# Streamlined Approach for Crediting FLEX 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 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 considering the benefits of FLEX equipment and strategies in risk-informed regulations, applications, and plant PRA models without imposing any undue regulatory burden.

## Purpose

The purpose of this white paper is to establish a streamlined approach for crediting FLEX in regulatory activities (e.g., SDPs, NOEDs, Recommendation 2.1 SPRAs, etc.). Currently there is no accepted consensus guidance for getting such credit. Activities are underway to establish acceptable guidance by the industry and NRC, but this guidance is not immediately available, and the timeline for development and acceptance is uncertain. In the meantime, nearly 2/3 of the industry will have completed FLEX implementation by the end of 2015 with the remainder to be completed by the end of 2016.

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 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 indicate 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 obtain an initial estimate of the calculated CDF/LERF reduction that may occur in certain applications of PRA models.

The semi-quantitative treatment described here is intended to provide an initial framework for near-term decision making and is intended to provide a 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 FLEX 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 FLEX 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 FLEX 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 FLEX strategies for the key contributors.
5) If the feasibility assessment indicates that crediting FLEX is viable and that doing so may impact the regulatory decision, document the basis for the credit and influence on decision.

This approach is outlined in Figure 1.

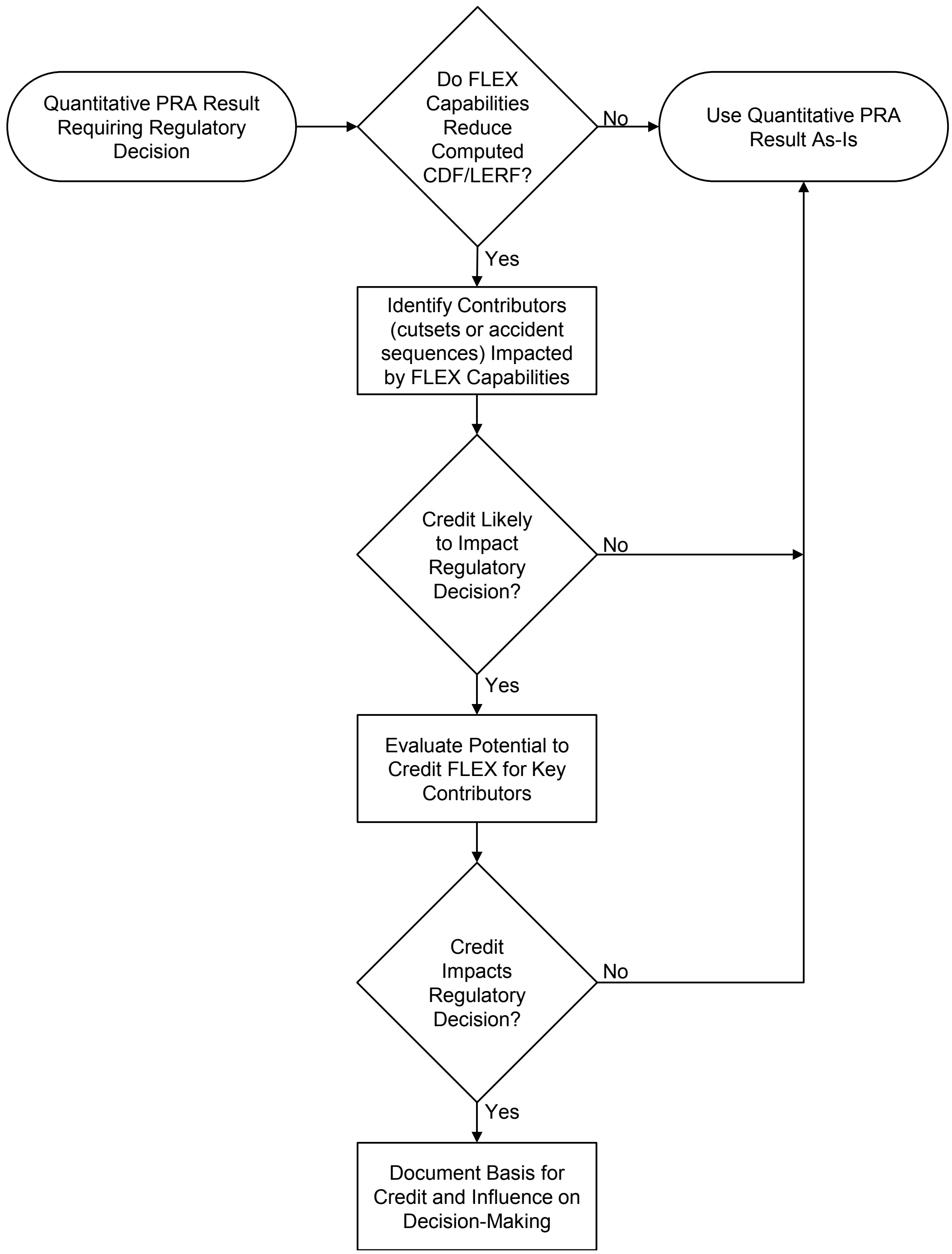


**Figure 1 –Assessment of Credit for FLEX in Decision Making**

## 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 in the model prior to the evaluation. Once the key contributors are identified, the analysts can look at the FLEX validation studies and related procedural direction to determine what scenarios would benefit from credit for the FLEX mitigation strategies. This requires ensuring that any installed equipment required in Phase 1 has not failed in the scenarios of interest. Scenarios where credit for the FLEX mitigation strategies is feasible can be determined by reviewing cutsets and/or accident sequences and identifying those that would have the Phase 1 equipment available, but could benefit from implementation of deploying Phase 2 FLEX equipment to avoid core damage. Ancillary actions required for implementation of the Phase 2 equipment must 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 switchyard-centered loss of offsite power may be treated differently than a severe 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 Phase 2 portions of the FLEX mitigation strategy. 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 backup generators for prolonged DC availability, and
- Deploy and install one FLEX pump to provide RPV or suppression pool makeup.

That set of actions 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 human error probability (HEP) of 0.1 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 screening value of 0.1 is used for nominal deployment of the applicable FLEX mitigation strategy. Then, based on a detailed assessment for the issues identified above, the actual failure probability used in the assessment can range from ~0.05 (highly 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.

Note that much 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).

## *Base HEP Value*

The base HEP 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,
  - It is assumed that 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 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 an average 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, 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 FLEX is low, and are not modeled explicitly. The nominal value is characterized as being the average value over the spectrum of these conditions.

A failure probability of 1.0E-01 is assigned for this base value, which is consistent with a screening HEP value from NUREG-1792 (NRC 2005).

## *Time Margin*

The first branch in the decision tree is based on determining if there is sufficient time to perform the mitigation 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 time margin definition is borrowed from NUREG-1921 (NRC 2012) and modified to address the deployment assessment:

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 FLEX mitigation strategy. This time is measured from the time the hazard impacts the plant to the time at which the FLEX equipment must be installed and performing its function.
- $T_{Delay}$ = time delay, or the duration of time it takes to begin initiating FLEX deployment for the analyzed unit, measured from the time the hazard impacts the plant. This includes the time required for operators to meet the criteria to implement the FLEX strategy, as applicable.
- $T_{Debris}$ = 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 adequate to introduce impediments that would require additional time to address. Sites may store heavy equipment, such as bulldozers, with the FLEX equipment to provide the capability

to move larger debris. In the event that this equipment is stored with the FLEX equipment or is otherwise stored such that its use would be feasible by a qualified member of the deployment team, the FLEX 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 FLEX 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 FLEX implementation action is inherently included in the base HEP 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 FLEX mitigation 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 FLEX mitigation strategy or equipment deployment would be procedurally directed in the scenarios of interest and that sufficient cues and indications are available for the direction of the actions. As is the practice for incorporation into PRA models, manual actions must be procedurally directed, trained upon, and able to be successfully performed in order to receive realistic credit for the risk-informed decision. The associated procedures should be adequate to support confidence in successful completion of the manual action, but not necessarily incorporated into the plant's formal 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 FLEX deployment is desired to be credited, 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 FLEX deployment. 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 FLEX 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 FLEX deployment that is not stored with the FLEX 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 FLEX 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 FLEX 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 FLEX is desired to be credited, it must be established that the FLEX 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 FLEX equipment, for example:
    - Building collapse that damages the FLEX equipment, or
    - Building collapse that prevents access to the FLEX equipment.
- Failures of structure(s) along the access path between the FLEX 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 sources to remove.
- Failures of the structure(s) where the FLEX equipment is installed (if applicable).
- Fire in an area where FLEX deployment activity is required.
    - No credit should be taken for FLEX 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 FLEX deployment activity is required.
    - No credit should be taken for FLEX 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 FLEX deployment in conditions that exceed any safety limits established for personnel protection by the plant. For example, no credit should be taken for a FLEX deployment activity for high wind events 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.

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 FLEX 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).
- A small quantity of water in a flooded area that would not significantly impact the deployment activity after a sufficient amount of time passes.

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 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.

In this node, in most cases, a full complement of equipment is most likely available. Per the NEI 12-06 (NEI 2012) 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 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, three sets of hoses & cables, 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 this guide. 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, equipment reliability should not be a serious concern. 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 FLEX equipment for potentially longer time periods, it is deemed appropriate, however, to utilize a conservative value of 1E-2 in this node assuming that the N+1 requirement is maintained. If the reliability of one of the trains of equipment is questionable or it is known that one train of the FLEX equipment would not be available for the subject analysis (NOED, SDP, etc.), then a conservative value of 1E-1 would be applied for the single train of equipment that is available to support the FLEX mitigation strategy deployment. Additionally, if the time margin is nominal, conservatively, no credit is taken for the additional train.

## Decision Tree Summary

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

The nominal failure value for crediting FLEX mitigation strategy in applicable scenarios starts at 0.1. This is a well-established screening value for feasible actions under nominal conditions. This is the entry condition for the decision tree.

Depending on the available time margin for deploying and implementing the FLEX 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 FLEX mitigation 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 FLEX 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.

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 0.01 or 0.1 additional term to the overall credit for deploying the FLEX mitigation strategy depending on whether N or N+1 (or more) FLEX 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 0.01 (0.1 * 0.1) 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 FLEX equipment, determine there is a hardware failure, and replace the affected equipment with a spare.

<u>Equipment Availability Branch Descriptions</u>
- N = 1 Train of FLEX Equipment Available (Add 0.1)
- >=N+1 = More than 1 Train of FLEX Equipment Available (Add 0.01)

In summary, when feasibility has been demonstrated, the final calculated value is derived from the following expression.

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

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 0.01 or 0.1 depending on whether N+1 or more of equipment is available and sufficient time exists to deploy the spare equipment.

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 FLEX mitigation 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 FLEX mitigation 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.

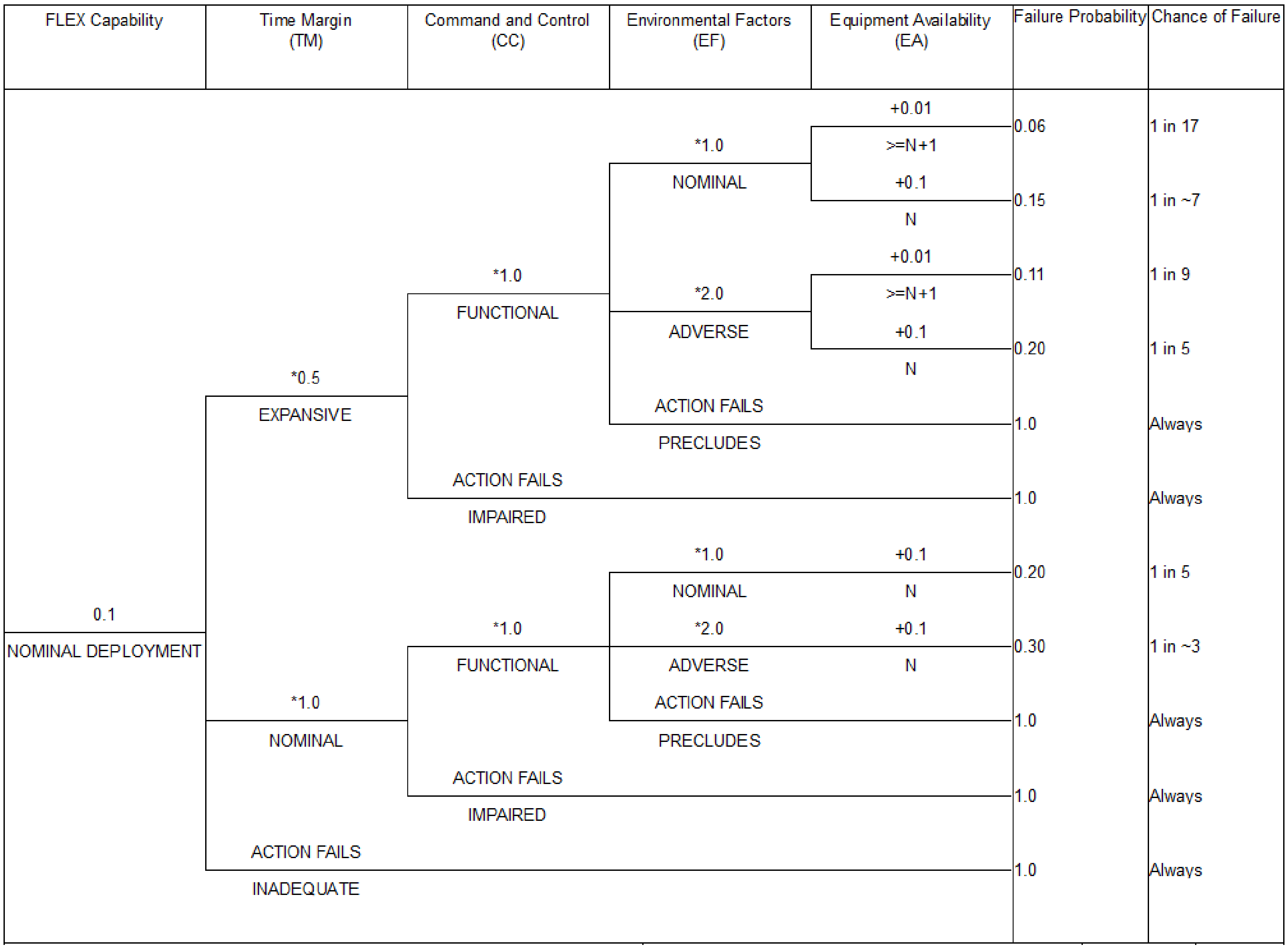


**Figure 2 –Streamlined Decision Tree for FLEX in Decision Making**

## References

NRC 2005 — NRC (U.S. Nuclear Regulatory Commission). 2005. *Good Practices for Implementing Human Reliability Analysis*. NUREG-1792. A. Kolaczkowski et. al. April.

NEI 2015 — NEI (Nuclear Energy Institute. 2015. *Diverse and Flexible Coping Strategies (FLEX) Implementation Guide*. NEI 12-06, Revision 1A. October (ADAMS Accession No. ML15279A426).

NRC 2012 — NRC (U.S. Nuclear Regulatory Commission). 2012. *EPRI/NRC Fire Human Reliability Analysis Guidelines*. NUREG-1921. S. Lewis. July.

PSAM 2014 — Probabilistic Safety Assessment and Management PSAM 12. 2014. *Simplified Human Reliability Analysis Process for Emergency Mitigation Equipment (EME) Deployment.* Honolulu, HI Conference Proceedings. D.E. MacLeod et. al. June.

# Appendix A
# Example Application of the Process

## 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 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 with no credit for implementation of FLEX mitigation strategies 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.

**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 mitigation 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, 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, 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.

## FLEX Mitigation Feasibility Assessment

In this 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 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.

### *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 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 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:

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

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

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 mitigation 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 mitigation strategies.

To obtain command and control credit in the decision tree, the FLEX mitigation strategy or equipment deployment must be shown to be procedurally directed and that sufficient cues and indications are available for the 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 mitigation 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 A-2 shows the results of this analysis. An additional adjustment is made to the Fire PRA results to exclude those scenarios where the 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:

$$EA_{FPIE} = 0.01$$

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.

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

Therefore, for the internal events results:

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

$F_{FPIE} = 0.1 * 0.5 * 1.0 * 1.0 + 0.01 = 0.06$

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 mitigation 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 * 0.06 = 3.14E-07 / yr | 1.91E-05 / yr * 0.20 = 3.81E-06 / yr | 4.13E-06 / yr |
| Total Adjusted ΔCDF | 7.79E-07 / yr | 7.25E-06 / yr | 8.03E-06 / yr |
| Exposure Time (T) | 1 month / 12 months / yr | | 0.0833 yr |
| SDP CDF | (ΔCDF * T) < 1.0E-06 for Green | | 6.69E-07 (Green) |

(1) Note that in this example, the credit for the FLEX mitigation 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.