis, then a value of 0.05 is applied. Note that this term is added to the values in the decision tree derived up to this point, since the equipment reliability represents an additional potential mode of failure for deployment. When applicable, in this portion of the decision tree, it has already been determined that sufficient time is available to deploy the equipment (at least once), that procedural direction, cues, and sufficient staffing exist to deploy the equipment, and that environmental factors have not precluded deployment of the equipment. Credit for the N+1 branch is only given when the Time Margin was assessed to be expansive (>100% margin) and therefore the operators have time to deploy the portable equipment, determine there is a hardware failure, and replace the affected equipment with a spare.

Equipment Availability (EA) Branch Descriptions

N = 1	Train of Portable Equipment Available (Add 0.1)
>=N+1	More than 1 Train of Portable Equipment Available (Add 0.05)
<N	Less than N Trains of Portable Equipment Available (Fail Strategy)

In summary, when feasibility has been demonstrated, the final calculated value (F, the multiplier for the applicable scenarios) is derived from the following expression.

$$F = 0.1 * TM * CC * EF + EA$$

Where TM is 1.0 or 0.5 depending on whether the time margin available is nominal or expansive, CC is 1.0 when functional, EF is 1.0 or 2.0 depending on whether the environmental factors are nominal or adverse, and EA is 0.05 or 0.1 depending on whether N+1 or more of equipment is available and sufficient time exists to deploy the spare equipment.

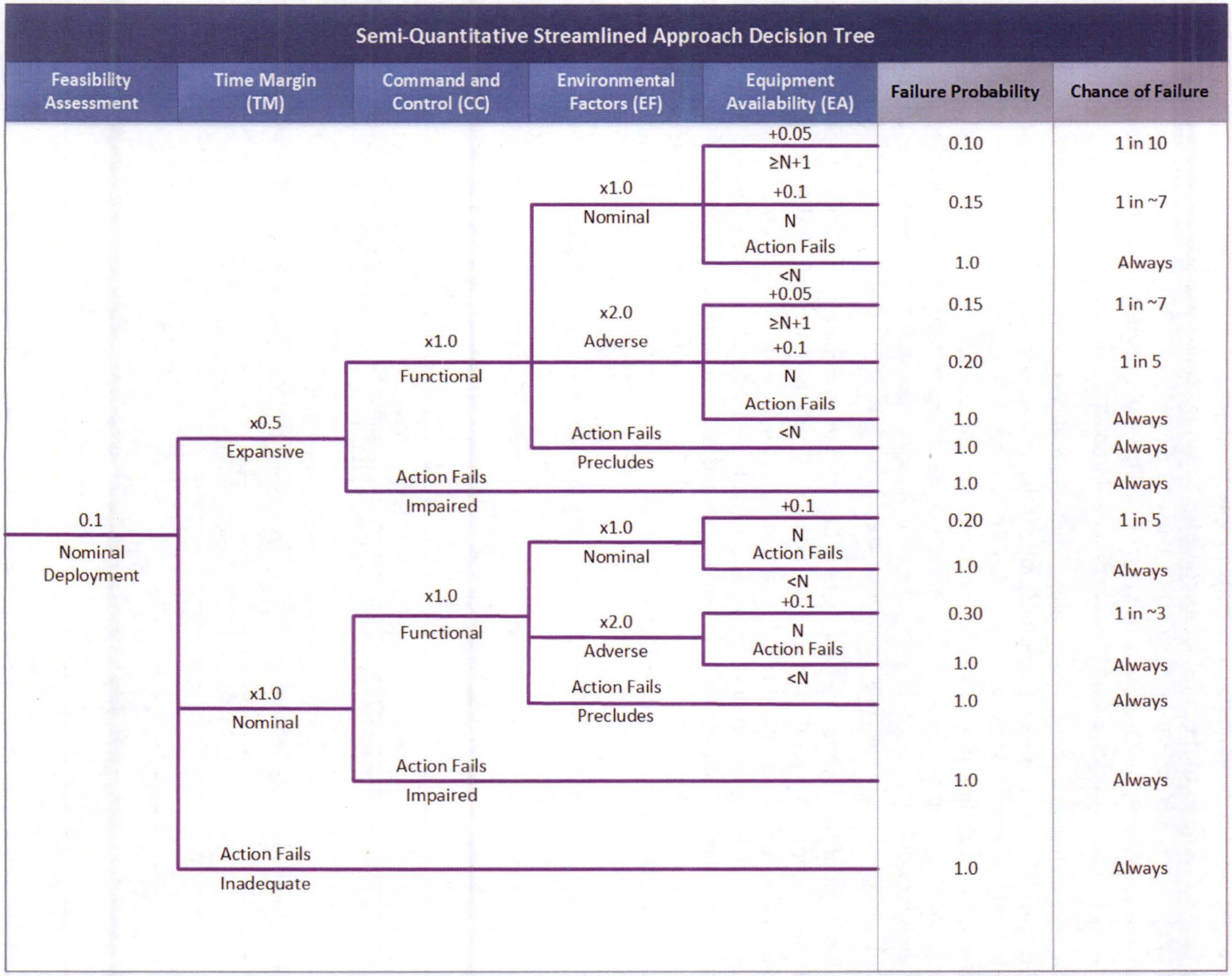

Figure 6-2: Semi-Quantitative Streamlined Approach Decision Tree

6.3 Base Failure Probability for the Initial Feasibility Assessment

An initial estimated probability of 0.1 is used for nominal failure of a mitigating strategy where a successful outcome of the initial feasibility assessment has been demonstrated. Then, based on quantitative estimates of the considerations described in Section 5, the actual failure probability used in the assessment can range from 0.1 (likely to succeed) to 1.0 (will not provide additional mitigation capability) for the scenarios of interest. The total assigned value(s) would then be applied to the applicable scenarios to see if it could impact the decision or not.

Variations, such as changes in temperature from day to day could have an influence on performance (e.g., performance could degrade if the actions were being taken at very high or very low temperatures). However, since they are random with respect to when the demand could occur, their probability of occurrence coincident with the implementation of the strategy is low, and are not evaluated explicitly. The nominal value is characterized as being the average value over the spectrum of these conditions. The base value is assumed to account for these factors in that it is a representative average over these conditions.

The construct of the decision tree uses a holistic approach for determining an appropriate failure probability to apply for a given mitigating strategy. A failure probability of 0.1 is assigned for the base value upon entry into the decision tree. This failure probability is consistent with a typical PRA model assumption for assigning a conditional probability value to an event with "state-of-knowledge" uncertainties for an occurrence that is qualitatively judged to be "likely" to succeed. Refer to Table 6-1 which includes excerpts from NUREG/CR-6771, "GSI-191: The Impact of Debris Induced Loss of ECCS Recirculation on PWR Core Damage Frequency" (Reference 13).

Table 6-1: Conditional Success Probabilities for Events with State-of-Knowledge Uncertainty

Value	Description
0.999	The indicated outcome is ALMOST CERTAIN.
0.99	The indicated outcome is EXTREMELY LIKELY.
0.95	The indicated outcome is VERY LIKELY.
0.9	The indicated outcome is LIKELY.
0.5	The indicated outcome is fully POSSIBLE.
0.1	The indicated outcome is UNLIKELY.
0.05	The indicated outcome is VERY UNLIKELY.
0.01	The indicated outcome is EXTRMELY UNLIKELY.
0.001	The indicated outcome is ALMOST IMPOSSIBLE.

Additionally, this failure probability is consistent with the midrange value for a "likely" outcome and is a lower bound estimate for something that is deemed "very likely" to occur based on recent guidance to technical authors for the consistent treatment of uncertainties provided by the Intergovernmental Panel on Climate Change (IPCC) as shown in Table 6-2 (Reference 14).

Table 6-2: IPCC Success Likelihood Scale

Term	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

However, specific applications of the streamlined approach may involve certain scenarios where successful implementation of the strategy is hindered or precluded by the nature of the hazard (e.g., very high magnitude earthquakes with potential for aftershocks). These environmental factors are considered on a case by case basis within the construct of the decision tree methodology. For cases that are ultimately deemed less likely to succeed (but there is still confidence that the mitigating strategy can be successful), then the final value from the decision tree is one that falls further into the "likely" range from the IPCC likelihood scale. If confidence cannot be established that the strategy is at least likely to succeed, then no credit is taken in this streamlined approach.

6.4 QUANTIFICATION FOR TIME AVAILABILITY AND MARGIN

This branch of the decision tree is based on determining if there is sufficient time to diagnose and perform the mitigating strategy. Development of scenario timelines should be consistent with the guidance provided in Section 5.3. The time margin is calculated consistently with that section such that the diagnosis time is included in the delay time. The formula below can be used to determine the ratio of the time margin to the time needed to implement the strategy expressed as a percentage:

$$100\% * [(T_{SW} - T_{Delay} - T_{Debris}) - (T_{Trans} + T_{Install} + T_{Exe})] / (T_{Trans} + T_{Install} + T_{Exe})$$

In order to establish feasibility, it must be demonstrated that the time required to diagnose, deploy and initiate the use of the equipment is less than or equal to the time available, considering potential impacts on the timeline for each scenario.

In this streamlined approach, three timing categories are established (inadequate, nominal, or expansive) based on the time margin available.

Time Margin (TM) Branch Descriptions

Inadequate	Time Margin Negative (Fail strategy)
Nominal	Time Margin < 100% (Retain nominal value)
Expansive	Time Margin >= 100% (Reduce nominal value by factor of 2)*

*The adjusted value is consistent with the mean value from the IPCC likelihood scale for something that is deemed very likely to succeed.

6.5 Quantification for Command and Control Evaluation

The next branch in the decision tree is based on establishing whether or not sufficient direction is provided, staffing is available, and any communications or other required equipment to employ the mitigating strategy is available. This branch is a Yes or No determination (i.e., either functional or impaired) and either leads to a pass-through to assess environmental factors and equipment availability issues in the last two branches of the decision tree, or it leads to guaranteed failure of the action. Guidance on the qualitative considerations that should be addressed in this determination is provided in Section 5.4. Insights specific to the semi-quantitative assessment are also provided below.

The first consideration is that the mitigating strategy execution is procedurally directed in the scenarios of interest and that the cues and indications are sufficient and would be available for diagnosis of the situation and direction of the actions. As is the practice for incorporation into PRA models, manual actions must be procedurally directed for the scenarios of interest, trained upon, and able to be successfully performed in order to receive realistic credit for the risk-informed decision. The associated procedures or instructions should be adequate to support confidence in successful completion of the manual action, but not necessarily incorporated into the plant's formal Emergency Operating Procedures (EOPs). However, they do need to be incorporated and maintained in other, appropriate, administratively-controlled processes.

Each hazard presents different impacts on the plant and may require the performance of different activities by the available staff. For each scenario where mitigating strategies are to be credited, it should be confirmed that the staffing requirements are appropriate and personnel are qualified to perform required duties and will not be diverted to other tasks such that they would not be available to support the strategy. Any special fitness requirements for performing deployment tasks, such as performing debris removal activities, should be considered as part of the staffing assessment.

Lastly, if deployment of equipment relies on communication between the deployment team and any other group, it must be verified that the communication equipment will be available. If any other equipment is required that is not stored with the equipment, it should be demonstrated that this additional equipment will be available and the time required to obtain it must be accounted for in the timing assessment. For example, if self-contained breathing apparatus (SCBA) or portable lighting is required, but not included with the equipment, it should be demonstrated that the location of the additional equipment is known, that it can be accessed, and the deployment time should account for obtaining and using the equipment.

6.6 QUANTIFICATION FOR ENVIRONMENTAL FACTORS

The next branch in the decision tree is based on establishing whether the equipment and staff are capable of operating in the scenarios in which credit is desired. The environmental conditions should be evaluated consistent with the qualitative guidance provided in Section 5.5. In this streamlined quantitative approach, there are three possible outcomes:

1) it is deemed that nominal environmental conditions exist
2) it is deemed that adverse environmental conditions exist that will challenge but not preclude deployment
3) it is deemed that the environmental conditions will preclude deployment or other conditions exist to make the necessary equipment unavailable for deployment.

In the first case, no adjustment is made in the decision tree to the calculated value. In the second case, a factor of two increase is applied to the calculated value. In the third case, the action is assumed failed and no credit is taken.

For each hazard that is evaluated, it should be established that the equipment will not be damaged to the extent that it cannot function and that it will be possible to access the equipment, transport it to the installation area, and that it is possible to work in the installation area. Events that could prevent this include:

- Failure of the structure(s) that house the mitigating strategies equipment, for example:
    - Building collapse that damages the mitigating strategies equipment, or
    - Building collapse that prevents access to the mitigating strategies equipment.
- Failures of structure(s) along the access path between the storage location and the point where the equipment is to be installed, or structural failures of the access paths.
- Obstruction of path due to debris accumulation that is beyond the capability of on-site sources to remove.
- Failures of the structure(s) where the equipment is to be installed.
- Fire in an area where deployment activity is required.
    - No credit should be taken for deployment in fire scenarios where part of the activity must be performed in the immediate vicinity of the fire.
- Flooding in an area where deployment activity is required.
    - No credit should be taken for deployment in internal or external flooding scenarios where part of the activity must be performed in a location that is flooded unless plant procedures specifically address this condition.

In some scenarios, the environmental factors in the scenarios of interest may also preclude deployment. For example, if the communications equipment requires an antenna that would be failed in certain seismic events, then that equipment should be considered to be unavailable for those events. Additionally, no credit should be taken for deployment in conditions that exceed any safety limits established for personnel protection by the plant. For example, no credit should be taken for a deployment activity or for executing tasks during a high wind event which exceeds the safety limits established for plant personnel. If these or other similar conditions exist for the scenarios of interest, then the action is assumed failed and no credit is taken in the risk-informed decision making process. However, if the success criteria and timing allow for later deployment of the equipment, then it can be considered.

Adverse conditions would be present if conditions did not make deployment totally infeasible, but would still hinder the deployment activities. Events that could represent adverse conditions include:

- Partial collapse or other damage, such as door buckling, that requires an alternate deployment scheme for the equipment.
- Conditions that would generally warrant assignment of adverse conditions due to the length of the event (e.g., extreme external flooding events, hurricane events, or relatively high magnitude seismic events due to the potential for aftershocks).

If conditions do not exist that preclude deployment or present adverse conditions as described above, then nominal conditions are assumed to apply and no adjustment is made in the decision tree to the calculated value.

6.7 Quantification for Equipment Reliability and Availability

For simplicity the last branch of the decision tree is used to assign the likelihood of failure of the equipment. When applicable, in this portion of the decision tree, it has already been determined that sufficient time is available to deploy the equipment, that procedural direction, cues, and sufficient staffing exist to deploy the equipment, and that environmental factors have not precluded deployment of the equipment.

Qualitative considerations for equipment reliability and availability are provided in Section 5.2. In most cases where credit for mitigating strategies is desired, a full complement of equipment is likely available. For example, the NEI 12-06 criteria requires the site have sufficient equipment to address all functions at all units on-site, plus one additional spare. Thus, a two-unit site would nominally have at least three portable pumps (N+1), three sets of portable ac/dc power supplies, etc.

It is also acceptable to have a single resource that is sized to support the required functions for multiple units at a site (e.g., a single pump capable of all water supply functions for a dual unit site). In this case, the N+1 could simply involve a second pump of equivalent capability. In addition, it is also acceptable to have multiple strategies to accomplish a function (e.g., two separate means to repower instrumentation). In this case the equipment associated with each strategy does not require N+1. The existing 50.54(hh)(2) pump and supplies can be counted toward the N+1, provided they meet the functional and storage requirements outlined in NEI 12-06. The N+1 capability applies to the equipment that directly supports the success of the mitigating strategy. Other support equipment only requires an N capability.

Assuming that the site has fully met the intent of this requirement and has implemented a sufficient program for maintaining the equipment (e.g., via use of the applicable EPRI maintenance templates), equipment reliability should not be a significant contributor to the overall failure probability for implementing the mitigating strategy. Multiple trains of equipment typically lead to unreliability values in the E-3 range or lower in most PRA models, and in the E-2 range for single trains of equipment. Given the uncertainty of deploying equipment during potentially longer time periods, it is deemed appropriate, however, to utilize a value of 0.05 in this node assuming that the N+1 requirement is maintained. This conservatively accounts for the potential for common cause failure between the two trains of equipment. It is noted that this

value may be refined for specific assessments as more reliability data becomes available for the equipment in question.

If the reliability of one of the sets of equipment is questionable or it is known that one set of the equipment would not be available for the subject analysis (NOED, SDP, etc.), then a conservative value of 0.1 would be applied for the single train of equipment that is available to support the mitigating strategy. Additionally, if the time margin is nominal, no credit is taken for the additional train. For completeness, in the unlikely situation where it cannot be demonstrated that at least N trains of equipment are available for the subject unit[1], then the action is assumed failed and no credit is taken in the risk-informed decision making process.

6.8 Accounting for Impact on Base Case Results

To accurately assess the change in risk for the risk-informed application, the analysis must consider the risk reduction provided by the use of mitigating strategies in the base case. The final multiplier, F, is applied to the applicable scenarios in the base case before calculating the actual change in risk. For example, if the sum of the applicable scenarios where credit can be obtained is 1.0E-6/yr in the base case and 5.0E-06/yr in the application case, then the F multiplier needs to be applied to the base case and the application case to get the actual change in risk when credit for the portable equipment is provided. If the application represents a very large change to the base case (e.g., by setting a value from 5E-3 to 1.0 or TRUE), the impact from accounting for the base case reduction and the application case reduction may be negligible but should be noted as such for that specific application. (For example, refer to the application of the process in Appendix B and the note to Table B-3.)

6.9 Application of the Semi-Quantitative Process

It may be worthwhile to examine the base model results in advance to determine which scenarios would benefit from credit for the mitigating strategies and pre-determine the associated feasibility for each one. This should greatly reduce the overall effort required to perform the assessment should a situation arise where a short turnaround is needed (e.g., NOED). Additionally, this effort is envisioned to provide the framework for establishing which accident sequences would be candidates for incorporating the mitigating strategies into the PRA model (See Section 7) and which human error probability events would need to be developed.

6.10 Other Considerations

As part of the NRC review of the draft version of a white paper developed to support this document, there were two other items that merited additional discussion. The first issue is the achievement of a safe stable state from implementation of the mitigating strategies and the second issue relates to addressing the potential increase in risk associated with implementation of the mitigating strategies in the PRA model. Each of these issues is discussed in turn.

[1] Note that N is defined in the context of FLEX as previously described but may be defined differently in the context of using the decision tree depending on the application or if other portable equipment is being employed.

6.10.1 Achieving a Safe and Stable State

It was noted that the requirements for bringing a plant to a safe and stable state must be considered to assess the mitigating strategy reliability. In the context of PRA model development, NUREG-2122, "Glossary of Risk-Related Terms in Support of Risk-Informed Decisionmaking" (Reference 15), provides the following definition for a "Safe Stable State":

> "In a PRA, safe stable states are represented by success paths in modeling of accident sequences. A safe stable state implies that the plant conditions are controllable within the success criteria for maintenance of safety functions.
>
> The ASME/ANS PRA Standard [Reference 16] defines the term safe stable state as 'a plant condition, following an initiating event, in which reactor coolant system conditions are controllable at or near desired values.'"

For example, the implementation of the FLEX mitigating strategies is consistent with the PRA Standard definition of a Safe Stable State and is consistent with other success paths in many PRA models (e.g., alternate injection and containment venting in a boiling water reactor (BWR) or feed and bleed with recirculation in a pressurized water reactor (PWR)). That is, conditions afforded by implementation of the mitigating strategies result in conditions that are controllable within the success criteria of the safety functions (e.g., RPV level maintained at certain levels or containment controlled below a certain temperature and pressure). Specific requirements to reach cold shutdown or have off-site power restored are not part of the PRA definition of a safe stable state. Furthermore, the additional off-site resources available from the industry-wide implementation of FLEX provide further confidence that these safe stable conditions can be maintained for much longer than typical PRA mission times, if need be.

6.10.2 Potential Risk Increases from Implementing FLEX Mitigating Strategies

There may be scenarios where the implementation of FLEX mitigating strategies could increase risk by performing deep load shedding of 125V dc buses. This might preclude recovery of off-site or on-site power because of a lack of instrumentation and/or control power. This potential risk increase issue is acknowledged and may have already been evaluated or incorporated based on review of procedure changes into the plant base PRA model (See Section 7).

For example, restoration of off-site power or on-site power may take longer if a deep dc load shed is performed and it also may introduce additional operator or random failures (e.g., for breakers failing to reclose). However, these increases should be small in the context of the reasonably conservative nature of crediting the mitigating strategies provided in the streamlined approach.

More specifically, the major impact of the deep load shed when an extended loss of ac power (ELAP) is declared is on the potential time required to restore off-site (or on-site) power. For example, if recovery of off-site power takes 1 hour longer than normal

following a deep load shed, LOOP non-recovery probabilities[2] utilized in model may shift. The hypothetical example, illustrated in Figure 6-3, depicts a weighted average LOOP non-recovery probability for the "No ELAP" case derived using NUREG/CR-6890, , "Reevaluation of Station Blackout Risk at Nuclear Power Plants" (Reference 17). In the "ELAP" case, the non-recovery probability is shifted by one hour at the time of load shed, but includes a 0.1 failure probability credit for installation of portable generators at 8 hours.

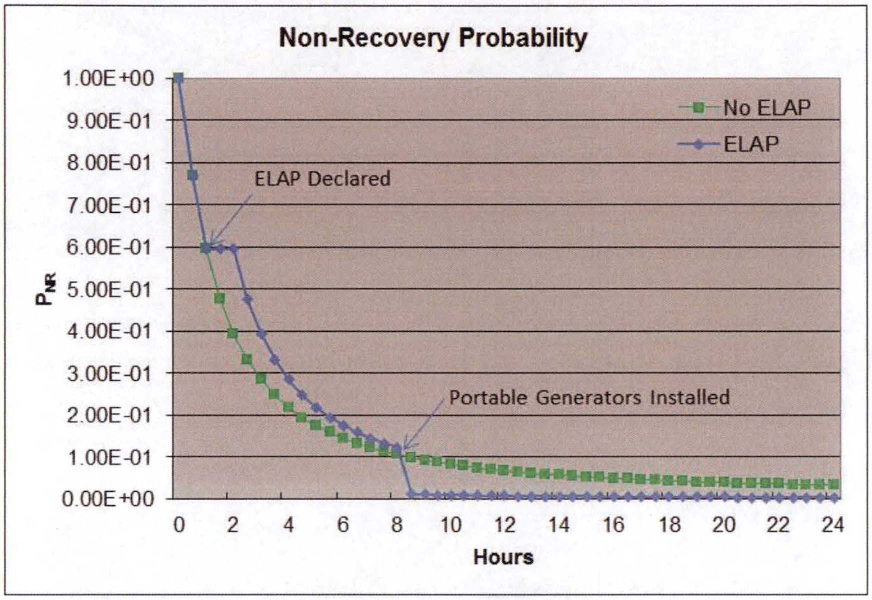

Figure 6-3: Non-Recovery Probabilities With and Without Implementation of FLEX Mitigating Strategies

As an example, adjustments could potentially be made to base case (i.e., no credit for the FLEX mitigating strategy) cutsets or sequences that did not have off-site power restored by five hours. If the off-site power non-recovery probability is shifted by one hour because of implementation of deep dc load shed as part of the FLEX mitigating strategy, then a risk increase would exist for those cutsets or accident sequences. This is illustrated in Figure 6-4 at the five hour mark. Correspondingly, however, the risk decrease afforded by successfully extending the available battery life to 8 hours and implementing the FLEX portable generators is shown in Figure 6-4 at the 8 hour mark.

In the streamlined approach, there would be an unaccounted for risk increase at the five hour mark and an unaccounted risk decrease at the 8 hour mark (or longer if time to core damage was specifically assessed). Figure 6-5 shows the unaccounted for increases and decreases and also shows the credited risk decrease using the streamlined approach and the actual risk decrease.

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[2] The probability that off-site power is not recovered in a given period of time

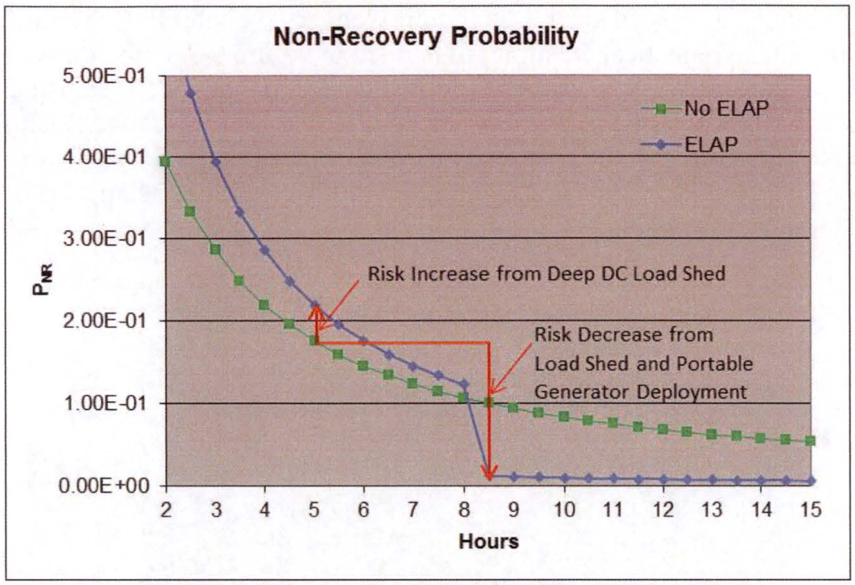

Figure 6-4: Risk Increases and Decreases from Implementation of FLEX Mitigating Strategies

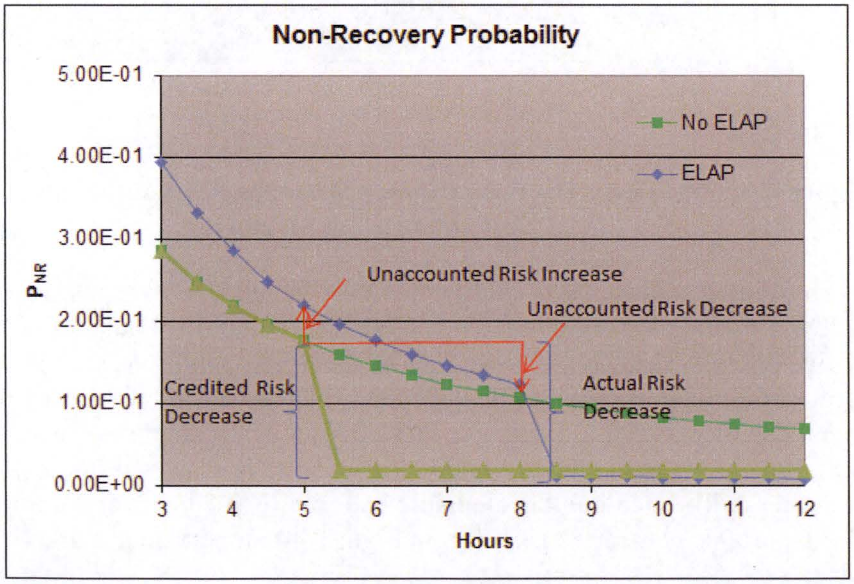

Figure 6-5: Credited versus Actual Risk Decreases from Implementation of FLEX Mitigating Strategies

In summary, as long as the extra time available from extended battery life is more than the extra time required to restore power if it becomes available (and the contributions from random failures and operator action failure to restore alignments are small in the context of the reasonably conservative nature of crediting the mitigating strategies provided in the streamlined approach), then the unaccounted for risk decrease should always be larger than the unaccounted for risk increase. The exception would be if the deep load shed totally precludes timely off-site or on-site power restoration. This should be addressed as part of the analysis.

7 MODELING MIGITATING STRATEGIES EQUPIMENT IN A PRA

PRA models for nuclear power plants are designed to model the as-built, as-operated plant. The PRA model allows the analyst to identify potential vulnerabilities and risk insights based on the how the plant is built and how the operators respond to initiating events. When procedures dictate the use of portable mitigation equipment to cope with initiating events, it is appropriate to include this equipment in the PRA.

The benefit that can be realized by incorporating the portable equipment into the PRA will be site and scenario-specific. The semi-quantitative streamlined approach in Section 6 can be used to estimate the magnitude of the expected benefit from including the equipment in the PRA. Even if the expected benefit for internal events is small, there may be significantly more benefit for external events such as seismic or external flooding. As the PRA models are expanded to include additional initiating events, there may be a stronger case for including the portable equipment in the PRA.

In most cases, the modeling of portable equipment in a PRA is very similar to modeling of permanently-installed equipment. This section will call attention to aspects that might be different from what has been encountered previously in building a PRA model for a nuclear power plant.

The process for incorporating the portable equipment into a PRA model is expected to be iterative and parallel in nature. The following sections are not conducted sequentially leading to the final PRA model. Rather, many of the sections are performed in parallel and information learned in one area may cause a change in another as the model is developed. In particular, the review of the results can often identify impacts to the model that need to be addressed. The magnitude of each impact would dictate whether a change is needed immediately, or if the change can be tracked for inclusion in a future PRA model update per normal site processes.

It is possible that changes to the operating procedures or modifications to the plant to support the use of portable equipment may alter the as-built, as-operated plant. In this case, the plant procedures for updating the PRA model should be followed to determine when a PRA model update is required to incorporate those changes.

It is anticipated that incorporating plant procedure changes and modifications associated with the use of additional portable equipment, when performed in a manner consistent with the base PRA model, represents PRA maintenance activities, and will not generally fall into the PRA upgrade category as defined in the ASME/ANS PRA Standard. Since representation of the portable equipment and associated actions can often be handled through the direct use or extension of existing methods, a focused scope peer review should not be warranted unless the incorporation of these changes results in significant changes "that impact the significant accident sequences or the significant accident progression sequences" per the ASME/ANS PRA Standard.

The intent of this guidance is to allow the PRA practitioner to identify the unique aspects of modeling portable equipment and the use of mitigating strategies in a PRA model with the intent of meeting RG 1.200. Each of the following sections covers one high level requirement from the ASME/ANS PRA Standard.

7.1 Initiating Events

As part of evaluating new structures, systems, and components (SSCs), in this case the portable equipment, the PRA analyst must evaluate if a failure of the SSC could cause an initiating event and determine which existing initiating events are applicable to the use of the SSC.

Portable equipment, even if it is permanently staged, is normally not connected to the permanently-installed plant equipment. As a result, the failure of any portable equipment should not be able to cause or demand an immediate plant trip, so no new initiating events would be expected. Similarly, the addition of portable equipment should not cause any change in the calculated frequency of currently-modeled initiating events. Any permanently-installed equipment to support the use of the portable equipment (e.g., a new valve that could be a potential source of an interfacing system loss of coolant accident initiating event) needs to be evaluated as part of the normal PRA maintenance update process.

As described in Section 5, the use of portable equipment is not applicable to all initiating events. The PRA analyst must review the plant operating procedures and identify which initiating events will lead operators to use the portable equipment. If the procedures for the plant do not direct the use of portable equipment for a particular initiating event, then that equipment should not be credited for that initiating event.

7.2 Accident Sequence Modeling

The goal of accident sequence modeling with respect to the use of portable equipment is to determine which scenarios could benefit from the use of the equipment. Accident sequences are graphically modeled in event trees in a PRA model. PRA analysts may choose to alter existing event trees to add a new branch based on the success or failure of the portable equipment and the mitigating strategy. Alternatively, the success or failure of the equipment and strategy may be added to the fault tree corresponding to an existing branch in the event tree. The changes to the fault trees are covered in Section **Error! Reference source not found.**.

Some of the sequences applicable to crediting portable equipment were identified in Section 5, however a detailed analysis may identify additional accident sequences that are also applicable.

The existing accident sequence modeling methodologies are adequate for determining whether or not portable equipment can be credited for any particular sequence. The following items should be considered when crediting the portable equipment for a given sequence:

- Procedural direction for use of the portable equipment
- Equipment capability and performance characteristics
- Time available to initiate use of the portable equipment based on thermal-hydraulic analyses
- Time required for deployment, installation, and initiation of portable equipment

In performing the accident sequence analysis, it is possible to determine that the site's portable equipment cannot be credited for various reasons (e.g., procedures or timing), but a change in procedures or some other minor change may enable the use of the portable equipment for this sequence. The PRA model can be used to determine the risk-benefit of incorporating the

changes. The portable equipment cannot be credited in these sequences until the changes have been implemented at the site.

7.3 Success Criteria

Determining the success criteria involves calculating the minimum number of components required to satisfy a requirement to mitigate the event based on thermal-hydraulic and/or electrical analyses. Success criteria are based on the minimum requirements for the strategy to be successful. The results of the success criteria analysis impact the accident sequence modeling and the system analysis. The existing methodologies for determining PRA success criteria apply to portable equipment; however, there may be some unique aspects to consider such as:

- Portable equipment capability
- Plant conditions required for the strategy (e.g., steam generator pressure)
- Limitations on the use of portable equipment and installation
- Multiple locations for installing and staging the portable equipment may be available which could impact the success criteria
- Equipment performance with various water quality sources
- Extended mission times may be required to reach a safe stable state

In assessing the success criteria, the PRA analyst must verify that the portable equipment is capable of mitigating the event for each sequence in which it is credited. Refer to the feasibility study in Section 5.1. It is possible that the success criteria would be different for different sequences (e.g., two sequences with different steam generator pressures requiring a different number of pumps to inject a sufficient amount of water).

7.4 System Analysis

System analysis includes determining which failures can lead to a loss of a given function. This can include components failures, human failure events, and support-system failures. The system analysis leads to the development of fault trees to model the combinations of failures that lead to the loss of the modeled function based on the success criteria in Section 7.3. The assessment of human failure events is covered in Section 7.5; however, the system analysis determines how the human failure event fits into the system fault tree.

The fault trees developed in the system analysis are used to determine the success or failure of the branches in the event trees created in the accident sequence modeling in Section 7.2. It is possible that different fault trees are needed to model different conditions for the same system based on the initial conditions set up by the path through the event tree. The system analysis will include the documentation of the equipment capabilities to satisfy the success criteria for each accident sequence in which the equipment is credited.

The existing system analysis methodologies are sufficient for modeling portable equipment. Some unique aspects of the implementation of portable equipment may need to be considered in the system analysis, including:

- Deployment and installation of the portable equipment
- Refueling of diesel- or gasoline-powered equipment
- Dependency on other portable equipment (e.g., an ac powered portable pump may be dependent on a portable ac generator)
- Multiple sources and quality of water
- Environmental conditions that could impact the deployment or use of the portable equipment based on the initiating event (e.g., external flooding)

It is expected that some aspects of mitigating strategies will not need to be modeled explicitly. These failures may be subsumed into HRA failure rates or other system failure modes through surrogate modeling. This is consistent with ASME/ANS PRA Standard supporting requirement SY-A15 that allows exclusion if the failure rate or probability is less than 1% of the total failure rate or probability.

7.5 HUMAN RELIABILITY ASSESSMENT

Human reliability analysis is an important aspect of PRA modeling to consider the possibility that the crew could make an error in responding to an initiating event. The current HRA methods are largely based on observed behavior that does not necessarily translate directly to some human actions required when implementing mitigating strategies with portable equipment. In some cases, engineering judgement will be required to estimate human error probabilities until new guidance on these issues is developed. In these cases, a sensitivity study should be performed to evaluate the impact of these estimates on the PRA results.

The systems analysis in Section 7.4 identifies which actions are necessary to implement a mitigating strategy. The HRA process includes identifying clear cues to enter the procedure and clear direction within the procedure on the steps required to be performed. The PRA analyst must also perform an assessment to consider the manpower requirements and the time available to determine that the human action can be completed successfully (Refer to Section 5). The analyst also identifies the steps required for successful implementation through a task analysis of the procedures

An additional requirement for a PRA model is to assess the probability that multiple human actions are dependent on each other, so a dependency analysis will be required using existing guidance.

The maintenance procedures for the portable equipment should be reviewed for the possibility of a pre-initiator human failure that leaves the equipment unavailable for use during an event. The pre-initiator failure probability could be a separate basic event or subsumed in the equipment failure rate.

A list of gaps in the current HRA methodology is presented in EPRI 3002003151 "Incorporating Flexible Mitigation Strategies into PRA Models: Phase 1: Gap Analysis and Early Lessons Learned" (Reference 18). Until these gaps are addressed in future guidance, the best approach is to determine either equivalent failure probabilities that are currently addressed by the HRA methodology that can be used as surrogates for specific actions or use engineering judgement to

estimate the failure probability. Some of the actions that may not be explicitly addressed in existing guidance or provided in HRA tools include:

- Making decisions to enter a procedure using judgement based on a belief in a future event (e.g., the expectation that offsite power will not be restored in a certain time frame)
- Actions to transport and install portable equipment
- Actions that require many people working in coordination to complete a single task

Potential avenues to address these issues are covered in the example provided in Appendix C.

If the EPRI HRA Calculator (Reference 19) is used to create human failure events to be added to the PRA model, failure rates for errors of commission are determined by choosing a table that represents the type of action taken and an item reference within the table for the particular action. If there is no appropriate table or item available in the HRA Calculator tool, the analyst can choose a particular table and item that gives the probability of failure determined to be appropriate for the action based on engineering judgement. See the examples in Appendix D.

7.5.1 Quantification for Time Margin Evaluation

Assessing the probability of failure of a human action includes performing a timing analysis to identify how much time is available to complete the action compared to the time available before successfully completing the action no longer impacts the sequence of events. The differences in how this is done when considering human actions associated with portable equipment include:

- Diagnosis time associated with entering procedures to use portable equipment
- Potential for debris removal for external events that make the travel path more difficult
- Transportation and staging of portable equipment
- Installation of hoses or cables
- Pre-operational checks, electrical rotation checks, and/or alignments

7.5.2 Quantification for Command and Control Evaluation

Human reliability analysis includes the probability of failure of decision making. The analysis of the cognitive portion of the human error probability includes aspects such as cues, procedures, and training. The unique aspects of assessing the cognitive probability of failure when following a mitigating strategy that involves the use of portable equipment include:

- Cues may be complicated by the need to make decisions to enter a procedure using judgement based on a belief in a future event (e.g., the expectation that offsite power will not be restored in a certain time frame)

- Demands on the available manpower may require personnel to perform tasks that are not part of their normal duties

Existing information may be available to address these concerns in training documentation or the documentation supporting the use of the mitigating strategies that utilize the portable equipment.

7.5.3 Potions for Addressing the Use of Judgement

When assessing the human failure potential to initiate mitigating strategies (e.g., declare an ELAP), it is important to evaluate the procedural direction for these actions. The existing tools for assessing cognitive failures (failure to make the decision to take a particular action) assume the use of procedures that rely on explicit and unambiguous cues to take actions. If the procedure is unambiguous (e.g., "If power is not restored within 1 hour, declare an ELAP"), then the standard HRA methodology is applicable. If, on the other hand, there is some leeway in the decision (e.g., "If power is not expected to be restored within 4 hours, declare an ELAP"), engineering judgement must be used to provide a basis for the probability of failure given the subjective nature of the decision point. This could be a standalone basic event and may not necessarily be developed within any specific HRA tool. Considerations in the development of the basis for the probability include:

- Training on these scenarios
- Management expectations on how to treat these situations
- Reliance on grid operators for return-to-service estimates
- Reliance on weather forecast for future weather conditions

Sensitivity studies can be performed during quantification to assess the impact of assumptions on the PRA results.

If procedures are found to allow the operators leeway on whether or not to take action, this should be discussed with plant personnel. It may be that training focuses on this issue to ensure that operators will make the proper decision in these situations. In these cases, a high confidence can be assigned to the action. Alternatively, a risk insight from the PRA may result in a refinement to a procedure in order to obtain more credit for certain actions depending on the hazard. For well-defined cues and situations that are well trained, the existing HRA tools for assessing cognitive errors are sufficient.

7.5.4 Addressing the Actions Not Currently Addressed by Existing HRA Tools

There are actions that may be required when implementing mitigating strategies that do not match the data that was used to assess the failure probabilities in current HRA methodologies. These actions that are not explicitly covered may include:

- Debris removal
- Transportation of portable equipment
- Installation of equipment at a staging location
- Routing of cables and hoses

The EPRI HRA Calculator, used by most US utilities to assess human error probabilities (HEPs), provides options to assess a failure potential for a particular action. As of the publication of this guidance, there are no directly applicable options to explicitly cover actions like transportation of equipment or installation of portable hoses. Until these options are provided, engineering judgement is required to assess the probability of a human error that prevents the successful implementation of the strategy.

7.5.5 Addressing Complex Actions in Mitigating Strategies

Mitigating strategies may include actions that require many steps over an extended period of time, multiple personnel and locations, evolving command and control, and extended time delays. These types of actions pose several challenges when using existing HRA tools that sum probabilities of failure for each step in a procedure. For example, modeling this type of execution with the Technique for Human Error Rate Prediction (THERP) may lead to unrealistically high HEPs, even for relatively simple actions that are well trained, because of the potentially large number of control manipulation execution error probabilities that must be added together. This may especially be a factor for cases in which time and personnel constraints limit the available recovery options.

Current HRA methods do not readily lend themselves to credit partial success of the action. For example, failure to open one breaker in a dc load shed procedure may reduce the extended battery life by only a small fraction. Additionally, the timing constraints may not represent absolute end points for performance of the action. For example, if the battery calculations assume load shed is complete by a certain time, there may actually only be a small change in the extended battery life if the actions are completed one half-hour or so later. One approach to address the battery load shed is to group sets of breakers at the panel or room level based on the effect on the battery depletion rate. For example, isolation of a single large dc load may be treated as an individual execution step while isolation of multiple small loads on a panel may also be treated as a single step based on the relative importance of the loads on that panel. This approach may also reduce the cumulative uncertainty associated with treating many repetitive actions as individual execution steps in the THERP method.

The development of these HEPs should include a review of relevant analyses (e.g., the associated battery calculations) and detailed procedure steps to ensure that the derived

HEP value appropriately reflects the risk of not performing the action, and is not overly conservative given potential limitations of existing HEP methodologies.

7.6 Data Analysis

Data analysis is the process of determining the failure probabilities and initiating event frequencies for the basic events in the PRA model. As discussed in Section 7.1, initiating event frequencies are not expected to be affected by portable equipment at a site. While there are adequate sources of generic failure rates for permanently-installed equipment at nuclear power plants, there is limited failure data available for portable equipment.

Until sufficient industry data is compiled to estimate generic industry failure rates for the portable equipment in use at nuclear power plants, each site including portable equipment in their PRA models will have to use engineering judgements regarding the failure rates. Some of the issues involved in assessing the failure rates of portable equipment are addressed in Section 4 of EPRI 3002003151. This report compared failure rates of portable military equipment to that of permanently-installed nuclear equipment. The report found that portable military failure rates were higher than corresponding permanently-installed equipment failure rates assessed, but in all cases, they were less than 10 times the permanently-installed equipment failure rates.

Refer to Section 5.2 for an assessment of the portable equipment's availability and reliability.

The following techniques could be used to create initial failure rates for portable equipment until enough industry and plant-specific experience is available to calculate failure rates:

- Assume a bounding failure rate based on a multiple (e.g., 2 to 10 times) of the failure rate of similar permanently-installed equipment based on engineering judgement.
    - In lieu of using a multiple on the permanently installed equipment failure rates, address any potential increase in the failure rates by crediting spare portable equipment not modeled in the PRA, when sufficient time is available for deployment.
- Assume an equivalent failure rate as that of similar permanently-installed plant equipment and perform sensitivity studies to determine the impact of that assumption on the PRA results.
- Section 2.5 in PWROG-14003, "Implementation of FLEX Equipment in Plant-Specific PRA Models," (Reference 20) presents an approach for assessing the probability of failure of portable equipment
- Common cause data may not be available, initially, and the generic common cause factors in NUREG/CR-5496, "Evaluation of Loss of Offsite Power Events at Nuclear Power Plants, 1980 – 1996" (Reference 21), or WCAP-16672, "Common Cause Failure Parameter Estimates for the PWROG" (Reference 22), can be used until such data becomes available

Note that it would not be appropriate to combine portable equipment and permanently-installed equipment in the same common cause group.

7.7 Quantification

Quantification is the process of solving the PRA model, analyzing the results, and verifying that the results are reasonable. The process of quantification is not affected by the inclusion of portable equipment, therefore the normal process for quantification and review of results should be followed.

Sources of model uncertainty are identified and sensitivity studies are often performed to characterize the impact of assumptions on the model's results. An assumption that does not impact the PRA model's results does not need as much scrutiny as an assumption that causes a significant impact on the results. As with all uncertainties, new or additional sensitivity studies may be required for specific applications of the PRA model. Sensitivity studies may also be appropriate to characterize assumptions made in how the portable equipment was modeled in the accident sequence modeling (Section 7.2), success criteria (Section 7.3), systems analysis (Section 7.4), the human failure probabilities (Section 7.5), or data analysis (Section 7.6).

The cases where portable equipment may be of highest benefit may also involve failure rates that violate the rare event approximation (e.g., a seismic PRA model that involves high failure probabilities for low frequency events). If this is the case, the quantification process may benefit from the use of a tool, such as ACUBE, that improves the accuracy of the result when the rare event approximation does not hold. Note that this consideration is not unique to the incorporation of portable equipment into the PRA.

7.8 Large Early Release Frequency (LERF) Analysis

Portable equipment can be credited in the Level 1 model that feeds into the Level 2 or LERF PRA model, and it could be credited in the Level 2 or LERF model directly following core damage. In both cases, Sections 7.1 through 7.7 cover the general aspects of modeling the portable equipment that need to be addressed for the Level 2 or LERF analysis. When crediting actions with portable equipment after core damage, these actions may need to be reassessed based on the expected environmental conditions including radiological effects.

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APPENDIX A: EXAMPLE OF THE QUALITATIVE APPROACH

This example is based on a pressurized water reactor (PWR) with only a single turbine driven auxiliary feedwater (TDAFW) pump. The TDAFW pump is assumed to be out for maintenance and the time necessary to complete repairs will exceed the Technical Specifications' allowed completion time. The plant desires to submit a NOED to request an additional 36 hours to complete the repairs while at power. The plant wants to credit a portable FLEX pump that can be used to provide water to the steam generators in the event of a loss of feedwater as part of the NOED submittal. The FLEX pump is not included in the plant's PRA model, so the plant will use a qualitative argument for crediting the FLEX pump in the NOED risk-informed submittal.

A.1. Initial Feasibility Assessment

The purpose of the feasibility assessment is to collect the necessary information to perform the qualitative assessment and make an initial determination if mitigating strategies could be used to support the identified scenarios.

A.1.1 Scenario Assessment

The scenarios that would benefit from the use of the FLEX pump to provide water to the steam generators involve conditions where the TDAFW pump would have been credited to provide an alternate source of feedwater to the steam generators. These scenarios include a loss of feedwater, LOOP and SBO.

The timeline for use of the FLEX pump in the mitigating strategies procedures assumes that the TDAFW pump provides feedwater for six hours while the FLEX equipment is deployed. Since the TDAFW pump is not available, the implementation strategy must be changed to take credit for the FLEX pump by pre-staging the pump at the installation location.

The required portable equipment for the strategy includes the portable, diesel-driven FLEX pump and hoses. The hoses will be connected to permanently-installed hose connections and manual valves will be manipulated to align the pump to the suction source and the discharge path. Normal controls in the Control Room will be required to reduce pressure in the steam generators to enable the portable FLEX pump to feed the steam generators.

Operators have been trained in the use of the FLEX pump to feed the steam generators as part of the FLEX training. Written instructions are available to the operator in the form of FSGs to implement the strategy and placards on the pump for operation and alignment. Operators would typically use the FLEX pump based on entry into the EOPs following an ELAP. In addition, the FSGs are written assuming that the TDAFW pump is initially available for some time period, so additional written instructions will be developed for this particular situation to account for the pre-staging of the pump. Just-in-time training will be used to instruct the operators on the use of the pre-staged FLEX pump for the duration of the NOED.

The depressurization of the steam generators as well as the installation and use of the FLEX pump to feed the steam generators were validated when the FLEX mitigating strategies were implemented at the site. The validation provides the basis to show that the operators can perform the required actions in the time frames available.

A.1.2 Function Applicability

The function which is desired to be credited is to use the FLEX pump to feed water into the steam generator to remove decay heat from the reactor.

A.1.3 Equipment Capability

For this example, as verified as part of the FLEX program, the FLEX pump is capable of pumping sufficient water into the steam generator to remove decay heat in the reactor at a discharge pressure of 500 psi. Since the normal steam generator pressure is 1000 psi, the steam generators will need to be depressurized below 500 psi to allow the FLEX pump to be able to feed sufficient water to remove the decay heat. Since the FLEX validation assumed that the TDAFW pump would be available for the first six hours following reactor trip, an additional analysis was performed to verify that at 500 psi discharge pressure, the FLEX pump provides enough flow to remove the decay heat load immediately following plant trip.

The suction source is the condensate storage tank (CST) and the discharge path is the feedwater line to the steam generators. FLEX connection points are available for both of these flow paths and portable hoses will be pre-aligned with the FLEX pump to make up these connections. Manual alignment of the FLEX connection isolation valves will be required for both suction and discharge flowpaths. Instrumentation for steam generator and CST levels will be available from the main control room. The CST will provide sufficient water for eight hours of operation of the FLEX pump. Procedures are available to refill the CST following this initial eight hours of operation. All hoses and connections were verified as part of the FLEX program to be capable of handling the shutoff head of the portable pump. Refueling capability of the FLEX pump is readily available.

A.2 Availability and Reliability

The availability and reliability of equipment should be considered to determine if credit can be taken for the scenario being evaluated in the applicable risk-informed decision making process. In addition, the capability to deploy the equipment should be accounted for as a part of the qualitative assessment.

A.2.1 Equipment Availability

Multiple sets of FLEX equipment are available at the site, and one additional set is available beyond the minimum required to meet the FLEX mitigating strategy. The FLEX pump as part of the additional set will be pre-staged for the duration of the NOED. The remaining sets of FLEX equipment will remain in their normal storage locations. The normal and alternate connection points as established by the FLEX program are available for use for the suction and discharge flowpaths. If the pre-staged FLEX pump is conservatively assumed to be unavailable for meeting the FLEX requirements, the total unavailability will be significantly less than the 90-day allowed unavailability.

A.2.2 Reliability, Testing, and Maintenance

As part of the FLEX program, the plant performs periodic testing to ensure the FLEX pump is reliable. In addition, the pump can be tested prior to being pre-staged to ensure it will successfully start and run.

A.2.3 Location and Transportation Capability

The pump will be transported from the normal FLEX storage location to the pre-staged location prior to exceeding the TDAFW Technical Specification completion time. The required hoses for connection to the suction and discharge flowpaths will also be pre-aligned with the pump. As a result, the location and transportation aspects will be successful prior to relying on the portable equipment for this particular application (the NOED).

A.3 Time Availability and Margin

For this application, there are two separate timelines that need to be assessed. The first is the timeline for depressurizing the steam generators, and the second is the timeline for initiating feed into the steam generator with the portable pump. Both of these actions can be performed concurrently, but the steam generators must be depressurized to 500 psi before injection into the steam generator can commence from the portable pump. The timelines presented in this example are assumed to be based on a limiting timeline from an SBO event.

The overall Time to Mitigate is assumed to be 60 minutes based on the time to steam generator dryout. In both timelines, the start of the timeline is the initiating event (i.e. LOFW or LOOP), and the delay time (T_{delay}) is estimated to be 5 minutes for operators to take immediate actions associated with the initiating event, evaluate the plant conditions, and evaluate the procedures/written instructions.

For the first timeline for depressurizing the steam generators, no time is required for deployment of the equipment (T_{deploy}) nor does installation time ($T_{install}$) apply since these actions take place in the Control Room using normal plant equipment. The Time to Execute (T_{exe}) is assessed to be 30 minutes. The Time Margin for the first timeline is therefore 25 minutes.

For the timeline for feeding the steam generator with the portable FLEX pump, no time is required for deployment of the equipment (T_{deploy}) because the FLEX pump is pre-deployed. The Time to Install ($T_{install}$), which includes opening the manual isolation valves to align the suction and discharge paths is assessed to be 15 minutes. Finally, the Time to Execute (T_{exe}) to start the pump and initiate flow into the steam generator is assessed to be 5 minutes. The Time Margin based on the second timeline is 35 minutes.

The overall Time Margin for the scenario is 25 minutes driven by the limiting timeline of depressurizing the steam generators. Both timelines are shown graphically below:

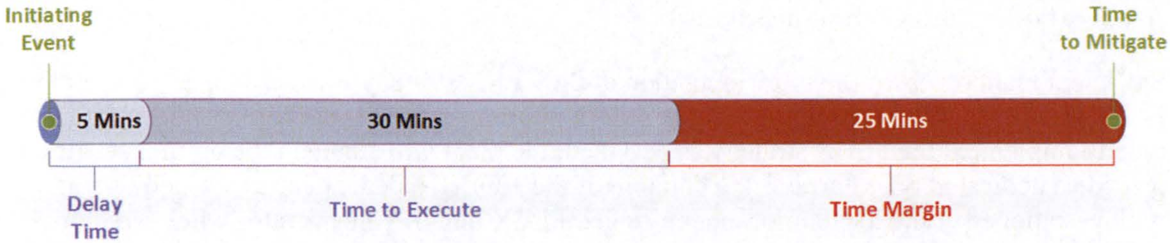


Figure A-1: Example Timeline for Depressurizing Steam Generators

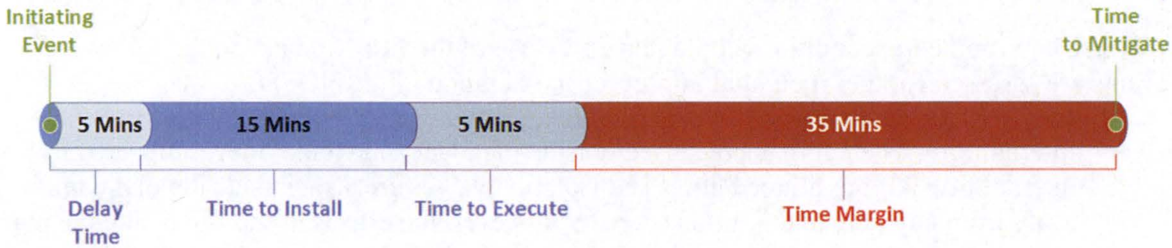


Figure A-2: Example Timeline for Feeding Steam Generators

A.4 Command and Control

The credit for use of mitigating strategies is dependent on the quality of knowledge of when and how to use the portable equipment in a given scenario. Therefore, associated procedures, written instructions, training and availability of the implementation staff are very important to provide confidence that the appropriate mitigation or prevention activities will be successful.

A.4.1 Procedures and Written Instructions

Existing plant procedures that are credited for this application are ECA 0.0 (Loss of AC) for steps to depressurize the steam generator, and the FLEX Support Guidelines for the steps to feed the steam generator with the FLEX pump. In addition, specific written instructions created explicitly for the NOED would be evaluated to verify that the operators would have clear instructions to direct the use of the FLEX pump to feed the steam generators for all of the scenarios under consideration.

A.4.2 Training

Existing training is credited for preparing the operators for use of ECA 0.0 and the FSGs. Just-in-time training would be conducted on the specific written instructions created explicitly for the NOED. This training helps to justify that the estimated 5 minute time delay is appropriate.

A.4.3 Staffing and Communications

Sufficient manpower for the implementation of the FLEX strategy was verified as part of the FLEX staffing studies; however, since the TDAFW pump is not available to provide sufficient time to implement the FLEX strategy as designed, the plant will augment the normal staffing to provide a dedicated operator. For the duration of the NOED, a dedicated and trained operator will be stationed at the location of the pre-staged FLEX pump. This operator will have normal radio communications with the Control Room and simple written instructions for the required actions in the event that the FLEX pump is needed for makeup to the steam generator.

A.5 Environmental Challenges

Adverse environmental conditions could impair the use of the FLEX pump, so the following events are assessed for their potential impact for the duration of the NOED:

- Internal Fire: The pump is pre-staged outside the plant and would not be impacted by an internal fire. All pre-aligned hoses and isolation valves are also outside the plant and away from any potential ignition sources. However, the effects of the fire inside the plant may challenge the implementation of this strategy. Fire damage to control cables supporting the steam generator atmospheric dump valves or valves in the flow path could prevent the valves from opening or cause them to spuriously close. Fire damage to instrument cables for steam generator level and pressure indication may also present a challenge. The routing for the cables supporting these functions were reviewed to ensure spatial separation is sufficient to prevent the fire from disabling all available flow paths or indications. A few fire scenarios were identified that could challenge these functions; therefore compensatory risk management actions (RMAs) such as fire watches, transient combustible exclusion zones, and preventing hot work were identified to reduce the risk from these scenarios.

  The fire mitigation strategies that require local operation of the AFW valves were reviewed to ensure sufficient guidance is available to perform these actions, and operators will be briefed on this potential condition. Control room indication for the steam generators could be damaged causing a loss of or spurious indication, and the operators will be briefed on the potential need to rely on alternate indication.

  In summary, the areas where an internal fire could challenge the execution of this strategy due to equipment damage or the development of a hazardous environment should be identified, and RMAs should be implemented to minimize the likelihood of these events.

  All actions for depressurizing the steam generator can be accomplished from the Control Room given the availability of the required equipment and indication. RMAs have been identified as necessary to minimize the likelihood this equipment will be lost, and alternate strategies have been identified to compensate for this potential. As a result the strategy is expected to be successful for any fire outside of the Control Room.

- Internal Flooding: Similar to fire, the internal flooding analysis was reviewed to ensure a success path is available given the expected equipment damage and environmental hazards resulting from any flood. Given availability of equipment and appropriate risk

management, the strategy is expected to be successful for all internal flooding scenarios that occur outside of the Control Room.

- Seismic: The pre-staged FLEX pump will use tie-downs to reduce the potential for damage in a seismic event. Because the FLEX pump is pre-staged, there should be no impact based on debris. The pre-staged location is adjacent to a CAT-1 building and, therefore, no debris is expected to directly impact the pump. A likely consequence of a seismic event is a LOOP due to the fragility of switchyard components. The primary mitigation strategy should rely on fixed plant equipment rather than the FLEX pump. As a result, protecting the EDGs was identified as an RMA to ensure power would be available to multiple trains of equipment.
- External Flooding, High Winds, and Extreme Temperatures: The weather forecast was evaluated for the duration of the NOED to identify any potential impacts. No significant challenges were deemed likely for the duration of the NOED.

A.6 Summary

Following the assessment following Section 5 of this document, the plant judges that the use of the pre-staged FLEX pump should be considered in the qualitative assessment for the request for the NOED. This assessment and recommended RMAs would be included in the NOED submittal.

APPENDIX B: EXAMPLE OF SEMI QUANTITATIVE APPROACH

For this example, an SDP evaluation is performed for a hypothetical Emergency Diesel Generator failure with a representative BWR model. The hypothetical situation is that a diesel fail to start occurs and it is determined that the condition would have existed since its last successful start such that the exposure time is one month.

The internal events and internal fire PRA models were quantified to represent the SDP boundary conditions. This included adjustments to the EDG common cause basic event values consistent with guidance in the NRC RASP handbook (Reference 23). The internal events PRA model results were similar to that obtained with the NRC developed site Standardized Plant Analysis Risk (SPAR) model. An internal fire SPAR model was not available for the site. The impact from seismic and other external events hazards was determined to be negligible and would not impact the characterization of the SDP evaluation.

B.1 Initial Feasibility Assessment

The CDF and LERF results from the analysis with no credit for implementation of FLEX mitigating strategies are shown in Table B-1. The initial results indicate that the SDP would result in a White finding based on the SDP CDF being greater than 1.0E-06 (and less than 1.0E-05). The SDP LERF Green-White threshold is not challenged. It was noted that the FLEX mitigating strategies have been implemented at the site and it was desirable to determine if credit for FLEX could influence the outcome of the SDP evaluation.

Table B-1: Initial PRA Model Results (Without Credit for FLEX)

Figure of Merit	Internal Events	Internal Fires	Total
Increase in CDF (ΔCDF)	5.70E-06 / yr	2.25E-05 / yr	2.82E-05 / yr
Increase in LERF (ΔLERF)	9.00E-09 / yr	2.40E-07 / yr	2.49E-07 / yr
Exposure Time (T)	1 month / 12 months / yr		0.0833 yr
SDP CDF	(ΔCDF * T) < 1.0E-06 for Green		2.35E-06 (White)
SDP LERF	(ΔLERF * T) < 1.0E-07 for Green		2.07E-08 (Green)

B.1.1 Scenario and Function Assessment

The first step in the assessment is to determine if credit for FLEX mitigating strategies could reduce the calculated CDF and LERF results shown above. As can be seen in Table B-1, LERF is already below the threshold for a White finding such that the focus can be on the CDF results.

Based on a review of the CDF cutsets with the SDP impacts applied (i.e., with changes to the EDG fail to start and associated common cause events), the dominant contributors to the increase in risk involve SBO sequences which lead to core damage after initial battery depletion. These sequences would clearly benefit from deployment of the FLEX generators (to extend dc availability), and from deployment of a FLEX pump to provide RPV or suppression pool makeup. Since the cutset review concluded that the majority of the risk increase evolves from these scenarios, a reduction in the frequency of these scenarios could impact the regulatory decision. As such, a feasibility assessment is performed to evaluate the potential credit obtained using the semi-quantitative approach described here.

As an aside, it is noted that this initial step may result in determining that credit for FLEX would not impact the decision and further review of the feasibility assessment is not warranted. For example, an SDP associated with a High Pressure Coolant Injection (HPCI) or Reactor Core Isolation Cooling (RCIC) pump may lead to risk increases that are dominated by scenarios where early core damage occurs (i.e., prior to the time that the FLEX equipment could be deployed). These scenarios would clearly not benefit from deployment of the FLEX equipment as it was likely not pre-staged for the exposure time of the SDP. As such, potential credit for FLEX can be screened from consideration in these cases.

B.1.2 Equipment Capability

In this EDG example, from the review of the sequences contributing to the increase in risk, the key actions for success were determined to be:

- Deploy and install two backup generators for prolonged DC availability within 6 hours, and
- Deploy and install one FLEX pump to provide RPV injection or suppression pool makeup within 6 hours.

These are the major actions, but would also need to be supported by several ancillary actions. The key ancillary actions are listed below:

- Debris removal completed by two hours from initiating event (not applicable for internal events and internal fires for this assessment).
- Initiate and complete DC load shed by 1.5 hours. Takes 30 minutes to complete once initiated. Initiation expected by 15 minutes from initiating event (i.e., loss of offsite power). Completion by 45 minutes would lead to expected battery capacity of more than 8 hours. Completion by 1.5 hours would lead to expected battery capacity of 6 hours.
- Direct RPV depressurization to between 150 and 300 psig. Initiation is expected within the first hour with a gradual depressurization to the desired band before 3 hours from the

time of the initiating event. FLEX validation showed the desired band could be reached within 1.6 hours of the initiating event.

For this assessment, none of the key ancillary actions challenge the available timeline and the likelihood of their failures is subsumed within the conservative approach taken for the evaluation of the use of the FLEX portable equipment.

The next step is to complete the feasibility assessment for the deployment of the FLEX equipment identified above with respect to the four nodes of the streamlined decision tree in Figure 6-2. In each case, the applicable factor will be applied to the full power internal events (FPIE) or to the internal fire (FIRE) scenarios, respectively.

B.1.3 Time Availability

The first branch in the decision tree is for Time Margin. The time margin definition is defined as:

Time Margin (expressed as a percentage) =

$$100\% * [(T_{SW} - T_{Delay} - T_{Debris}) - (T_{Trans} + T_{Install} + T_{Exe})] / (T_{Trans} + T_{Install} + T_{Exe})$$

In this case, the following values apply.

- T_{SW} = the system window, is 6 hours.
- T_{Delay} = time delay, is assumed to be 1 hour for the internal events assessment when loss of all EDGs is confirmed following the LOOP event. For the internal fire events, this is conservatively assumed to be 2 hours given the initial potential delays from responding to the fire, diagnosing the situation, and confirming loss of all EDGs.
- T_{Debris} = debris removal time is 0 hours for internal events and internal fire events.
- T_{Trans} = the time required to transport the FLEX equipment from the storage area to the area where it is deployed and unload any equipment that is required. The site validation study indicates that the time is 45 minutes for the portable generators and cabling and 23 minutes for the FLEX pumps and hoses. These activities occur concurrently with minimum manning. Therefore, 0.75 hours is used in this assessment.
- $T_{Install}$ = the time to make any necessary temporary piping and power connections when directed. The timed demonstration from the site validation study indicates that it takes 81 minutes to align the portable generators to the 480V load centers, and 16 minutes to complete the hose deployment and connect to the RHR header. These activities can occur concurrently with minimum manning. Therefore, 81 minutes (1.35 hours) is used in this assessment.
- T_{Exe} = the time to perform the steps required to initiate water flow and/or energize electrical equipment from the time when it is directed. The FLEX validation study showed the aligning the valves and starting the pump can occur in about 5 minutes. For the generators, once everything is installed, energizing the 480V ac buses took 7 minutes in the timed demonstration. These activities can occur concurrently with minimum manning. Therefore, 7 minutes (0.12 hours) is used in this assessment.

In summary for the internal events scenarios of interest, the time margin is determined as:

Time Margin = 100% * [(6 – 1 - 0) – (0.75 + 1.35 + 0.12)] / (0.75 + 1.35 + 0.12)

Time Margin = 100% * [5 – 2.22] / 2.22 = 126%

In the decision tree, this equates to the 'expansive' branch for the internal event scenarios of interest (i.e., TM_{FPIE} = 0.5).

For the internal fire events scenarios of interest, an additional 1 hour delay in initial deployment is assumed.

Time Margin = 100% * [(6 – 2 - 0) – (0.75 + 1.35 + 0.12)] / (0.75 + 1.35 + 0.12)

Time Margin = 100% * [4 – 2.22] / 2.22 = 80%

In the decision tree, this equates to the 'nominal' branch for the internal fire event scenarios of interest (i.e., TM_{FIRE} = 1.0).

B.2 Command and Control

The next branch in the decision tree is based on establishing whether or not sufficient direction is provided, staffing is available, and any communications or other equipment required to employ the FLEX mitigating strategy is available. This node is simply a Yes or No evaluation (i.e., either functional or impaired) and either leads to a pass-through to assess environmental factors and equipment availability issues in the last two nodes of the decision tree, or it leads to guaranteed failure of the action. In practice, however, this part of the assessment can also be used to determine what fraction of scenarios leading to the calculated risk increase can benefit from credit for FLEX mitigating strategies.

To obtain command and control credit in the decision tree, the FLEX mitigating strategy or equipment deployment must be shown to be procedurally directed and that sufficient cues and indications are available for diagnosis and direction of the actions. A review of the dominant sequences and the plant procedures indicated that the SBO scenarios with initial injection from HPCI or RCIC but failure of all diesels would clearly result in procedural direction to deploy the FLEX mitigating strategies. The site validation studies support that all necessary actions can be performed given the sequence of events represented in the applicable event tree sequences.

The sequence results were examined to determine what fraction of the calculated risk increase actually resulted from the event tree sequence (i.e., SBO-017) where clear procedural direction would exist and sufficient time would be available to support the use of the FLEX equipment. Other scenarios involved very early core damage scenarios where FLEX mitigation would not be feasible or non-SBO scenarios where procedural direction for use of FLEX is not as specific. Table B-2 shows the results of this analysis. An additional adjustment is made to the Fire PRA results to exclude those scenarios in which the MCCs and/or battery chargers that connect to the FLEX generators are damaged by the fire scenario.

Table B-2: Initial PRA Model Results (Without Credit for FLEX)

Figure of Merit	Internal Events	Internal Fires	Total
Increase in CDF (ΔCDF)	5.70E-06 / yr	2.25E-05 / yr	2.82E-05 / yr
ΔCDF from SBO-017	5.24E-06 / yr	1.95E-05 / yr	2.47E-05 / yr
ΔCDF from Excluded Fire Scenarios	N/A	4.42E-07 /yr	4.42E-07 / yr
ΔCDF from Applicable Scenarios	5.24E-06 / yr	1.91E-05 / yr	2.43E-05 / yr
Percent Applicable	91.8%	84.7%	86.1%

In the decision tree for the internal events results:

CC_{FPIE} = 1.0 (functional) for 91.8% of the calculated delta CDF, and fails (impaired) for the remaining 8.2%

For the internal fire events results:

CC_{FIRE} = 1.0 (functional) for 84.7% of the calculated delta CDF, and fails (impaired) for the remaining 15.3%

B.3 Environmental Factors

The next branch in the decision tree is based on establishing whether the equipment and staff are capable of operating in the scenarios in which it is desired to be credited. In this streamlined approach, there are three possible outcomes:

1. it is deemed that nominal environmental conditions exist,
2. it is deemed that adverse environmental conditions exist that will challenge deployment but will not preclude deployment, or
3. it is deemed that the environmental factors will preclude deployment or other conditions exist to make the portable equipment unavailable for deployment.

For the analysis of internal events and internal fires (which already exclude fires which damage critical FLEX strategy support equipment), it is assessed that nominal environmental factors are applicable.

In the decision tree for the internal events scenarios of interest:

$EF_{FPIE} = 1.0$

For the internal fire events scenarios of interest:

$EF_{FIRE} = 1.0$

B.4 Equipment Availability

The last node of the decision tree is used to assign the likelihood of failure of the FLEX equipment. When applicable, in this portion of the decision tree, it has already been determined that sufficient time is available to deploy the equipment, that procedural direction, cues, and sufficient staffing exist to deploy the equipment, and that environmental factors have not precluded deployment of the equipment. For this assessment, credit for N+1 is deemed feasible for the expansive time margin case, but only for N in the nominal time margin case. In the case of the internal fire scenarios, the path through the decision tree does not offer credit for the N+1 option.

Therefore, in the decision tree for the internal events scenarios of interest:

$EA_{FPIE} = 0.05$

For the internal fire events scenarios of interest:

$EA_{FIRE} = 0.1$

B.5 Decision Tree Results Summary

In summary, the final calculated value is derived from the following expression.

$F_{FLEX} = 0.1 * TM * CC * EF + EA$

Therefore, for the internal events results:

$F_{FPIE} = 0.1 * TM_{FPIE} * CC_{FPIE} * EF_{FPIE} + EA_{FPIE}$

$F_{FPIE} = 0.1 * 0.5 * 1.0 * 1.0 + 0.05 = 0.10$

For the internal fire events results:

$F_{FPIE} = 0.1 * TM_{FIRE} * CC_{FIRE} * EF_{FIRE} + EA_{FIRE}$

$F_{FPIE} = 0.1 * 1.0 * 1.0 * 1.0 + 0.1 = 0.20$

B.6 Final Adjusted Results

The CDF results from the analysis with credit for implementation of FLEX mitigating strategies when warranted are shown in Table B-3. The results indicate that the SDP would result in a Green finding based on the SDP CDF being less than 1.0E-06.

Table B-3: Adjusted PRA Model Results (With Credit for FLEX)

Figure of Merit (ΔCDF)	Internal Events	Internal Fires	Total
Initial Increase in CDF	5.70E-06 / yr	2.25E-05 / yr	2.82E-05 / yr
Applicable Scenarios (No Credit for FLEX)	5.24E-06 / yr	1.91E-05 / yr	2.43E-05 / yr
Excluded Scenarios	4.65E-07 / yr	3.44E-06 / yr	3.91E-06 / yr
Applicable Scenarios (Credit for FLEX)[1]	5.24E-06 / yr * 0.10 = 5.24E-07 / yr	1.91E-05 / yr * 0.20 = 3.81E-06 / yr	4.34E-06 / yr
Total Adjusted ΔCDF	9.89E-07 / yr	7.25E-06 / yr	8.24E-06 / yr
Exposure Time (T)	1 month / 12 months / yr		0.0833 yr
SDP CDF	(ΔCDF * T) < 1.0E-06 for Green		6.78E-07 (Green)

[1]Note that in this example, the credit for the FLEX mitigating strategies in the base model is not specifically accounted for since the contribution would be negligible. That is, the EDG fail-to-start event and associated CCF events are increased by a factor of ~132 from their base values for this SDP case such that accounting for similar credit for FLEX in the base case would only reduce the adjusted ΔCDF by less than 1%. In certain applications, it may be necessary to separately account for the credit in the base case to ensure that the ΔCDF is properly determined. Additionally it was assessed that the performance of the deep dc load shed would not significantly impact the ability of the site to restore off-site power if it became available.

APPENDIX C: EXAMPLE OF MODLEING MITIGATING STRATEGIES EQUIPMENT IN THE PRA

For this example, a LOOP affects a PWR followed by a failure of all permanent on-site alternate ac power sources (e.g. emergency diesel generators). The FLEX equipment credited for this scenario includes a portable diesel-driven generator to recover the dc battery chargers and a portable diesel-driven pump to inject water into a steam generator. The following assumptions apply to the example:

- The plant procedures are written to use the FSGs for any LOOP followed by the subsequent failure of all permanently-installed alternate ac power sources (Station Blackout).
- The plant only has one TDAFW pump.
- The TDAFW pump is required for the first 4 hours of the scenario to provide sufficient time to deploy the FLEX equipment.
- An ELAP will be declared within one hour of the loss of offsite power based on procedures.
- Operators will begin a deep dc load shed after the declaration of the ELAP based on procedures.
- The portable equipment requires transportation from a storage building to the implementation location.
- The portable pump and generator are required to be refueled prior to 24 hours.
- Operators will begin to cool down and depressurize the steam generators beginning at the declaration of an ELAP.
- Steam generator atmospheric dump valves may be controlled manually if dc power is not available.

This example focuses on adding the FLEX mitigating strategies to the Internal Events PRA, so it does not include any adverse environmental conditions. Other hazard groups may add additional environmental impacts that affect the probability that a function will succeed. These impacts may lead to longer times required to accomplish the strategy (such as the need to clear debris following a seismic initiating event), or may prevent certain actions (such as performing any actions outside while a hurricane is present). The strategy and human actions need to be assessed for each hazard group to determine any appropriate changes to accident sequence modeling, system analysis, or human reliability analysis based on these environmental impacts.

C.1 Initiating Events

This scenario is applicable to initiating events that lead to a LOOP and subsequent failures that lead to station blackout, but do not require debris removal. Failure of the FLEX equipment cannot lead to a plant trip, so there are no new initiating events stemming from this equipment.

The plant procedures are written to use the FSGs for any LOOP followed by the subsequent failure of all permanently-installed alternate ac power sources (i.e., SBO). Therefore, the credited initiating events are limited to LOOP and other initiating events that directly result in a LOOP.

C.2 Accident Sequence Modeling

A representative event tree for a PWR SBO scenario is shown in Figure C-1. For this example, the TDAFW pump is successful in providing steam generator heat removal in the branch SGHR E. The portable mitigating strategies equipment would be used to provide the late steam generator heat removal under branch SGHR L. Success of this branch leads to the consequence "OK" indicating no core damage. The event tree could be modified to follow the failure path for SGHR L and add a new branch, SGHR ALT, that shows success or failure of the alternate steam generator heat removal capability with the portable equipment. Alternatively, the fault tree for assessing branch SGHR L could be modified to include failure of the portable equipment.

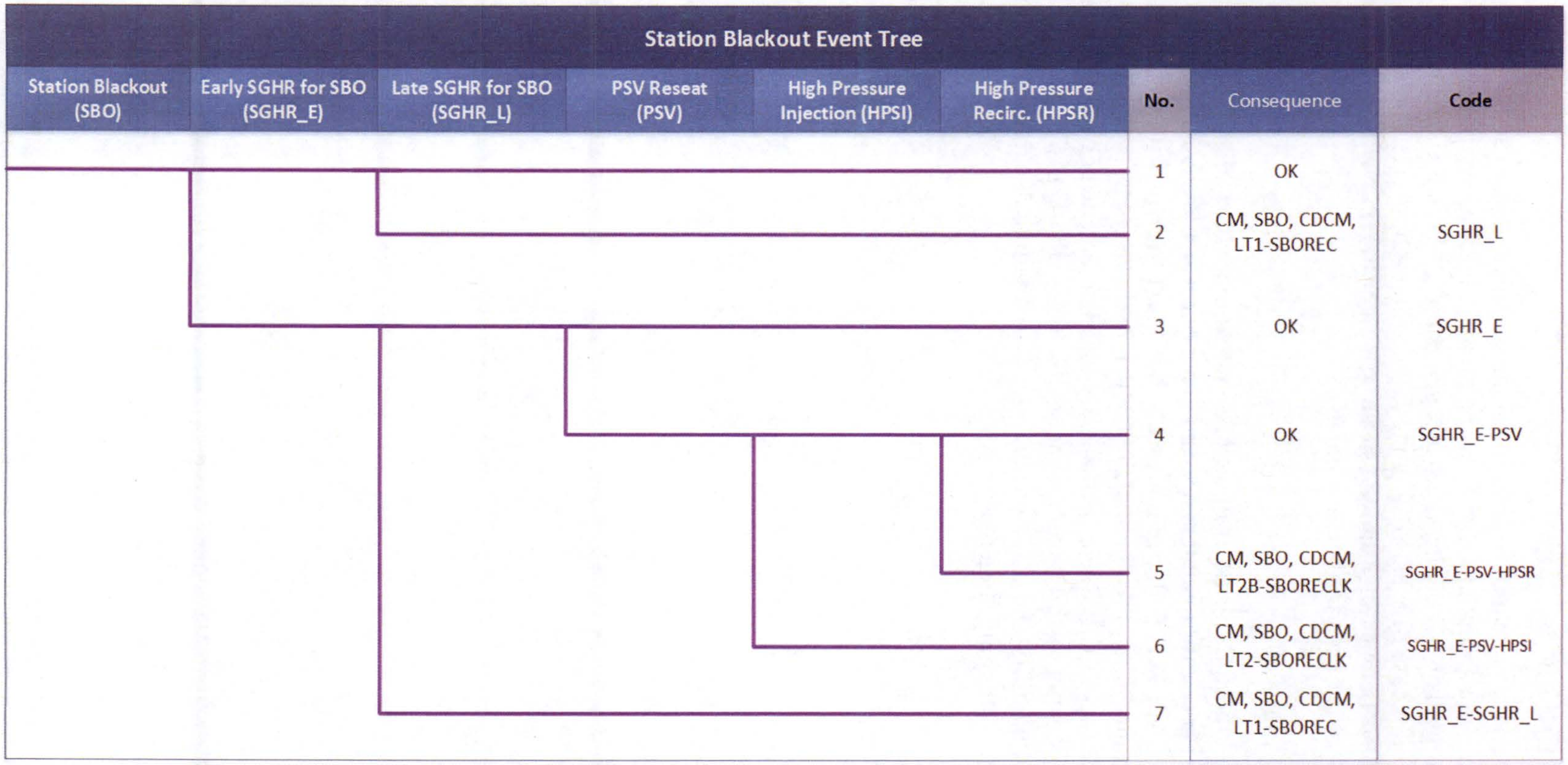


Figure C-1: Representative Station Blackout Event Tree

C.3 Success Criteria

The success criteria for late heat removal from the steam generator (SGHR L) requires injection to the steam generator from the TDAFW pump or one diesel-driven, portable pump. Operators can cool down the plant by opening the steam generator's ADVs while using the TDAFW pump to maintain level. In case of a TDAFW pump failure after 4 hours (late), the portable pump can be used to inject sufficient water into the steam generator to remove the decay heat load if the steam generator is depressurized below 500 psi.

C.4 System Analysis

The fault tree in Figure C-2 is an example of a system model for a FLEX strategy to credit a FLEX pump and generator to maintain steam generator water level. The scenario for this example is an ELAP. This fault tree represents the failure to provide the long-term steam generator heat removal required in branch SGHR L in the event tree (See Section C.2). The fault tree is applicable to a LOOP where permanently-installed on-site power sources are not available and offsite power is not restored within 4 hours. Failure of the TDAFW pump within the first 4 hours or its unavailability due to maintenance leads to a failure due to insufficient time available to implement the mitigating strategy.

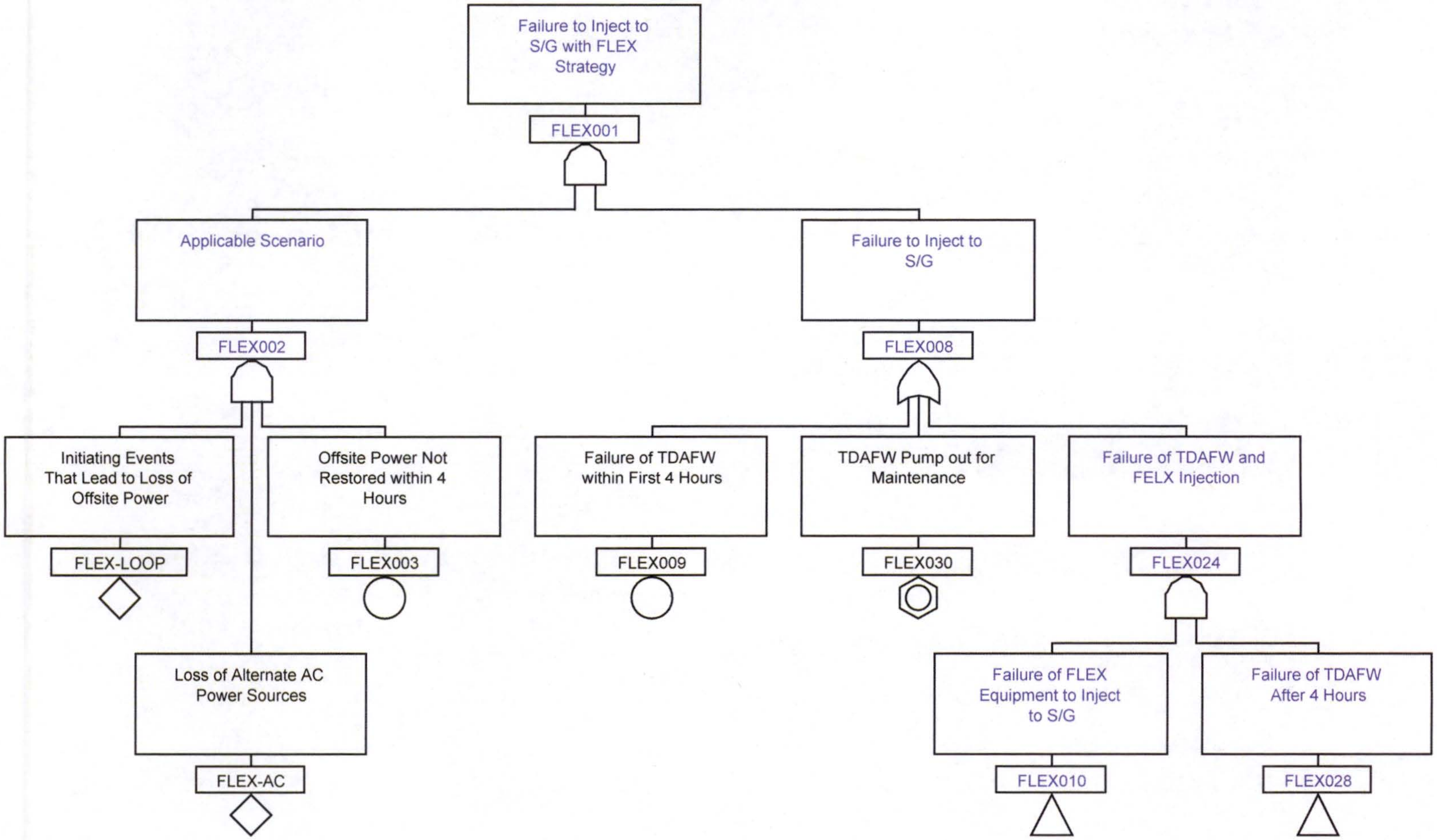


Figure C-2: Fault Tree for Failure of FLEX Strategy to Feed Steam Generator

Multiple paths for success exist given that the TDAFW pump ran for the first 4 hours following the LOOP event. One path for success given SBO conditions lies in keeping the TDAFW pump running after the initial 4 hours. In this path, a FLEX diesel generator is needed to maintain dc power to provide control and indication to the operators. Success of this path requires declaration of an ELAP and operator actions to perform dc load shed and deploy the FLEX generator. The fault tree for this path is shown in Figure C-3.Another path to success involves the use of a FLEX pump to provide makeup to the steam generator. For this path to succeed operators had to succeed at cooling down the plant so that the steam generator remains below 500 psi. Operators must control the steam generator's ADVs (manually or with power from the FLEX generator) to maintain the steam generator below the FLEX pump's shutoff head and allow sufficient flow rate into the steam generator for decay heat removal. Success of this path requires declaration of an ELAP and operator actions to perform dc load shed, cool down the primary and depressurize the steam generator, manually control steam generator ADVs, deploy the FLEX generator, and deploy the FLEX pump. The fault tree for this path is shown in Figure C-4.

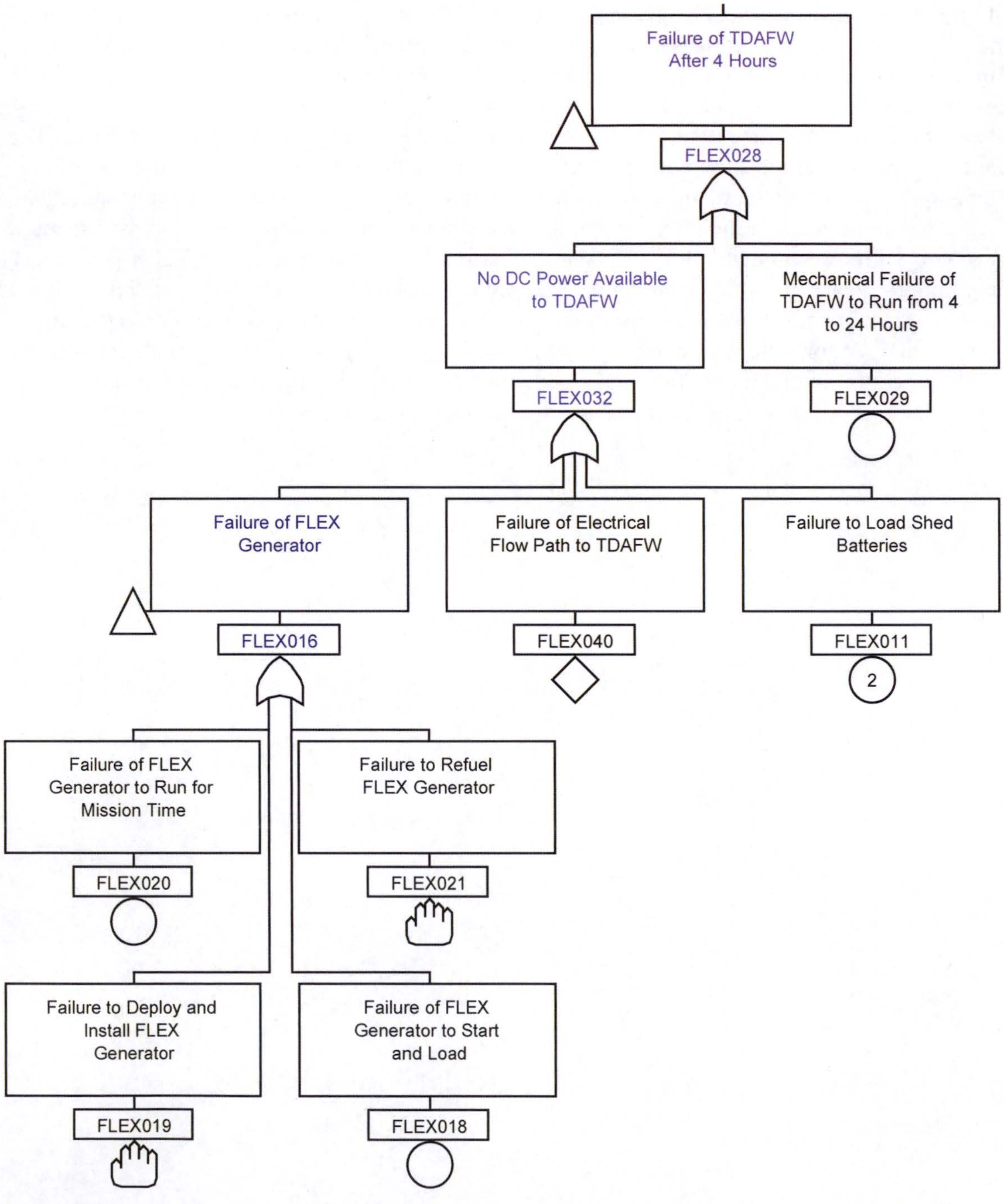


Figure C-3: Fault Tree for Failure of TDAFW Pump after the First Four Hours

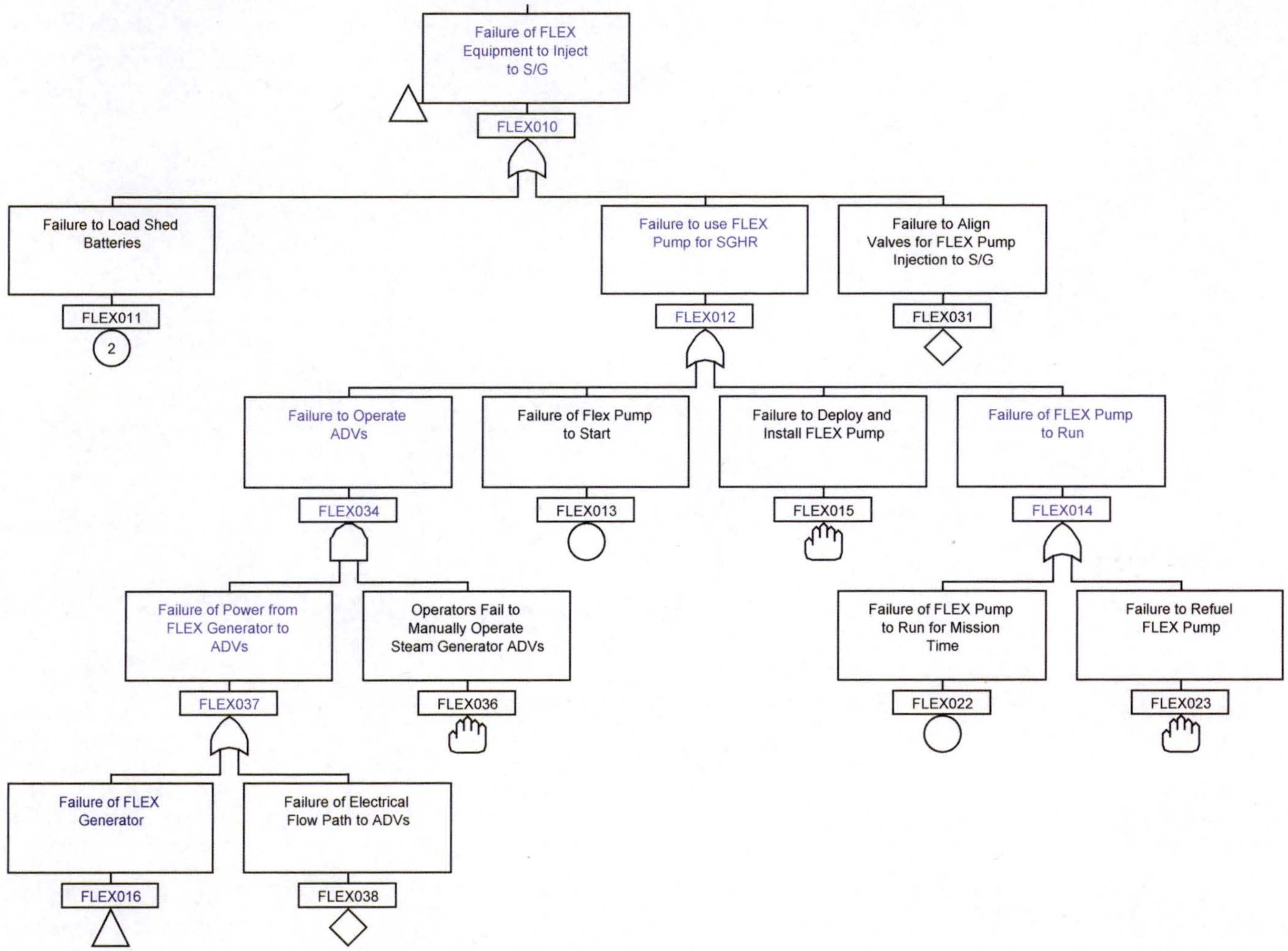


Figure C-4: Fault Tree for Failure of Portable FLEX Pump to Feed Steam Generator

C.5 Human Reliability Analysis

The following human actions were identified through the system analysis described in Section C.4:

1. Declare an ELAP
2. Load shed dc buses (See Appendix D for detailed example)
3. Cool down the primary to reduce steam generator pressure below 500 psi
4. Manually operate the steam generator ADVs to depressurize the steam generator
5. Deploy and install FLEX Generator (See Appendix D for detailed example)
6. Deploy, install, and use the portable pump to provide water to a steam generator

Action 1: Declare an ELAP

For the purposes of this example, it is assumed that the procedures are explicit and require an ELAP to be declared after 1 hour following the loss of offsite power. Due to this, no separate human failure event (HFE) is required to model this decision. The declaration is instead included in the cognitive portions of other HFEs.

Action 2: Load shed dc buses

Given the considerations discussed in Section 7.5.5 for complex actions, the development of load shed HEP included a review of the associated battery calculations and detailed procedure steps to ensure that the derived HEP value appropriately reflects the risk of not performing the action.

Based on this review, the detailed HEP example for dc load shed in Appendix D makes the following assumptions:

- Opening the breakers on each panel is assumed to be completely dependent such that only one execution error per panel is applied.
- Completion of the action by 90 minutes would provide sufficient extended battery life to align the FLEX generators to avoid core damage.
- The available time margin and the simplicity of the actions allows for credit of self-review for ensuring that the right breakers on each panel are opened before moving to the next panel.

Action 3: Cool down the primary to reduce steam generator pressure below 500 psi

The HFE for cooling down the primary to reduce steam generator is already modeled in the PRA model. The timing for the existing HFE bounds the requirements for this strategy, therefore the existing HFE is used.

Action 4: Manually operate the steam generator ADVs to depressurize the steam generator

The HFE for manually controlling the steam generator ADVs is already modeled in the PRA model. The timing for the existing HFE bounds the requirements for this strategy, therefore the existing HFE is used.

Action 5: Deploy and install FLEX Generator

For the modeling of failure to deploy and install the FLEX generator, engineering judgement was used in the development of the applicable HEPs. In the absence of an external event that could require additional steps such as debris removal, for this example, the probability of failure to transport and stage the portable generator is judged to be about 1E-3; therefore, in the EPRI HRA Calculator, the Table (Reference 19) 20-13, Locally Operated Valves, is chosen and Item 1 is picked to give a probability of failure of 1.3E-3. The remaining execution steps are represented in the calculator table and are selected appropriately (See FLEX generator example in Appendix D).

Action 6: Deploy, install, and use the portable pump to provide water to a steam generator

A similar process used for Action 5 was followed for the human actions associated with use of the FLEX pump.

Sensitivity studies can be performed to evaluate how sensitive the model is to the assumptions utilized to develop the final HEP values.

C.6 Data Analysis

Without sufficient plant-specific or generic industry failure rates for the portable equipment, in this example, the failure rates for permanently-installed equipment were used, and a sensitivity study performed to increase those failure rates by a factor of 10 to determine if the PRA results are sensitive to that assumption. Once the generic industry failure rates are available, the probabilities of failure will be updated as part of the normal PRA update process.

C.7 Quantification

Quantification of the PRA model was performed in the same way that it is normally done. For this example, the only difference was some additional sensitivity studies. In particular, sensitivity studies to assess the impact of the failure probabilities of the portable equipment assumed to be the same as that of permanently-installed equipment was performed. The failure rates of the portable equipment were increased by a factor of 10 and then the model re-quantified to determine the change in CDF based on this change. Similarly, sensitivity studies were performed to assess the impact of the assumptions made in the development of the HEPs. A small increase in CDF indicates that the model is not sensitive to this assumption.

C.8 LERF

No additional analysis was needed for Level 2 or LERF, because none of the mitigating strategies were applied after core damage. LERF was re-calculated to assess the impact of the mitigating strategies.

APPENDIX D: EXAMPLE OF HUMAN FAILURE EVENT ANALYSIS

Two HEPs were developed in the EPRI HRA Calculator based on the example in Appendix C.

- Operators fail to load shed dc buses
- Operators fail to deploy and install FLEX generator

The rest of this appendix includes portions of the exported HRA Calculator report based on the development of these HEPs. The probabilities calculated in these examples may differ for each site because of differences in procedures, timing, system configuration and other factors. For example, a lower error of commission may be applicable for the battery load shed HEP if the procedure contains graphics that show the battery panel with the breaker positions very well delineated.

1. OPERATORS FAIL TO LOAD SHED DC BUSES

Note that this section provides a representative HEP development for failing to perform a deep dc load shed. The procedure and FSG nomenclature are not in direct alignment with the hypothetical example described in Appendix C, but the detailed HEP development is included for illustrative purposes.

Table 1: QHULS-DCDXIO SUMMARY

HEP Summary				
	P_{cog}	**P_{exe}**	**Total HEP**	**Error Factor**
Method	CBDTM	THERP	CBDTM + THERP	
Without Recovery	2.0e-03	3.2e-02		
With Recovery	5.0e-04	1.9e-02	1.9e-02	5

Assigned Basic Events:

Related Human Interactions:

Initial Cue:

ELAP Declared (As defined in SE-11, Sht 1)

Recovery Cue:

Additional Cues:

Cue Comments:

Once ELAP has been declared, there is minimal cognitive work required to initiate ELAP load shed. The FLEX Strategies leg directs it without the need to meet any specific conditions.

Degree of Clarity of Cues & Indications:

Very Good

Procedures:

Cognitive: SE-11 SHEET 6 (LOSS OF OFF-SITE POWER) Revision: 15

Execution: FSG-012-3 (ELAP DC LOAD SHED) Revision: 0

Other: Not Selected

Cognitive Procedure:

Step: FLEX STRATS. ELEC LEG

Instruction: · PERFORM DC LOAD SHED IAW:

- FSG-012-3, "ELAP DC LOAD SHED"

Procedure and Training Notes:

The procedure directing the initiation of the action is listed, but there is no significant cognitive work associated with performing this action. Once SE-11 Sheet 6 has been entered it is only a matter of following the steps in the FLEX strategies leg. For this assessment, ELAP is not assume to be declared until 60 minutes from loss of power to the 4kV busses, which directs immediate performance of FSG-012-3.

Training:

Classroom, Frequency: 0.5 per year

Simulator, Frequency: 0.5 per year

JPM Procedure:

Not Selected

Identification and Definition:

This HFE represents the task to perform the ELAP load shed steps directed in FSG-012-3 for a single unit for the battery loads required to ensure that sufficient time exists to align the FLEX generator.

1. Initial Conditions: Steady state, full power operation

2. Initiating Event: Non-LOCA internal events initiators leading to extended loss of AC power conditions.

3. Accident Sequence (preceding functional failures and successes)

A. Non-LOCA transient

B. Plant trip/scram successful

C. Loss of offsite power

D. Failure of EDGS to supply power to the emergency busses

E. ELAP declared

4. Preceding operator error or success in sequence:

- Loss of offsite power successfully diagnosed and SE-11 has been entered
- Manual EDG start/alignment attempted, but hardware fails
- ELAP declared and SE-11 Sheet 6 entered.

5. Operator action success criterion: Complete the ELAP load shed steps within 90 minutes of the loss of AC power to the battery chargers.

6. Assumptions:

A. All AC power is assumed to be lost at the time of the initial plant trip.

B. ELAP was declared at 1 hour and SE-11 Sheet 6 was entered.

C. For internal events initiators, debris removal for FLEX alignment is not required.

D. Based on the site validation plan, one EO per unit is assigned to the ELAP load shed task to ensure there is adequate time margin for completion.

E. The quantification is based on the Unit 2 validation walk-though time and execution steps, but the Unit 1 procedure is similar and this assessment is applicable to both units.

F. As identified in the breaker manipulation assessments, breaker manipulations that are directed by a single procedure step on a single panel that would be performed by the same operator at about the same time are considered to be completely dependent. The implication is that failure to correctly manipulate all of the breakers on a single panel (e.g the entire panel is omitted) results in the overall failure of the loadshed action. This is conservative given that even the failure to shed the loads on an entire panel would not likely reduce battery life enough to prevent success of the FLEX generator alignment.

G. The execution time for this action is based on the validation that was performed for completing all of FSG-012-3; however, only the first three panels listed in Section 4.1 would be required for success.

Operator Interview Insights:

Manpower Requirements:

Crew Member	Included	Total Available	Required for Execution	Notes
Shift Manager	Yes	1	0	
Shift Supervisor	Yes	1	0	
STA	Yes	1	0	
Reactor operators	Yes	2	0	
Plant operators	Yes	2	1	One EO per unit for ELAP load shed.
Mechanics	Yes	2	0	
Electricians	Yes	2	0	
I&C Technicians	Yes	2	0	
Health Physics Technicians	Yes	2	0	
Chemistry Technicians	Yes	1	0	
Security	Yes	4	0	

Execution Performance Shaping Factors:

Environment:	Lighting	Portable
	Heat/Humidity	Normal
	Radiation	Background
	Atmosphere	Normal
Special Requirements:	Tools	Required
		Adequate
		Available
	Parts	Required
		Adequate
		Available
Complexity of Response:	Cognitive	Complex
	Execution	Simple
Equipment Accessibility (Cognitive):	Control Room	Accessible
Equipment Accessibility (Execution):	Cable Spreading Room	Accessible
Stress:	**Moderate**	
	Plant Response As Expected:	Yes
	Workload:	Low
	Performance Shaping Factors:	Negative

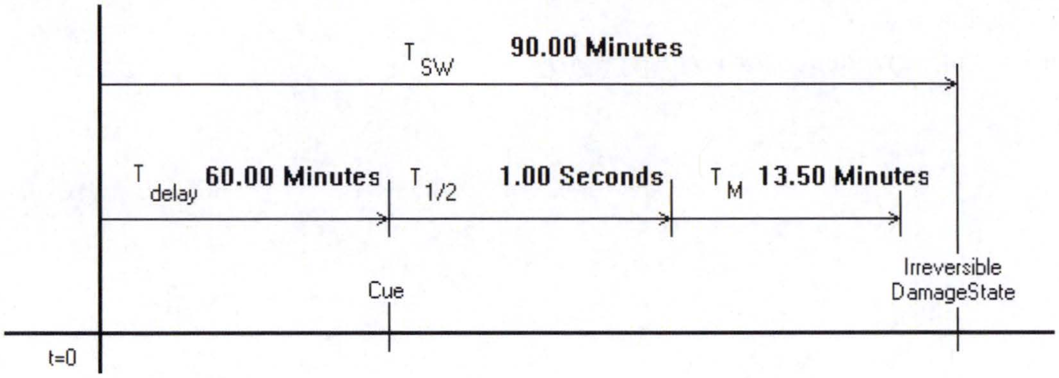
Performance Shaping Factor Notes:

- In this case, the event is in its early stages, the plant is under control, and the operators would not perceive that the plant is progressing to core damage. This action will provide additional battery life beyond what is normally available.
- There action has about a 45% time margin for even the slowest validation time (the execution could almost be performed twice by the slowest EO, including the time to go to the FLEX

cabinet to obtain procedures and a flashlight, which they would not have to do given that all EOs carry a flashlight and the procedure would be available in the MCR when they report to obtain the keys). With one EO per unit, this is not a high workload task.

- The EOs would be working in SBO condition in which portable lighting would be required (negative PSFs).

Timing:



Timing Analysis: Tsw: The FLEX validation plan indicates that the time constraint for performing the ELAP load shed is that it is completed by 90 minutes from the loss of power to the battery chargers.

Tdelay: The cue for this action is the declaration of ELAP. The FSG-012-3 ELAP load shed actions are only directed after entry into SE-11 sheet 6. Based on the validation timeline, ELAP must be declared by 60 minutes from loss of power to the station battery chargers to ensure there is adequate time to perform all of the other mitigating tasks in an ELAP scenario. The worst case "success" time for ELAP declaration of 60 minutes is used as the cue time for this action.

T1/2: Not used in either the ASEP or CBDTM methodology. 1 second is used as a placeholder value. Note that the 1 second value entered for the median response time (T1/2) does not represent the actual expected median response time. It is entered as work-around for an HRAC warning.

Tm: The site validation exercises demonstrated that one EO is able to perform the load shed task for one unit within the time required. Five different EOs were used to perform the task five separate times as part of the validation exercise. The median completion time from the validation exercises was determined to be 13.5 minutes, which is used as the execution time for this HFE. This time conservatively includes the time to travel from the MCR to obtain a flashlight and a procedure even though the EOs normally carry a flashlight and the procedure would be available in the MCR.

While the entire validation time of 13.5 minutes is used for the execution time for this HFE, only the first three steps of the procedure in Section 4.1 are required for success.

Time available for cognition and recovery: 16.50 Minutes

Time available for recovery: 16.48 Minutes

SPAR-H Available time (cognitive): 16.50 Minutes

SPAR-H Available time (execution) ratio: 2.22

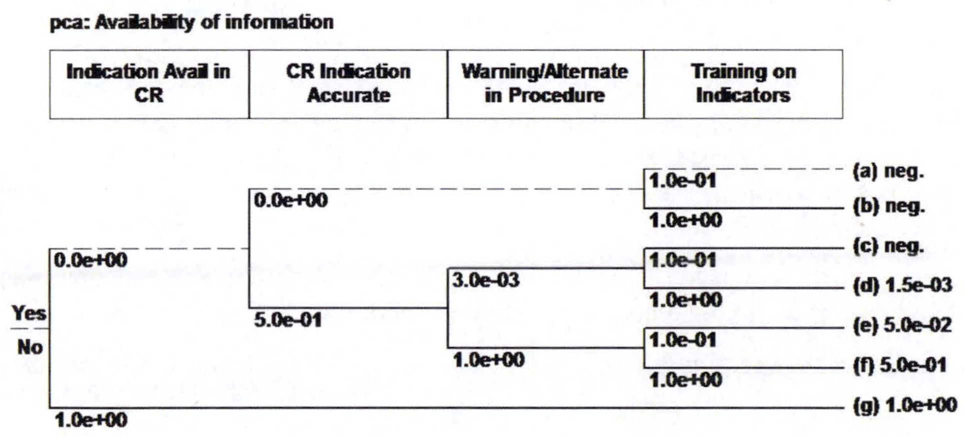
Minimum level of dependence for recovery: MD

Cognitive Unrecovered

QHULS-DCDXIO

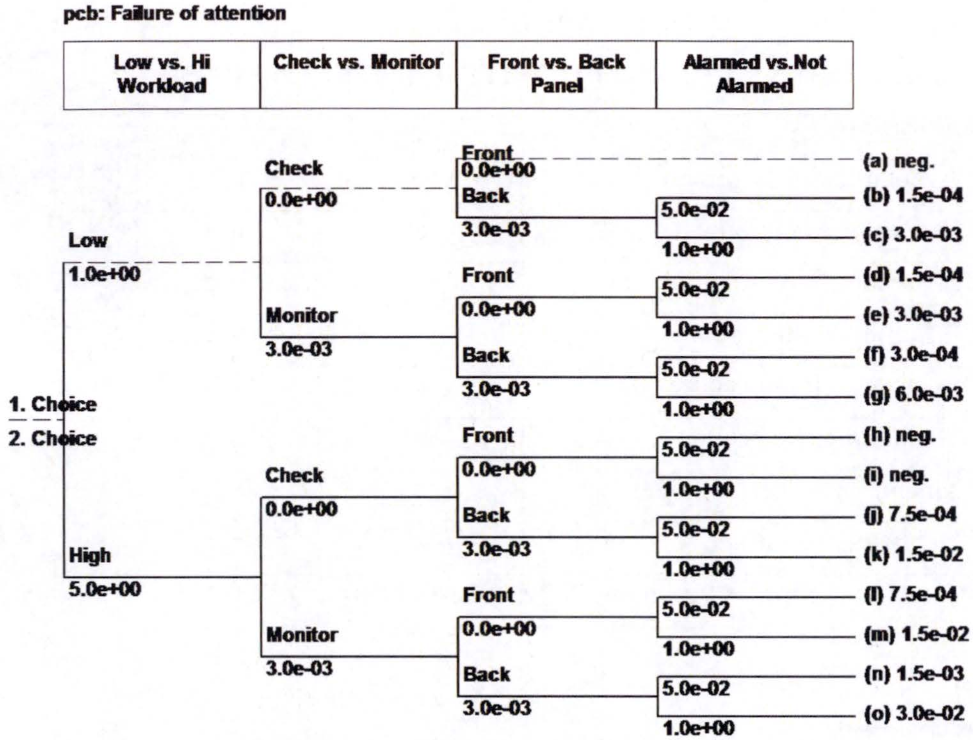
Table 2: QHULS-DCDXIO COGNITIVE UNRECOVERED

Pc Failure Mechanism	Branch	HEP
Pc_a: Availability of Information	a	neg.
Pc_b: Failure of Attention	a	neg.
Pc_c: Misread/miscommunicate data	a	neg.
Pc_d: Information misleading	a	neg.
Pc_e: Skip a step in procedure	e	2.0e-03
Pc_f: Misinterpret instruction	a	neg.
Pc_g: Misinterpret decision logic	k	neg.
Pc_h: Deliberate violation	a	neg.
Sum of Pc_a through Pc_h = Initial Pc =		2.0e-03



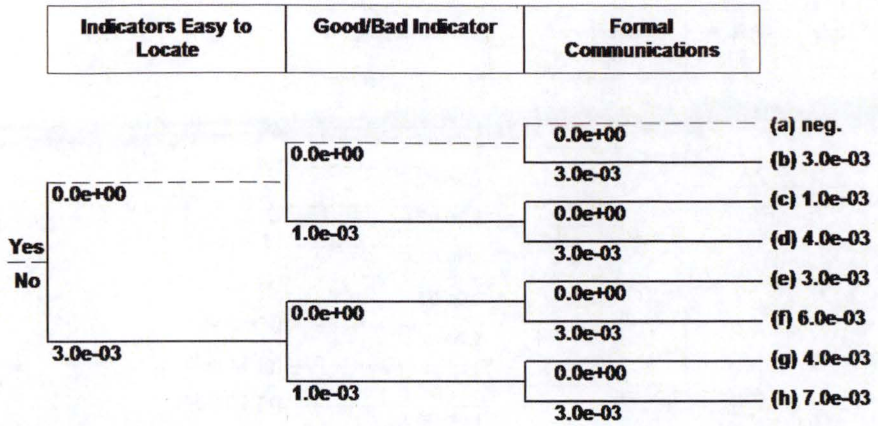
Once SE-11 Sheet 6 has been entered on ELAP, there is minimal cognitive work required to initiate FSG-012-3. The FLEX strategies leg lists the procedures to be performed, which includes FSG-012-3.

- The cue is a procedure step and accuracy is not relevant. Treated as accurate.
- NA
- The crew has been trained on how to use SE-11 in ELAP cases.



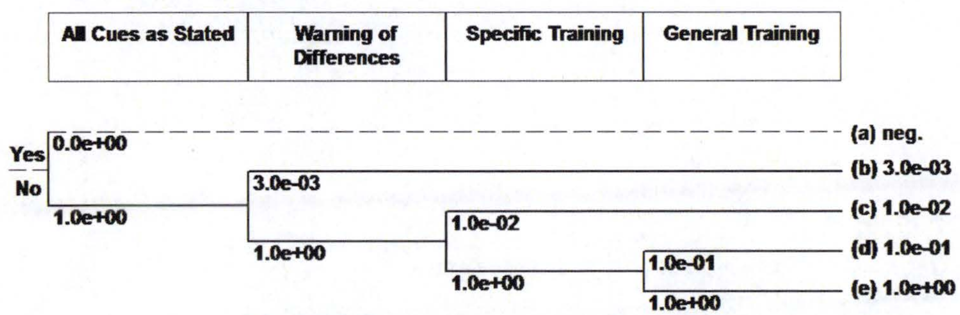
- At the time when the crew begins to consider ELAP DC Load Shed, over 1 hour has passed since the plant trip and the major plant stabilization actions have been completed. The workload is low, or at least consistent with the conditions in which the operators have practiced these types of scenarios (i.e., the workload is not so great that they are challenged to complete all of their tasks on time).
- The cue structure is most similar to a "check" structure as there are no plant limits that must be monitored and confirmed to have been met before the action would be directed.
- No additional indicators are required to be used for this action. Treated as front panel case.
- NA.

pcc: Misread/miscommunicate data



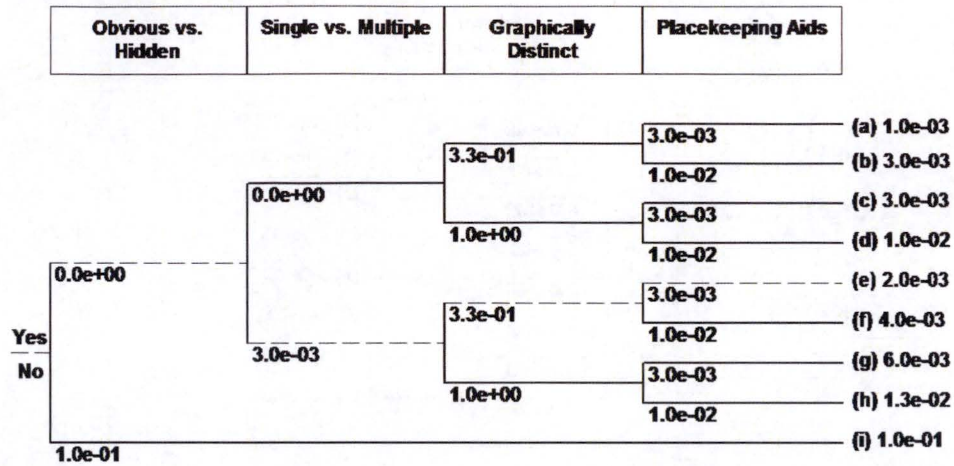
- Not applicable to a procedure based cue. Treated as "easy to locate".
- Not applicable to ad procedure based cue. Treated as a "good" indicator.
- Formal communications are required for the site staff.

pcd: Information misleading



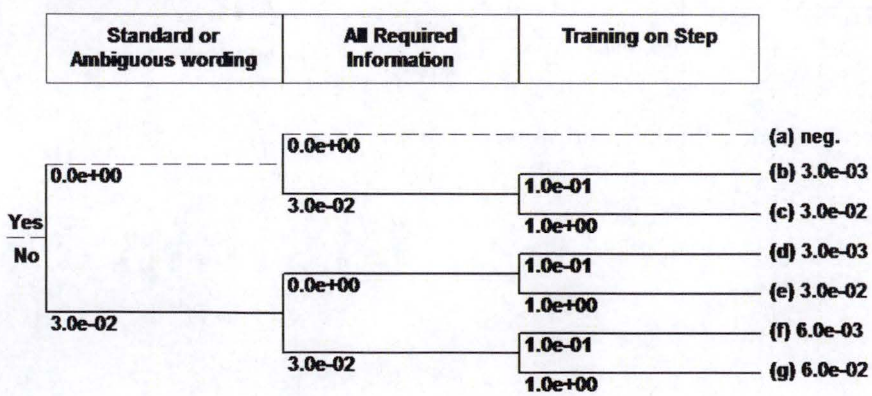
- The procedures are consistent with the conditions of the scenario.
- NA
- NA
- NA

pce: Skip a step in procedure

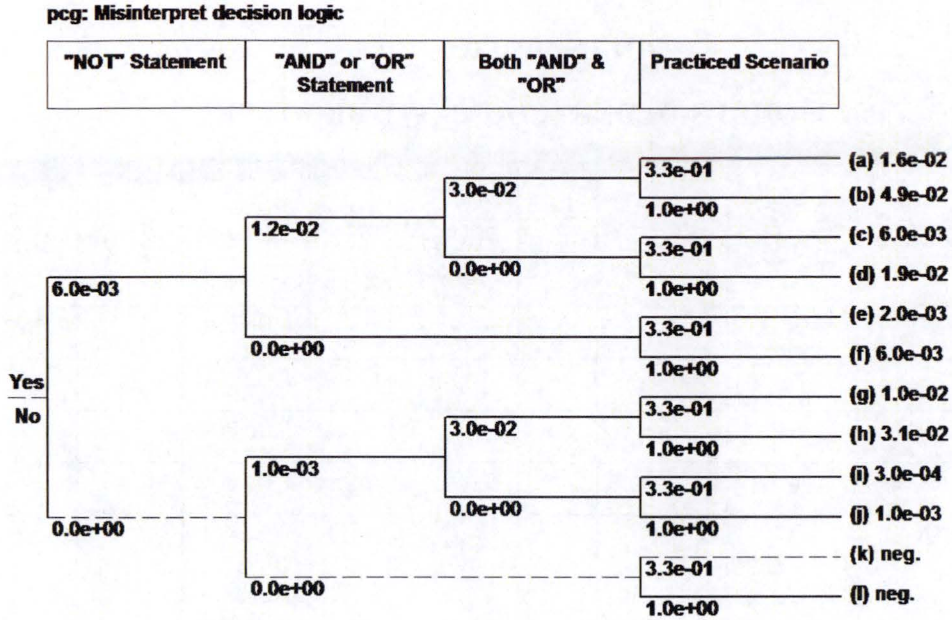


- The step directing ELAP load shed is part of a standard BWR EOP style flowchart box (i.e., not hidden).
- There are multiple legs of SE-11 Sheet 6 that must be used simultaneously.
- The step directing ELAP load shed is graphically distinct. There is a large red arrow pointing to the step with the word "priority" next to it. There are only 4 of these markings on the flow chart, and there is only one in the "FLEX Strategies " leg.
- The circle/slash method of placekeeping is used in the plant procedures, which is considered to be a placekeeping aid.

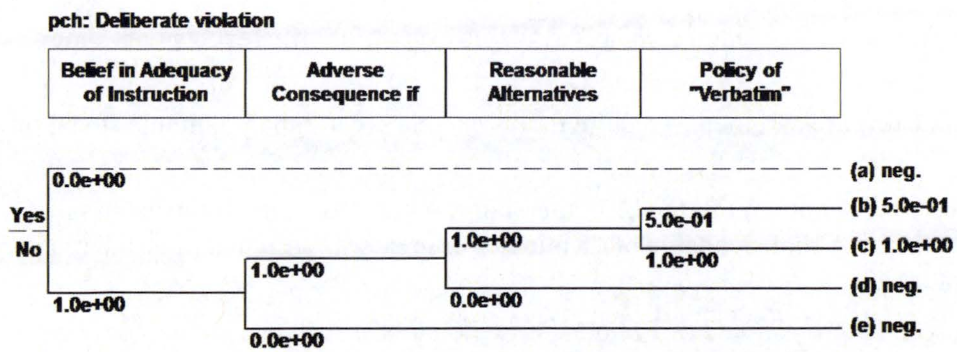
pcf: Misinterpret instruction



- The instructions related to ELAP load shed are clear an unambiguous.
- The procedure provides all of the information required.
- NA



- There are no NOT statements in the decision logic for ELAP load shed.
- There are no AND or OR statements in the decision logic.
- NA
- This is a practiced scenario for the site.



- The crew believes that the procedure steps are appropriate and there are no significant negative consequences associated with this action that have been identified that would be a reason for the crew to deliberately not perform this action.
- NA
- NA
- NA

Cognitive Recovery

QHULS-DCDXIO

Table 3: QHULS-DCDXIO COGNITIVE RECOVERY

	Initial HEP	Self-Review	Extra Crew	STA Review	Shift Change	ERF Review	DF	Multiply HEP By	Override Value	Final Value
Pc_a:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_b:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_c:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_d:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_e:	2.0e-03	X	X	-	-	-	HD	2.5e-01		5.0e-04
Pc_f:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_g:	neg.	-	-	-	-	-	-	1.0e+00		
Pc_h:	neg.	-	-	-	-	-	-	1.0e+00		
Sum of Pc_a through Pc_h = Initial Pc =										5.0e-04

Notes:

Cognitive Recovery:

Self Review: Self Review is considered always available except for basic events with time constraints.

Extra Crew: Extra Crew are assumed to require time available greater than 5 minutes to be fully functional.

STA Review: The STA is not required to be in the Main Control Room at all times but is required to be available. A time available of 15 minutes or greater is assumed to be the required time for STA availability.

Shift Change: A shift length is noted as 12 hours. Based on this, a shift change will only be effective for basic events with a time allowed greater than 12 hours to bound all possible accident start times.

ERF Review: ERF operability would take at least 1 hour to be fully operational. Time available greater than 120 minutes is assumed to be required before ERF review can be accounted for to account for assessment of the situation (activation at 1 hour plus 1 hour to coordinate with Operations).

Execution Unrecovered

QHULS-DCDXIO

Table 4: QHULS-DCDXIO EXECUTION UNRECOVERED

Procedure: FSG-012-3, ELAP DC LOAD SHED		Comment				Stress Factor	Over Ride
Step No.	Instruction/Comment	Error Type	THERP		HEP		
			Table	Item			
4.1, PNL 3AD025	Shed 125 VDC loads by opening the following breakers:	Because the breaker manipulations for each panel are directed by the same procedure step, would be performed by the same operator in quick succession, and would be performed for the same reason, they are assumed to be completely dependent. The same assumption is applicable to each group of breaker manipulations for each of the panels addressed in the procedure.				2	
	Location: Cable Spreading Room	EOM	20-7b	2	1.3e-03		
		EOC	20-12	12	3.8E-3		
		EOC	20-12	8a	2.7E-4		
						Total Step HEP	1.1e-02
4.1, PNL 30D021	Shed 125 VDC loads by opening the following breakers:					2	
	Location: Cable Spreading Room	EOM	20-7b	2	1.3e-03		
		EOC	20-12	12	3.8E-3		
		EOC	20-12	8a	2.7E-4		

Procedure: FSG-012-3, ELAP DC LOAD SHED		Comment				Stress Factor	Over Ride
Step No.	**Instruction/Comment**	**Error Type**	**THERP**		**HEP**		
			Table	**Item**			
						Total Step HEP	1.1e-02
4.1, PNL 3CD025	Shed 125 VDC loads by opening the following breakers:					2	
	Location: Cable Spreading Room	EOM	20-7b	2	1.3e-03		
		EOC	20-12	12	3.8E-3		
		EOC	20-12	8a	2.7E-4		
						Total Step HEP	1.1e-02
EXEC RECOV - OCR	Execution recovery provided by independent personnel (outside control room)	This execution recovery factor is applied to the individual execution steps with a dependence factor based on the time available for recovery. Note that the execution stress factors applied to the execution subtasks are not applied to the execution recovery factor. The EOM does not apply. Self review is part of the STAR (STAR - Stop, Think, Act, Review) practices, which would be adhered to while performing the load shed steps.				2	0.5
	Location: Cable Spreading Room	EOM	20-7b	2	1.3e-03		
						Total Step HEP	5.0e-01

Execution Recovery

QHULS-DCDXIO

Table 5: QHULS-DCDXIO EXECUTION RECOVERY

Critical Step No.	Recovery Step No.	Action	HEP (Crit)	HEP (Rec)	Dep.	Cond. HEP (Rec)	Total for Step
4.1, PNL 3AD025		**Shed 125 VDC loads by opening the following breakers:**	**1.1e-02**				**6.3e-03**
	EXEC RECOV - OCR	Execution recovery provided by independent personnel (outside control room)		5.0e-01	MD	5.7e-01	
4.1, PNL 30D021		**Shed 125 VDC loads by opening the following breakers:**	**1.1e-02**				**6.3e-03**
	EXEC RECOV - OCR	Execution recovery provided by independent personnel (outside control room)		5.0e-01	MD	5.7e-01	
4.1, PNL 3CD025		**Shed 125 VDC loads by opening the following breakers:**	**1.1e-02**				**6.3e-03**
	EXEC RECOV - OCR	Execution recovery provided by independent personnel (outside control room)		5.0e-01	MD	5.7e-01	
		Total Unrecovered:	**3.2e-02**		**Total Recovered:**		**1.9e-02**

2. OPERATORS FAIL TO DEPLOY AND INSTALL FLEX GENERATOR

Note that this section provides a representative HEP development for alignment of a FLEX generator. The timing aspects are not in direct alignment with the hypothetical example described in Appendix C, but the detailed HEP development is included for illustrative purposes.

HEP Summary				
	Pcog	**Pexe**	**Total HEP**	**Error Factor**
Method	CBDTM	THERP	CBDTM+THERP	
Without Recovery	2.00E-03	1.18E-01		
With Recovery	2.90E-04	5.06E-03	5.35E-03	5

Identification and Definition
This HEP is for an SBO that is declared to be an ELAP and then the BDB 120/240V generator is utilized to reenergize a vital bus. This HEP is evaluated for operators maintaining control in the control room. The procedure progression is operators enter ECA-0.0 due to both emergency AC buses are de-energized. At ECA-0.0 Step 15 RNO operators declare an ELAP and initiate FSG-4, "ELAP DC BUS LOAD SHED/MANAGEMENT". FSG-4, Step 4 directs operators to Restore/Maintain Vital Instrumentation Power Using Flex Equipment. In parallel, step 15 of ECA-0.0 initiates 0-FSG-5, Initial Assessment and Flex Equipment Staging. Step 6 of 0-FSG-5 has on-site personnel transport the 480 VAC generators from the on-site storage building and stage generators using Attachment 8. After on-site personnel report back that equipment is staged (completion of Attachment 8) operators will proceed in 1-FSG-4 step 4.a.1 to perform Attachment 4 to prepare the generator and then Transfer Vital Bus load to BDB 480 VAC generator IAW Attachment 5 of 1-FSG-4.

Cues and Indications	
Initial Cue	Procedural driven CUE: 1-ECA-0.0 Step 15 CHECK IF AC POWER CAN BE RESTORED TO AT LEAST ONE EMERGENCY BUS WITHIN 60 MINUTES RNO - a) Declare ELAP and Do the following: Initiate 0-FSG-5, Flex Equip Staging
Recovery Cue	
Cue Comments	
Degree of Clarity	Clarity of Cues and Indications are modeled explicitly in CBDTM

Procedures	
Cognitive Procedure	1-ECA-0.0 (LOSS OF ALL AC POWER) Revision: 31
Cognitive Step Number	15

Cognitive Instruction	CHECK IF AC POWER CAN BE RESTORED TO AT LEAST ONE EMERGENCY BUS WITHIN 60 MINUTES RNO: Declare ELAP and Initiate 1-FSG-4, ELAP DC BUS LOAD SHED/MANAGEMENT. and 0-FSG-5
Execution Procedure	1-FSG-4 (ELAP DC Bus Load Shed/Management) Revision: 1
Execution Instruction	
Job Performance Measure	JPM: Not Selected
Other Procedures	0-FSG-5 (Initial Assessment and Flex Equipment Staging) Revision: 2
Notes	
After equipment is staged per 0-FSG-5 by on-site personnel, operations is notified and can then prepare, hookup, and re-energize vital bus with Attachments 4 and 5 of 1-FSG-4.	

Training	
Classroom Training	1 per year
Simulator Training	1 per year

Crew Member	**Included**	**Total Available**	**Required for Execution**	**Notes**
Shift Manager	No	1	1	---
Shift Supervisor	No	1	1	---
STA	No	1	1	---
Reactor operators	Yes	2	1	---
Plant operators	Yes	2	2	---
Electricians	Yes	2	2	---
Mechanics	Yes	2	0	
I&C Technicians	Yes	2	0	
Health Physics Technicians	Yes	2	0	
Chemistry Technicians	Yes	2	0	
Security	Yes	2	1	
Reactor Operators	Yes	2	1	
Plant Operators	Yes	2	2	

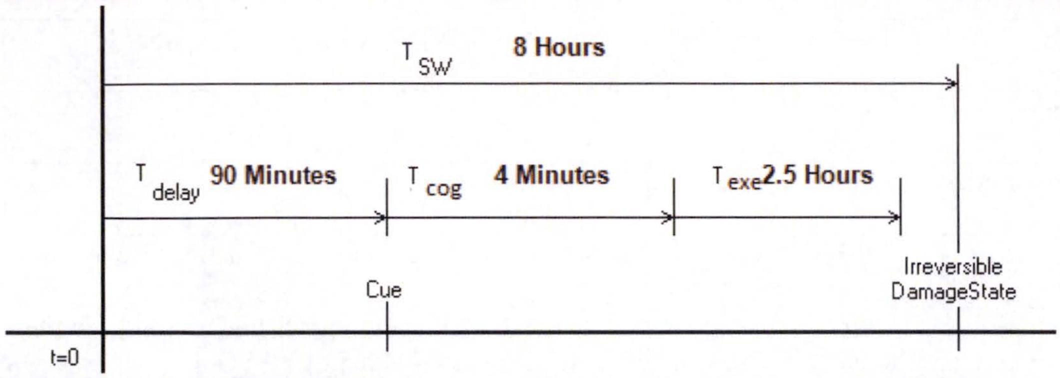
Notes

Security transports RCS Injection Pump from FLEX Dome to staging area in the Protected Area. A staffing study concluded that with minimum administrative limit staffing, these actions can be performed in the time required to be successful.

Dependencies (Related Human Interactions)
This HEP is applicable to SBO events in the internal events PRA Model where an ELAP has been declared.

Operator Interview Insights

Timing Analysis



Time available for cognition and recovery	240 Minutes
Time available for recovery	236 Minutes
SPAR-H Available time (cognitive)	240 Minutes
SPAR-H Available time (execution) ratio	2.57 Minutes
EPRI Minimum level of dependence for recovery	ZD

Notes

Tsw = 8 hours which is the capacity of batteries when load shed is successful. As long as this action is completed within about 8 hours from the start of the SBO, the Steam Generators will not overfill or boil dry. Although the plant could stay in this condition longer without drying out the Steam Generator, or overfilling and failing the TDAFW pump, it will be assumed that after 8 hours the portable generator or other source of AC power is required or FLEX actions will not be successful.

Td = 90 minutes. Since this HFE is used for internal events only, there should not be any debris to clear between the FLEX storage area and the staging location of the portable generator within the protected area. It is reasonable to assume that within 90 minutes, operations (and on-site personnel) will be ready to perform applicable steps in FSG-5 to transport the generator to the staging area and applicable steps in FSG-4 to re-power the 120 VAC Vital Buses and DC buses.

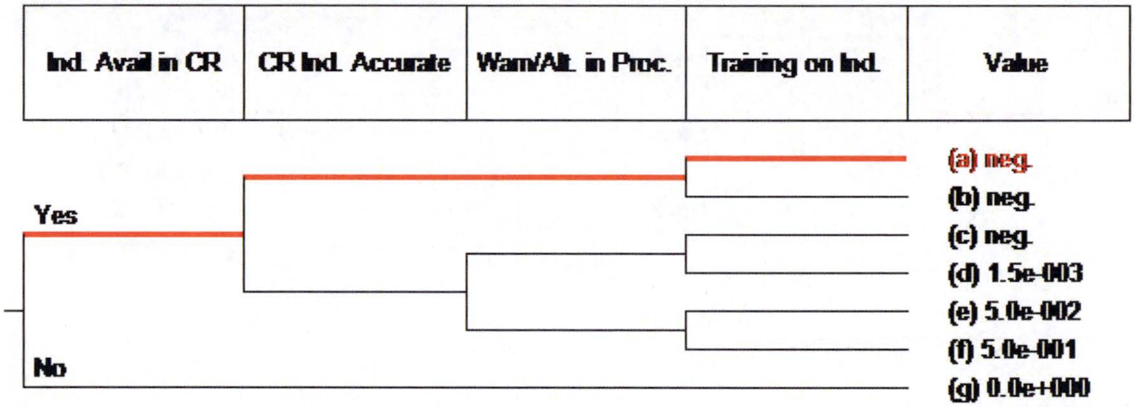
Tcog = 4 minutes. Although this is a procedurally directed action, a longer than typical Tcog will be used here. Possibly there could be some extra time taken to make the decision due to coordination with security since it is a security person that brings the portable generator to the protected area from the dome even though all the actions are in the FSG procedure and security is trained and knowledgeable of their responsibilities.

Texe = 150 minutes. The validation times provided in the site specific FLEX implementation to transport the generator for Unit 1 is 41.5 minutes (site specific reference) and the time to start the generator and re-power the Vital Buses for Unit 1 is 45 minutes (site specific reference) for a total of 87 minutes. The value is increased to 150 minutes to account for possible adverse conditions such as inclement weather.

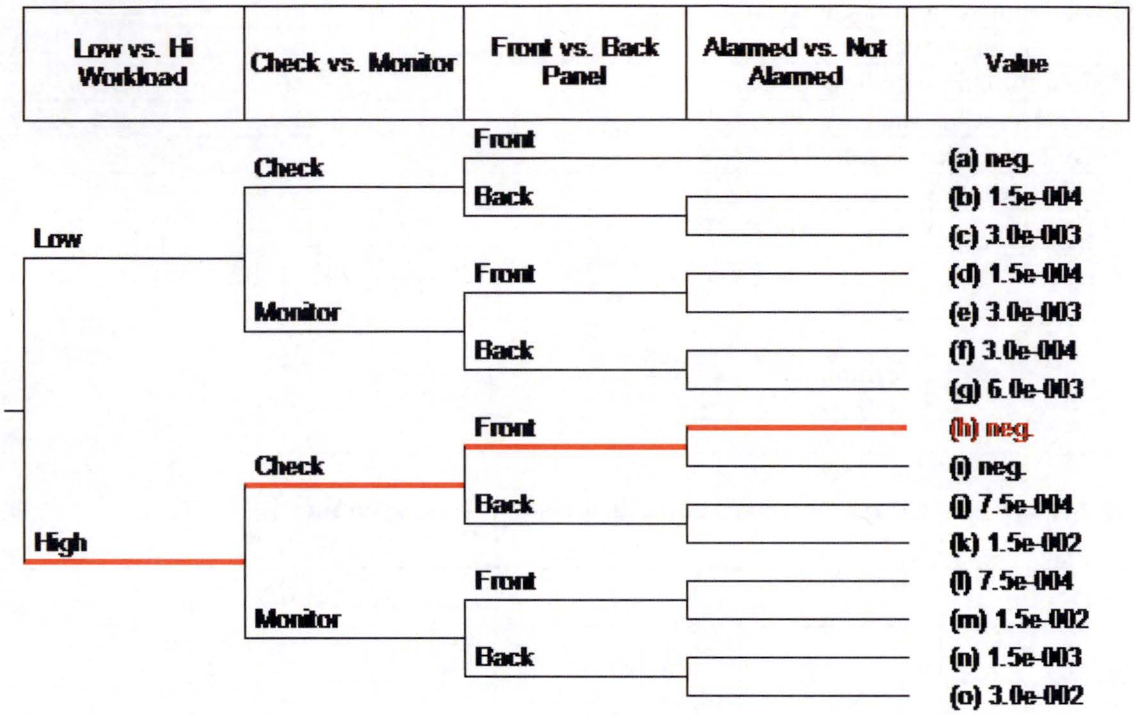
Cognitive Analysis		
Pc Failure Mechanism	**Branch**	**HEP**
Pca: Availability of Information	a	n/a
Pcb: Failure of Attention	h	n/a
Pcc: Misread/miscommunicate data	a	n/a
Pcd: Information misleading	a	n/a
Pce: Skip a step in procedure	e	2.00E-03
Pcf: Misinterpret Instructions	a	n/a
Pcg: Misinterpret decision logic	l	n/a
Pch: Deliberate violation	a	n/a
Initial Pc(without recovery credited)		2.00E-03
Notes		

Pca: Availability of Information

Notes/Assumptions:

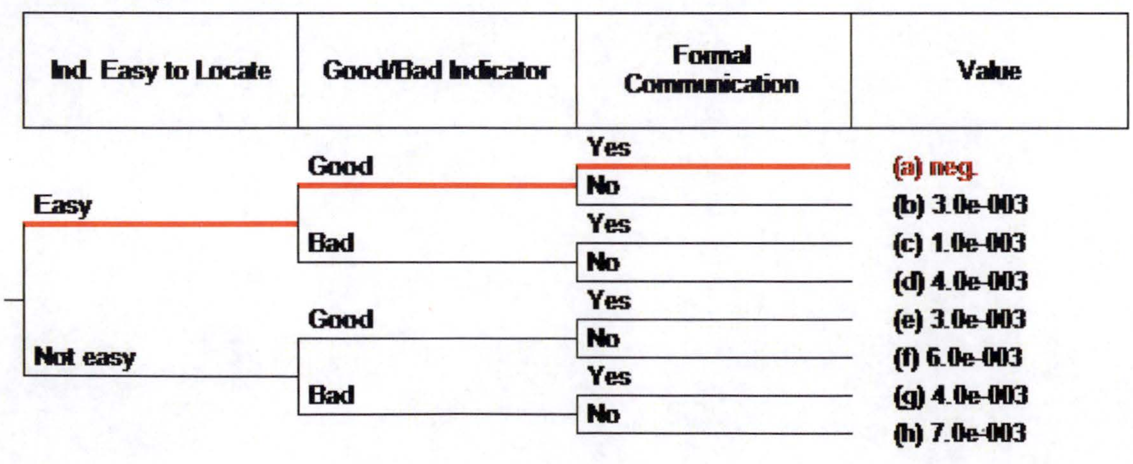


Pcb: Failure of Attention *Notes/Assumptions: Workload is high due to loss of power requiring operators to perform actions manually that normally could be performed from the control room. The cue to get operators into FSG-4 is by checking AC power available at step 18 are evident from the control room front panels and will be as noticeable as an alarm.*



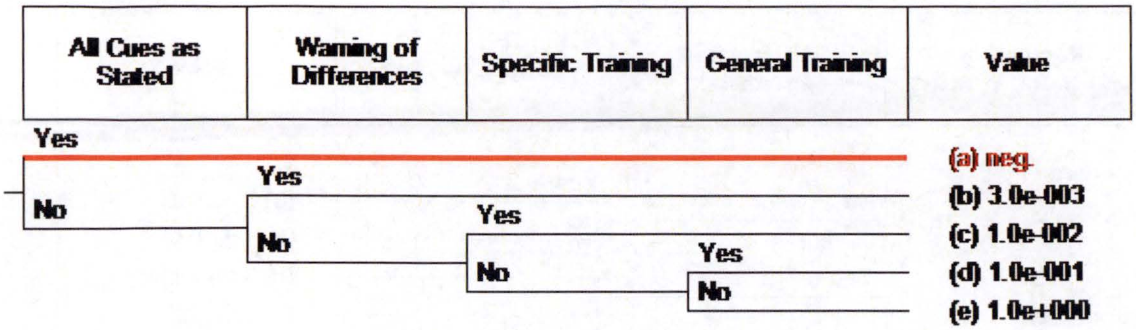
Pcc: Misread/miscommunicate data

Notes/Assumptions:



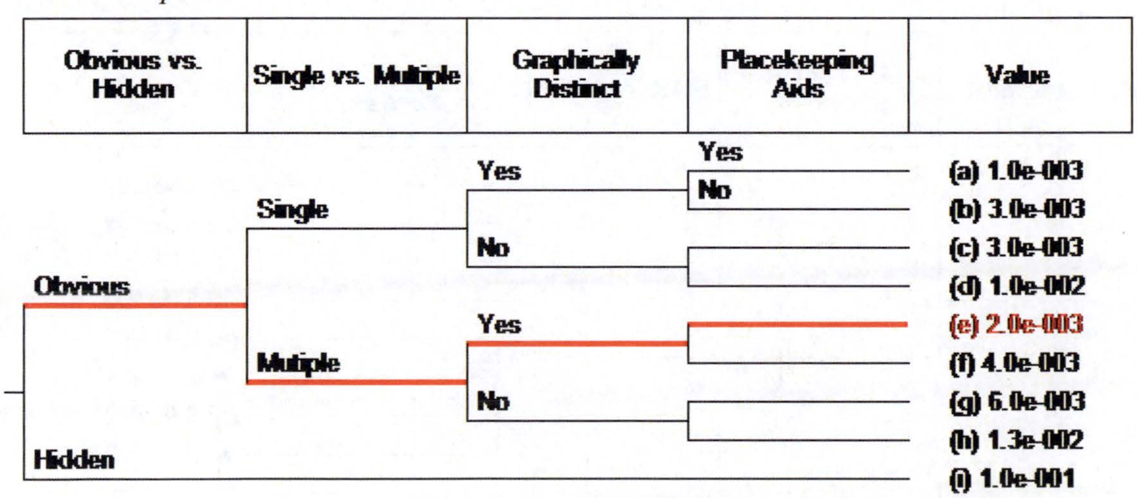
Pcd: Information misleading

Notes/Assumptions:



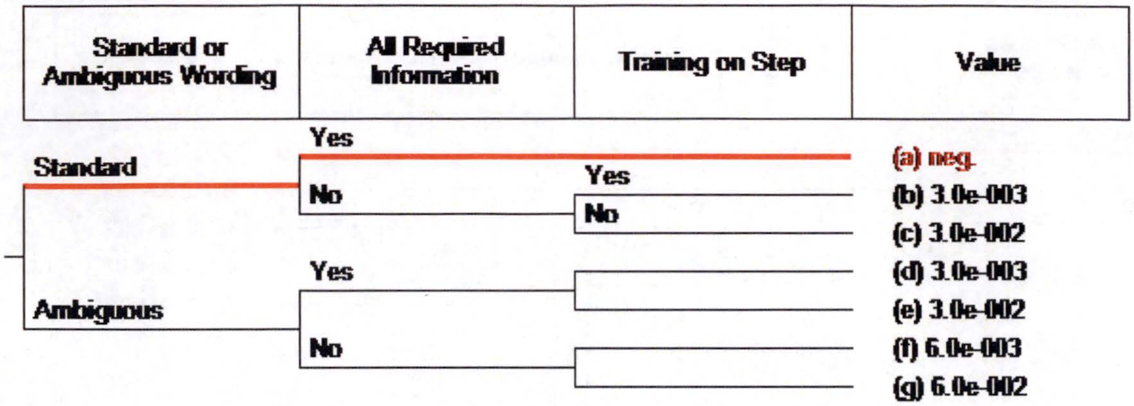
Pce: Skip a step in procedure

Notes/Assumptions:



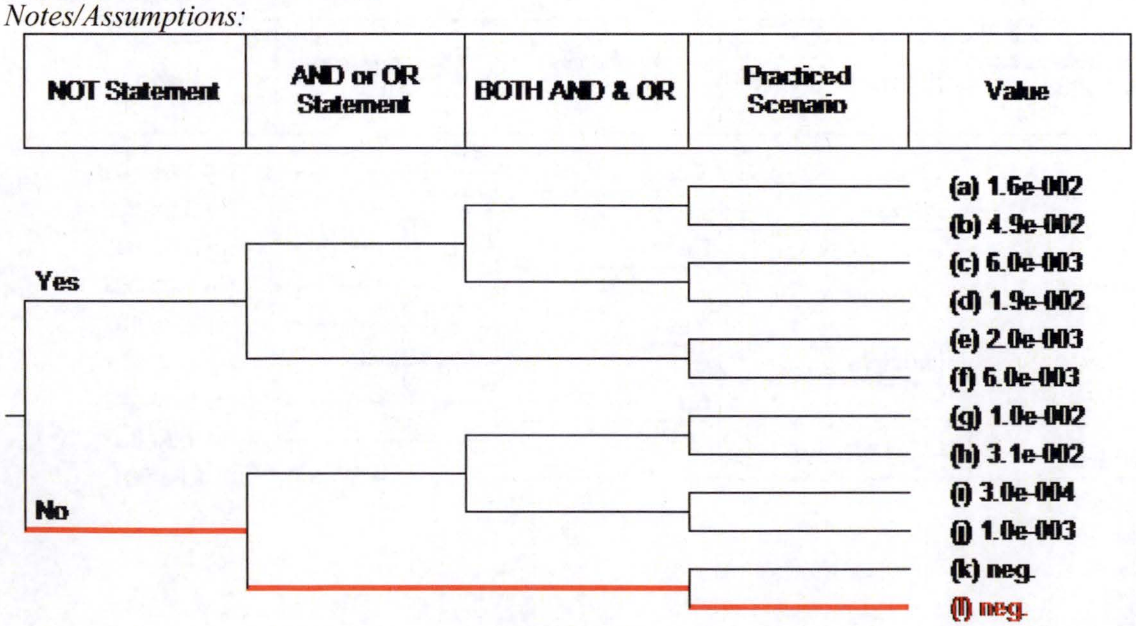
Pcf: Misinterpret Instructions

Notes/Assumptions:



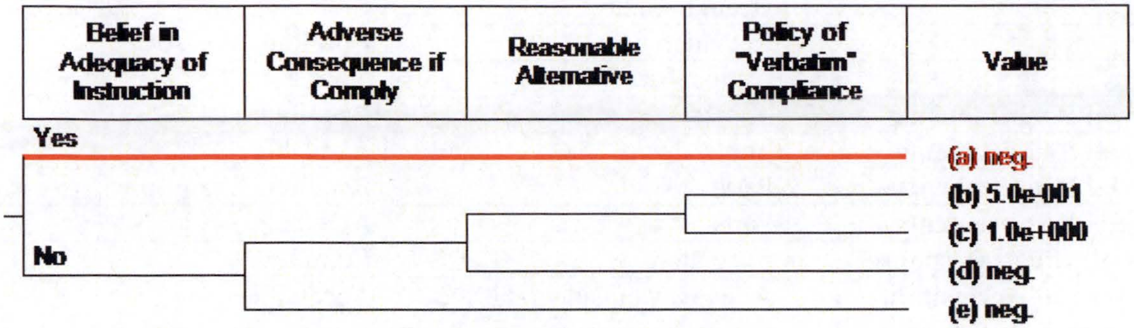
Pcg: Misinterpret decision logic

Notes/Assumptions:



Pch: Deliberate violation

Notes/Assumptions:



Cognitive Recovery											
	Initial HEP	Self Review	Extra Crew	STA Review	Shift Change	ERF Review	Recovery Matrix	Dependency Level	Multiply HEP by	Override Value	Final Value
Pca	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pcb	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pcc	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pcd	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pce	2.00E-03	X	-	-	-	-		MD	1.45E-01		2.90E-04
Pcf	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pcg	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Pch	n/a	-	-	-	-	-		N/A	1.00E+00		0.0
Final Pc (with recovery credited)											2.90E-04
Notes											
The Dependency Factor was increased from ZD to MD to compensate for any additional uncertainty due to this being a FLEX action with portable equipment.											

Execution Performance Shaping Factors		
Environment	Lighting	Portable
	Heat/Humidity	Cold
	Radiation	Non Radiation Area
	Atmosphere	Normal
Special Requirements	Tools	Required
Special Requirements	Tools	Available
Special Requirements	Parts	Required
Special Requirements	Parts	Available
Complexity of Response	Execution	Complex
Equipment Accessibility (Cognitive)	Alley way outside rod drive	Accessible
Equipment Accessibility (Execution)	Alley way outside rod drive	Accessible

Stress	
High	
Plant Response As Expected:	No
Workload:	N/A
Performance Shaping Factors:	N/A
Notes	

Execution Unrecovered							
Procedure		Comment					
Step No.	Instruction / Comment	Error Type	THERP Table	THERP Item	HEP	Stress Factor	Override
0-FSG-5, Step 6	Security to stage equipment	EOM	20-7b Note 1	1	4.3E-4	High	
		EOC	20-13 Note 2	1	1.30E-03		
	Location:	Alley way outside rod drive			Total Step HEP		8.65E-03
1-FSG-4 att 4	Step 4 after equip staged setup generator	EOM	20-7b Note 1	2	1.3e-03	High	
		EOC	20-12 Note 3	13	1.30E-02		
	Location:	Alley way outside rod drive			Total Step HEP		7.15E-02
1-FSG-4 att 5	Step 4 Reenergize bus from generator.	EOM	20-7b Note 1	2	1.3e-03	High	
		EOC	20-12 Note 3	11	6.30E-03		
	Location:	Alley way outside rod drive			Total Step HEP		3.80E-02
FSG-4, Att 5 Note	Note states that Vital Bus Instrumentation should be restored prior to transferring next vital bus	EOM	20-7b Note 1	2	1.3E-3	High	
		EOC	20-11 Note 4	2	1.30E-03		
	Comment	The note for Attachment 5 Steps 1, 5, and 8 are credited as an opportunity to realize one of the previous steps was not properly completed. In addition, 1-FSG-4, Step 5 is an additional check that vital instrumentation is working properly.					
	Location:	Alley way outside rod drive			Total Step HEP		1.30E-02

Note 1 – Table 20-7b item 1 is appropriate for clear written procedures with signoff steps and a short list of steps (<10 items). Item 2 is selected for greater than 10 steps in this example.

Note 2 - Table 20-13 item 1 (locally operated valves). Although personnel other than operators are performing this action including transportation of equipment from outside of the protective

area to inside the protective area, this initial unrecovered value can be used as a surrogate provided that there is sufficient time margin, personnel are trained, and other factors are selected to account for any uncertainty (e.g. high stress selected). Additionally, this action is not following an external event resulting in the requirement for debris removal. Item 1 is selected if FLEX equipment and locations are clearly marked and labeled.

Note 3- Table 20-12 Item 13 (Improperly mate a connector) used for actions to install cable from generator to connections by operators. FLEX equipment cables are clearly marked, use color coding and standardized connections, and adequate training of operations personnel. Item 11 is used for operators to operate breakers and re-energize the buses for breakers which are appropriately labeled.

Note 4 – Table 20-11 item 2 (Errors of Commission in check-Reading Displays) used as an example of analog readings with easily seen limit marks.

Execution Recovered							
Critical Step No.	Recovery Step No.	Action	HEP (Crit)	HEP (Rec)	Dep.	Cond. HEP (Rec)	Total for Step
0-FSG-5, Step 6		Security to stage equipment (Att 8).	8.65E-03				1.12E-04
	FSG-4, Att 5 Note	Note states that Vital Bus Instrumentation should be restored prior to transferring next vital bus		1.30E-02 Note 5	ZD	1.30E-02	
1-FSG-4 att 4		Step 4 after equip staged setup generator	7.15E-02				4.46E-03
	FSG-4, Att 5 Note	Note before step 1,5, 8 states that Vital Bus Instrumentation should be restored prior to		1.30E-02 Note 5	LD	6.24E-02	

		transferring next vital bus					
1-FSG-4 att 5		Step 4 Reenergize bus from generator.	3.80E-02				4.94E-04
	FSG-4, Att 5 Note	Note states that Vital Bus Instrumentation should be restored prior to transferring next vital bus		1.30E-02 Note 5	ZD	1.30E-02	
Total Unrecovered:			1.18E-01	**Total Recovered:**			5.06E-03

Note 5: Recovery was determined to be applicable due to adequate time margin to support another generator to be installed should the initial actions to setup and install the initial generator were to fail. The FLEX equipment accounts for sufficient equipment for all units on site plus a spare set, so if the equipment is damaged during transport or setup, another set of equipment would be available.