Streamlined Approach for Crediting Portable Equipment in Risk-Informed Decision Making

As part of the FLEX in Risk-Informed Decision Making (FRIDM) Task Force established by NEI, the objective of this white paper is to develop a streamlined quantitative approach for crediting mitigating strategies involving portable equipment (such as FLEX) in risk-informed decision making activities via use of a decision tree for post quantification techniques to better reflect the actual plant condition or configuration. This is one of several activities that the FRIDM Task Force is developing to establish an effective path forward for crediting the benefits of portable equipment and strategies in risk-informed regulations, applications, and plant probabilistic risk assessment (PRA) models without imposing any undue regulatory burden.

Purpose

The purpose of this white paper is to establish a streamlined approach for crediting portable equipment in regulatory activities where meeting the RG-1.200 PRA requirements is not a prerequisite for the application (e.g., in Significance Determination Process (SDP) assessments, Notices of Enforcement Discretion (NOEDs), etc.). Currently there is no accepted consensus guidance for getting such credit in these non RG-1.200 applications.

As specified in NEI 12-06 [NEI 2015], FLEX capabilities will help reduce the risk from some contributors in plant-specific PRAs (e.g., station blackout and loss of normal access to the ultimate heat sink scenarios). As such, the degree of potential benefit is highly plant-specific and is dependent on the implementation details. However, the FLEX validation studies that have been performed at most sites demonstrated that the actions and responses are highly feasible and warrant consideration to reduce the site risk profile when the actions are directed. Therefore, the approach described here is intended to provide a means to establish where credit is feasible and obtain an initial estimate of the calculated core damage frequency (CDF) / large early release frequency (LERF) reduction that may occur in certain applications of PRA models. Similar evaluations (outside of the scope of the FLEX validation study) could be done to establish high feasibility for utilizing other mitigating strategies such as B.5.b pumps for 50.54(hh)(2) and other portable equipment used at stations, or if it is desired to credit FLEX equipment beyond the purpose of the validation study.

The semi-quantitative treatment described here is intended to provide an initial framework for near-term decision making and is also intended to provide an initial foundation for the longer term solution of developing consensus guidance for direct implementation in PRA models.

Initial Assessment

The approach taken is to focus the credit for mitigating strategies using portable equipment on the key contributors to a decision. That is, the risk reduction would be applied after initial quantification of the existing PRA models is performed. There are five initial steps associated with this approach:

1) Review the initial PRA model results to determine if the mitigating strategies using portable equipment capabilities could reduce the calculated CDF/LERF values for the specific application of the PRA model.
2) Identify the applicable contributors (cutsets or sequences) impacted by the mitigating strategy capabilities.
3) Determine if a reduction in risk in the applicable scenarios will impact the regulatory decision.
4) If it could impact the decision, perform a feasibility assessment to evaluate the potential to credit the portable equipment and associated strategies for the key contributors.

5) If the feasibility assessment indicates that crediting the mitigating strategies is viable and that doing so may impact the regulatory decision, document the basis for the credit and influence on the decision.

This approach is outlined in Figure 1.

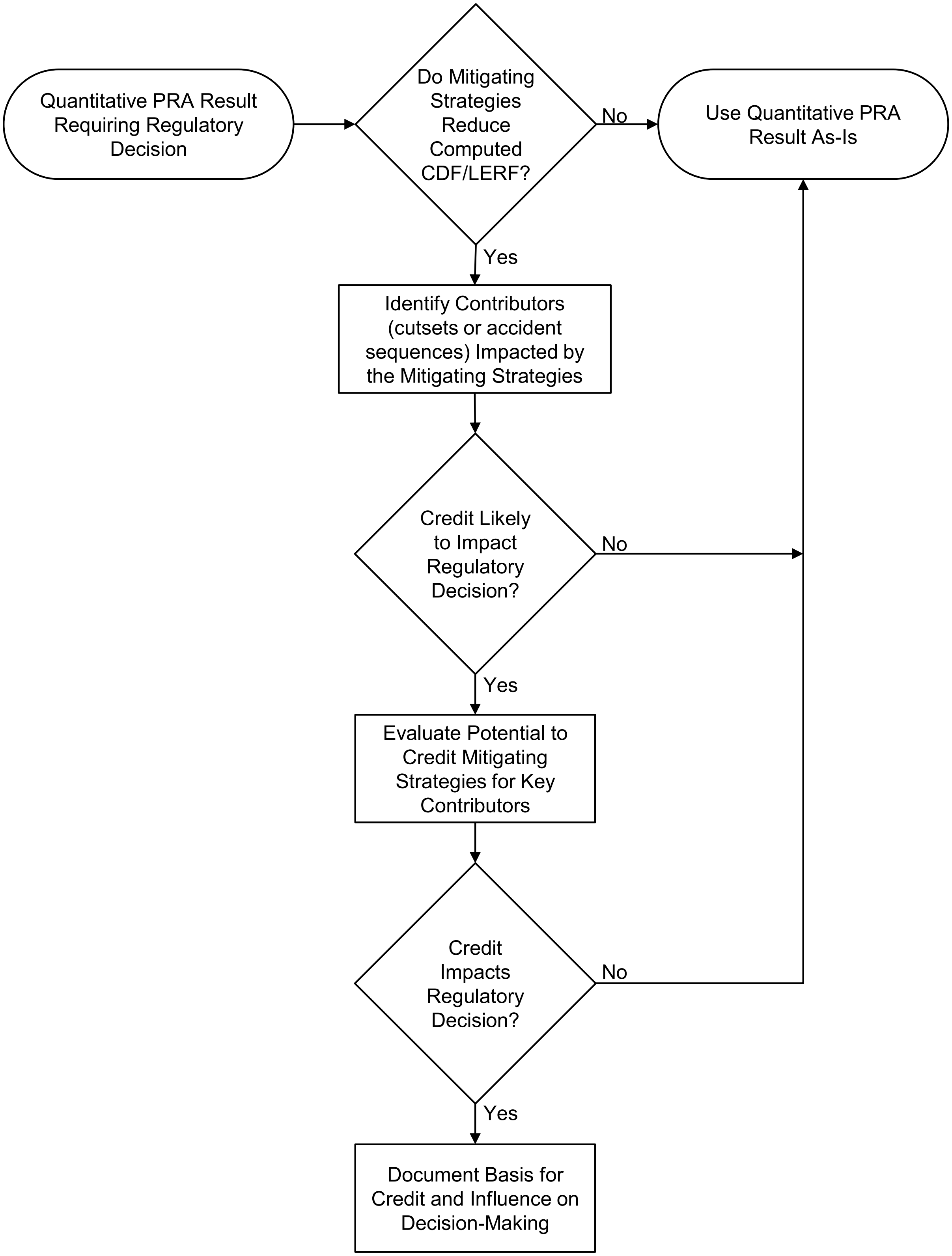

Figure 1 –Assessment of Credit for Mitigating Strategies in Decision Making

Semi-Quantitative Approach

In the process outlined in Figure 1, the focus is on the key contributors to the decision. This will allow for a more realistic assessment while circumventing the need to have everything included in the model prior to the evaluation. Once the key contributors are identified, the analysts can look at the FLEX validation studies, for example, and related procedural direction to determine what scenarios would benefit from credit for the mitigating strategies. This requires ensuring that any installed equipment required in the initial portion of the scenario (e.g., FLEX Phase 1) 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 initial required equipment available, but could benefit from implementation of deploying portable equipment (e.g., FLEX Phase 2 equipment) 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 below. 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 loss of offsite power may be treated differently than a weather-related loss of offsite power based on timing and environmental factors. These cutsets or accident sequences represent the scenarios that are used in the process.

Therefore, the focus on the evaluation would be on the portions of the mitigating strategy which implement portable equipment. For example, the key action for success from the review of the cutsets and/or sequences could be determined to be something like:

- Deploy and install two FLEX backup generators for prolonged DC availability, and
- deploy and install one FLEX pump to provide Reactor Pressure Vessel (RPV) or suppression pool makeup.

or

- Deploy and install one B.5.b DC portable generator for steam generator level indication.

or

- Deploy a portable generator for powering a positive displacement pump for makeup and seal injection.

That set of actions required for successful mitigation 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 a simple decision tree to determine the numerical benefit that could be obtained.

The decision tree accounts for the following factors which are then discussed in turn.

1) Time Margin
    a. Time available versus time required
2) Command and Control
    a. Procedures, cues and indications
    b. Staffing
    c. Communications and other equipment
3) Environmental Factors
4) Equipment Availability (N, N+1)

The process assumes a base failure probability of 0.1 for deployment and execution of the mitigating strategy and a base availability/reliability rate of 0.1 per available train. Each of these base values can be modified, as applicable, based on the process outlined in this paper.

An initial failure probability of 0.1 is used for nominal deployment of the applicable mitigating strategy. Then, based on a detailed assessment for the issues identified above, 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 impact on the total failure probability from equipment availability is accounted for separately in the evaluation as described later. The total assigned value(s) would then be applied to the applicable scenarios to see if it could impact the decision or not.

Base Failure Probability Value

The base failure probability value is used as the starting point in the decision tree. It is considered to represent the failure probability of a deployment activity that:

- Is governed by procedures that provide all of the information required to effectively perform the task. For example,
    - The applicable action is following the FSG procedural guidance directly as intended.
    - There are step-by-step instructions for the installation task, such as making the temporary power and piping connections, aligning valves, and starting and loading the generators and/or pumps.
    - The level of detail associated with procedures for acquiring and transporting equipment is expected to be lower, but the procedure should identify what equipment or vehicles are available and capable of supporting the task.
- Includes adequate training for the responsible plant personnel. Determining the adequacy of training is somewhat subjective, but adequate training could be described as:
    - Having received classroom training on deployment as a prerequisite for being part of the deployment team, including walkdowns of the locations where deployment is to be performed to familiarize the crew with the physical nature of the tasks, and
    - Re-performing the training on a periodic basis.
- Has been demonstrated to be feasible under nominal conditions. For the internal events analysis, the environmental conditions in which the deployment will occur are likely similar to those conditions in which the validation exercise was performed. It is possible that other environmental conditions may exist that were not present in the validation exercise, such as:
    - Extreme cold weather
    - Extreme hot weather
    - Heavy rain
    - Heavy snow
    - High winds
    - Other adverse conditions

However, the base deployment value is assumed to account for these factors in that it represents a nominal value over these conditions for internal events. These are underlying random conditions that are not modeled in the PRA. These variations, such as changes in temperature from day to day could have an influence on performance. However, since they are random with respect to when the demand could occur, their probability of occurrence coincident with the implementation of the mitigating strategy is low, and are not modeled explicitly. The nominal value is characterized as being an appropriate initial value for use over the spectrum of 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 1 which includes excerpts from NUREG/CR-6771 (NRC 2002).

Table 1 – Conditional 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 2 (IPCC 2010).

Table 2 – IPCC 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.

Time Margin

The first branch in the decision tree is based on determining if there is sufficient time to diagnose and perform the mitigating strategy. In order to establish feasibility, it must be demonstrated that the time required to 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.

- Inadequate = Time Margin Negative (Fail action)
- 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 NUREG/CR-6771 recommended conditional probability for something that is judged very likely to succeed, and is also consistent the mean value from the IPCC likelihood scale for something that is deemed very likely to succeed.)

The time margin definition is borrowed from NUREG-1921 (NRC 2012) and modified to focus on the deployment assessment such that the diagnosis time for cognitive recognition is included in the delay time:

Time Margin (expressed as a percentage) =

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

Where,

- T_{SW} = the system window, or the time window within which the action must be performed to achieve the function provided by the mitigating strategy. This time is measured from the time the hazard impacts the plant to the time at which the portable equipment must be installed and performing its function.

- T_{Delay} = time delay, or the duration of time it takes to diagnose the situation and begin initiating portable equipment deployment for the analyzed unit, measured from the time the hazard impacts the plant. 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.

- T_{Debris} = debris removal time (if applicable). In some scenarios, the additional time for debris removal introduced by the hazard initiating event under consideration would need to be factored into the time margin assessment. For example, the hazard initiating event (e.g., seismic or high winds event) is sufficient to introduce impediments that would require additional time to address. Sites may store heavy equipment, such as bulldozers to provide the capability to move larger debris. In the event that this equipment is stored such that its use would be feasible by a qualified member of the deployment team, the portable equipment may be credited for higher severity events that may result in the deposition of obstructions in the areas where deployment activities are required.

- T_{Trans} = the time required to transport the portable equipment from the storage area to the area where it is deployed and unload any equipment that is required.

- $T_{Install}$ = the time to make any necessary temporary piping and power connections when directed.

- 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 after transport and installation is complete. [Note that the failure probability of this portion of the mitigating strategy implementation action is inherently included in the nominal failure value and is not assessed by this node, but the timing assessment for the deployment portion of the action is required to account for the execution time in the time margin assessment.]

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 required equipment to employ the mitigating strategy is available. This node is simply a go / no-go 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.

The first requirement is that the mitigating strategy involving portable equipment deployment would be 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 requirements on the plant and may require the performance of different activities by the available staff. For each scenario in which portable equipment deployment is desired to be credited, sufficient staffing needs to be determined to be available. The staffing study performed as part of FLEX implementation assessments can be referenced in cases where the FLEX strategies are desired to be credited as intended. For applicable scenarios not using FLEX as intended, it must be confirmed that the deployment team personnel that are qualified to perform required duties will not be diverted to other tasks such that they would not be available to support deployment of the portable equipment. Any special fitness requirements for performing deployment tasks, such as operating chainsaws (to facilitate clearing debris for example), should be considered as part of the staffing assessment.

If deployment 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 for deployment that is not stored with the portable equipment, it must 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 portable equipment, it must be demonstrated that the location of the additional equipment is known, that it can be accessed, and the deployment time must account for obtaining and using the equipment.

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 conditions exist, (2) it is deemed that adverse conditions exist that will challenge but 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. 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 in which the portable equipment is desired to be credited, it must be established that the equipment will not be damaged to the extent 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 portable equipment, for example:
  - Building collapse that damages the portable equipment, or
  - Building collapse that prevents access to the portable equipment.
- Failures of structure(s) along the access path between the portable equipment storage location and the point where it 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 resources to remove.
- Failures of the structure(s) where the portable equipment is installed (if applicable).
- Fire in an area where the portable equipment deployment activity is required.
  - No credit should be taken for deployment in fire scenarios where part of the activity must be performed in the same (or very nearby) location as 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, for some very extreme events, 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 exceed 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 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 portable 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.

Equipment Availability

The last node of the decision tree is used to assign the likelihood of failure of the portable 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.

In this node, in most cases, a full complement of equipment is most likely available. For example, per the NEI 12-06 criteria, the site should have sufficient equipment to address all functions at all units on-site, plus one additional spare, i.e., an N+1 capability, where "N" is typically the number of units on-site. Thus, a two-unit site would nominally have at least three portable pumps, 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 it meets the functional and storage requirements outlined in NEI 12-06. The N+1 capability applies to the portable FLEX equipment that directly supports maintenance of the key safety functions. Other FLEX support equipment only requires an N capability.

Given this requirement and 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 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 the portable equipment for 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 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 trains of equipment is questionable or it is known that one train of the portable 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 deployment. Additionally, if the time margin is nominal, conservatively, 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.

Decision Tree Summary

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

The nominal failure value for crediting the mitigating strategy in applicable scenarios starts at 0.1. 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.

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 Branch Descriptions

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

The Command and Control node of the decision tree is then used as a go / no-go 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.

Command and Control Branch Descriptions

- Impaired = Command and Control Impaired (Fail action)
- Functional = Command and Control Functional (Retain nominal value)

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 it is desired to be credited. There are three possible outcomes: (1) it is deemed that nominal conditions exist, (2) it is deemed that adverse 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. In the first case, no adjustment is made in the decision tree to the calculated value. In the

[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.

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.

Environmental Factor Branch Descriptions

- Nominal = Environmental Factors Nominal (Retain nominal value)
- Adverse = Environmental Factors Adverse (Increase nominal value by factor of 2)

Finally, 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 both 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 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 Action)

In summary, when feasibility has been demonstrated, the final calculated value (F, the multiplier applied to 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.

Accounting for Impact on Base Case Results

When the final F multiplier is applied to the applicable scenarios, it should be noted that one also needs to account for the change in base case results to these same scenarios before calculating the actual change in risk for the specific assessment in question. 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 A and the note to Table A-3.)

Application of Process

An example application of this process is included in Appendix A. Note that it might be about a day or so worth of effort to go through the full process. Therefore, it is probably worthwhile to examine the base model results in advance to determine what sequences or cutsets would be candidates that could 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. Additionally, this effort is envisioned to provide the framework for establishing what sequences would be candidates for more detailed PRA modeling of the mitigating strategies and what human error probability events would need to be developed and incorporated into the model should more detailed analysis or results refinements be desired.

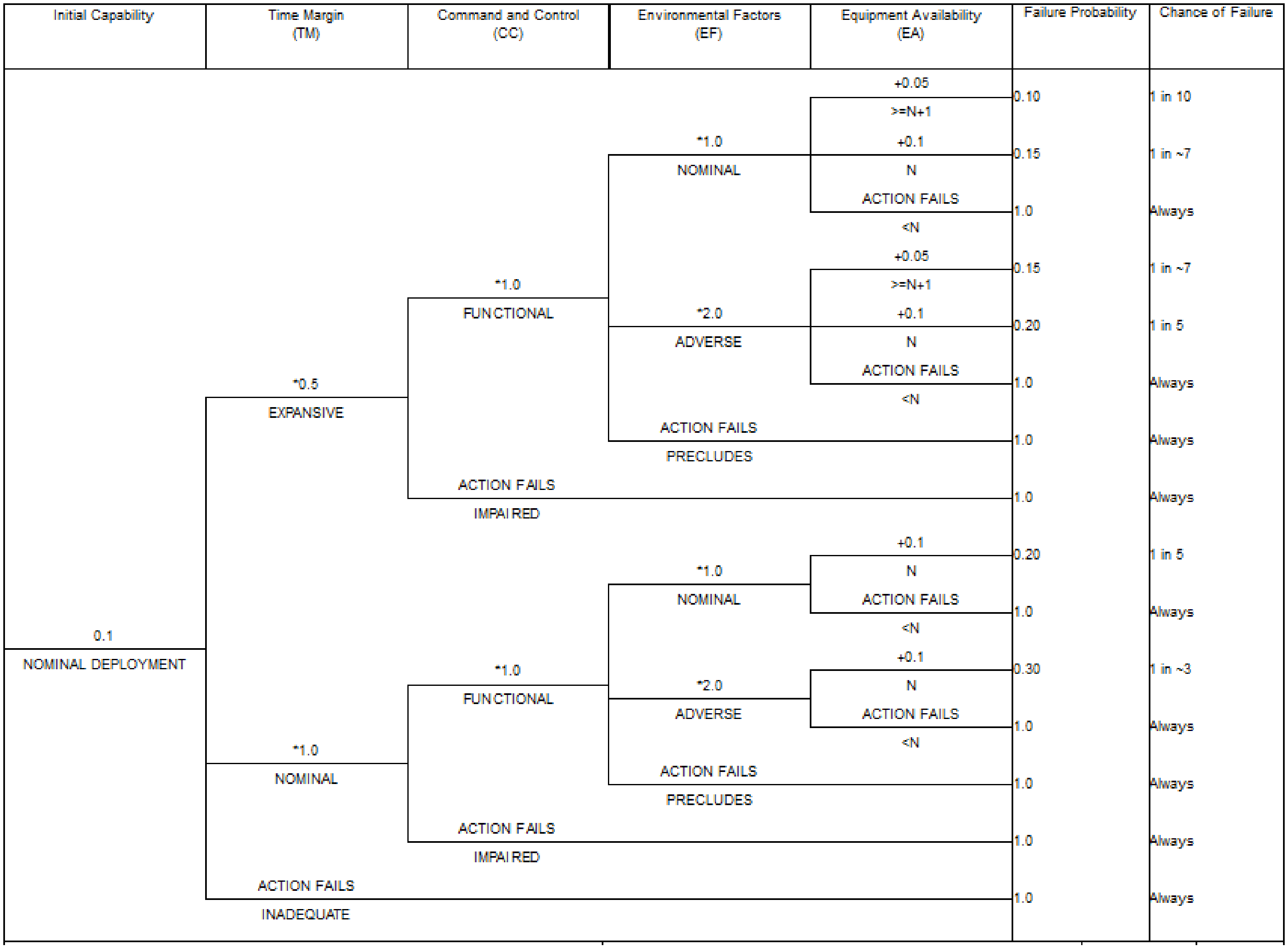

Figure 2 –Streamlined Decision Tree for Crediting Portable Equipment in Decision Making

Miscellaneous Issues

As part of the NRC review of the draft version of 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.

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 (NRC 2013), *Glossary of Risk-Related Terms in Support of Risk-Informed Decisionmaking* 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 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 BWR or feed and bleed with recirculation in a 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.

Potential Risk Increases from Implementing FLEX Mitigating Strategies

It was noted that there may be scenarios where operators implement FLEX mitigating strategies, for a loss of offsite power (LOOP) and/or loss of heat sink (LOHS) event where they increase risk to the public by performing deep load shedding of 125V DC buses, which might preclude recovery of off-site or on-site power because of a lack of instrumentation and/or control.

This potential risk increase issue is acknowledged. For example, restoration of off-site power or on-site power may take longer than if a deep dc load shed is not performed and it also may introduce additional operator or random failures (e.g., for breakers failing to reclose) that did not need to be reclosed before. 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 with a deep load shed, non-recovery probabilities utilized in model may shift. This could be envisioned in this hypothetical example as shown in Figure 3 where a weighted average LOOP non-recovery probability from NUREG/CR-6890 (NRC 2013a) is shown for the "No ELAP" case. In the "ELAP" case, the non-recovery probability is shifted by one hour but then also includes a 0.1 failure probability credit for installation of portable generators by 8 hours.

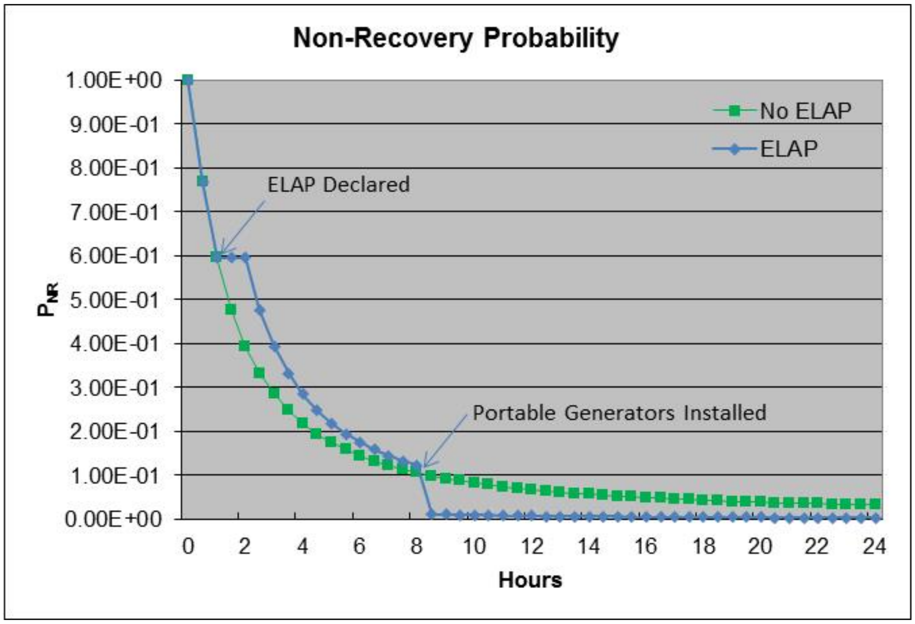

Figure 3 – Non-Recovery Probabilities With and Without Implementation of FLEX Mitigating Strategies

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 indeed 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 sequences. This is illustrated in Figure 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 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 5 shows the unaccounted for increases and decreases and also shows the credited risk decrease using the streamlined approach and the actual risk decrease.

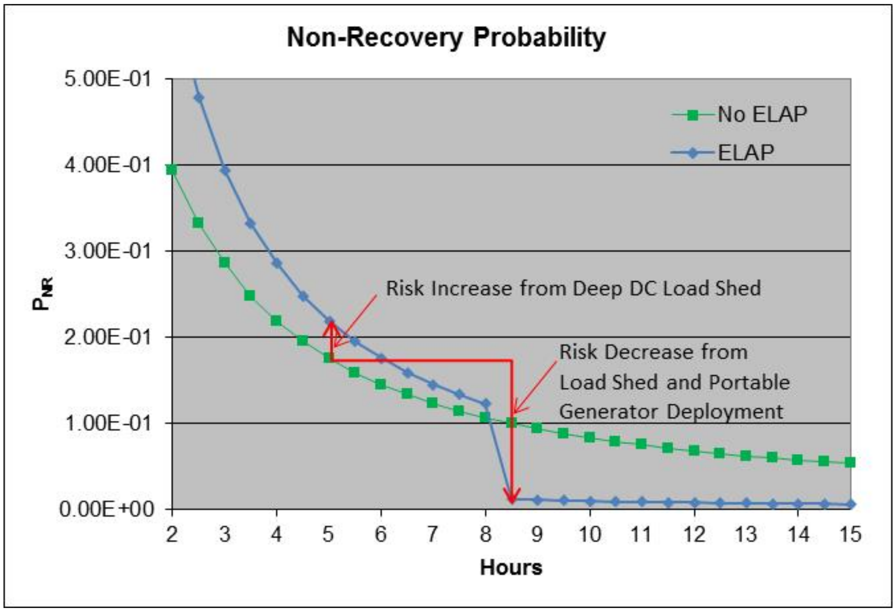

Figure 4 – Risk Increases and Decreases from Implementation of FLEX Mitigating Strategies

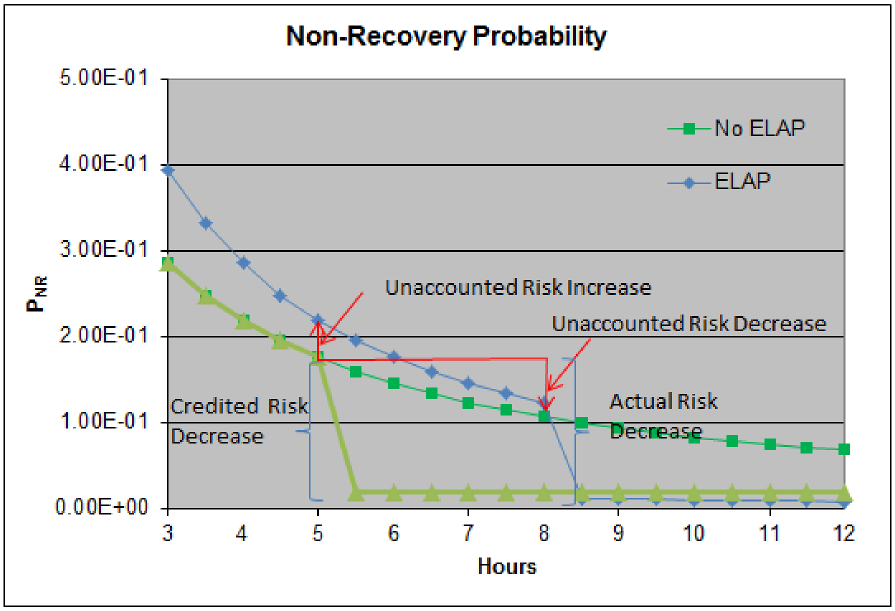

Figure 5 – Credited versus Actual Risk Decreases from Implementation of FLEX Mitigating Strategies

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.

Acknowledgment

Note that some of the discussion provided here was adapted from a paper presented at PSAM 12 for crediting Emergency Mitigation Equipment Deployment in CANDU plants (PSAM 2014).

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Appendix A
Application of the Process Using FLEX as an Example

Overview

A Significance Determination Process (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 emergency diesel generator (EDG) common cause basic event values consistent with guidance in the NRC RASP handbook. The internal events PRA model results were similar to that obtained with the site 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.

Initial Results

The CDF and LERF results from the analysis are shown in Table A-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 A-1 – Initial PRA Model Results (No 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)

FLEX Credit 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 A-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 majority of the risk increase evolves from these scenarios for this plant, 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 that case.

FLEX Mitigation Feasibility Assessment

In the 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 FLEX 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 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 Phase 2 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 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.

Time Margin

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 residual heat removal (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 that aligning the valves and starting the pump can occur in about 5 minutes. For the generators, once everything is installed, energizing the 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 (where all the times are in hours) is determined as:

$$\text{Time Margin} = 100\% * [(6 - 1 - 0) - (0.75 + 1.35 + 0.12)] / (0.75 + 1.35 + 0.12)$$

$$\text{Time Margin} = 100\% * [5 - 2.22] / 2.22 = 126\%$$

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.

$$\text{Time Margin} = 100\% * [(6 - 2 - 0) - (0.75 + 1.35 + 0.12)] / (0.75 + 1.35 + 0.12)$$

$$\text{Time Margin} = 100\% * [4 - 2.22] / 2.22 = 80\%$$

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

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 go / no-go 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 mitigating would not be feasible or non-SBO scenarios where procedural direction for use of FLEX is not as specific. Table A-2 shows the results of this analysis. An additional adjustment is made to the Fire PRA results to exclude those scenarios where the motor control centers (MCCs) and/or battery chargers where the FLEX generators connect are damaged by the fire scenario.

Table A-2 – Delineation of PRA Model Results

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 for 91.8% of the calculated delta CDF, and fails for the remaining 8.2%

For the internal fire events results:

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

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 conditions exist, (2) it is deemed that adverse 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 FLEX 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:

$EF_{FIRE} = 1.0$

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:

$EA_{FIRE} = 0.1$

Decision Tree Results Summary

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

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

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:

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

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

Final Adjusted Results

The CDF results from the analysis with credit for implementation of FLEX mitigating strategies when warranted are shown in Table A-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 A-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		6.87E-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.