Incorporating Flexible Mitigation Strategies into PRA Models

Phase 1: Gap Analysis and Early Lessons Learned

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EPRI Project Manager

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ABSTRACT

In response to the accident at Fukushima Daiichi, nuclear power plants (NPPs) across the world have implemented various types of diverse and flexible mitigation strategies—including use of portable, commercially available equipment—to increase their ability to cope with beyond-design-basis scenarios. For example, in the U.S., FLEX strategies are being implemented across the fleet. While often there is no requirement for plants to incorporate these strategies in their Probabilistic Risk Assessments (PRAs), many plants see an advantage to doing so. Modeling the extra protective measures in their PRAs improves the fidelity of the model and can allow these plants to credit the additional safety margin, for instance, in risk informed applications. This report intends to lay the groundwork to ultimately provide the necessary guidance to incorporate FLEX and similar strategies into a plant PRA model.

The short hand “FLEX” is used in this document to describe a set of diverse and flexible mitigation strategies involving portable equipment that may be available on-site and/or from an off-site facility. This terminology is NOT used to imply that this report is only applicable to U.S. FLEX strategies, but takes a broader look at incorporation of FLEX and FLEX-like strategies internationally.

Ultimately, this project will be conducted in two phases. The objectives of this first phase of research documented in this report are to scope out the unique issues associated with modeling flexible mitigation strategies in PRA, to perform a state-of-knowledge review on current PRA technologies with respect to implementing FLEX equipment and strategies into PRA models, and to provide lessons learned from early implementers. The second phase, to be performed later, will attempt to address the identified gaps through directed research efforts.

A survey was conducted and several example FLEX strategies and operating procedures were examined in detail to identify the unique issues associated with modeling the FLEX equipment in PRA models. The format of the state-of-knowledge review refers to the applicable PRA elements from the ASME/ANS PRA Standard (that is, accident sequence analysis, success criteria, systems analysis, human reliability analysis, data analysis, quantification, and LERF analysis). Each of these PRA elements are discussed and investigated, and based on that analysis special focus is applied to the HRA and Data elements since they are identified as an area requiring additional research for implementing FLEX strategies in PRA models. A detailed gap assessment of existing methods is then presented for implementing FLEX strategies with respect to the HRA and Data technical elements.

Keywords

ASME/ANS PRA standard
Flexible mitigation strategies (FLEX)
Human reliability analysis (HRA)
Portable equipment
Probabilistic risk assessment (PRA)

LIST OF ACRONYMS

Acronym	Definition
AC	Alternating Current
ADAMS	Agencywide Documents Access and Management System
ADS	Automatic Depressurization System
ADV	Atmospheric Dump Valve
AFW	Auxiliary Feedwater
ANS	American Nuclear Society
ASEP	Accident Sequence Evaluation Program HRA Procedure
ASME	American Society of Mechanical Engineers
ATHEANA	A Technique for Human Event Analysis
ATWS	Anticipated Transient Without Scram
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owner’s Group
CAFTA	Computer Aided Fault Tree Analysis
CBDT	Cause Based Decision Tree
CBDTM	Cause Based Decision Tree Method
CCF	Common Cause Failure
CDF	Core Damage Frequency
CFM	Crew Failure Mode
DC	Direct Current
DG	Diesel Generator
DT	Decision Tree
EDG	Emergency Diesel Generator
EFW	Emergency Feedwater
ELAP	Extended Loss of AC Power
EME	Emergency Mitigation Equipment
EOC	Error of Commission

Acronym	**Definition**
EOF	Emergency Offsite Facility
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
FLIM	Failure Likelihood Index Methodology
FPIE	Full Power Internal Events
FSG	FLEX Support Guideline
FW	Feedwater
HCR	Human Cognitive Reliability
HEP	Human Error Probability
HFE	Human Failure Event
HRA	Human Reliability Analysis
HRAC	HRA Calculator
HVAC	Heating, Ventilation and Air Conditioning
IDHEAS	Integrated Decision-Tree Human Event Analysis System method
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Labs
IP	Inspection Procedure
JHEP	Joint Human Error Probability
LERF	Large Early Release Frequency
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LPCI	Low Pressure Coolant Injection System
LPCS	Low Pressure Core Spray
MAAP	Modular Accident Analysis Program
MCC	Motor Control Center
MCR	Main Control Room
MPR	Mechanical Pressure Regulator

Acronym	Definition
MR	Maintenance Rule
NEI	Nuclear Energy Institute
NPP	Nuclear Power Plant
NPRD	Non-electronic Parts Reliability Data
NRC	Nuclear Regulatory Commission
NUREG/CR	Nuclear Regulatory Commission Contractor Report
OIP	Overall Integrated Plan
OPG	Ontario Power Generation
ORE	Operator Reliability Experiments
OREDA	Offshore Reliability Data
PORV	Power Operated Relief Valves
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factor
PWR	Pressurized Water Reactor
PWROG	Pressurized Water Reactor Owner's Group
RCIC	Reactor Core Isolation Cooling
RCS	Reactor Coolant System
RHR	Residual Heat Removal
RHRSW	Residual Heat Removal Service Water
RMP	Risk Management Plan
RPM	Radiation Protection Manager
RPV	Reactor Pressure Vessel
RRC	Regional Response Center
RSP	Remote Shutdown Panel
RWST	Refueling Water Storage Tank
SBO	Station Blackout

Acronym	Definition
SFP	Spent Fuel Pool
SG	Steam Generator
SLIM/MAUD	Success Likelihood Index Methodology/Multi-Attribute Utility Decomposition
SPAR-H	Standard Plant Analysis Risk – Human Reliability Analysis
SPC	Suppression Pool Cooling
SRV	Safety Relief Valve
THERP	Technique for Human Error Rate Prediction
TSC	Technical Support Center
USNRC	United States Nuclear Regulatory Commission

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Purpose

The purpose of this document is to scope out the unique issues associated with modeling flexible mitigation strategies in Probabilistic Risk Assessments (PRA), to perform a state-of-knowledge review on current PRA technologies with respect to implementing FLEX equipment and strategies into PRA models, and to provide lessons learned from early implementers. Several example FLEX strategies and operating procedures are examined in detail to identify the unique issues associated with modeling the FLEX equipment in PRA models. The format of the state-of-knowledge review refers to the applicable PRA elements from the ASME/ANS PRA Standard (that is, accident sequence analysis, success criteria, systems analysis, human reliability analysis, data analysis, quantification, and LERF analysis). Each of these PRA elements is discussed and investigated, and based on that analysis special focus is applied to the HRA and Data elements since they are identified as areas requiring additional research for implementing FLEX strategies in PRA models. A detailed gap assessment of existing methods is then presented for implementing FLEX strategies with respect to the HRA and Data technical elements.

Note: The short hand “FLEX” is used in this document to describe a set of diverse and flexible mitigation strategies involving portable equipment that may be available on-site and/or from an off-site facility. This terminology is NOT used to imply that this report is only applicable to U.S. FLEX strategies, but takes a broader look at incorporation of FLEX and FLEX-like strategies internationally.

1.2 Background

In response to the accident at Fukushima Daiichi, nuclear power plants (NPPs) across the world have implemented various types of diverse and flexible mitigation strategies—including use of portable, commercially available equipment—to increase their ability to cope with beyond-design-basis scenarios. For example, in the U.S., FLEX strategies are being implemented across the fleet. While often there is no requirement for plants to incorporate these strategies into their Probabilistic Risk Assessments (PRAs), many plants see an advantage to doing so. Modeling the extra protective measures in their PRAs improves the fidelity of the model and can allow these plants to credit the additional safety margin, for instance, in risk informed applications. This report intends to lay the groundwork to ultimately provide the necessary guidance to incorporate FLEX and similar strategies into a plant PRA model.

The strategies for coping with these beyond-design basis scenarios are described in the NEI Diverse and Flexible Coping Strategies Implementation Guide [1] as three-phases:

1. Initially cope by relying on installed plant equipment.
2. Transition from installed plant equipment to on-site FLEX equipment.
3. Obtain additional capability and redundancy from off-site equipment until power, water and coolant injection systems are restored or commissioned.

This report focuses guidance on Phase 2, with some considerations for Phases 1 and 3.

1.3 Report Organization

Section 2 of this report provides an overview by relevant internal events PRA Standard technical elements of a state-of-knowledge review and unique considerations associated with incorporating flexible mitigation strategies into PRA models. This overview is provided to help identify those specific areas that require further analysis.

Of the many challenges associated with incorporating FLEX capabilities into a PRA, the performance of the HRA may be one of the more difficult tasks. Section 3 provides a detailed gap assessment of the current HRA methodologies that are commonly used in the U.S. nuclear industry with respect to developing human error probabilities for implementing the FLEX strategies.

Another challenge associated with incorporating FLEX capabilities into a PRA is that associated with data development. Section 4 provides a gap assessment of the current data approaches that are commonly used in the U.S. nuclear industry with respect to developing data values for implementing the FLEX strategies.

Section 5 provides conclusions and recommendations for future research activities.

Appendix A presents the results of a survey that was distributed to help with the development of this report.

For completeness, Appendix B presents excerpts from IDHEAS [19] referenced in the recommendations of this report.

2

CONSIDERATIONS FOR INCORPORATING FLEXIBLE MITIGATION STRATEGIES BY PRA ELEMENT

The process discussed in this chapter is organized by the relevant PRA technical elements from the internal events portion of the ASME/ANS PRA Standard [2] as listed below:

- Initiating Event Analysis (IE)
- Accident Sequence Analysis (AS)
- Success Criteria (SC)
- Systems Analysis (SY)
- Human Reliability Analysis (HR)
- Data Analysis (DA)
- Quantification (QU)
- LERF Analysis (LE)

Incorporation of FLEX into PRA is not expected to impact the Initiating Event Analysis technical element. However, consideration should be made to ensure that FLEX is only credited for those initiators where it has been shown to provide an alternate success path (for example, ATWS and some LOCAs would likely be excluded by definition); this may require subdividing initiating events. This aspect is addressed in the accident sequence analysis. For each remaining technical element (starting with accident sequence analysis), a discussion is provided indicating the objectives of that element of the PRA standard. Following that introduction, a table is provided where each high level requirement is summarized, and a state of knowledge review is performed indicating where existing methodologies have been and can be used appropriately or where methodology gaps have been identified. Additionally, special considerations associated with FLEX implementation in the PRA models with respect to that technical element are identified in the table. Following the table, discussions are provided describing examples of the methodologies that have been used, where areas exist which require development of new techniques or methods, and where special uncertainty considerations exist. For each PRA element, specific examples and lessons learned from early implementation of FLEX in PRA models are also provided.

Note that the special considerations associated with the human reliability analysis technical element are further discussed in Section 3 of this report, and that special considerations associated with the data analysis technical element are further discussed in Section 4 of this report.

2.1 Accident Sequence Analysis

The accident sequence analysis element of the ASME/ANS PRA Standard provides high level and supporting requirements to ensure that the accident sequence analysis describes the plant-specific scenarios that can lead to core damage for each modeled initiating event. The objectives of the requirements are to ensure that the scenarios address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage. Additional requirements also ensure that dependencies that can impact the ability of the mitigating systems to operate and function are addressed.

In general, the existing accident sequence analysis methods should be acceptable for incorporating FLEX into the PRA models. Table 2-1 provides the state-of-knowledge review for the accident sequence analysis technical element by the corresponding high level requirements.

Table 2-1
State-of-Knowledge Review for the Accident Sequence Analysis Element

<table>
<tr><td>Topic of High Level Requirement</td><td>HLR-AS-A: Develop plant-specific accident sequence analysis scenarios representing the key safety functions necessary to prevent core damage.</td></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing accident sequence analysis methods encompassed by the HLR-AS-A supporting requirements are generally appropriate for extending the accident sequence analysis to incorporate FLEX mitigation strategies. Consideration should be made to clearly delineate the key safety functions being addressed by the FLEX modifications (for example, FLEX pumps provide alternate means of RPV inventory control or decay heat removal). Additional consideration should also be made to clearly delineate what initiating events that the alternate FLEX strategies can successfully mitigate (for example, FLEX can provide an alternate means of RPV inventory control after six hours in transient [non-LOCA] scenarios).

With those two aspects complete, it should then be rather straightforward to determine what event tree nodes need to be modified to incorporate the FLEX strategies into the PRA model. In a few cases, however, the alternate strategies may require the development of new event tree nodes (for example, early RPV depressurization and containment venting to support extended RCIC operation). Additionally, special consideration should also be introduced in the accident sequence models to ensure that the FLEX strategies are only credited when applicable (for example, some procedure modifications may limit the potential benefit for the FLEX strategies to specific extended loss of AC power scenarios).</td></tr>
<tr><td>Topic of High Level Requirement</td><td>HLR-AS-B: Address dependencies impacting mitigating systems.</td></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing accident sequence analysis methods encompassed by the HLR-AS-B supporting requirements are generally appropriate for extending the accident sequence analysis to incorporate FLEX mitigation strategies. Consideration should be made to ensure that FLEX is only credited for those initiators where it has been shown to provide an alternate success path (for example, ATWS and some LOCAs would likely be excluded by definition). Additionally, the dependencies on the accident sequence progression need to be specifically addressed (for example, FLEX injection to the RPV requires that depressurization be successful first).

Other considerations include the need to develop the accident sequence models to a level of detail sufficient to capture intersystem dependencies. For example, FLEX portable generator tie-ins at the 480V AC level may still need specific MCCs and breakers to support providing power to the battery chargers. Correspondingly, the battery chargers and batteries may still have to be successful to support extended battery life needed to support instrumentation and/or SRVs required for RPV depressurization. This can usually be handled at the system fault tree logic level.</td></tr>
</table>

Table 2-1 (continued)
State-of-Knowledge Review for the Accident Sequence Analysis Element

Topic of High Level Requirement	**HLR-AS-B: Address dependencies impacting mitigating systems (continued).**
Finally, the time phased dependencies and potential multi-unit impacts need to be incorporated into the model. For example, use of just installed plant equipment and associated strategies may be in place for the first 4-12 hours of accident sequence modeling, and then the use of on-site portable equipment and associated strategies may not be able to be credited until after that time period. To account for multi-unit impacts, spare equipment may need to be only partially credited or assumed to be in use by the opposite unit(s). Additionally, credit for implementation of off-site portable equipment may not be viable in the typical 24-hour mission time used in internal events PRA models, but might be integral to other external hazard group evaluations that need to establish reaching a safe stable state over longer PRA mission times.	
Topic of High Level Requirement	**HLR-AS-C: Document the accident sequence analysis.**
The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.	

2.1.1 Insights for Accident Sequence Analysis Development

<u>Example Implementation Methods</u>

To implement credit for the FLEX mitigation strategies, one must determine the modeled safety functions from the existing accident sequence models that are applicable to each of the FLEX modifications and strategies. For example, a representative BWR Mark II plant will rely on extended RCIC operation and the following strategy as outlined in their conceptual design submittal to the NRC to meet the required safety functions:

1. Maintain RCIC injection to RPV with suction from the suppression pool.
2. Commence cooldown and complete depressurization of RPV to ~200 psig.
3. Initiate and complete SBO DC load shedding by 1.5 hours.
4. Establish natural ventilation to the RCIC room by 1.5 hours.
5. Complete additional DC load shed by 2 hours.
6. Initiate early containment venting.
7. Connect portable pumps to RHRSW by 6 hours.
8. Align portable generators to battery chargers by 6.5 hours.

This strategy has been developed to satisfy the core cooling, containment heat removal, and spent fuel pool makeup safety functions. Note that the function to maintain spent fuel pool cooling is not needed to prevent core damage as modeled in the full power internal events sequence modeling so that function is not discussed further here.

To support use of the installed equipment and transition to use of portable equipment, the representative site also included the following modifications as part of their FLEX strategy development:

- A hardened containment vent modification will be installed (note that this modification is in response to a separate NRC order applicable to Mark II plants, but is included for completeness).
- Two FLEX pumps will take suction from the spray pond and discharge into the RHRSW system.
- A new RHRSW to RHR cross-tie will be added to both units.
- EDG MCC connections for FLEX 480 VAC generator(s) to supply power to 480 VAC buses (Div. 1, 2, and 3) on each unit will be installed.
- Connections will be provided for FLEX 480 VAC generator(s) to supply power directly to the 125 VDC battery chargers.

Table 2-2 summarizes the safety functions associated with each of the relevant strategies and/or modifications and indicates where the changes to the PRA model are implemented. This includes an indication of the specific event tree nodes and/or system models that are impacted by the hardware modification and/or the associated proposed mitigation strategy.

Table 2-2
Example FLEX Accident Sequence Analysis Treatment

Modification	Relevant Safety Function(s)	Part of PRA Model Impacted
Extended RCIC Operation	Maintain Core Cooling	The current accident sequence model for the representative site only includes credit for extended RCIC operation if suppression pool cooling is available. If suppression pool cooling is not available and other high pressure injection systems are also not available, then RPV depressurization and injection from a low pressure injection system is required to maintain adequate core cooling. The currently credited low pressure injection systems include LPCI, CS, and RHRSW or fire water through the RHR cross-tie. In lieu of including all of the requirements to maintain extended RCIC operation, and since RPV depressurization and containment venting are both eventually required in the existing event sequence modeling, specific representation of extended RCIC operation was not added to the accident sequence model in the initial screening evaluation pursued for the representative plant. Alternatively, transition from RCIC to use of the FLEX pumps for RPV injection was included in the modeling. If explicit representation of extended RCIC operation were to be added, then it would need to include all of the system and operator action requirements identified above to ensure meeting the PRA success criteria and mission time.

Table 2-2 (continued)
Example FLEX Accident Sequence Analysis Treatment

Modification	Relevant Safety Function(s)	Part of PRA Model Impacted
Hardened Containment Vent System	Maintain Containment	The current accident sequence model for the representative site includes operation of containment venting before reaching the Primary Containment Pressure Limit (PCPL). Analyses have indicated that this occurs at about 15 hours from sequence initiation in the scenarios of interest. The addition of the hardened containment vent represents an additional vent path that can be included in the current event tree node for containment venting. Therefore, representation of this vent path and the required support systems were added to the fault tree logic that is referenced by the containment vent node. Based on the specified FLEX strategy for the representative site, successful vent operation would need to begin at about six hours. This timing assumption is factored into the operator action for opening the hardened containment vent as part of the FLEX strategy. Additionally, the hardened containment vent eliminates the potential deleterious impacts due to harsh reactor building environment currently included in the PRA model for venting through the existing soft duct vent paths. The deleterious impacts to the injection systems were removed in the continued RPV injection node that is included in the event tree sequence logic if the hardened vent is successful.
FLEX Pumps	RPV Injection/ Suppression Pool Makeup	Note that although the primary strategy for the representative site is prolonged RCIC operation, the strategy does recognize that injection from the FLEX pumps can be provided should RCIC eventually fail. Therefore, the event tree nodes for alternate injection and injection after containment venting were modified to include representation of RPV injection from the FLEX pumps through the RHR cross-tie as another viable means of alternate injection. Suppression Pool Makeup would not be required for more than 60 hours at the example site, so specific modeling of the suppression pool makeup function was not included. (However, it should be noted that some Mark I sites have reported needing suppression pool makeup prior to 24 hours so that the requirement for suppression pool makeup would need to be included in the internal events PRA model to establish a safe stable state for the PRA mission time.)

Table 2-2 (continued)
Example FLEX Accident Sequence Analysis Treatment

Modification	Relevant Safety Function(s)	Part of PRA Model Impacted
FLEX Pumps (continued)	RPV Injection/ Suppression Pool Makeup	To accommodate credit for RPV injection from the FLEX pumps, the alternate injection event tree nodes were updated to reference the system model that was developed for the FLEX pumps including the required operator action for performing the alignment and support for opening the cross-tie valves once the FLEX pumps are aligned to the system. The alternate injection event tree nodes are only included in the event sequence modeling if initial high pressure injection and eventual RPV depressurization is successful. This approach ensures that acceptable RPV conditions for injection from FLEX exist such that these accident sequence dependencies did not need to be explicitly represented in the system model for RPV injection from the FLEX pumps.
RHR Cross-tie	RPV Injection/ Suppression Pool Makeup	This modification allowed for additional flexibility in the alignment of alternate injection systems. The current plant only allows for cross-tie into one RHR loop for each unit at the site. The future plant will allow for cross-tie into both RHR loops for each unit. This additional cross-tie capability was included in the system fault tree for alignment of alternate injection, including injection from the FLEX pumps. Note that although this modification was added for the FLEX pumps, the cross-tie could also theoretically be used by the existing credited alternate injection systems (RHRSW and fire water). Therefore, a separate operator action was included for alignment of this cross-tie since it was not clear if the currently credited alternate injection system procedures would be modified to include the capability to use the opposite division cross-tie.
MCC Connections	480 VAC Power to Select MCCS	Explicit representation of the MCCs is not included directly in the accident sequence model, but rather is included as a support system in the fault tree logic as applicable. Therefore, alignment of the portable generators to select 480 VAC MCCs was included in the system fault trees for the MCCs as an additional source of power. Flags were included in the system logic to ensure that credit for this alignment was not taken in the early event tree nodes, but was only credited after transition to the use of the portable equipment was viable. A unique operator action event was utilized for completion of the alignment to the MCCs in the system fault tree models.

Table 2-2 (continued)
Example FLEX Accident Sequence Analysis Treatment

Modification	Relevant Safety Function(s)	Part of PRA Model Impacted
Battery Charger Connections	125 VDC Power to Select Divisions	Similarly, explicit representation of the battery chargers is not included directly in the accident sequence model, but rather is included as a support system in the fault tree logic as applicable. Therefore, alignment of the portable generators to the battery chargers was included in the system fault trees for the battery chargers as an additional source of power. Flags were included in the system logic to ensure that credit for this alignment was not taken in the early event tree nodes, but was only credited after transition to the use of the portable equipment was viable. A unique operator action event was utilized for completion of the alignment to the battery chargers in the system fault tree models.

Areas Requiring Further Development

In general, the existing accident sequence analysis methods should be appropriate for incorporating FLEX into the PRA models. However, event tree nodes may need to be modified, or new ones added and time phase dependencies and multi-unit impacts need to be considered. The strategies using installed equipment can be handled similarly to other (or existing) modeled systems. The transition to on-site portable equipment can also be similarly handled with existing accident sequence modeling techniques (note that systems, data and, human reliability aspects are discussed separately). These two initial phases of the FLEX implementation strategies are all that would typically be included in PRA models with 24 hour mission times (for example, internal events and internal fires). Additionally, although not included in the internal events models surveyed, the transition to credit the use of off-site portable equipment and associated strategies involving off-site resources in other external hazards evaluations can be handled in a similar fashion as existing accident sequence models implementing time-phased dependencies.

Special Uncertainty Considerations

The only special uncertainty considerations associated with the integration of the FLEX mitigation strategies in the accident sequence models would be that associated with the corresponding success criteria development. The success criteria aspect is considered later in the Success Criteria PRA element discussed in Section 2.2.

2.2 Success Criteria

The success criteria element of the ASME/ANS PRA Standard provides high level and supporting requirements to ensure that success criteria are developed to define the plant-specific measures of success and failure that support the other technical elements of the PRA in such a way that:

1. Overall success criteria are defined (that is, core damage and large early release).
2. Success criteria are defined for critical safety functions, supporting systems, structures, components, and operator actions necessary to support accident sequence development.
3. The methods and approaches have a firm technical basis.
4. The resulting success criteria are referenced to the specific deterministic calculations.

In general, the existing success criteria analysis methods should be acceptable for incorporating FLEX into the PRA models. Table 2-3 provides the state-of-knowledge review for the success criteria technical element by the corresponding high level requirements.

Table 2-3
State-of-Knowledge Review for the Success Criteria Element

<table>
<tr><td>Topic of High Level Requirement</td><td>HLR-SC-A: Define and reference success criteria consistent with the as-built, as-operated plant.</td></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing success criteria methods encompassed by the HLR-SC-A supporting requirements are generally appropriate for extending the success criteria analysis to incorporate FLEX mitigation strategies. The definition of core damage should not change, but the FLEX strategies will lead to the identification of alternate means to meet selected key safety functions. Additionally, extended mission times, which may include credit for additional equipment and resources from off-site facilities, might be appropriate for certain strategies to ensure a safe and stable state for different hazard groups (for example, external events). The actual mission time to be used is not defined, and current industry efforts are ongoing to provide better definitions in this area.

Credit for off-site resources is not expected to be taken in the existing internal events PRA models which utilize PRA mission times of 24 hours. Although offsite resources may become available prior to 24 hours, it would be difficult to fully credit these offsite resources prior to 24 hours without sufficient justification that they would be available considering the nature of the hazard. Whatever FLEX strategies are credited will need to be consistent with the eventual procedures and operating philosophy of the plant.</td></tr>
<tr><td>Topic of High Level Requirement</td><td>HLR-SC-B: Provide appropriate engineering analysis to support the success criteria and event timing used in the quantification of CDF and LERF.</td></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing success criteria methods encompassed by the HLR-SC-B supporting requirements are generally appropriate for extending the success criteria analysis to incorporate FLEX mitigation strategies. The credit for the FLEX strategies should be realistic with an appropriate basis provided using accepted tools (for example, MAAP). Reasonableness checks on the results should also be made (for example, sufficient injection capability exists compared to other credited systems in the PRA model).</td></tr>
<tr><td>Topic of High Level Requirement</td><td>HLR-SC-C: Document the success criteria.</td></tr>
<tr><td colspan="2">The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.</td></tr>
</table>

2.2.1 Insights for Success Criteria Development

Example Implementation Methods

Table 2-4 summarizes the relevant success criteria associated with each of the relevant strategies for the representative plant described above and discusses the basis for the success criteria that was utilized in the model development process.

Table 2-4
Example FLEX Success Criteria Treatment

Modification	Success Criteria Element	Basis for Success Criteria
Extended RCIC Operation	Maintain Adequate Core Cooling	The basis for the success criteria are the MAAP runs which indicate that the RPV level and pressure can be maintained as desired, and that the suppression pool temperature can be maintained below the assumed temperature limit for continued operation of the pump (which may also require disabling some automatic trips). Separate engineering calculations are referenced for the DC load shedding requirements, RCIC room temperature limits, and RCIC suction temperature limits assumed in the strategy development.
Hardened Containment Vent System	Maintain Containment Pressure and Suppression Pool Temperature	The basis for the associated success criteria are the MAAP runs which indicate that the containment pressure and suppression pool temperature can be maintained below the assumed temperature limit for continued operation of RCIC. These same runs and reference to other MAAP runs support use of the vent to support operation of the other credited alternate injection systems.
FLEX Pumps	Maintain Adequate Core Cooling	The FLEX pumps have a larger flow capacity to the RPV than other currently credited systems in the representative PRA model. That is, since fire water injection has already been demonstrated to represent a viable RPV injection system at low pressures, then the FLEX pumps are adequate by comparison. The use of the FLEX pumps would only be viable after initial injection from installed equipment is successful.
RHR Cross-tie	Maintain Adequate Core Cooling	The RHR cross-tie was sized sufficiently to support injection from the FLEX pumps. Validation that the additional cross-tie capability was also adequate for the other credited alternate injection systems would need to be performed to remove this assumption as a potential key source of uncertainty.
MCC Connections	Provide 480 VAC Power to Select MCCS	Since the generators will provide power to the MCCs directly, validation that the MCC connections could be made in time to support the credited loads (and any load shedding requirements can also be performed) is all that would need to be done to support the success criteria.

Table 2-4 (continued)
Example FLEX Success Criteria Treatment

Modification	Success Criteria Element	Basis for Success Criteria
Battery Charger Connections	Provide Power to the Battery Chargers to Support 125 VDC Power to Select Divisions	Similarly, since the generators will provide power to the battery chargers directly, validation that the connections could be made in time to support the chargers prior to battery depletion is all that would need to be done to support the success criteria.

Areas Requiring Further Development

In general, the existing success criteria methods should be appropriate for incorporating FLEX into the PRA models. The initial strategies using installed equipment can be handled similarly to establishing success criteria for other modeled systems. The transition to the use of on-site portable equipment can also be similarly handled with existing thermal/hydraulic modeling techniques. Again, these two initial phases of the FLEX implementation strategies are all that would typically be included in PRA models with 24 hour mission times (for example, internal events and internal fires). Additionally, the transition to credit strategies involving off-site resources in other external hazards evaluations should also be similarly handled.

However, care should be taken to ensure that conservative assumptions do not unduly influence the results (for example, establishment of portable ventilation equipment may be required based on bounding calculations, but this requirement may only realistically be needed during certain times of the year). In these cases, development of variable success criteria may be warranted to obtain more realistic results.

Special Uncertainty Considerations

There are likely to be some assumptions and potential key sources of uncertainty associated with the success criteria development. This would include some of the examples provided in Table 2-4 which include such things as the capability of the installed systems to continue to operate (for example, at elevated suppression pool temperatures and with no room cooling), and the assumed timelines for establishing the portable equipment and associated required actions (for example, load shedding requirements).

2.3 Systems Analysis

This section will discuss the systems analysis requirements associated with implementing the FLEX strategies into the plant PRA models, specifically with respect to implementation in the fault tree models. The objectives of the systems analysis element are to identify and quantify the causes of failure for each plant system represented in the initiating event analysis and accident sequence analysis in such a way that system-level success criteria, mission times, time windows for operator actions, and assumptions provide the basis for the system logic models as reflected in the model.

The system model development must also ensure that a reasonably complete set of system failure and unavailability modes for each system is represented, and that human errors and operator actions that could influence the system unavailability or the system's contribution to accident sequences are identified for development as part of the Human Reliability Analysis (HRA) element. Additionally, different initial system alignments should be evaluated to the extent needed for CDF and LERF determination, and intersystem dependencies and intra-system dependencies including functional, human, phenomenological, and common-cause failures that could influence system unavailability or the system's contribution to accident sequence frequencies are identified and accounted for.

In general, the existing systems analysis methods should be acceptable for incorporating FLEX into the PRA models. Table 2-5 provides the state-of-knowledge review for the systems analysis technical element by the corresponding high level requirements.

Table 2-5
State-of-Knowledge Review for the Systems Analysis Element

<table>
<tr><th>Topic of High Level Requirement</th><th>HLR-SY-A: Provide a reasonably complete treatment of failure modes and unavailability in the system models.</th></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing systems analysis methods encompassed by the HLR-SY-A supporting requirements are generally appropriate for extending the systems analysis to incorporate FLEX mitigation strategies. The systems models can be developed based on the plant diagrams for the systems and operating procedures (once they are developed) for the strategies. This information can be used to establish the system components and boundaries, dependencies on other systems, and any instrumentation or control requirements. If the system or components are modeled at a super component level, then care must be taken to ensure that the super component boundary does not include portions that may appear elsewhere in the model (for example, at the breaker or power supply level).

The FLEX system models are likely subject to many unique considerations. These include incorporation of unique time dependence issues, variable success criteria, multi-unit impacts, and phenomenological considerations into the system models. That is not to say that the existing system modeling techniques cannot handle these considerations, but care must be taken to ensure that the associated impacts are accurately reflected in the system models. Additionally, since the requirements for FLEX ensure that there is sufficient equipment redundancy to support all of the units at the site, there should not be many unique multi-unit impacts from a system model perspective. The multi-unit impacts are more likely related to the human reliability assessments that need to ensure that sufficient manpower exists to potentially support simultaneous implementation of FLEX equipment at all of the units at a site.

The system models are also likely to include direct representation of the pre-initiator and post-initiator HFEs needed to support successful operation of the system. Maintenance unavailability terms should also be included, but these may only be initial estimates until enough time elapses such that plant-specific unavailability data can be collected.

In the U.S., utilities are required to have n+1 set of equipment stored on site, meaning that one set of equipment is potentially available as a spare part for replacement. Modeling spare parts for FLEX equipment should be done in a way consistent with crediting spare parts for other equipment. For example, reasonable assumptions can be make such at assume <50% availability of spare part to account for equal probability that it is needed by the second unit, or not crediting the spare equipment.</td></tr>
</table>

Table 2-5 (continued)
State-of-Knowledge Review for the Systems Analysis Element

Topic of High Level Requirement	**HLR-SY-B: Address common cause failures and system dependencies in the system models.**
In the context of integrating FLEX into the PRA models, the existing systems analysis methods encompassed by the HLR-SY-B supporting requirements are generally appropriate for extending the systems analysis to incorporate FLEX mitigation strategies. Common cause failure representations might need to be included for the FLEX pumps (if the spare pumps are explicitly modeled), or more likely for any similar breakers or other components that could be used by the overall complement of FLEX strategies. Support system requirements should be based on sound engineering analyses. Any interfaces with other systems should be clearly identified and included in the fault tree models.	
Topic of High Level Requirement	**HLR-SY-C: Document the systems analysis.**
The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.	

2.3.1 Insights for Systems Analysis Development

<u>Example Implementation Methods</u>

In some of the models surveyed, systems analysis methods that have been employed include not developing the system models to a typical level of detail for all components recognizing that the total failure probability of implementing the FLEX strategy is likely dominated by other factors (for example, the associated HEPs or other component screening values utilized). Table 2-6 summarizes the systems analysis treatment associated with each of the relevant strategies for the representative plant described above.

Table 2-6
Example FLEX Systems Analysis Treatment

Modification	Systems Analysis Treatment
Extended RCIC Operation	No changes would be required for the representation of extended RCIC operation directly in the RCIC system fault trees. The dependencies can be handled with changes to the related support system fault trees (that is, DC load shedding requirements and alignment of portable generators can be handled in the electric power fault trees, and room ventilation requirements can be handled in the room cooler fault trees), or in the accident sequence modeling (RPV depressurization and containment venting initiation).
Hardened Containment Vent System	The addition of the hardened containment vent represents an additional vent path that can be included in the current event tree node for containment venting. Therefore, representation of this vent path and the required support systems were added to the fault tree logic that is referenced by the containment vent node.

Table 2-6 (continued)
Example FLEX Systems Analysis Treatment

Modification	Systems Analysis Treatment
FLEX Pumps	A system model was developed for the FLEX pumps including the required operator action for performing the alignment and support for opening the cross-tie valves once the FLEX pumps are aligned to the system. *Note that no credit was taken for the spare FLEX pump in the system fault tree model for the representative site.*
RHR Cross-tie	This modification allowed for additional flexibility in the alignment of alternate injection systems. The current plant only allows for cross-tie into one RHR loop for each unit at the site. The future plant will allow for cross-tie into both RHR loops for each unit. This additional cross-tie capability was included in the system fault tree for alignment of alternate injection, including injection from the FLEX pumps.
MCC Connections	Alignment of the portable generators to select 480 VAC MCCs was included in the system fault trees for the MCCs as an additional source of power. Flags were included in the system logic to ensure that credit for this alignment was not taken in the early event tree nodes, but was only credited after transition to the use of the portable equipment was viable. Additionally, a unique operator action event was utilized for completion of the alignment to the MCCs in the system fault tree models.
Battery Charger Connections	Similarly, alignment of the portable generators to the battery chargers was included in the system fault trees for the battery chargers as an additional source of power. Flags were included in the system logic to ensure that credit for this alignment was not taken in the early event tree nodes, but was only credited after transition to the use of the portable equipment was viable, and a unique operator action event was utilized for completion of the alignment to the battery chargers in the system fault tree models.

<u>Areas Requiring Further Development</u>

In general, the existing systems analysis methods should be appropriate for incorporating FLEX into the PRA models. However, there are some special considerations:

- Better understanding of CCFs for FLEX components needed (part of Data Analysis gaps).
- FLEX system models may be subject to many unique plant-specific considerations, including variable success criteria, multi-unit impacts, and phenomenological considerations. Care must be taken to ensure that the associated impacts are accurately reflected in the system models.
- Use of non-typical water sources may raise issues (for example, clogging if FLEX equipment does not have filters and strainers of the type assumed in the raw water performance data).

Special Uncertainty Considerations

The special uncertainty considerations associated with the integration of the FLEX mitigation strategies in the system models would be that associated with the data utilized for the related HFEs and for the component reliability and unavailability values. The associated HEP values are considered in the Human Reliability Analysis PRA element discussed in Section 2.4. The component reliability and system unavailability aspects are covered later in the Data Analysis discussion in Section 2.5.

2.4 Human Reliability Analysis

This section will discuss the requirements associated with implementing the FLEX strategies into the plant PRA models, specifically in the context of crediting the FLEX-related operator actions in the PRA model. The objective of the human reliability element of the PRA standard is to ensure that the impacts of plant personnel actions are reflected in the assessment of risk in such a way that both pre-initiating event and post-initiating event activities, including those modeled in support system initiating event fault trees, are addressed. The HRA elements also ensure that logic model elements are defined to represent the effect of such personnel actions on system availability/unavailability and on accident sequence development, that plant-specific and scenario-specific factors are accounted for, including those factors that influence either what activities are of interest or human performance, and that human performance issues are addressed in an integral way so that issues of dependency are captured.

A broader approach to the gap analysis will be applied for this important PRA element. Table 2-7 provides an overview of the state-of-knowledge review for the post-initiator human reliability analysis technical element by the corresponding high level requirements. The detailed gap assessment for the human reliability analysis element is further described in Section 3.

Table 2-7
State-of-Knowledge Review for the Human Reliability Analysis Element

Topic of High Level Requirement	**HLR-HR-A: Identify routine activities that could impact system availability if not completed correctly.**
In the context of integrating FLEX into the PRA models, the existing Type A action identification/screening methods encompassed by the HLR-HR-A supporting requirements are generally appropriate for extending the process to incorporate FLEX mitigation strategies. In some cases, the integration of FLEX equipment into the PRA may introduce additional standard pre-initiator actions (misalignments of valves in flow paths, mis-calibrations of local flow indicators) that can affect the availability of both existing and FLEX equipment; for example addition of a hook up point for FLEX equipment can now introduce the potential for a diverted flow path that did not previously exist for an installed piece of equipment. In other cases, some new types of pre-initiators may be relevant to the FLEX equipment. For example, the vehicle required for portable equipment transportation may have been used for another task and not returned to its designated location.	

Table 2-7 (continued)
State-of-Knowledge Review for the Human Reliability Analysis Element

Topic of High Level Requirement	**HLR-HR-B: Screen routine activities based on plant-specific practices that limit the likelihood of errors in those activities.**
In the context of integrating FLEX into the PRA models, the approaches to screening out events with strong recovery mechanisms are generally appropriate for extending the process to incorporate FLEX mitigation strategies. Consideration would have to be given to determine if some of these types of failures should be addressed as a Type A human error or as a subset of a hardware failure, but at this time, there is not a standardized approach to address this issue.	
Topic of High Level Requirement	**HLR-HR-C: Include appropriate pre-initiator events in the system fault trees.**
In the context of integrating FLEX into the PRA models, the approaches to the development of events to represent Type A actions are generally appropriate for extending the process to incorporate FLEX mitigation strategies. Consideration would have to be given to non-standard actions to determine if these types of failure should be addressed as a Type A human error or as a subset of a hardware failure, but at this time, there is not a standardized approach to address this issue.	
Topic of High Level Requirement	**HLR-HR-D: Estimate the pre-initiator HEPs using a systematic process.**
In the context of integrating FLEX into the PRA models, the existing Type A action quantification methods encompassed by the HLR-HR-A supporting requirements are generally appropriate for extending the process to incorporate FLEX mitigation strategies. THERP would address the standard Type A errors, but the non-standard errors could include events that would not currently have a technical basis for evaluation. While the range of events that may be defined as Type A errors for FLEX-like activities has not yet been defined, such events may include the failure to maintain FLEX equipment in the pre-staged area (that is, the equipment is being used for another task).	
Topic of High Level Requirement	**HLR-HR-E: Review plant procedures to identify operator actions required to meet the safety functions in the accident sequences.**
In the context of integrating FLEX into the PRA models, the existing human reliability analysis methods encompassed by the HLR-HR-E supporting requirements are generally appropriate for extending the systems analysis to incorporate FLEX mitigation strategies. Key human response actions that can be credited can be identified by reviewing the associated procedures and ensuring that direction to implement the procedures is viable for the given set of accident scenarios under consideration. The use of the procedures will likely need to be supported by talking through with plant operations and training personnel the procedures and expected sequence of events.	
Topic of High Level Requirement	**HLR-HR-F: Define human failure events in a manner consistent with the level of detail of the accident sequences.**
In the context of integrating FLEX into the PRA models, the existing human reliability analysis methods encompassed by the HLR-HR-F supporting requirements are generally appropriate for extending the systems analysis to incorporate FLEX mitigation strategies. The identified Human Failure Events (HFEs) can be defined to include: (a) accident sequence specific timing of cues, and time window for successful completion, (b) accident sequence specific procedural guidance, (c) the availability of cues and other indications for detection and evaluation errors, and (d) the specific high level tasks required to achieve the goal of the response. (Note that a detailed task evaluation at the component level is only required to meet Capability Category III for Supporting Requirement HR-F2.)	

Table 2-7 (continued)
State-of-Knowledge Review for the Human Reliability Analysis Element

<table>
<tr><td>Topic of High Level Requirement</td><td>HLR-HR-G: Develop probabilities of the post-initiator HFEs using a well-defined and self-consistent process.</td></tr>
<tr><td colspan="2">The existing HRA methods encompassed by the HLR-HR-G supporting requirements may not be totally acceptable for developing HEPs to incorporate FLEX mitigation strategies.
Some cognitive and execution tasks are not well characterized by the EPRI HRA methodology. This is discussed in more detail in Section 3 of this report.</td></tr>
<tr><td>Topic of High Level Requirement</td><td>HLR-HR-H: Model recovery actions.</td></tr>
<tr><td colspan="2">Similarly, the methods encompassed by the HLR-HR-G supporting requirements may not be totally acceptable for developing HEPs to incorporate FLEX mitigation strategies.
Some actions require extensive set up and/or coordinate with offsite resources such that a physical demonstration of the action is not practical. Other practices used for some internal events actions, such as simulated walkdowns, equipment, surveillance, and procedure review can be used to validate the actions. This is discussed in more detail in Section 3 of this report.</td></tr>
<tr><td>Topic of High Level Requirement</td><td>HLR-HR-I: Document the human reliability analysis.</td></tr>
<tr><td colspan="2">The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.</td></tr>
</table>

2.4.1 Insights for Human Reliability Analysis Development

<u>Example Implementation Methods</u>

The majority of the models surveyed employed utilizing screening HEP values for the representation of the FLEX mitigation strategies as detailed procedures had not yet been developed. This may be acceptable for initial use to determine the risk significance of the different events before a detailed HEP analysis is performed. A few models surveyed did include detailed representations of the HFEs associated with the FLEX strategies; however, existing HRA methodologies are not capable of addressing all of the elements that are part of the FLEX strategies, as described in Section 3 of this report.

Also refer to Section 3 of this report for a summary of human reliability analysis areas requiring further development and special uncertainty considerations.

2.5 Data Analysis

This section will discuss the data analysis requirements associated with implementing the FLEX equipment and related components into the plant PRA models. The objectives of the data analysis elements are to provide estimates of the parameters used to determine the probabilities of the basic events representing equipment failures and unavailabilities modeled in the PRA in such a way that parameters, whether estimated on the basis of plant-specific or generic data, appropriately reflect that configuration and operation of the plant. Additionally, the data supporting requirements ensure that component or system unavailabilities due to maintenance or repair are accounted for, and that uncertainties in the data are understood and appropriately accounted for.

Table 2-8 provides the state-of-knowledge review for the data analysis technical element by the corresponding high level requirements.

Table 2-8
State-of-Knowledge Review for the Data Analysis Element

Topic of High Level Requirement	**HLR-DA-A: Define data parameters and event probability values to support the logic model development consistent with the component boundaries.**
In the context of integrating FLEX into the PRA models, the existing data analysis methods encompassed by the HLR-DA-A supporting requirements are generally appropriate for extending the data analysis to incorporate FLEX mitigation strategies. Boundaries for the FLEX components can be established and appropriate probability models can be used for each basic event. Note that the estimation of the parameters used for the basic events is covered by the HLR-DA-C supporting requirements discussed below.	
Topic of High Level Requirement	**HLR-DA-B: Consider the as-built, as-operated plant when grouping components for parameter estimation.**
In the context of integrating FLEX into the PRA models, the existing data analysis methods encompassed by the HLR-DA-B supporting requirements are generally appropriate for extending the data analysis to incorporate FLEX mitigation strategies. Grouping of the FLEX components can occur according to type which can consider the design, environmental, and service conditions for the components.	
Topic of High Level Requirement	**HLR-DA-C: Choose parameter estimates and collect plant-specific data consistent with data parameters and grouping defined in HLR-DA-A and HLR-DA-B.**
In the context of integrating FLEX into the PRA models, the HLR-DA-C supporting requirements represent where additional guidance and refinement is needed by the industry. Generic parameter estimates from recognized sources may not be available for all of the components that are part of the FLEX strategy implementation. Although estimating and determining plant-specific data for FLEX equipment can be performed in a manner similar to current installed equipment, sufficient plant-specific evidence may not be available for some time. Related data analysis aspects are discussed in more detail in Section 4 of this report.	
Topic of High Level Requirement	**HLR-DA-D: Base the parameter estimates on relevant generic industry and/or plant-specific evidence, and characterize the uncertainty.**
In the context of integrating FLEX into the PRA models, the methods encompassed by the HLR-DA-D supporting requirements are also an area where additional guidance and refinement is needed by the industry. Although the methods for combining the generic and plant-specific evidence are well established, the lack of relevant generic data and plant-specific evidence (see HLR-DA-D) could potentially hinder the uncertainty characterization of the parameters in the near future. Similarly, the methods for developing common cause parameters are well established, but the lack of relevant available data for some FLEX components may lead to additional uncertainty associated with these parameters. These aspects are discussed in more detail in Section 4 of this report.	
Topic of High Level Requirement	**HLR-DA-E: Document the data analysis.**
The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.	

2.5.1 Insights for Data Analysis Development

Example Implementation Methods

Data for FLEX equipment in the surveyed models was typically based on traditional data sources (for example, NUREG/CR-6928 for pumps and generators) [3]. Plants with FLEX equipment already installed or on-site performed Bayesian updating of the generic data with plant-specific data. However, most plants have not yet implemented FLEX, so plant specific data is not available. In a few cases, unavailability was projected based on plant-specific maintenance and testing expectations.

Also refer to Section 4 of this report for a summary of data analysis issues and findings.

2.6 Quantification

This section will discuss the quantification requirements associated with implementing the FLEX strategies into the plant PRA models. The objectives of the quantification element are to provide an estimate of CDF (and support the quantification of LERF) based upon the plant-specific core damage scenarios, in such a way that:

1. The results reflect the design, operation, and maintenance of the plant.
2. Significant contributors to CDF (and LERF) are identified such as initiating events, accident sequences, and basic events (equipment unavailability and human failure events).
3. Dependencies are accounted for.
4. Uncertainties are understood.

In general, the existing quantification methods should be acceptable for incorporating FLEX into the PRA models. Table 2-9 provides the state-of-knowledge review for the quantification technical element by the corresponding high level requirements.

Table 2-9
State-of-Knowledge Review for the Quantification Element

<table>
<tr><th>Topic of High Level Requirement</th><th>HLR-QU-A: Quantify CDF and support the quantification of LERF.</th></tr>
<tr><td colspan="2">In the context of integrating FLEX into the PRA models, the existing quantification methods encompassed by the HLR-QU-A supporting requirements are generally appropriate for extending the quantification to incorporate FLEX mitigation strategies. The accident sequences, system models, data, and HRA can be integrated to account for system dependencies to arrive at accident sequence frequencies. The mean CDF and LERF values accounting for the state-of-knowledge correlation between event probabilities can be estimated. Recovery actions can be included as appropriate and the accepted methods are capable of discriminating the contributors to CDF and LERF.</td></tr>
</table>

Table 2-9 (continued)
State-of-Knowledge Review for the Quantification Element

Topic of High Level Requirement	**HLR-QU-B: Use appropriate models and codes for quantification.**
In the context of integrating FLEX into the PRA models, the existing quantification methods encompassed by the HLR-QU-B supporting requirements are generally appropriate for extending the quantification to incorporate FLEX mitigation strategies. Establishing truncation limits, breaking circular logic, and applying mutually exclusive rules can occur in the same fashion as the current accepted processes. In some cases (depending on how the FLEX strategies are implemented into the PRA models, and the final system failure probabilities that are derived), complementary logic in event tree branches may need to be employed for any down branches with failure probabilities equal to 0.1 or higher or alternate post-processing techniques (for example, the use of ACUBE) may need to be employed. Otherwise, the currently accepted software codes and products are also suitable for FLEX implementation.	
Topic of High Level Requirement	**HLR-QU-C: Address dependencies during quantification.**
The HLR-QU-C supporting requirements include two separate aspects. The first aspect relates to the deployment of dependent human failure events. The quantification aspects are unchanged by the incorporation of FLEX, but issues associated with incorporating FLEX actions in the HRA dependency analysis are discussed further in Section 3 of this report. The second aspect relates to ensuring that sequence characteristics (for example, failed equipment) are transferred when event trees are linked together. Incorporation of FLEX does not introduce any new considerations associated with this issue and the currently accepted methods for meeting these requirements are appropriate for FLEX PRA modeling.	
Topic of High Level Requirement	**HLR-QU-D: Review and identify significant contributors to CDF (and LERF) so results are traceable to the inputs and assumptions made in the PRA.**
The HLR-QU-D high level requirement includes supporting requirements to review the significant and non-significant results to assure that they are reasonable and make logical sense. Incorporation of FLEX does not introduce any new considerations associated with these issues and the currently accepted methods for meeting these requirements are generally appropriate for FLEX PRA modeling.	
Topic of High Level Requirement	**HLR-QU-E: Identify and characterize sources of uncertainty.**
The HLR-QU-E high level requirement includes supporting requirements to identify and characterize sources of model uncertainty and related assumptions. The incorporation of FLEX will likely introduce several sources of model uncertainty and related assumptions. These will need to be identified and characterized in the documentation, as they may become potential key sources of uncertainty in some specific future applications of the PRA model. The uncertainty interval for CDF and LERF will also need to be estimated. This is rather straightforward once the parameter estimates are completed along with their individual group (or type code) uncertainty distributions.	
Topic of High Level Requirement	**HLR-QU-F: Document the quantification process.**
The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.	

2.6.1 *Insights for Quantification Development*

Example Implementation Methods

The PRA models surveyed did not employ any unique or alternate methods for quantification once the FLEX strategies and equipment were incorporated into the PRA models. As such, it is anticipated that the existing quantification methods employed for each model will still suffice when implementing the FLEX strategies into the existing PRA models. The one potential exception is that, for some models (depending on how the FLEX strategies are implemented into the PRA models, and the final system failure probabilities that are derived), additional available post-processing techniques (for example, the use of ACUBE) may need to be employed. This is not judged to be likely however, as the potential number of high probability of failure events by incorporating FLEX strategies should be small compared to seismic models where the use of ACUBE has been established to be more useful.

Areas Requiring Further Development

No unique considerations related to implementing the FLEX strategies should arise that would make the existing accepted quantification techniques unusable.

Special Uncertainty Considerations

The special uncertainty considerations include all of the related success criteria, data, and human reliability assumptions utilized in the implementation of the FLEX strategies in to the PRA model. These will need to be identified and characterized in the documentation, as they may become potential key sources of uncertainty in some specific future applications of the PRA model.

2.7 LERF Analysis

This section will discuss the LERF analysis requirements associated with implementing the FLEX strategies into the plant PRA models. The objectives of the LERF analysis element are to identify and quantify the contributors to large early releases, based upon the plant-specific core damage scenarios, in such a way that:

1. The methodology is clear and consistent with the Level 1 evaluation, and creates an adequate transition from Level 1.
2. Operator actions, mitigation systems, and phenomena that can alter sequences are appropriately included in the LERF event tree structure and sequence definition.
3. Dependencies are reflected in the accident sequence model structure, if necessary.
4. Success criteria are available to support the individual function successes, mission times, and time windows for operator actions and equipment recovery for each critical safety function modeled in the accident sequences.
5. End states are clearly defined to be LERF or non-LERF.

Table 2-10 provides the state-of-knowledge review for the quantification technical element by the corresponding high level requirements.

Table 2-10
State-of-Knowledge Review for the LERF Analysis Element

Topic of High Level Requirement	**HLR-LE-A: Bin core damage sequences into plant damage states.**
In the context of integrating FLEX into the PRA models, the existing core damage grouping methods encompassed by the HLR-LE-A supporting requirements are unchanged by extending the modeling to incorporate FLEX mitigation strategies. Sequence and physical characteristics will still need to be identified and a method to explicitly account for those characteristics will still need to be employed.	
Topic of High Level Requirement	**HLR-LE-B: Evaluate initiating events, phenomenological behavior, equipment failures, and human action failures that can lead to a large early release.**
In the context of integrating FLEX into the PRA models, the methods used for existing accident progression analyses encompassed by the HLR-LE-B supporting requirements are unchanged by extending the modeling to incorporate FLEX mitigation strategies. Although, the availability of FLEX equipment may change the likelihood of water being available prior to or at the time of vessel failure, the LERF contributors and set of containment challenges will not change. Given that however, the implementation of the FLEX strategies will require that the accident progression sequences be examined for potential timing impacts and the state of containment at the time of core damage or vessel failure.	
Topic of High Level Requirement	**HLR-LE-C: Identify sequences that result in a large early release.**
In the context of integrating FLEX into the PRA models, the methods used for existing accident progression analyses encompassed by the HLR-LE-C supporting requirements are unchanged by extending the modeling to incorporate FLEX mitigation strategies. However, the availability of FLEX equipment may change the likelihood of water being available prior to or at the time of vessel failure. The procedural direction provided in the FLEX Support Guidelines (FSGs) will likely need to be incorporated into the LERF sequence modeling to ensure that a realistic treatment of operator actions following the onset of core damage are included in the PRA model. The feasibility of the actions post core damage will also need to be assessed.	
Topic of High Level Requirement	**HLR-LE-D: Evaluate the containment structural capability for challenges that can lead to a large early release, and include in the accident progression analysis.**
Unless the containment itself is modified by incorporation of components needed for FLEX implementation, the containment structural analysis should not be altered by the incorporation of the FLEX mitigation strategies into the PRA model. As such, the containment ultimate capacity for the containment challenges that can result in a large early release should not change. For PWRs, however, the implementation of the FLEX mitigation strategies post core damage could influence the likelihood of induced steam generator tube ruptures. If FLEX strategies are incorporated into the PRA model, then this aspect should be factored into the LERF evaluation to ensure a realistic treatment of the accident progression modeling that could lead to LERF.	

Table 2-10 (continued)
State-of-Knowledge Review for the LERF Analysis Element

Topic of High Level Requirement	**HLR-LE-E: Quantify the frequency of different containment failure modes that can lead to a large early release.**
In the context of integrating FLEX into the PRA models, the methods used for existing accident progression analyses encompassed by the HLR-LE-E supporting requirements are unchanged by extending the modeling to incorporate FLEX mitigation strategies. However, the availability of FLEX equipment may change the likelihood of water being available prior to or at the time of vessel failure. The considerations associated with the presence of water in containment or on the secondary side of the steam generators should be factored into the LERF evaluation to ensure that the appropriate failure modes leading to large early release can be appropriately quantified and aggregated. One special consideration is the potential for early containment venting (which is part of the FLEX strategy implementation at some BWRs) followed by loss of RCIC and the FLEX pumps and failure to re-isolate containment may need to be considered as a potential additional LERF sequence that was not included previously. Other than that, the existing quantification methods encompassed by the reference QU supporting requirements are generally appropriate for extending the LERF quantification to incorporate FLEX mitigation strategies.	
Topic of High Level Requirement	**HLR-LE-F: Review and identify the significant contributors to LERF so results are traceable to the inputs and assumptions made in the PRA.**
In the context of integrating FLEX into the PRA models, the presentation of the LERF results encompassed by the HLR-LE-E supporting requirements are unchanged by extending the modeling to incorporate FLEX mitigation strategies. However, additional credit for FLEX post core damage to prevent LERF may introduce new sources of model uncertainty and related assumptions that need to be identified and characterized.	
Topic of High Level Requirement	**HLR-LE-G: Document the LERF analysis.**
The existing documentation methods are acceptable for integrating FLEX mitigation strategies into the PRA models.	

2.7.1 Insights for LERF Analysis Development

<u>Example Implementation Methods</u>

Of the models surveyed, the most common method that has been employed includes taking no additional credit for FLEX mitigation strategies post core damage. This means the benefit to LERF reduction is limited to that portion of CDF reduction that may have ended up as LERF. This likely provides a conservative representation of LERF, and may be acceptable in some applications of the PRA model.

A summary of additional considerations include:

- Availability of FLEX equipment may change the likelihood of water being available prior to or at the time of vessel failure.
  - Considerations associated with the presence of water in containment or on the secondary side of the steam generators should be factored into the LERF evaluation.
- Procedural direction provided in the FLEX Support Guidelines (FSGs) will likely need to be incorporated into the LERF sequence modeling.

- For PWRs, implementing FLEX strategies post core damage could influence the likelihood of induced steam generator tube ruptures (SGTR).
- For BWRs, early containment venting followed by loss of RCIC and the FLEX pumps and failure to re-isolate containment may need to be considered as a potential additional LERF sequence.

Areas Requiring Further Development

The impact of integrating the FLEX equipment into the Severe Accident Management Procedures may require additional refinements to the PRA model. This is more important to a full Level 2 model (rather than a LERF-only model), though as the larger impact will likely be on the non-LERF release categories.

Special Uncertainty Considerations

For those FLEX mitigation actions that are incorporated into the model to prevent LERF, the feasibility of the actions post core damage may represent a unique source of uncertainty that should be identified. Additionally, the potential for early containment venting (which is part of the FLEX strategy implementation at some BWRs) followed by loss of RCIC and the FLEX pumps and failure to re-isolate containment may need to be considered as a potential additional LERF sequence that was not included previously.

3
HUMAN RELIABILITY ANALYSIS GAP ASSESSMENT

Of the many challenges associated with incorporating FLEX capabilities into a PRA, the performance of the HRA may be one of the more difficult tasks. This is because the current HRA methodologies that are commonly used in the U.S. nuclear industry are not designed to address many of the human actions required in the FLEX strategies, such as the transportation of portable equipment and making temporary piping connections. In addition to the actions typically associated with portable equipment, there are some FLEX actions performed on permanently installed equipment that are also not well characterized by current methodologies and present modeling problems, such as controlling RPV pressure locally with a turbine driven makeup pump. The types of challenges presented by the modeling of FLEX actions are associated not only with the assessment of execution errors, but also with certain cognitive activities, as well as other issues that are unique to FLEX like activities (for example, human performance limits). In this section, the potential challenges associated with the modeling of FLEX-like actions will be assessed against the capabilities of the EPRI HRA approach.

In order to assess the challenges posed by modeling FLEX-like actions in HRA, it is necessary to identify the types of actions and conditions that must be evaluated as part of FLEX implementation. A systematic, but not comprehensive, process is considered to be required to identify typical HRA modeling challenges. A review of plant procedures can provide insights into the nature of the assessments that would be required for both the cognitive and execution elements of FLEX related actions at a site; however, most plants do not have complete procedures developed for all aspects of their FLEX strategies. An effort was made to collect the FLEX procedures that have been developed from selected sites, but because the range of available procedures was limited, the Overall Integrated Plans for Mitigation Strategies for Beyond Basis External Events were reviewed for several plants to supplement the review process. In general, the Overall Integrated Plans (OIPs) provided insights into potential execution issues, but not clear examples of cognitive challenges because plant procedures are required to assess how the FLEX capabilities are integrated into the plant response.

The “challenge” identification process was separated into three separate portions:

- Review of OIPs for selected plants
- Review of procedures related to FLEX like actions for contributing plants
- “Other” issues based on analyst insights and industry experience

3.1 Scope of HRA Capabilities Considered

In order to identify challenges in modeling FLEX actions, it is necessary to understand the scope and capabilities of available HRA methodologies. There are many methodologies that have been developed and used for different applications, both within the U.S. and abroad, but to limit the scope of this review, the methodologies considered here are those that are part of the EPRI HRA approach:

- Technique for Human Error Rate Prediction (THERP) [4]
- Accident Sequence Evaluation Program HRA procedure (ASEP) (for diagnosis errors) [5]
- Human Cognitive Reliability (HCR)/Operator Reliability Experiments (ORE) Method [6, 7]
- Cause Based Decision Tree (CBDT) Method [6]

Other methodologies are available that can theoretically model nearly any type of human failure event, such as ATHEANA, SLIM/MAUD, and FLIM [8]; however, the goal of this analysis is to identify gaps in the methodologies that have been recently used to provide a foundation for a practical and consistent approach to performing HRA in the U.S. nuclear industry. Methodologies such as ATHEANA SLIM/MAUD, and FLIM are flexible, but they are not consistent with this goal because they are highly dependent on expert judgment and require extensive plant resources and planning to implement.

SPAR-H, which is included in the EPRI HRA Calculator, is potentially flexible enough to address many FLEX-like actions, but it was developed to support the Significance Determination Process and is not a Capability Category II methodology. Because of this, SPAR-H is not considered to be a long term option for integrating FLEX-like actions into nuclear power plant PRAs.

Based on these considerations, the gap analysis will focus on the challenges to the use of the methodologies included in the EPRI HRA approach, as documented above.

3.2 Review of Selected Integrated Plans for Mitigation Strategies for Beyond Basis External Events

While it was not practical to review all of the industry's OIPs to identify the full set of FLEX activities, the strategies from two boiling water reactors (BWRs) and two pressurized water reactors (PWRs) were reviewed to help identify examples of the types of actions that will be employed by the plants. Because the OIPs provide only conceptual strategies, the expectation is that the reviews will help identify the types of actions that will be part of the plant responses, but not any of the procedure level details associated with FLEX deployment.

The approach for the review of the OIPs was to first identify higher level operator actions that are part of those strategies and then to decompose them into subtasks. The decomposition of the actions into subtasks is required because some of the action subtasks can be characterized by existing HRA methods while others cannot. Because the OIPs do not provide a detailed description of the mitigating actions, some judgment was required in the action decomposition task. Also, without procedures, the details of how the FLEX capabilities are integrated into the plant response are not known, which does not lend to the identification of cognitive modeling challenges. The OIP reviews are, therefore, focused on identifying challenges associated with execution task modeling.

3.2.1 Action Decomposition

The value of the action decomposition task is highly dependent on the methodology that would be used to assess a given action. For example, decomposing the action to install a portable generator into subtasks may be meaningful for a methodology that assigns failure probabilities at a step level, but may not be required for a methodology that is based on performance shaping factors and general action characteristics. For this review, an attempt has been made to decompose the actions to the control manipulation level because the EPRI HRA approach is limited to the use of THERP [4] for execution evaluation. For some actions, such as transportation of portable equipment, the level of decomposition that is required is not clear and the subtasks that have been identified are arbitrary.

Each of the subtasks that were identified were then reviewed and subsequently grouped into generic subtasks that were considered to share the same main characteristics.

Table 3-1 provides a list of the FLEX-like actions that were identified, the site at which the action is performed, the potential subtask associated with the FLEX activity, and the generic subtasks into which they were grouped.

Table 3-2 lists the generic subtasks that were identified as part of the review and provides an assessment of the potential challenges of addressing the subtask using THERP.

Table 3-1
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use the existing diesel driven Auxiliary Feedwater (AFW) Pump to provide steam generator (SG) makeup with local, manual control of the Power Operated Relief Valves (PORVs) (when required).	PWR #1	SG Level control using AFW from the MCR	Level/pressure/temperature control – MCR
		Local operation of SG PORVs for SG	Level/pressure/temperature control – local
		Local operation of a diesel driven AFW pump for SG level control	Level/pressure/temperature control – local
Use a portable pump to provide makeup to the reactor cavity to make up for boiloff in cases where the RPV head is off.	PWR #1	Loading/unloading portable pump	Loading/unloading portable equipment
		Transportation of portable pump and supporting equipment	Transportation of portable equipment (vehicle)
		Clear debris from haul path	Clear debris from haul path
		Connect portable pump hoses/pipes	Connect hose to equipment
		Start of portable pump using a local control panel	Operation of equipment on a local panel
		RCS cavity level control with portable pump (instrumentation availability for level not clear)	Level/pressure/temperature control – MCR/local
		Refuel pump	See activity "Locally start a permanently installed 480V AC generator" below

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Locally start a permanently installed 480V AC generator.	PWR #1	Generator start using a local control panel	Operation of equipment on a local panel
		Circuit breaker manipulation	Select circuit breaker – local Open/close a circuit breaker – local
		Refuel: Connect hoses to portable pump	Connect hose to equipment
		Refuel: Local valve manipulations in the fuel lines	Local, manual valve operation
		Refuel: Local pump operation	Operation of equipment – control located on equipment
		Refuel: Fuel tank transportation and/or vehicle operation	Transportation of portable equipment (vehicle)
Use a portable pump to provide SG makeup.	PWR #1	Loading/unloading portable pump	Loading/unloading portable equipment
		Transportation of portable pump and supporting equipment	Transportation of portable equipment (vehicle)
		Clear debris from haul path	Clear debris from haul path
		Connect portable pump hoses/pipes	Connect hose to equipment
		Start of portable pump using a local control panel	Operation of equipment on a local panel
		Locally control portable pump flow with manual valve manipulation	Level/pressure/temperature control – local
		Locally control SG PORVs for pressure control.	Level/pressure/temperature control – local
		Fuel tank transportation and/or vehicle operation	Transportation of portable equipment (vehicle)

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Alignment of the Regional Response Center Pump[1].	PWR #1	This task in, addition to the above, includes: Transportation of portable pumps from the RRC to the site	Transportation of portable equipment (offsite)
Align Regional Response Center Generator (480V AC and/or 4KV AC).	PWR #1	Transportation of portable generators from the RRC to the site	Transportation of portable equipment (offsite)
		Loading/unloading portable generator	Loading/unloading portable equipment
		Transportation of portable generator and supporting equipment	Transportation of portable equipment (vehicle)
		Generator start using a local control panel	Operation of equipment on a local panel
		Circuit breaker manipulation	Select circuit breaker – local Open/close a circuit breaker – local
		Refuel: Connect hoses to portable pump	Connect hose to equipment
		Refuel: Local valve manipulations in the fuel lines	Local, manual valve operation
		Refuel: Local pump operation	Operation of equipment – control located on equipment
		Refuel: Fuel tank transportation and/or vehicle operation	Transportation of portable equipment (vehicle)

[1] In general, the RRC equipment is intended to replace and/or supplement the on-site FLEX equipment and the subtasks identified for the PWR #1 actions are representative of the types of subtasks that would be required at most sites. The OIPs are generally not detailed enough to provide specific information about challenges associated with transporting offsite RRC equipment to a particular site. These subtasks are not repeated for each site in the OIP review.

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use existing steam driven emergency feedwater (EFW) pump to provide SG makeup with local, manual control of the pump and Atmospheric Dump Valves (if required).	PWR #2	SG Level control using EFW from the MCR	Level/pressure/temperature control – MCR
		Local control of the steam driven EFW pump for SG level control	Level/pressure/temperature control – local
		Local operation of SG ADVs for SG pressure/temperature	Level/pressure/temperature control – local
When the emergency feedwater pump is not available (head off), use gravity feed from the borated water storage tank or the core flooder tank to provide makeup for boiloff.	PWR #2	RCS cavity level control using either remote or local, manual valve manipulations	Level/pressure/temperature control – MCR/local
Manually close containment isolation valves, if required.	PWR #2	Remote containment isolation valve closure	Remote valve operation
		Local manual containment isolation valve closure	Local, manual valve operation
Perform battery load shed.	PWR #2	Open circuit breakers	Select circuit breaker – local Open/close a circuit breaker – local
Provide alternate battery room and inverter room cooling by opening doors.	PWR #2	Open door/prop open door	Prop Open Door

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Align permanently installed electric FLEX emergency RCS charging pumps for inventory makeup.	PWR #2	Locally open manual valves for injection	Local, manual valve operation
		Start permanently installed pump locally	Operation of equipment on a local panel
		Control RCS inventory	Level/pressure/temperature control – local
Align portable diesel AFW FLEX pump with permanent electric FLEX FW pumps for SG inventory makeup.	PWR #2	Locally open manual valves for injection	Local, manual valve operation
		Local pump operation	Operation of equipment – control on equipment
		Control SG inventory	Level/pressure/temperature control – local
		Loading/unloading portable generator	Loading/unloading portable equipment
		Transportation of portable generator and supporting equipment	Transportation of portable equipment (vehicle)
		Connect portable FLEX pump to emergency FLEX FW pump discharge	Connect hose to equipment
		Connect portable FLEX pump to SG header	Connect hose to equipment
Use refueling vehicle to re-supply diesel pump fuel tank.	PWR #2	Refuel: Stage fuel truck for DG refueling	Operation of vehicle - onsite
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX DG generator tank - open flowpath	Local, manual valve operation

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Align portable diesel AFW FLEX pump for RCS inventory makeup.	PWR #2	Loading/unloading portable generator	Loading/unloading portable equipment
		Transportation of portable generator and supporting equipment	Transportation of portable equipment (vehicle)
		Locally open manual valves for injection	Local, manual valve operation
		Local pump operation	Operation of equipment – control on equipment
		Control RCS inventory	Level/pressure/temperature control – local
		Connect portable AFW FLEX pump to charging line	Connect hose to equipment
Use permanently installed FLEX 480V AC diesel generators for system support.	PWR #2	Start generator	Operation of equipment on a local panel
		Align generator to emergency busses	Select circuit breaker – local Open/close a circuit breaker – local
		Initial fueling: Add fuel to FLEX DG generator tank – hose alignment	Connect hose to equipment
		Initial fueling: Start refuel pump	Operation of equipment on a local panel
		Initial fueling: Add fuel to FLEX DG generator tank – open flowpath	Local, manual valve operation
Use refueling vehicle to re-supply DG fuel tank.	PWR #2	Refuel: Stage fuel truck for DG refueling	Operation of vehicle (onsite)
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX DG generator tank - open flowpath	Local, manual valve operation

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Directly align FLEX DG to critical MCC with temporary cable to bypass the emergency buss.	PWR #2	Connect FLEX generator output to MCCs with portable conductor	Make a temporary power connection – non-household
Use reactor core isolation cooling (RCIC) and depressurize to 150-250 psig to maintain steam head for long term injection (procedure change for no emergency depressurization on Heat Capacity Temperature Limit).	BWR #1	Installation of jumpers (to bypass high back pressure trip)	Install jumpers on electrical panel
		RPV level control with RCIC from MCR	Level/pressure/temperature control – MCR
		RPV pressure control with RCIC from MCR	Level/pressure/temperature control – MCR
Align bottled air to support SRV operation.	BWR #1	Open local, manual air tank isolation valve	Local, manual valve operation
Perform battery load shed.	BWR #1	Open circuit breakers	Select circuit breaker – local Open/close a circuit breaker – local
Use portable fans to provide alternate room cooling for the control room, inverter room, battery room, and RCIC room.	BWR #1	Installation of portable fans	Placement/installation of a portable fan
		Install power connection for portable fans (potentially household type connections)	Make a temporary power connection – household
		Install temporary ducts for use with fans	Installation of temporary duct work
		Open/prop open doors	Prop Open Door

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use portable pumps to provide RPV makeup (or suppression pool makeup) through RHR/LPCS via fire hoses.	BWR #1	Locally open manual valves for injection	Local, manual valve operation
		Local pump operation	Operation of equipment on a local panel
		Control RPV inventory	Level/pressure/temperature control – local
		Loading/unloading portable pump	Loading/unloading portable equipment
		Transportation of portable pump and supporting equipment	Transportation of portable equipment (vehicle)
		Connect portable FLEX pump discharge to emergency RHR/LPCS header	Connect hose to equipment
		Connect portable FLEX pump suction to external water source hard pipe header	Connect hose to equipment
Use refueling vehicle to re-supply diesel fuel tank.	BWR #1	Refuel: Stage fuel truck for DG refueling	Operation of vehicle - onsite
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX DG generator tank - open flowpath	Local, manual valve operation
Use diesel FLEX air compressor to charge ADS air supply bottles.	BWR #1	Loading/unloading portable compressor	Loading/unloading portable equipment
		Transportation of portable compressor	Transportation of portable equipment (vehicle)
		Connect portable diesel FLEX compressor to charging station	Connect hose to equipment
		Start compressor	Operation of equipment on a local panel

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use refueling vehicle to re-supply diesel fuel tank.	BWR #1	Refuel: Stage fuel truck for refueling	Operation of vehicle (onsite)
		Refuel: Connect refueling truck to diesel fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX compressor tank - open flowpath	Local, manual valve operation
Use 480V AC FLEX pump to circulate water from the suppression pool to the RHR HX and align cooling water from an external source.	BWR #1	Loading/unloading portable pump	Loading/unloading portable equipment
		Transportation of portable pump	Transportation of portable equipment (vehicle)
		Connect FLEX pump to staged AC emergency power cable	Make a temporary power connection – non-household
		Connect portable FLEX pump to RHR steam condensing piping	Connect hose to equipment
		Align flowpath for flow from the suppression pool to the RHR HX with return to the suppression pool	Local, manual valve operation
		Provide water to the shell side of the RHR HX from external source	Similar to the task for “Use portable pumps to provide RPV makeup through RHR/LPCS via fire hoses”, but with temperature control rather than inventory control
Use permanently installed FLEX 480V AC diesel generators for system support.	BWR #1	Start generator	Operation of equipment on a local panel
		Align generator to emergency busses	Make a temporary power connection – non-household Select circuit breaker – local Open/close a circuit breaker – local

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use refueling vehicle to re-supply DG fuel tank.	BWR #1	Refuel: Stage fuel truck for DG refueling	Operation of vehicle (onsite)
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX DG generator tank – open flowpath	Local, manual valve operation
Use reactor core isolation cooling (RCIC) and containment vent to maintain suppression pool temperature below 230°F.	BWR #2	MCR level control with RCIC	Level/pressure/temperature control – MCR
		MCR suppression pool pressure control	Level/pressure/temperature control – MCR
Use portable FLEX pumps to provide RPV makeup (or suppression pool makeup) through the RHRSW to RHR cross-tie.	BWR #2	Locally open manual valves for injection	Local, manual valve operation
		Local pump operation	Operation of equipment on a local panel
		Control RPV inventory	Level/pressure/temperature control – local
		Loading/unloading portable pump	Loading/unloading portable equipment
		Transportation of portable pump and supporting equipment	Transportation of portable equipment (vehicle)
		Connect portable FLEX pump discharge to emergency RHRSW	Connect hose to equipment
		Connect portable FLEX pump suction to the spray pond hydrant	Connect hose to equipment

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use refueling vehicle to re-supply diesel fuel tank.	BWR #2	Refuel: Stage fuel truck for DG refueling	Operation of vehicle - onsite
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
Use portable 480V AC diesel generator to support battery chargers and SRV operation.	BWR #2	Start generator	Operation of equipment on a local panel
		Loading/unloading portable generator	Loading/unloading portable equipment
		Transportation of portable generator	Transportation of portable equipment (vehicle)
		Align generator to emergency busses	Select circuit breaker – local Open/close a circuit breaker – local Make a temporary power connection – non-household
Use refueling vehicle to re-supply diesel fuel tank.	BWR #2	Refuel: Stage fuel truck for DG refueling	Operation of vehicle (onsite)
		Refuel: Connect refueling truck to DG fuel tank	Connect hose to equipment
		Refuel: Start refuel pump	Operation of equipment on a local panel
		Refuel: Add fuel to FLEX DG generator tank - open flowpath	Local, manual valve operation
Use direct connection from FLEX DG to power an individual battery charger.	BWR #2	Connect FLEX generator output directly to a battery charger with pre-staged cable	Make a temporary power connection – non- household
Perform battery load shed.	BWR #2	Open circuit breakers	Select circuit breaker – local Open/close a circuit breaker – local

Table 3-1 (continued)
Generic FLEX Subtask Identification

FLEX Activity	Site	Potential Subtasks in FLEX Action	Associated Generic Subtask
Use N2 bottles to support SRV operation.	BWR #2	Local open/close manual isolation valves	Local, manual valve operation
Use portable fans to provide alternate room cooling for the control room.	BWR #2	Installation of portable fans	Placement/installation of a portable fan
		Install power connection for portable fans (potentially household type connections)	Make a temporary power connection – household
		Open/prop open doors	Prop Open Door
Open RCIC room doors and blowout panels for alternate room cooling.	BWR #2	Installation of portable fans	Placement/installation of a portable fan
		Install power connection for portable fans (potentially household type connections)	Make a temporary power connection – household
		Install temporary ducts for use with fans	Installation of temporary duct work
		Open/prop open doors	Prop Open Door

Note:
The tasks included in this table are the result of a review of OIPs that are still in development and are subject to change. The subtasks themselves, and details such as control bands or parameter vales, should be considered as examples and not representations of final FLEX designs.

Table 3-2
Quantification Challenges for Generic FLEX Execution Tasks

Generic Subtask Description	Potential Challenges for THERP
Circuit Breaker/Jumper Manipulations Operation	
Open/close a circuit breaker – local	The operation of circuit breakers is addressed by data in Table 13-3 of THERP by the "turn a two position switch in wrong direction or leave it in the wrong setting" error. The overview section of Chapter 13 indicates that while most operating controls in a nuclear power plant are located in the main control room, the data in Chapter 13 applies to controls, in general, regardless of location.
Select circuit breaker – local	The selection of circuit breakers is addressed by data in Table 13-3 of THERP by specific entries for circuit breaker selection errors. The overview section of Chapter 13 indicates that while most operating controls in a nuclear power plant are located in the main control room, the data in Chapter 13 applies to controls, in general, regardless of location.
Install jumpers on electrical panel	The installation of jumpers appears to be addressed by the data in Table 13-3 of THERP by the "improperly mate a connector" error. This is described within that chapter as applying to cables, jumpers, and interlocks.
Control Actions	
Level/pressure/temperature control – MCR	The level control action is an interactive process that involves the use of feedback from instrumentation to make continuous adjustments to the system controls. In this sense it is a hybrid task that includes both cognitive and execution work. Potential failures associated with this process are not explicitly addressed by THERP. Many of the subtasks of the level control action are represented by the failure rates included in NUREG/CR-1278, such as valve control manipulations and instrumentation checks, but even combinations of these failures were not meant to characterize these types of dynamic tasks. This issue is generally overlooked in industry HRAs and it does not represent a capability gap that is unique to FLEX-like actions, but existing HRA methodologies are not well suited to address these issues.

Table 3-2 (continued)
Quantification Challenges for Generic FLEX Execution Tasks

Generic Subtask Description	Potential Challenges for THERP
Control Actions (continued)	
Level/pressure/temperature control – Local	Refer to “Level/pressure/temperature – MCR”, with the following additional issues: Instrumentation: For local control actions, the operators may be relying on temporary indicators (for example, a multimeter) or other non-standard indicators (for example, communication of parameters via radio). These types of issues may be present for some SBO mitigation actions and are not necessarily unique to FLEX applications, but they are additional complicating factors for level control actions. In addition, the actual control schemes may be more complex in FLEX-like applications than in non-FLEX-like applications. In one example, steam generator level control with a portable makeup pump is dependent on a local throttle valve that limits flow to one steam generator and diverts the balance of the flow to the other steam generator. This particular design may ultimately be changed, but it serves as an example of how FLEX-like designs could present additional modeling challenges for HRA (that is, how would an HRA methodology capture the complexity of the control design?).
Control Panel Manipulations	
Operation of equipment on a local panel	The overview section of Chapter 13 indicates that while most operating controls in a nuclear power plant are located in the main control room, the data in Chapter 13 applies to controls, in general, regardless of location. However, the types of controls that are part of some FLEX components are not addressed by the THERP failure data. For example, the control panel for a FLEX diesel driven pump uses a touch screen interface. In cases such as these, there are no means of representing control selection or manipulation failure rates for the start or control of local equipment.
Operation of equipment – control located on equipment	The overview section of Chapter 13 indicates that while most operating controls in a nuclear power plant are located in the main control room, the data in Chapter 13 applies to controls, in general, regardless of location. However, the types of controls that are located of some FLEX components are not addressed by the THERP failure data. For example, a portable generator may have a pull start, which is not represented in NUREG/CR-1278. In cases such as these, there are no means of representing execution failure rates for the start of the local equipment.

Table 3-2 (continued)
Quantification Challenges for Generic FLEX Execution Tasks

Generic Subtask Description	Potential Challenges for THERP
Portable Equipment Transportation and Installation	
Loading/unloading portable equipment	The use of portable equipment, such as a generator, may require the equipment to be moved from its storage location to its staging location. Subtasks of the transportation activity that could result in failure are the loading and unloading phases (due to equipment damage). There are no means in THERP of representing errors in the loading and unloading tasks for portable equipment. Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates; however, this is not a standardized approach.
Transportation of portable equipment (vehicle)	The transportation of portable equipment, such as a generator, may require the equipment to be moved from its storage location to its staging location. Another example would be to drive a fire pumper truck from its storage location to the staging area. Errors could occur during this phase of portable equipment installation that would result in failure of the equipment (for example, a truck crash). There are no means in THERP of representing transportation errors. Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates; however, this is not a standardized approach.
Operation of vehicle – onsite	In some cases, portable pumps are integrated with the vehicle (for example, a fire truck) or a fuel truck is used to resupply engine driven equipment. Errors could occur during this phase of portable equipment installation that would result in failure of the equipment (for example, a truck crash). There are no means in THERP of representing transportation errors. Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates; however, this is not a standardized approach.
Transportation of portable equipment – offsite	In addition to the challenges associated with the transportation of portable equipment using a vehicle on-site, there would be added complications associated with collecting complete information about the staff training, offsite PSFs, and timing estimates. Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates; however, this is not a standardized approach.
Connect hose to equipment	This subtask is not addressed by the THERP data.
Install/remove section of hard pipe or a flange	This subtask is not addressed by the THERP data.

Table 3-2 (continued)
Quantification Challenges for Generic FLEX Execution Tasks

Generic Subtask Description	Potential Challenges for THERP
Portable Equipment Transportation and Installation (continued)	
Make a temporary power connection – non- household	The overview section of Chapter 13 indicates that while most operating controls in a nuclear power plant are located in the main control room, the data in Chapter 13 applies to controls, in general, regardless of location. The installation of cables for temporary power connections appears to be addressed by the data in Table 13-3 of THERP by the "improperly mate a connector" error. This is described within that chapter as applying to cables, jumpers, and interlocks. It is not clear that a cable connection of the type used with a portable generator was intended to be addressed by this error, but the description is consistent with this general type of action and it is not unreasonable to assume it is applicable.
Make a temporary power connection – household	The "improperly mate a connector" error in Table 13-3 of THERP is described as applying to cables, jumpers, and interlocks, which are more complex manipulations than using household outlets. The use of the Table 13-3 data could be used as bounding failure rate for making household-type power connections, but this approach could create an overly conservative bias in the results. Other options within the THERP framework could be used to address this subtask, such as characterizing the failure with an error of omission and an assumption that the failure rate for making the connection is negligible; however, this is not currently a standardized approach.
Clear debris from haul path	For some initiating events, such as high wind events, the pathway between the storage area for the portable equipment and the staging area could become blocked with trees, branches, or other objects located on or near the site. For plants without equipment to move such objects, the feasibility analysis would preclude credit for the use of portable equipment, but for plants with equipment available for this task, the approach to addressing the task is less clear. Debris removal presents at least two different types of modeling difficulty; the determination of "manipulation time" and an error rate. Because the degree of haul path blockage could vary from event to event, it is difficult to provide an assessment of the time that would be required to perform the task. THERP, of course, does not address this type of an action, but it is not yet clear if it would be necessary to assign a failure probability to the task (that is, it may only be necessary to account for the time to clear the path and treat it as part of the "travel time").

Table 3-2 (continued)
Quantification Challenges for Generic FLEX Execution Tasks

Generic Subtask Description	Potential Challenges for THERP
Portable Room Cooling Installation	
Placement/installation of a portable fan	This subtask is not addressed by the THERP data. Other options within the THERP framework could be used to address this subtask, such as characterizing the failure with an error of omission and an assumption that the failure rate for placing the fan is negligible; however, this is not currently a standardized approach.
Installation of temporary duct work	This subtask is not addressed by the THERP data.
Prop open door	This subtask is not addressed by the THERP data. Other options within the THERP framework could be used to address this subtask, such as characterizing the failure with an error of omission and an assumption that the failure rate for opening the door is negligible; however, this is not currently a standardized approach.
Valve Manipulations	
Remote valve operation	Addressed by the control selection and operation errors in THERP Table 13-3.
Local, manual valve operation	Local valve manipulations are addressed by Table 14-1 of THERP. The characteristics of the local valve groups are representative of valves that are mounted on permanently installed equipment. While it is not clear that the failure rates were intended to be used for valves attached to temporary hoses or on portable pumps, there are also not clear differences in the operational characteristics of these types of valves that would preclude the use of the THERP data for these applications.

Note:
The ASEP methodology [5], which is based on THERP, does provide generic post diagnosis task failure rates that could potentially be applied to non-standard subtasks; however, it is not clear that the scope of the generic tasks was intended to envelop the range of ex-MCR types of tasks that are common in FLEX-like applications.

3.3 FLEX Procedure Review

In some cases, utilities were able to provide complete or nearly complete procedures that were helpful in assessing the characteristics of how the FLEX strategies would be implemented at the site. These procedures were reviewed to identify characteristics that would pose potential challenges for evaluating the actions using the EPRI HRA approach (both cognitive and execution issues). Specifically, procedures related to the following actions were reviewed:

- Task 1: Spent fuel pool makeup (BWR #3)
- Task 2: Align SG makeup pump (PWR #4)
- Task 3: Align portable AC generator to SG level instruments (PWR #4)
- Task 4: Open door for EDG room cooling (PWR #4)
- Task 5: Align FLEX pump to provide RPV, SFP, or SP makeup water from the spray pond via RHRSW and RHR piping (BWR #2)
- Task 6: Align FLEX generator to support the battery charger (BWR #2)
- Task 7: Align portable room ventilation (BWR #2)
- Task 8: ADS valve emergency operation (BWR #4)
- Task 9: FLEX pump operation (BWR #5)
- Task 10: Portable gasoline powered generator (PWR #5)
- Task 11: Align Portable 120V AC diesel generator for instrumentation support (PWR #6)
- Task 12: Notify Regional Response Center of ELAP (PWR #6)
- Task 13: Alternate RCS injection with portable pump (PWR #6)
- Task 14: Alternate RCS boration (PWR #6)
- Task 15: Deploy Regional Response Center equipment (PWR #6)
- Task 16: Re-supply critical loads using temporary cables (PWR #7)
- Task 17: Use mobile fire pump to pressurize injection header (PWR #7)

Table 3-3 provides the results of the procedure review.

Table 3-3
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 1: Provide spent fuel pool makeup.	The EOP for secondary containment control currently includes guidance to maintain fuel pool level first by the normal method, and then by alternate methods if level falls below the control band. The B.5.b pumps are listed as potential means of restoring level with references to the governing procedures. The FLEX capabilities will be similarly integrated when the procedures are completed.	The procedure structure is similar to what is used for alternate injection strategies that are currently credited in PRAs and there are no issues unique to FLEX introduced by this procedure structure; however, it does present a potential difficulty in the timing assessment. The challenge associated with defining a time line when multiple other alignments are available and may or may not be attempted before the use of the FLEX equipment. Unless there is preferred order dictated by the procedures, crediting FLEX equipment may require an assumption that all other options are attempted first. The action cue is also ambiguous in these cases (for example, would it be fuel pool level out of range or failure of the last makeup source preferred over FLEX)?	N/A – The procedure provided did not include the execution steps.	N/A – The procedure provided did not include the execution steps.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 2: Align SG makeup pump.	The governing procedure includes different steps that could result in the deployment of the portable SG makeup pump. "Step 4" directs operators to be dispatched to align the pump if they are available "Step 5" directs the alignment and use of the pump "as necessary".	Determining operator "availability" would likely not be an issue for operations personnel in the scenario, but it is an area of ambiguity in the direction to initiate the action. Unless there are dedicated personnel for portable makeup up alignment, it would be difficult to credit initiation of the action at step 4. For step 5, the determination of "as necessary" would likely correlate to conditions in which AFW has failed or is in maintenance and should not present any unique issues. The larger issue for the use of the procedure, which is not necessarily only an HRA issue, is that it is written for a loss of command and control and the entry conditions do not cover the situations in which FLEX would be used in the PRA.	Step by step guidance is provided for pump transportation, hose connections, flange removal, valve de-energization, valve movements, and so on	The types of subtasks involved with this activity are addressed in Table 3-2. One issue that is not addressed is that the large number of steps involved with the activity (30-40) can be problematic for any THERP application. The large number of steps can result in unrealistically large HEPs, primarily because it is difficult to identify all of the recovery mechanisms that could realistically recover errors for each of the steps.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 3: Align portable AC generator to SG level instruments (and control level).	The cue for alignment of the generator is not clearly stated. The “scope” subsection of the section directing alignment of the portable SG makeup pump indicates that at least one SG level loop is energized with a reference to the section governing generator alignment. In addition, there is a step that states if SG level indication can be recovered, it should be maintained on scale with a reference to the section governing generator alignment.	This is not a FLEX specific issue; but the guidance is not clear about when the step should be initiated (that is, before the portable SG makeup pump is aligned, or after flow has been established and the step directing level control is read). This is a generic procedure structure/quality issue and not a FLEX specific challenge.	Portable Generator Deployment: Step by step guidance is provided for the alignment action, including temporary power connections, generator placement, and breaker manipulations. SG Level Control: Step by step guidance is provided for local operation of the AFW pumps, which includes local breaker and valve manipulations.	The generic tasks associated with this action are addressed in Table 3-2.
Task 4: Open door for EDG room cooling.	No guidance currently exists. A procedure enhancement was suggested as part of the action evaluation.	N/A.	No guidance currently exists. A procedure enhancement was suggested as part of the action evaluation.	The types of subtasks involved with this activity are addressed in Table 3-2.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 5: Align FLEX pump to provide RPV, SFP, or SP makeup water from the spray pond via RHRSW and RHR piping.	Link to procedure not yet defined.	N/A.	Step by step guidance is provided for the alignment action. Requires the use of security personnel to open normally locked areas. FLEX pump must be transported by trailer from storage location to staging location. Requires fire hose runs and connections. Requires removal of flanges. Flow control by RPM via digital controls (engine RPM up/down) based on communication from shift supervisor (level instrument not specified there). Refueling of FLEX pump directed, but the guidance is not yet complete and refers to the instructions on the fuel pump to support operation (which are not reproduced in the procedure).	The types of subtasks involved with this activity are addressed in Table 3-2. The reliance on security personnel to provide access to areas where work must be performed is not necessarily an issue unique to FLEX-like applications, but it does add an additional element to the timing assessments that must be accounted for relative to most FPIE tasks. Extensive number of steps making THERP modeling a challenge. The refueling task is similar in nature to the alignment of a portable pump for RPV makeup. It is not clear if a separate HEP is required to model refueling failure, or if this type of task can be assumed to be negligible (or completely dependent on initial alignment of the equipment).

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 6: Align FLEX generator to support the battery charger.	Link to procedure not yet defined.	N/A.	Portable Generator Deployment: Step by step guidance is provided for the alignment action, including temporary power connections, generator placement, and breaker manipulations. Step by step guidance is provided for the electrical connection of the generator to the MCC. Refueling the generator is a multi-step process requiring the use of a portable, electric transfer pump and temporary hoses.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge. The refueling task is similar in nature to the alignment of a portable pump for RPV makeup. It is not clear if a separate HEP is required to model refueling failure, or if this type of task can be assumed to be negligible (or completely dependent on initial alignment of the equipment).
Task 7: Align portable room ventilation.	Directed from within FLEX generator alignment procedure using language common to internal events procedures. Directs portable ventilation to be aligned within 24 hours.	No FLEX-specific challenges.	There is step by step guidance directing the placement of fans and the positioning of doors.	The types of subtasks involved with this activity are addressed in Table 3-2.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 8: ADS valve emergency operation.	The link to the step by step alignment procedure is provided by contingency procedures. The contingency procedure itself is entered on conditions that are also general (plant conditions require taking actions to cope with beyond design basis events). The contingency procedures activate the step-by-step procedure by general guidance that says to use the procedure if "operation of ADS SRVs is required" combined with conditions that represent this case (DC control power not available or safety related air not available to ADS SRVs).	Initiating an action or procedure path that is based on judgment is difficult to assess. In this case, there may be some ambiguity about when the contingency procedure would be activated. For example, if there are other abnormal operating procedures that include potential success paths, the timing of the entry into the contingency procedure may depend the operators' assessment of potential success paths outside of the contingency procedures. The entry into the contingency procedures is ultimately based on a judgment that they are required and the operators' knowledge that they contain useful processes. The CBDTM has some capability of assessing the characteristics of procedures, but it generally focuses on the structure and language of the procedure rather than on the use of judgment.	Step by step guidance is provided for ADS operation and connection of control circuits, but only general guidance is provided for portable generator and compressor setup. References hard card procedure for generator and compressor use, but they were not included for review. Includes hose/air line connections, temp power connections, jumper work. Selection/identification of connection points on portable equipment is required. Operation of ADS valves requires the use of a temporary control box.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 8: ADS valve emergency operation (continued).		ASEP and HCR/ORE depend on having a cue defined, so if there is difficulty determining what specific events would represent the conditions that would warrant entry into the procedure (a cue), it would difficult to apply these methods without using some type of bounding assumptions. This approach may lead to overly conservative results.		
Task 9: FLEX pump operation.	The link to the step by step alignment procedure is provided by contingency procedures. The contingency procedure itself is entered on conditions that may not represent all of the conditions in which FLEX could be used. While an entry condition such as “Significant Plant Damage” could be interpreted to allow use in scenarios where a transient event initiated the accident scenario, there is still some judgment required to assess this condition.	Initiating an action or procedure path that is based on judgment is difficult to assess. In this case, there may be some ambiguity about when the contingency procedure would be activated. For example, if there are other abnormal operating procedures that include potential success paths, the timing of the entry into the contingency procedure may depend the operators’ assessment of their ability to control the plant using non-contingency methods.	Step by step guidance is available for pump setup and various water sources, and injection paths are addressed. Pump flow control is governed by interpreting a pump curve with discharge head, pressure, and engine RMP. Pump design appears to include a means of failing the pump by opening a pressurized suction source before engine start (a potentially important error of commission (EOC)).	Most of the types of subtasks involved with this activity are addressed in Table 3-2, but the level of difficulty of the control task is complicated by the need to interpret pump curves to obtain flow rates. In this case, there is the added complication of an EOC that may be significant (that is, a simple alignment error could fail the pump).

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 9: FLEX pump operation (continued).	The contingency procedures activate the step-by-step procedure through a clear step that indicates the FLEX pump should be used when no other injection sources are available.	This is not necessarily a FLEX specific issue, but it may be more common in FLEX applications where the procedures directing the alignment of the equipment are separate from the EOPs (rather than integrated into the EOPs). The CBDTM has some capability of assessing the characteristics of procedures, but it generally focuses on the structure and language of the procedure rather than on the use of judgment.	Engine start guidance is step by step and the controls appear to be similar to MCR controls. For ASEP and HCR/ORE, when there is difficulty determining what the cue is, the time it is reached is difficult to define. Within the contingency procedure, there is a list of the primary procedures for station response for each function. For RPV control, the contingency procedure is one of several procedures. In this case, the procedure is clear in that it states the pump should be used if no other installed makeup source is available. No specific challenges with this guidance.	None of the methodologies included in the EPRI approach are designed to quantify EOCs. Extensive number of steps making THERP modeling a challenge.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 10: Portable gasoline powered generator for AFW support.	The abnormal operating procedure for loss of AC bus power sources provides clear guidance to initiate attachments that lead to the deployment of the portable generator. If power to the essential 480V buses cannot be restored within 15 minutes, then the attachment is initiated that directs load shedding and portable generator deployment as part of the procedure path (no additional cognitive work required).	This is no different than typical FPIE actions and is well characterized by current HRA methods.	A procedure attachment governs deployment of the portable generator, which is limited to the high level step of "Place the portable gasoline powered generator in a suitable location on the Turbine Deck." The equipment location is noted in the procedure. Step by step guidance is available for the electrical connections, which include temporary power connections and breaker manipulations. Engine start steps are not listed. Refueling is directed, but no details about fuel sources or equipment is provided.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge. The refueling task details are not provided. It is not clear if a separate HEP is required to model refueling failure, or if this type of task can be assumed to be negligible (or completely dependent on initial alignment of the equipment).

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 11: Align portable 120V AC diesel generator for instrumentation support.	The alignment of the generator is directed from a FLEX support guideline, which is entered from the plant's loss of all AC power procedure based on the condition that AC power cannot be recovered within 60 minutes. Within the FLEX support guideline, the procedure questions whether or not the portable generator is in service and if it is not, the guidance directs alignment of the generator. One component action that is included in the FLEX support guideline is to remove debris from the haul path of the generator. The action is directed as part of the procedure path typical of PWR EOPs, but it does indicate that the areas to be cleared can be prioritized based on the FLEX equipment deployment sequence.	There is some judgment involved, but the procedure structure appears to limit the potential delay time to transition to the FLEX support guideline to 60 minutes. It may be difficult to justify entry into the FLEX support guideline prior to 60 minutes, but the EPRI HRA approach includes methodologies that are capable of modeling this type of guidance. The step in the FLEX support guideline governing the deployment of the generator is consistent with typical PWR procedures and does not present any unique challenges. The step in the FLEX support guideline directing debris removal is clear, but if it is necessary to credit a particular sequence of debris removal to ensure success, none of the methodologies in the EPRI HRA approach provide a clear means of quantifying that the prioritization would be done correctly. Depending on the conditions of the scenario, priority of the deployment may vary.	Portable Generator Deployment: Step by step guidance is provided for the alignment action, including temporary power connections, generator placement, and breaker manipulations. The power supply configuration includes the use of a local distribution panel. Refueling is directed as a long term consideration, but only general guidance is provided, such as to deploy portable fuel transfer pumps/carts. The guidance for debris removal is limited to the direction to use the designated equipment to do so. A diagram is provided to indicate the correct path.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge. It is not clear if a separate HEP is required to model refueling failure, or if this type of task can be assumed to be negligible (or completely dependent on initial alignment of the equipment). Debris removal is a skill of the craft type action and detailed guidance is not required, but the action is not characterized by the THERP failure data.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 12: Notify regional response center of ELAP.	The direction to contact the Regional Response Center (RRC) is directed from a FLEX support guideline (FSG), which is entered from the plant's loss of all AC power procedure based on the condition that AC power cannot be recovered within 60 minutes. Within the FLEX support guideline, the procedure directs the contact to be made without any other conditions. There is a note indicating that the contact should be made within one hour of ELAP declaration.	There is some judgment involved in when to transition to the FSG, but the procedure structure appears to limit the potential delay time to transition to the FSG to 60 minutes. It may be difficult to justify entry into the FSG prior to 60 minutes, but the EPRI HRA approach includes methodologies that are capable of modeling this type of guidance. The step to initiate RRC contact is consistent with typical PWR EOPs and no challenges have been identified for an evaluation of this step.	N/A	N/A

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 13: Alternate RCS injection with portable pump.	The loss of AC power procedure directs the use of an FSG for RCS inventory control when AC power has not been restored, personnel are available, and specific RCS pressure and level conditions are met.	The structure is typical of PWR EOPs and the conditions for action initiation are clear with the exception of the condition of time and personnel availability. Establishing when the action would be initiated may be difficult because it may depend on a judgment about the priority of competing tasks. Crediting the action may require the development of a detailed resource chart and timeline and an assumption about plant conditions to determine a realistic time about when deployment could begin.	Step by step guidance is provided for the pump deployment, including temporary hose connections, pump placement, and valve manipulations. Level control is via communication with the MCR and pump start and stop. Refueling is directed as a long term consideration, but only general guidance is provided, such as to deploy portable fuel transfer pumps/carts.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge. It is not clear if a separate HEP is required to model refueling failure, or if this type of task can be assumed to be negligible (or completely dependent on initial alignment of the equipment).

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 14: Alternate RCS boration.	Similar to Task 13, but the action is initiated on a specified time from event initiation. One step includes both cognitive and execution elements, which is the step to mix the borated water solution for cases when the RWST is not available.	The cue is clear for this action, but the time from the event would be a parameter tracked by the operator rather than an instrument gauge. None of the EPRI HRA approach cognitive methodologies are geared toward quantifying errors when performing calculations (see execution assessment).	Similar to Task 13, but the steps related to the alignment of the portable batch tank are less detailed (for example, specific hose connections points are not identified). The alignment appears to include steps similar to those for a portable pump, such as making temporary hose connections and performing local valve manipulations. The procedures provide step by step for performing boron mixing.	Similar to Task 13, but with the additional challenge of modeling the boron mixing task. THERP provides limited capabilities for quantifying arithmetic errors in execution steps. There are failure probabilities in Chapter 11 related to performing simple calculations when interpreting instrument displays, but it is not clear that they were intended to be used or would be applicable to performing calculations to determine the correct boron concentration. Further, there is no process to determine if an error in the arithmetic would be significant enough that it would result in a boron concentration that would lead to re-criticality.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 15: Deploy regional response center equipment.	The direction to prepare for the arrival of the RRC equipment is directed from a FLEX support guideline (FSG). Within the FLEX support guideline, the direction to perform the preparation actions is part of the procedure path without any additional conditions for action. The detailed guidance for the preparation actions is not complete, but will include the deployment of temporary 4KV cables and water tank makeup actions. The procedure indicates that the 4KV generator alignment is a top priority when the RRC equipment is delivered, but the priority of deploying the remaining equipment is left to judgment.	The procedure directs the RRC preparation actions without any additional conditions and it represents a clear cue for the actions to be performed, but the time when the step would be reached may be difficult to establish. Some preceding actions may not be taken depending on plant conditions while others may require continuous attention depending on how successful the mitigation actions have been. The timing assessment will require the development of a detailed timeline with resource loading estimates. Leaving the prioritization of RRC equipment deployment to the operators provides flexibility, but the methodologies in the ERPI HRA approach are not well suited to assessing this type of cognitive work. The CBDTM has some capability of assessing the characteristics of procedures, but it generally focuses on the structure and language of the procedure rather than on the use of judgment.	There are some unique steps related to using the RRC equipment, but the guidance is not fully developed for those steps. The remaining steps of the RRC equipment deployment guidance reference the same procedure steps used for the on-site FLEX equipment.	The types of subtasks involved with this activity are addressed in Table 3-2. Extensive number of steps making THERP modeling a challenge.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 15: Deploy regional response center equipment (continued).		ASEP and HCR/ORE depend on having a cue defined, but for a prioritization task, the cognitive work depends on the equipment failures that have occurred in the event. By definition, these events are variable making the timing and nature of the conditions that would inform the prioritization task unknown. ASEP and HCR/ORE are not well suited to assessing this type of cognitive work.		

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 16: Re-supply critical loads using temporary cables.	The procedure containing the cognitive link to the guidance governing the alignment was not provided.	N/A.	The guidance is written at the step-by-step level with visual aids, such as diagrams and photo figures, to support the alignment process. The guidance is separated into different sections, each of which is associated with supplying a specific load. The subtasks include running temporary cable to loads, making temporary power connections, manipulation of breakers, and other steps associated with accessing and securing the electrical terminations. One subtask includes checking that the polarity of a connection was correctly performed by temporarily connecting power to the pump to check the direction of rotation.	Most of the types of subtasks involved with this activity are addressed in Table 3-2. There are some unique items, such as the polarity check subtask, that are not included in Table 3-2 and represent an additional gap in failure data.

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 16: Re-supply critical loads using temporary cables (continued).			This example highlights that there will be cases where step by step evaluations will require a means of accommodating unique actions, (unique even from a FLEX perspective). The ability to credit this type of check and the probability that can be justified for it could significantly influence a final HEP. It is not clear that a general self-check HEP can be applied when a unique action is taken that was not part of the original performance steps. How this type of step is addressed could mean the difference in recovery credit from 1.0, to 0.5, to some lower value (for example, 1E-3).	

Table 3-3 (continued)
FLEX Procedure Review

FLEX Activity	Cognitive Guidance Description	Comments/Issues	Execution Guidance Description	Comments/Issues
Task 17: Use mobile fire pump to pressurize injection header.	The procedure containing the cognitive link to the guidance governing the alignment was not provided.	N/A.	The guidance is generally written at the step-by-step level with visual aids, such as diagrams and photo figures, to support the alignment. Actions to start the pump and alter the engine speed are not detailed beyond that level. Control of the pump is directed from the MCR. Local actions are taken to adjust pump engine speed to meet demand with direction not to exceed an ultimate discharge pressure on the pump.	The types of subtasks involved with this activity appear to be addressed in Table 3-2, but because the details of the pump controls are not provided, it is not clear if the pump controls are of a type that would be addressed by THERP or if they are of a design that is not covered (for example, digital controls).

3.4 Issues Identified By Other Means

In addition to the issues identified through OIP and procedure review, other potential challenges can be identified a priori and through previous industry experience. These issues are listed, in no particular order, and discussed below. These issues are general to FLEX; issues that arise specifically in the context of external flooding are further discussed in [9]; human performance factors specific to seismic are further discussed in [10].

Changes to command and control centers. In some accident scenarios, it becomes necessary to evacuate the MCR (for example, in a fire), which can leave the operators with reduced capabilities relative to the MCR. The types of degradations include:

- A reduced set of instrumentation/controls: If the operators establish control at an alternate shutdown panel, the range of instruments/controls may be limited to a single division. Most instruments and system controls that are not critical to reactor control are not available at all. If the alternate shutdown panel is unavailable, the instrumentation and controls could be limited to local controls and/or the use of multimeters to measure and convert voltages to the appropriate units of measure.
- Communications: In most cases, the alternate shutdown panel would be equipped with adequate communication, but some local action locations may preclude reception. In the case where the alternate shutdown panel is not available, the plant control would likely be dependent on the transmittal of plant information via radio.
- Adverse environment: Rather than operating in a controlled environment, the operators may be required to work in physically demanding conditions.

The time reliability curves, such as ASEP and HCR/ORE, do not account for these types of issues. The CBDTM can address many of the characteristics related to the availability/quality of the cue indications and the level of training the operators have had on the indicators, but it is not designed to address the impact of environmental PSFs.

For the execution error, most controls that would normally be taken in the MCR would have remote shutdown panel or local controls that are addressed by the THERP data. For example, if a pump must be started by manipulation of a local breaker, THERP does address breaker operations. In some cases, ex-MCR actions may require the use of controls that are not addressed by THERP. These cases, like some of those related to the installation of portable FLEX equipment, would not have a technical basis for evaluation.

In some cases, the chain of command becomes more complicated; plant actions may be directed or influenced by an outside agency, such as the utility headquarters, state government, or federal government. Input, or pressures from these types of organizations may impact the timing of actions that are either directly modeled in the PRA such as flooding preventative actions, containment venting, or other actions that are indirectly modeled, such as the time when the evacuation of the local population is ordered. Outside organizations may also devise potential recovery processes that could mitigate equipment failures. There are generally no functions in the EPRI HRA methodologies to model the impact of these external influences on human reliability.

Performance of HEP dependency analysis including FLEX actions. The incorporation of FLEX equipment into a PRA will, in many cases, result in the combination of FLEX-related HFEs with other HFEs from the PRA model. There are no specific characteristics related to the FLEX-like actions that would preclude the application of the THERP dependency model to these combinations; however, the industry has limited experience in performing this task and good practices for addressing the combinations have not yet been developed. One issue that has the potential to confound the dependency analysis is the application of a "floor" value for JHEPs. In many scenarios where FLEX equipment could be used, multiple other mitigating actions may have already been attempted. In these cases, it is possible that the total failure probability for the non-FLEX HFEs may already be at or near the NUREG-1792 [11] lower limit for human response in an accident scenario (1.0E-05). While the applicability of a floor value is currently an open issue in the industry, the benefit of incorporating FLEX equipment may be significantly limited depending on the resolution of this issue.

The potential need for FLEX specific pre-initiator HFEs in system models. In some cases, the integration of FLEX equipment into the PRA may introduce additional standard pre-initiator actions (misalignments of valves in flow paths, miscalibrations of local flow indicators) that can affect the availability of both existing and FLEX equipment; for example addition of a hook up point for FLEX equipment can now introduce the potential for a diverted flow path that did not previously exist for an installed piece of equipment. A review of the plant changes will be required to determine if any new events are warranted.

In other cases, some new types of pre-initiators may be relevant. For example, the vehicle required for portable equipment transportation may have been used for another task and not returned to its designated location. Some consideration would have to be given to determine if this type of failure should be addressed as a Type A human error or as a subset of a hardware failure, but at this time, there is not a standardized approach to address this issue.

THERP would address the standard Type A errors, but the non-standard errors could include events that would not have a technical basis for evaluation.

The detailed ASEP pre-initiator methodology, which is described by NUREG-1842 [8] is capable of supporting detailed pre-initiator calculations, uses general HEPs to address pre-initiator failures at the overall action level (that is, miscalibration of a sensor rather than failure to connect hose A to point B in the calibration task). The ASEP general HEP is not task specific, but it was developed based on a review of power plant tasks and it is not likely that all FLEX-like pre-initiator tasks, such as maintaining a full, fresh tank of fuel, were considered to be within the scope of the types of tasks for which the event was developed. ASEP does not appear to represent an alternate evaluation tool for Type A events that are not addressed by THERP.

FLEX-specific feasibility analysis. Part of the HRA process is to demonstrate that the action being credited is feasible. For FLEX-like actions, there are some additional challenges associated with this task, including:

- Validation of RRC deployment times. In the event that equipment from the RRC must be credited, it is unlikely that the full deployment action will have been practiced and timed. Timing estimates may only be supported by the judgment of the personnel responsible for the deployment or by a general assumption that 24 hours is sufficient time to perform the task.

For the range of initiating events that may require the deployment of RRC equipment, a full assessment of the impact on the RRC of the events (for example, a hurricane) may not be available. In most cases, the details related to the RRC deployment tasks will not be known to the HRA analyst.

- Validation of on-site FLEX action times. For some portions of the onsite FLEX deployment, it may not be practical to practice or simulate a full deployment and some manipulation times may only be supported by estimates (with no alignment experience specific to the FLEX task). For example, connecting a local, portable control board to the SRV control cables via jumper connections would be undesirable in most plant conditions.
- Addressing impacts of external events on deployment. Because FLEX-like actions may be credited for a range of external events scenarios, it may be necessary to justify the performance of tasks in extreme conditions. This may be a resource intensive process that involves more than the HRA practitioner given that the assessment could require projected impacts of high wind events on haul paths or an estimate of flood levels in equipment deployment areas over the course of the scenario. In addition, if the actions must be performed in extreme conditions, there is very limited guidance in Chapter 3 of NUREG/CR-1278 [4] on how to correlate environmental conditions to reliability.
- Addressing long term viability. Some portions of the portable equipment deployment plan, such as refueling, may not be documented in detail. If upkeep actions are required to maintain portable equipment, the feasibility analysis should address all the elements of that process. If the use of a fuel truck from an offsite source is required, some justification of its availability in extreme events (such as an earthquake or high wind event) would be required.

If there are elements of the feasibility analysis that cannot be supported with anything more than judgment, additional work will likely be required to develop an approach that will provide an acceptable basis for crediting the FLEX-like actions. This approach should include a method to estimate incorporate uncertainty.

Long term control actions. As identified in the generic subtask assessment in Table 3-2, “control” actions are not well characterized by the methodologies in the EPRI HRA approach. An additional concern, however, is that a control action is a dynamic task and it is not clear that a single assessment of the task at the time of alignment would address the potential for error over the entire period for which it is performed. While these actions may be easily recoverable in some instances, long term actions may involve complicating factors like level control with degraded instrumentation, such that a failure to keep the core covered may not be obvious until it is too late.

Multiple objective decision-making. The need to make decisions about how to allocate resources to support multiple mitigating actions is not unique to FLEX (for example, the direction to align injection sources in BWR EOPs is a non-FLEX example of this situation), but in FLEX-like applications, it may be more common for the governing procedure or procedure step to direct multiple actions to support completely different functions (for example, deploy battery chargers to support SG level instrumentation and portable pumps for primary RCS makeup). The distinction potentially indicates that the cognitive work in FLEX-like applications may be more complex, but ultimately, the same challenge of evaluating the probability of failing to prioritize actions is encountered. If there is a need to prioritize the performance of tasks for success and the procedures do not specify the required order of performance, the methodologies in the EPRI HRA approach are not well suited to assessing the probability of failing to determine the appropriate order of tasks. This type of task prioritization may also extend to the requirement to organize multiple, large groups of personnel where task order and coordination between groups is important. For example, it may be critical to initiate drain plugging actions as part of flood preparations in time to allow the same personnel to be available to support the installation of specific flood gates at a subsequent time in the same scenario.

Human performance limits. In the event that a long term scenario occurs with limited to no opportunity for relief from extra crew, the reliability of alignment, control, and upkeep tasks could degrade. In addition, it may be difficult to anticipate/identify all of the factors that could impact the operators. Depending on the scenario and the specific action, there may be concerns with ensuring plant personnel have a sufficient supply of food, water, or that HVAC is sufficient in the areas where work is required. There is not a standardized approach to assess how factors such as these, or even something as common as lack of sleep, might impact reliability.

Training and staffing uncertainty. Training programs vary in the frequency and depth of training provided on the plant procedures. EOP actions are generally considered to be well trained and that all MCR operators have had the training on the EOPs. For other types of actions, such as those in abnormal operating procedures, there may be limited training performed or in some cases, no training, and the level of training would vary from plant to plant. In this respect, the FLEX-like actions will not be significantly different from other actions.

For FLEX deployment, however, if there are actions that require the arrival of offsite personnel, it may be difficult to justify credit for the actions for all scenarios.

Recovering temporary equipment impacted by scenario conditions. Temporary equipment may be more susceptible to the consequences of environmental conditions than permanently installed equipment. In certain evolutions, some type of recovery work could be required to restore equipment functionality after a disruption in operation. For example, a portable injection pump could be impacted by debris in a high wind event or an aftershock in a seismic event could knock a portable generator over.

While these types of events are possible, accounting for them in a PRA would not only require an assessment of the corrective operator response, but also of the probability that a secondary event occurs during the mitigation phase of the event (for example, an aftershock) and the probability that such an event impacts the temporary equipment in a significant way. There are no means of reliably quantifying the probabilities of these types of types of evolutions. Conservative estimates could be used to account for these scenarios, but they are likely smaller contributors to the overall failure probabilities of temporary equipment and the development of strategies to evaluate the associated recovery actions is not considered to be a top priority.

Evaluating actions with cues from off-site sources. In some cases, FLEX-like actions may be based on information from an information source that is not located on-site and/or is associated with events that are not related to plant operations. These conditions could represent scenarios where it would not be possible to justify the timely performance of critical actions.

For example, for dam break scenarios, the successful deployment of portable pumps may rely on a timely notification of the dam break. If the plant response is dependent on a report of the dam break from an offsite source, there is a challenge of assessing a response by personnel to which the HRA practitioner may have no access. In addition, the means by which a dam break event would be identified and the guidance governing the response of the offsite personnel (as well as other factors) may be unknown.

Another example of challenges related to the use of off-site data is the use of weather reports as part of action cues. In the case where successful flood protection actions require one or more days of preparation, the daily collection of a weather report may be performed 4 hours before a 36 hour flood warning is issued. For actions that require 24 hours of preparation, the next day's collection time could theoretically come too late to ensure flood protection actions are started on time. It is unlikely that such a severe weather report would not come to the attention of plant personnel in the required time, but it is difficult to demonstrate that would be true in an HRA unless there are specific mechanisms in place to ensure the plant is notified of events that are critical to all action cues.

Phased cues. For FLEX–like applications that require the setup of portable equipment, there may be separate conditions that would (1) initiate deployment of the equipment, and (2) actuate the equipment. For example, deployment of a portable injection pump may be directed at the onset of SBO conditions, but the start of the pump may not be directed until a low SG level condition is reached. In other cases, a single cue may initiate a procedure path that directs both the setup and start of the portable equipment. In the event that the procedures are written adequately, these conditions do not challenge the capabilities of methodologies used in the EPRI HRA approach as long as the actions are decomposed properly. In the event that the procedures do not provide all of the required cues, the problem would be one of procedure adequacy rather than HRA capability.

Similarly, modeling the use of equipment from the RRC would depend on the availability of clear cues that define the conditions in which the equipment should be requested.

Multi-unit, multi-site coordination. For sites with multiple units, there may be situations at more than one unit that require the attention of the Technical Support Center (TSC), or equivalent, simultaneously. This could present a condition in which the resources required to resolve critical issues at both units are not available when required. In scenarios such as these, the credit taken for TSC activity could be limited. However, the resolution of the methodologies included in the EPRI HRA approach is not refined enough to address this type of issue. The treatment of TSC activity is limited to reducing the probabilities of specific cognitive failure mechanisms in the EPRI Cause Based Decision Tree Methodology in scenarios where sufficient time has passed to establish the TSC; there is no consideration of TSC task loading. The need to account for demands on the TSC staff is not an issue that is unique to FLEX-like applications; however, the timing of FLEX-like actions may dictate that TSC credit will play a more common role in HRA evaluations than for non-FLEX HFEs. The concern in these cases is that the benefit of the TSC may be overstated.

Additional effort could be expended to better define the composition of the TSC and the roles of the staff members to confirm/document that there are at least theoretically a sufficient number of people to address multi-unit accident scenarios; however, the dynamic nature of severe accident scenarios would make it difficult to ensure that a person with the required expertise would be available to address every challenge. The effort involved with performing a task analysis would likely be large compared with the benefit that is prescribed by the CBDTM. If there are competing priorities and inadequate staff to simultaneously address challenges, the methodologies in the EPRI HRA approach do not provide a means of assessing the failure probabilities related to task prioritization. A potential approach to address cases in which there are multi-unit accidents would be to preclude TSC credit for the analyzed unit.

Similarly, it may be necessary for the RRC to respond to events that have impacted multiple sites (for example, regional flooding). A detailed analysis of RRC resource loading could be attempted if enough information about the RRC's equipment and personnel can be obtained, but the resulting risk reduction benefit may be limited. Again, if there are competing priorities and inadequate staff/equipment to perform simultaneous deployments, the methodologies in the EPRI HRA approach do not provide a means of assessing the failure probabilities related to task prioritization. A potential approach to address cases in which there are regional events that would impact multiple sites would be to preclude RRC credit for the analyzed unit.

Applicability of HCR/ORE. The HCR/ORE data was collected from scenarios modeled in the simulator for actions diagnosed and performed in the MCR. The decision making process for these types of actions, which is represented by the median response time, may be significantly different than for FLEX-like actions. The decision to use FLEX equipment may, for example, require consultation with the technical support center or other personnel and the nature of the decision making process may be dissimilar to the processes captured by the HCR/ORE scenarios. The use of HCR/ORE to model the cognitive non-response probabilities for some FLEX-like actions may not be appropriate.

3.5 Gap Summary

The review of the FLEX OIPs and procedures resulted in the identification of HRA modeling challenges both unique to FLEX-like actions as well as some that are also applicable to the types of HFEs typically included in existing PRAs. Table 3-4 provides a summary of the issues that have been identified, methods that either have been or could be used to address the issues (ad-hoc methods), and areas for further investigation that could provide more permanent solutions to these challenges.

In addition to the information provided in Table 3-4, some areas for further development were identified that would benefit many of challenges associated with the modeling of FLEX-like actions:

- A systematic, Capability Category II HRA methodology that does not require the assignment of failure probabilities at the step level.
- Guidance on the types of subtasks that should be included as critical subtasks in the performance of FLEX-like actions. In FLEX-like applications, there are portions of the deployment that could be considered to be "critical subtasks", but the degree of decomposition required for the deployment action is not clear and in some cases, there are subtasks for which it is not clear that the assignment of a failure probability would be appropriate. For example:
  - Loading equipment onto a vehicle for transportation could be considered to be a critical subtask because omitting the equipment, or dropping it such that it is damaged, can lead to failure of the overall action. It is not clear, however, whether a separate subtask for equipment loading is necessary or appropriate.

- The placement of portable fans is critical for alternate room cooling strategies, but there is not a standardized approach for the treatment of the step to place the fan. Including a step to assess omission of fan placement appears to be appropriate, but what is less certain is whether or not it is necessary to account for placing the fan such that it forces air in the incorrect direction, or if it is placed in the incorrect doorway.
- Refueling is a required evolution for engine driven equipment, but if the task is feasible, it is not clear if it should be assumed to be performed given that the equipment was initiated and refueling is feasible, if it should be treated as a single high level task, or if it should be modeled on a step-by-step basis. This is an example of a recoverable action, and the success criteria for the recovery also need to be considered. For example, operators may fail to refuel before the pump stops, but will have time to refuel and restart the pump. The time available for the recovery may be quite long if the FLEX injection had been running for several hours, the vessel would be full and the reactor core power would be low on the decay heat curve.

Table 3-4
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Lack of execution task failure data: Connect hose to equipment.	Not addressed by current EPRI HRA approach.	• Treat execution errors with omission errors only. • Use OPG/Bruce Power Emergency Mitigation Equipment (EME) Deployment methodology [12] to address portable equipment deployment.	Failure data for non-standard tasks: Connecting temporary hoses.
Lack of execution task failure data: • Level/pressure/temperature control – MCR. • Level/pressure/temperature control – local.	Not addressed by current EPRI HRA approach.	• Model the control task with a cognitive error (fail to diagnose the need for control) combined with an execution error for operating the system controls. • In some cases, errors associated with checking/monitoring the instrumentation for the critical parameter are also included. • ASEP includes failure probabilities for dynamic tasks, but they are generic in nature. These probabilities could be used to represent the control actions, but it not clear that this approach would satisfy the requirements of a “detailed” calculation. For example, the ASEP events would not address any differences between an MCR control action and the potentially more complex interactions associated with a local control action.	Assessment of control actions: Some means of accounting for the dynamic nature of a control action must be developed either in either a new methodology or by devising a new approach to modeling the control step using an existing methodology.
Lack of execution task failure data: Operation of equipment on a local panel.	Not all control types are represented by the THERP data.	• The steps can be treated with only omission failures. • The THERP data for other control manipulations can be used as surrogate values in conjunction with assumptions that the failure rate is similar to that of the local panel control type.	Failure data for non-standard tasks: Digital/touch screen interfaces – throttle bars.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Lack of execution task failure data: Operation of equipment – control located on equipment.	Not all control types are represented by the THERP data.	• The steps can be treated with only omission failures. • The THERP data for other control manipulations can be used as surrogate values in conjunction with assumptions that the failure rate is similar to that of the local panel control type.	Failure data for non-standard tasks: Small engine controls such as pull-starts, fuel line operations.
Lack of execution task failure data: Loading/unloading portable equipment.	Not addressed by THERP.	• The steps can be treated with only omission failures. • Use OPG/Bruce Power EME Deployment methodology [12] to address portable equipment deployment. • Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates.	Failure data for non-standard tasks: Equipment loading (heavy load drop).
Lack of execution task failure data: Transportation of portable equipment (vehicle).	Not addressed by THERP.	• Treat as a negligible contributor to failure. • Use OPG/Bruce Power EME Deployment methodology [12] to address portable equipment deployment. • Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates.	Failure data for non-standard tasks: Vehicle operation.
Lack of execution task failure data: Operation of a vehicle – onsite.	Not addressed by THERP.	• Treat as a negligible contributor to failure. • Use OPG/Bruce Power EME Deployment methodology [12] to address portable equipment deployment. • Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates.	Failure data for non-standard tasks: Vehicle operation.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Lack of execution task failure data: Transportation of portable equipment – offsite.	Not addressed by THERP.	• Treat as a negligible contributor to failure. • Some applications assume portable equipment transportation errors/damage are subsumed by hardware failure rates.	Failure data for non-standard tasks: Vehicle operation (potentially including aircraft).
Lack of execution task failure data: Install/remove section of hard pipe or a flange.	Not addressed by THERP.	• The steps can be treated with only omission failures. • The THERP data for local valve manipulations can be used as surrogate values in conjunction with assumptions that the failure rate is similar to that of flange/spool piece connections. • Use OPG/Bruce Power EME Deployment methodology [12] to address portable equipment deployment.	Failure data for non-standard tasks: • Flange installation/removal. • Spool piece installation.
Lack of execution task failure data: Make a temporary power connection – household.	THERP includes failure data for making electrical connections, but they are not for household type connections.	• The steps can be treated with only omission failures. • The use of the Table 13-3 data could be used as bounding failure rate for making household-type power connections.	Failure data for non-standard tasks: Household electrical connections.
Lack of execution task failure data: Clear debris from haul path.	Not addressed by THERP.	• Account for step only in action timing (treat failure as negligible). • Use OPG/Bruce Power EME Deployment methodology [12] to address portable equipment deployment.	Failure data for non-standard tasks: Heavy vehicle operation.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Lack of execution task failure data: Placement/installation of a portable fan.	Not addressed by THERP.	The steps can be treated with only omission failures.	Failure data for non-standard tasks: Fan placement (wrong direction/ wrong door).
Lack of execution task failure data: Installation of temporary HVAC ducts.	Not addressed by THERP.	The steps can be treated with only omission failures.	Failure data for non-standard tasks: Installation of temporary HVAC ducts.
Lack of execution task failure data: Prop open door.	Not addressed by THERP.	The steps can be treated with only omission failures.	Failure data for non-standard tasks: Door propping.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Lack of execution task failure data: Locally confirm correct rotation of equipment.	Not clearly addressed by THERP. The checking functions in Section 19 are generally written for a person checking the status of equipment that was manipulated by another person. In the specific FLEX application reviewed, the pump rotation check was required to be performed by the original performer of the electric connection to confirm correct polarity of the connection. The THERP discussion is also in the context of display and valve position checks, although there are some references to the identification of leaking pipes or pumps. Apart from the distinction made for identifying mispositioned valves, however, the checking tasks themselves are not defined in detail and could potentially apply to this type of task.	• If the step is used for a recovery, do not credit the recovery. • THERP item 3 from Table 19-1 could potentially be used as a surrogate HEP for this type of task.	Failure data for non-standard tasks: Generic equipment operation checks.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Defining and determining the time of a cue for actions initiated based on crew availability.	In order to use the EPRI HRA methodologies, it is necessary to define a cue and to establish the time the cue occurs. For cases in which a condition of action performance is the availability of crew, it is necessary to know both when the crew members would be available and when the operators would consider them to be available for the task (that is, not assigned to other higher priority tasks). The development of a detailed time line to track resources during an accident scenario is not specifically addressed by the methodologies in the EPRI HRA approach; rather, it is a general management task that requires input from expert sources. For FLEX applications, the timing data collection is potentially more difficult than for standard HRA applications because the operators may have limited experience with the tasks, some portions may not be practical to simulate, the evolutions may be impacted by the conditions of the event, and others may be performed by offsite personnel.	Estimates of task times can be used based on interviews with the personnel that would perform the tasks.	Time for RRC response may be critical for some scenarios. Simulations of deployment or timing estimates from responsible personnel could be collected. Timing data for FLEX action walkdowns and/or simulations could be collected.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Defining and determining the time of a cue for actions initiated based on crew availability (continued)	See also "Assessing the probability of failure to properly prioritize tasks".		
Crediting FLEX actions when the procedure governing deployment is not written for the conditions of the scenario.	This is an area of ambiguity for HRA, in general: procedures exist for performing the action, but not for necessarily for the initiating event in question. The EPRI HRA methodologies do not clearly preclude credit from being taken for such actions, but there is also not a straightforward way to evaluate the probability that the operators would fail to use the existing procedures for an "unauthorized" scenario.	Coordinate with operations to enhance the procedures to include entry conditions for the relevant scenario.	An approach to evaluating HFEs that are governed by procedures that are not clearly directed for the required scenarios or for simple actions that are not directed by procedures could be beneficial; however, the HEPs for such actions would be high and likely to have little impact on the PRA results.
Realistically modeling an execution failure with THERP for a task with a large number of execution steps.	THERP is not limited by the number of steps in an execution, but for many FLEX-like actions with a large number of steps, the results may be unrealistically high. This may be due to a number of factors, including the difficulty in identifying all failure paths and the appropriate recovery factors for each of the steps.	Apply recovery credits to all tasks based on the availability of staff with the general duties to perform checking or to provide support (for example, extra crew execution review).	In both MCR and ex-MCR scenarios, an increased understanding of the nature and number of error recovery opportunities would improve the fidelity of modeling. For example, a control manipulation slip may be modeled only with a self-review recovery when in actuality, there may be a number of different alarms/signals that would alert multiple operators of the deviation that would initiate parallel review tasks that are not obvious to the analyst.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Account for non-operations personnel in action timing.	There are no specific methodology limitations for this issue. The involvement of personnel that are not familiar with the field deployment tasks may introduce additional uncertainty in timing estimates.	Use the doubling rule from NUREG/CR-1278 [4] to account for uncertainties in non-operations time estimates.	The development of good practices and/or guidance for obtaining timing estimates for non-operations personnel may be helpful.
Assessing the initiation of a procedure or task with an entry cue that is based on judgment.	It is not clear that the EPRI HRA methodologies were intended to provide a means of quantifying a failure probability for making a decision to implement a task by a required time when specific criteria are not provided for decision making.	Use the procedure direction as the action cue and assume that the ASEP or HCR/ORE time reliability curves provide appropriate failure probabilities for this type of cognitive work.	An approach to evaluating more complex and diverse cognitive tasks, such as those that are initiated based on operator judgment.
Evaluation of errors of commission.	The EPRI HRA methodologies do not address the assessment of the performance of non-proceduralized actions that result in the exacerbation of plant conditions.	There is no systematic process to either identify or quantify errors of commission. In most PRAs, errors of commission are not addressed and if they are treated similarly for the modeling of FLEX-like capabilities, it would be consistent with industry practices. If there are cases in which the assessment of errors of commission is determined to be critical, alternate methods, such as ATHEANA could be used.	This is a generic HRA weakness that is not specific to FLEX applications. A new means of identifying and assessing EOCs will be required in order to incorporate them into PRAs.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Assessing the probability of failure to properly prioritize tasks. Multi-unit/multi-site coordination.	The EPRI HRA methodologies do not provide a means of assessing the probability of failing to prioritize tasks when the procedures do not specify an order and order is important to success. In FLEX-like applications, this could extend to large scope resource management tasks, such as directing preparations for external flooding events that require coordination of multiple groups/organizations for a series of actions.	It can be assumed that the critical task is performed last out of all the available options. Use operator interviews to establish the preferred order of actions for specific scenarios and obtain timing estimates for the time spent on preceding actions. If the cognitive work associated with the task is not complex, the failure probability associated with task prioritization could be assumed to be negligible.	An approach or methodology with the capability of assessing prioritization tasks.
Assess the probability of performing errors in mathematical calculations.	THERP does not provide a robust means of accounting for the probability that an error will be committed in the performance of steps that require mathematical computation. There are failure probabilities in Chapter 11 related to performing simple calculations when interpreting instrument displays, but it is not clear that they were intended to be used or would be applicable to performing calculations to support other tasks.	The data in Chapter 11 of NUREG/CR-1278 [4] can be used as surrogate values for other types of simple mathematical errors.	The assessment of committing errors in calculations.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Model impact of changes to command and control location – physical challenges.	The time reliability curves, such as ASEP and HCR/ORE, do not account for these types of issues. The CBDTM can address many of the characteristics related to the availability/quality of the cue indications and the level of training the operators have had on the indicators, but it is not designed to address the impact of environmental PSFs. In the case where command and control is dispersed among multiple areas (for example, when neither the MCR nor the remote shutdown panel (RSP) are available), the EPRI HRA approach does not provide a means of assessing how operator reliability is impacted (for example, plant information may be available, but only by radio and no visual gauges are available).	• Ignore factors other than those addressed by the CBDTM. • Use a multiplier based on judgment to modify diagnosis errors. • Do not credit actions when neither the MCR nor the RSP are available.	<u>Impact of abnormal environmental conditions on cognitive tasks</u>: It is not clear how significant environmental factors are for the cognitive failure assessments, but an approach to modeling the impact of abnormal environmental conditions on the cognitive tasks could be developed. Modeling actions when neither the MCR nor the RSP are available: A simulation of a dispersed control scenario could be performed to support a detailed task analysis to provide the industry with a model of how the plant would be controlled in such a situation. This would aid in the identification of specific challenges that would require additional modeling.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Identification and modeling of non-standard pre-initiators. Standard types of pre-initiators, such as miscalibration of a flow meter on portable equipment, may not present any specific HRA challenges, but it is not clear how to treat other types of events related to portable equipment.	Events such as failing to return a vehicle to a designated position are not addressed by THERP and because the general ASEP pre-initiator HEP was based on a review of plant tasks, it is not clear that the ASEP HEP should be applied to these types of tasks.	• Include only valve misalignments and instrument miscalibration tasks for portable equipment. • Use the ASEP screening pre-initiator methodology and assume the general HEP is applicable to the FLEX-like task.	Additional work is required to define and establish boundaries for the types of events addressed by hardware failure data (for example, is leaving a fuel tank empty part of the start failure data) and of the events not addressed by data, what types of pre-initiator events are relevant to portable equipment. If any non-standard events are considered to be applicable (such as failing to return a vehicle to a designated position, or leaving a trailer and tow truck decoupled), an approach to evaluating the failure modes would be required.
RRC deployment time validation: For the range of initiating events that may require the deployment of RRC equipment, a full assessment of the impact on the RRC of the events (for example, a hurricane) may not be available and it not clear how equipment deployment times could be assured.	This is not a methodology deficiency but a practical issue in the feasibility assessment that would be a challenge for any methodology.	Rely on the assumption that 24 hours is sufficient time to allow equipment deployment regardless of initiating event.	The impacts of catastrophic events are variable and no specific potentially helpful tasks have been identified to address this issue, although there may be insights from Fukushima.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Validation of on-site FLEX-like action times: In some cases, there may be elements of a FLEX-like action performed on-site that may not be practical to practice. In these cases, lack of quality timing data may weaken both the feasibility analysis and any quantification that is sensitive to timing data. Also, the impact of external events on action timing is difficult to predict (that is, scope of impact of events and how the events would impact the actions).	This is not a methodology deficiency but a practical issue in the feasibility assessment that would be a challenge for any methodology.	• Rely on operator/staff estimates based on procedure and equipment review. • For significant actions, a mockup of the equipment could be constructed to support training and timing analysis.	Specific action timing issues would have to be resolved on a plant by plant basis.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Justification of offsite equipment availability: For long term evolutions, some off-site interface may be required in order to keep mitigation equipment in operation. For example, diesel fuel trucks may be required to replenish site fuel supplies. It is not clear how the availability of such resources could be confirmed for initiators such as severe hurricane events. Similarly if there was a radiation hazard present due to problems with another unit, there may be no cooperation with outside organizations.	This is not a methodology deficiency but a practical issue in the feasibility assessment that would be a challenge for any methodology.	• A general assumption is often made that for longer term evolutions that these types of activities would be possible. • Take no credit for offsite support.	The impacts of catastrophic events are variable and no specific potentially helpful tasks have been identified to address this issue, although there may be insights from Fukushima.
Long term control actions: In addition to the challenges associated with modeling control actions, as identified in Table 3-2, it is not clear how to address the potential for error in cases where the control function must be manually maintained for several days or more.	Not addressed by current EPRI HRA approach.	Assume no significant additional contribution from long term control errors.	Assessing error contributions from long term control actions.

Table 3-4 (continued)
Gap Summary

Challenge Description	EPRI HRA Approach	Ad Hoc Methods	Areas Requiring Further Development
Accounting for human limitations: Actions that are performed in physically or psychologically demanding conditions may have an increased probability of failure relative to those performed in nominal conditions, but there is limited guidance on how to quantify these impacts. In FLEX-like applications, these factors may be more prominent.	In general, the cognitive methods (ASEP, HCR/ORE, and CBDTM), do not directly address these types of issues. Chapter 3 of NUREG/CR-1278 [4] provides a discussion about these types of factors, but there is no quantitative structure provided to correlate the presence of physical or environmental factors to HEP modifiers beyond those identified as "stress".	• Address the factors in a qualitative manner only. • Apply a multiplier on the execution tasks based on judgment.	Correlating physical and psychological stress factors to quantitative impacts.
Modeling actions with cues from offsite sources.	The challenges associated with modeling actions with cues from offsite sources are related more to the lack of access to information than to the limitations of HRA methodologies.	Assumptions can be made about response times from offsite personnel.	Specific action timing issues would have to be resolved on a plant by plant basis.
Applicability of HCR/ORE.	The HCR/ORE methodology is available in the HRAC and the inputs required to quantify the HFEs can theoretically be collected, but it is not clear that the HCR/ORE data is representative of some FLEX-like applications.	Rely on the CBDTM to model the non-response probability. While not often used, the CBDTM does allow for the development of additional/alternate failure data, branch points, and/or decision trees to model the important contributors to failure.	Review of HCR/ORE scenarios to assess applicability of HCR/ORE to FLEX-like applications.

3.6 Insights for FLEX Implementation and HRA Development

The following insights have been developed based on the reviews that were performed:

- If the guidance that directs the use of FLEX equipment is not integrated directly into the EOPs, ensure there are clear and specific entry conditions that will trigger the use of the procedure for any initiating event. For example, if the use of 50.54x is desired to allow flexibility to enter the procedure, combine it with other concrete entry conditions that would help ensure that it would be implemented when required (for example, if there is no makeup flow to any SG).
  - In some cases, it is desirable to allow the operators to exercise judgment in the timing of FLEX equipment deployment, but providing an ultimate limit on the deployment time will help ensure the equipment is deployed in time to be of use while also providing a means of crediting the FLEX equipment in the PRA. For example, if the procedure is written to instruct the operators to align a portable 480V AC generator if "it is judged that AC power cannot be recovered", it is not clear when the operators would make the decision to initiate alignment of the portable generator. On the other hand, if the procedure is written to direct the operators to "align the portable 480V AC generator if AC power has not been restored within 60 minutes of the initial loss of power", the guidance supports the position that the generator alignment would begin no later than at 60 minutes after the initial loss of power to the bus.
- Ensure the procedures governing FLEX/portable equipment are developed to the same level of detail in typical system or abnormal operating procedures (step-by-step guidance). Relying on high level guidance, such as technical support guidelines, reduces the reliability of the actions to align and use the equipment. In addition, the use of high level guidance makes it difficult to evaluate the corresponding actions using the EPRI HRA approach and weakens the bases of the HRA. If any precautions or suggestions for use of protective equipment to deal with a particular hazard are relevant, the expectation would be that they would be included in the procedures, similar to how procedures account for entering a hi-rad area, or an area with energized electrical equipment.
  - Note: the level of detail needed is with respect to the expected skill level and state of knowledge of the personnel expected to follow the procedure. Where non-operations personnel (for example, security personnel) are expected to perform actions that would normally be considered "skill-of-craft" for operations personnel, additional detail in the procedure may be necessary. Likewise, if the actions are well-established as skill-of-craft, and there are no special features, then the procedure can be written at a higher level (for example, step-by-step instruction are not needed for driving a typical vehicle, but may be needed for installation of a piece of equipment).
- Include explicit steps in the procedure to validate that the action has been performed correctly, where possible. For example, if a portable pump is used, include a step in the procedure to verify discharge flow is in the required range or some other parameter check that will confirm the equipment is operating properly.
- In cases where portable equipment is used, include directions to validate the alignment at the time of the alignment rather than relying on corrections to be made when there is a demand on the equipment. This provides more recovery time for any alignment errors.

- Procedures can be optimized by including guidance to minimize organizational tasks where it is possible to do so. For example, if an evolution requires the performance of multiple actions by different groups of people with potentially overlapping responsibilities, providing a preferred order of task performance in the procedure with estimated completion times would support a more organized response in emergency conditions. If flexibility is desirable, include guidance to allow the operators to deviate from the preferred order if conditions require an alternate approach for success.
- Complete timing simulations and record the results for all portions of the FLEX-like actions for which it is practical. This type of timing data supports both the feasibility analysis and the timing portion of the HEP quantification task. In cases where it is not practical to perform a timing estimate on the actual equipment associated with an action and the action is important, consider alternative methods of obtaining timing estimates:
  – Walk down the execution path and simulate control manipulations.
  – Construct a mock-up of the equipment and use it in the timing evaluations.
  – Perform a larger set of interviews on different crew members, procedure developers, and trainers to obtain a broader set of timing estimates based on their judgments about timing requirements.
- Test the equipment and alignment as part of the feasibility analysis. The most effective way to do this is through realistic exercises/drills, where feasible. This will serve the purpose of demonstrating feasibility, providing some basic level of training to personnel and providing a basis for timing information for execution of the task. In some plants, it has been simply assumed that equipment will perform its function and that all of the parts required for implementation are available. However, there has been at least one industry example where portable pumps were tested and determined to be inadequate for the intended task.
- While thorough training and practice of the FLEX-like actions would be desirable from the perspective of improving the reliability of these actions, care should be taken that these actions are not overrepresented in the training. Dedicating significant training resources on actions that are not expected to be required during the life of the plant may reduce the time available to train on those tasks that are required to operate the plant, or on those required to respond to higher risk scenarios. However, individual sites must institute a process that will ensure the personnel responsible for performing the FLEX tasks are proficient in these tasks.
  – The personnel responsible for performing the FLEX actions must be qualified.
  – A suggested minimum requirement is that each active staff member with the responsibility of performing a FLEX-like action must be trained to perform the action and have practiced the action[2].

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[2] If there are larger scope actions that are performed by a team, it may not be necessary for all members of the team to have practiced the action, but at least one member of the team (for example, “team leader”) should have the experience such that he or she can use the experience to help troubleshoot problems. If this approach is taken, care must be exercised to show that manpower requirements are not challenged (for example, “team leader” does not become a manpower bottleneck).

- Portable equipment deployment should be simplified to the extent possible. For example, rather than requiring temporary cable to be transported and manually run between the power source and the load, providing a pre-staged connection point for the portable equipment would reduce the time required for deployment.

3.7 Special Uncertainty Considerations

There are likely to be some assumptions and potential key sources of uncertainty associated with the HRA development. This would include:

- Cue timing for offsite sources (such as calls to the site to identify emergency conditions)
- Execution times for Regional Response Center Activities
- Execution times for FLEX-like tasks that are impractical to perform or practice
- Failure rates for non-standard control manipulations (for example, using digital control panels on local equipment)
- The feasibility of actions performed in extreme conditions (for example, deploying temporary equipment during high wind events)
- Assessments of the impact of external events on the plant (for example, are haul paths for temporary equipment blocked by debris)
- Availability of offsite personnel and/or equipment during or after extreme external events

The number and types of issues will vary by plant according to the nature of the strategies that are employed.

4 DATA ANALYSIS GAP ASSESSMENT

Another identified challenge associated with incorporating FLEX capabilities into a PRA is that associated with data development. The primary gap is not data analysis methods, as described in Table 2-8, but rather the availability of suitable data sources.

As stated in NEI 12-06, *Diverse and Flexible Coping Strategies (FLEX) Implementation Guide* [1], FLEX has several attributes. From a data analysis perspective, FLEX consists of:

- **Portable equipment that provide a means of obtaining power and water to maintain or restore key safety functions for all reactors at a site**. This could include equipment such as portable pumps, generators, batteries and battery chargers, compressors, hoses, couplings, tools, debris clearing equipment, temporary flood protection equipment and other supporting equipment or tools.
- **Programmatic controls that ensure the continued viability and reliability of the FLEX strategies**. These controls would establish standards for quality, maintenance, testing of FLEX equipment, configuration management and periodic training of personnel.

From a PRA data analysis perspective, FLEX equipment is different from non-FLEX equipment for the following reasons:

- Some FLEX equipment is portable; it may be mounted on a trailer or skid, and need to be repositioned and connected to fixed plant equipment.
- FLEX may be stored outside of the main plant structures; non-FLEX equipment is typically installed in the plant.
- Maintenance and testing of FLEX equipment may be under programs that are different from existing plant equipment.
- Quality requirements for FLEX equipment may be different than requirements for current accident mitigation equipment.
- Duty cycles for FLEX equipment may be different from non-FLEX equipment.

Finally, there is little to no industry or plant-specific data on FLEX equipment, since FLEX has not been implemented at most sites. Sites that have implemented FLEX generally have very little experience collected. Although some B.5.b equipment may be similar to FLEX equipment, there is little industry information on failures, success or unavailability. Since it is not maintained in the Maintenance Rule, plant specific data may not be available or difficult to reconstruct.

4.1 Scope of Data Sources Considered

Several industry databases and publications provide data which may potentially be used for FLEX-type equipment reliability. EPRI 3002000774, EPRI Guidelines for PRA Data Analysis [13] was consulted; Table 2-3 in that document provides a list of common generic data references that could be used in the PRA. However, these data sources do not generally contain failure or unavailability information for portable or temporary equipment.

A review of several potential data sources was performed by EPRI. The review included: NUREG/CR-6928 [3], *IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations* (IEEE) [14], *Nonelectronic Parts Reliability Data* (NPRD) from the DoD Reliability Information Analysis Center (RAIC) [15], and the *Offshore Reliability Data Handbook* (ORED) [16].

Most U.S. PRAs use NUREG/CR-6928 [3] for industry-average component unreliability information. However, it does not explicitly cover portable or FLEX-type equipment; components in NUREG/CR-6928 are generally permanently installed. Additionally, it does not include data for the large variety of component types and capacities expected to be used in FLEX (for example, smaller electrical generators (diesel- or gas-driven), engine-driven compressors). Therefore, NUREG/CR-6928 is not necessarily a good source for estimating the unreliability of portable FLEX equipment. IEEE, NPRD, and ORED did not provide unreliability information for the types of portable components used in FLEX. Additionally, the data in some of those sources are old and may not represent present-day component unreliability. In general, sources for FLEX equipment reliability data are not readily available.

Although the above databases did not provide unreliability information for the types of portable components used in FLEX, some information was available on the relative reliability of mobile versus permanently installed equipment for various types of equipment. This data may be used to help inform an expert elicitation process to derive failure rates for portable equipment based on generic data available for its permanently installed counterpart. A review of the NPRD DoD-RAIC 2011 [15] and NUREG/CR-6928 [3] was done in order to:

- Compare military data[3] to nuclear data, to see if they are roughly comparable (challenge was finding corresponding component types [see Figure 4-1]).
- Compare portable military to fixed military data (to see if the portable was the same, higher or lower – and by how much [see Figure 4-2 and Table 4-1]).

[3] "Military data" here refers to the data from the NPRD DoD RAIC 2011 database, which includes data from multiple sources, including substantial military data – however, it is not exclusively military data. This data comes from many sources (for example, reports and papers, government sponsored studies, military maintenance data, commercial warranty repair data, commercial / industrial maintenance databases, data submitted directly from military or commercial organizations that maintain failure databases, and so on). The data used is a combination of actual equipment operating time and cumulative calendar time, depending on what was available. When known, actual equipment operating times were used; if equipment operating time was not known, the cumulative calendar time during the period over which the data was collected was used: "In virtually all field data collected by RIAC, time to failure was not available. Few DoD or commercial data tracking systems report elapsed time indicator (ETI) meter readings… RIAC's data collection efforts typically track only the total number of item failures, part populations, and the number of system operating hours" [15].

While definitive distributions cannot be extracted from the data, taken together, some general conclusions may be drawn from the two plots:

- Military and NPP component failure rates are not radically different.
- Military component failure rates are generally higher than NPP rates.
- Some of the larger differences between Military and NPP failure rates can be rationalized.
- Portable military component failure rates are generally higher than permanently installed failure rates, but not substantially (<10x).

In the absence of specific data, the plots above seem to support an increase (<10x) as an initial estimate in portable equipment failure rates for PRA applications until additional experience data is obtained to improve failure rate estimates. However, there are substantial differences between how portable equipment are used and maintained in military and commercial applications versus nuclear applications. Military portable equipment are regularly used and constantly maintained, whereas FLEX equipment is standby equipment that is only expected to be maintained periodically. These are some considerations that make it difficult to use the extrapolated military data in PRA applications, and introduce a potentially large source of uncertainty. Furthermore, the NPRD DoD RAIC 2011 database includes data from multiple sources – it is not exclusively military data, so the maintenance regimes of the raw data cannot be systematically compared. Efforts to gather data from other applications which use and maintain portable equipment in a fashion similar to that expected for FLEX (for example, back-up generators at hospitals) have not been successful to date.

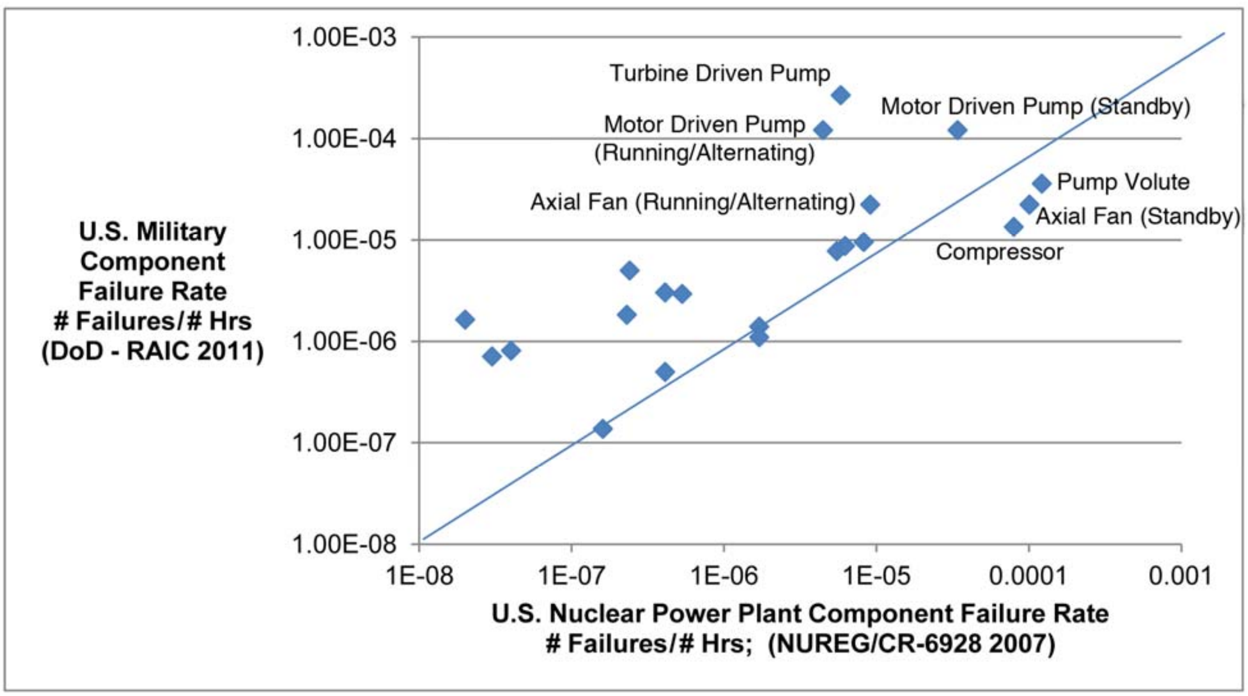

Figure 4-1
Comparison of Military and Nuclear Permanently Installed Equipment Performance*
** Data compared on basis of number of failures/number of hours of service; (NPRD DoD-RAIC 2011 [15] does not report failure to start, failure < 1 hour, failure > 1 hour)*

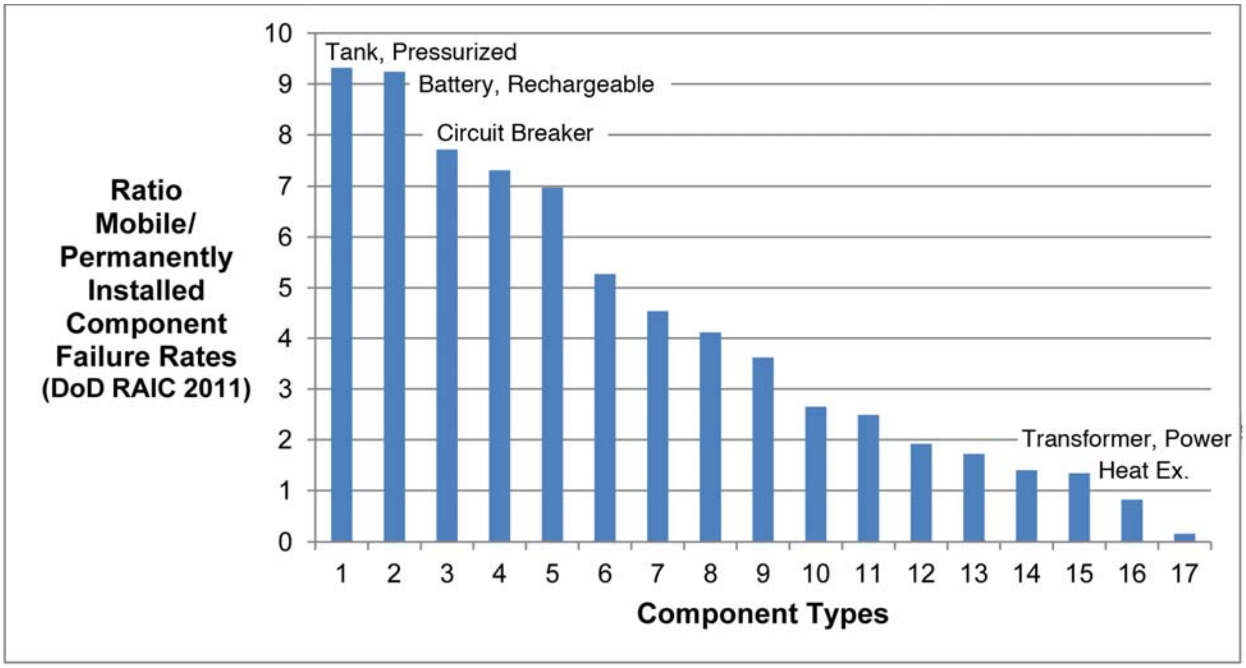

Figure 4-2
Comparison of Military Mobile and Permanently Installed Equipment Performance*
** "Military Mobile" came from "Ground Mobile" data set; "Military Permanently Installed" came from "Ground Benign" or "Summary" data sets in NPRD DoD-RIAC 2011 [15]*

Table 4-1
Comparison of Military Mobile and Permanently Installed Equipment Performance

Component #	Ratio	Component Type	Component #	Ratio	Component Type
1	9.32	Tank, Pressurized	10	2.65	Generator, AC
2	9.24	Battery, Rechargeable	11	2.49	Compressor
3	7.71	Circuit Breaker	12	1.92	Engine, Diesel
4	7.3	Connector, Plug Type	13	1.72	Pump, Hydraulic
5	6.97	Pump Volute	14	1.4	Valve, Check
6	5.27	Motor, AC	15	1.34	Transformer, Power
7	4.54	Transformer, Power-Single Phase	16	0.82	Heat Exchanger
8	4.12	Fan, Axial	17	0.16	Hose, Hydraulic
9	3.62	Tank, Non-Pressurized			

Unavailability due to maintenance and testing is typically based on plant specific information. Unavailability can initially be estimated based on the expected maintenance and testing periodicity and duration. After some experience is gained at the site, plant specific data can be used.

Common cause data is available from NRC/INL sources (for example, NUREG/CR-6268 [17], Rev. 1, INL/EXT-07-12969 Common-Cause Failure Database and Analysis System: Event Data Collection, Classification, and Coding). It also covers only installed nuclear plant components, not portable or temporary equipment. Additional environmental concerns, potentially contributing to higher common cause failure rates, exist due to the possibility of storage of equipment in less than ideal conditions (e.g, unheated buildings), use during potentially extreme environmental conditions, and the direct use of raw water sources.

4.2 Review of Data Methods Employed

Several plant PRAs have been modified or are in the process of being modified to include FLEX. The PRAs were reviewed to determine the data sources used for FLEX equipment. Most PRAs used the most applicable NUREG/CR-6928 [3] data for unreliability, Bayesian updated with plant-specific data where available. IEEE Standard 500 [14] was used at one site for small (3–15 kW) gasoline engine driven generators.

Supporting Requirement DA-D2 [2] allows the use of estimates, based on the most similar equipment available, adjusted as necessary for the differences. Expert judgment would be needed, which is also discussed in DA-D2.

Some general factors for consideration when choosing a generic distribution to best fit the data needs, include:

- Similar maintenance regimes
- Similar use (for example, high duty cycle vs. low duty cycle)
- Similar function

5

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

This report has provided a summary of the state-of-knowledge review associated with implementing FLEX equipment and strategies into PRA models with respect to the applicable elements of the internal events ASME/ANS PRA Standard (that is, accident sequence analysis, success criteria, systems analysis, human reliability analysis, data analysis, quantification, and LERF analysis).

Based on the lessons learned from the early implementers, while there may be some special considerations and additional uncertainties, generally the existing accident sequence analysis methods should be appropriate for incorporating FLEX into the PRA models. That is, no new techniques or methods have been identified beyond the existing capabilities of the tools and programs used for developing the PRA models. Similar conclusions were also made for the success criteria analysis, systems analysis, quantification, and LERF analysis portions of the internal events ASME/PRA Standard. However, several gaps were identified from the human reliability analysis and data analysis reviews. Addressing these gaps will help to ensure that an accurate assessment of the CDF and LERF reduction afforded by the FLEX strategies can be obtained. Table 5-1 below provides a summary, by PRA Standard Element of gaps found in this evaluation.

Table 5-1
Overall Gap Summary

PRA Element	Gap?	Special Considerations or Comments
Accident Sequence Analysis	No	• Event tree nodes may need to be modified, or new ones added. • Time phase dependencies and potential multi-unit impacts should be considered. • Consideration should be made to ensure that FLEX is only credited for those initiators where it has been shown to provide an alternate success path (for example, ATWS and some LOCAs would likely be excluded by definition).
Success Criteria	No	• Extended mission times may be a consideration for external hazard groups. • Key sources of uncertainty in success criteria (for example, capability of installed system to continue to operate at elevated suppression pool temperatures and no room cooling; assumed timelines for establishing portable equipment and associated requirements like load shedding) may require additional sensitivity studies. • Care should be taken to ensure that conservative assumptions do not unduly influence the results (for example, establishment of portable ventilation equipment may be required based on bounding calculations, but this requirement may only realistically be needed during certain times of the year). In these cases, development of variable success criteria may be warranted to obtain more realistic results.

Table 5-1 (continued)
Overall Gap Summary

PRA Element	Gap?	Special Considerations or Comments
Systems Analysis	No	• No generic considerations have been identified, however, FLEX system models may be subject to unique considerations, including variable success criteria, multi-unit impacts, and phenomenological considerations. Care must be taken to ensure that the associated impacts are accurately reflected in the system models. • May be sufficient to develop system models in a lower level of detail typical of installed systems since total failure probability likely dominated by other factors (for example, HRA). • Use of non-typical water sources (for example, clogging if FLEX equipment does not have strainers of the type assumed in the raw water performance data) may entail additional modeling challenges.
Human Reliability	Yes	Gaps in assessment methods for execution and cognitive components for FLEX-like actions (see Section 5.1).
Data Analysis	Yes	Data analysis methods generally applicable to portable equipment, but applicable failure data not currently available (see Section 5.2).
Quantification	No	Complementary logic in event tree branches may be needed for down branches with failure probabilities ≥0.1 or alternate post-processing techniques (for example, the use of ACUBE, which better deals with high probability events in PRA models) may need to be employed.
LERF Analysis	No	• Availability of FLEX equipment may change the likelihood of water being available prior to or at the time of vessel failure. • Procedural direction provided in FSGs will likely need to be incorporated into the LERF sequence modeling. • For PWRs, implementing FLEX strategies post core damage could influence the likelihood of induced SGTR. • For BWRs, early containment venting followed by loss of RCIC and the FLEX pumps and failure to re-isolate containment may need to be considered as a potential additional LERF sequence.

In addition to the gaps identified above, it should be noted that representation of FLEX strategies in PRA has the potential to be overly conservative if every aspect of the strategy is based on bounding conditions (for example, always requiring implementation of actions and hardware to provide ventilation even when the weather conditions may not always require additional ventilation). Stacking of these enveloping assumptions may yield conservative (very limited) credit; however, the alternative—being more explicit in the scenario definition and subdividing scenario—may result in extremely complex models. Therefore, a balance needs to be achieved between representing all of the operator actions and the level of detail included for the systems required for mitigation to obtain an accurate assessment of the risk reduction afforded by the FLEX strategies without over complicating the analysis.

Preliminary results from the early implementers indicate that the potential CDF and LERF reduction at the sites could vary from a few percent to forty percent or more. Not surprisingly, the actual benefit is strongly correlated to the types of sequences that dominate the current contribution to CDF (for example, from SBO type or other long-term events) for a give site.

To support the Containment Protection and Release Reduction (CPRR) dialog with the NRC, EPRI conducted a series of analyses for a representative BWR, Mark I plant. This research was focused just on extended loss of AC power (ELAP) conditions and attempted to characterize the contributors to core damage following an ELAP, with credit for FLEX. The goal was to see the degree to which FLEX resources could be used post-core damage to mitigate a severe accident. Details of this analysis, including assumptions and uncertainties considered, are documented in EPRI 3002003301 T*echnical Basis for Severe-Accident Mitigating Strategies* [18]; however, some of the conclusions of the analysis include:

- Crediting FLEX shifts the dominant core damage scenarios from long-term SBO toward short-term SBO type scenarios. This is because FLEX only really mitigates the long-term SBO scenarios (insufficient time to deploy portable equipment in the short-term).
- Another insight is that there are infrastructure failures that can cause an ELAP and fail FLEX, for example, seismically-induced DC failures. This limits the maximum benefit of FLEX (irrespective of the HEPs used).
- Operator actions are essential to management of the accident, both pre- and post-core damage. However, results were not extremely sensitive to the quantitative values unless HEPs became very high (for example, 0.5).
- FLEX provides a substantial safety benefit; reduction in ELAP CDF from FLEX ranged from a factor of 2.5 to 6, depending on assumptions used in the analysis.

While there were generally few gaps found with respect to incorporation of FLEX into PRA, in some cases (for example, time critical FLEX actions) there may be substantially more uncertainty associated with the failure probability of these strategies. A plant can credit gains in safety margin by adding FLEX into the PRA model; however, use of that model should appropriately consider those uncertainties. For example, when using the PRA for an on-line risk monitor application (for example, EOOS), the numerical results can indicate that the risk of a certain configuration is low (that is, green). However, if the driver behind that result was primarily reliance on a time-critical FLEX strategy, then the uncertainty associated with that risk may be high. In these cases the analyst can use other qualitative information, such as Defense-in-Depth models, to understand if additional actions (for example, pre-staging some equipment) or compensatory measures are necessary during that configuration.

The sections below address the research priorities associated with the major gaps found in Human Reliability Analysis and Data Analysis, respectively.

5.1 Human Reliability Analysis

There are numerous challenges to modeling FLEX-like activities in nuclear power plant PRAs, some of which have previously been identified through various industry applications; however, there has not yet been an attempt to systematically identify and define the specific challenges associated with modeling these types of actions. In this document, a review of industry FLEX implementation plans and procedures was performed for this purpose and a relatively large set of issues was compiled. In many cases, there are ad-hoc and/or temporary approaches that can be used to overcome the modeling challenges in a reasonable way, but in general, they do not represent long term solutions to these challenges. The issues identified should be used as a starting point for developing a path forward for modeling FLEX-like activities in PRA. For example, the capability gaps identified are clear indicators of the following points:

- A critical weakness of current HRA methodologies is the lack of capability for modeling execution errors for non-control room equipment. The contributions of some execution tasks to the overall reliability of FLEX-like actions are debatable, but for complex alignments, there is not a basis for excluding them and some approach must be developed to model these activities. A critical decision will be whether to develop an approach that models these activities on a step-by-step basis, or to develop a process that is more holistically based. For transportation and installation of portable equipment, failure rates may be incorporated into the equipment reliability estimates (see Section 5.2).
- Obtaining timing information is a significant challenge for modeling FLEX-like activities. To resolve this issue, it would be helpful to develop guidance on how to construct a timeline for modeling these activities and how to collect timing data for the associated components of the actions. This would include on-site equipment alignments, use of RRC equipment, cues from offsite sources, and arrival of off-site staff.
    - The timeline should consider the uncertainties associated with evolution of other mitigating strategies that may occur before implementation of the FLEX-like actions. For example, the plant may unsuccessfully attempt an inter-unit DC cross-tie prior to aligning a portable 480V AC generator to re-power the unit’s battery chargers, which may require the performance of restoration actions before the alignment of the 480V AC portable generator can be completed.

Not all of the challenges must be addressed with a new capability, but they should at least provide a starting point for discussion on where to focus research efforts and where guidance on the use of existing capabilities can be used to aid HRA practitioners attempting to integrate FLEX-like actions into the PRA. A key part of this discussion should include agreement on the appropriate level of detail/decomposition to be applied to modeling of these actions to avoid over or under estimation when aggregating multiple tasks.

As input to research plans going forward, Table 5-2, below, provides a summary of the HRA gaps, potential research approach to address the gaps and priorities.

Table 5-2
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
High Priority			
High	**Transportation & Installation of Equipment:** • Onsite transportation • Offsite transportation • Installation of pipe or flange • Installation of temp HVAC ducts • Power connections • Loading/unloading equipment • Clearing debris • Non-standard pre-initiators (for example, fail to return vehicle to designated position)	May be best addressed via equipment reliability data analysis task (see Section 5.2); pre-initiators should be based on maintenance procedures for that equipment.	
High	**Environmental Effects on Execution:** • Effect on timing and execution (onsite) • Effect on equipment availability and staffing (offsite)	TBD – interface with external flooding research task. Provide framework for application of adjustment factors determined by NRC research efforts.	Coordinate with NRC project on "Effects of Environmental Factors on Human Manual Actions for Flood Protection and Mitigation at Nuclear Power Plants" (update to NUREG 5680).

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
High Priority			
High	**Organizational Prioritization:** • Multi-unit/Multi-site coordination • Large scope resource management tasks • Soft Cues/Cues from outside organizations	TBD – interface with external flooding research task.	
High	**Procedures:** • Soft cues: entry cue based on judgment or requires prioritization that is not pre-defined • Prioritization when order is not specified but order is important to success	Complete development of IDHEAS[4] [19] Inappropriate Strategy and/or Delay Implementation decision trees (see Appendix B) as a method to evaluate prioritization of actions when significant decision making is necessary and not supported by procedures.	The procedures can be written in such a way so to provide a suggested order of actions so that some decision making can be eliminated. For the cases where scenario based failures dictate a need to identify critical actions, this will still be an issue. This item overlaps with ongoing research on MCR Abandonment for Loss of Control.

[4] *An Integrated Decision-Tree Human Event Analysis System (IDHEAS)* [19]. The IDHEAS method is currently under development through a joint project between EPRI and the NRC. This method is founded on the most current psychological literature as well as lessons learned from plant operating experience. While this method is geared towards internal events actions, it is considered applicable to any well proceduralized set of actions. Appendix B provides an excerpt of the alternate strategy decision tree from the draft report.

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
High Priority			
High	**Timing:** • Prioritization/Soft cues • Crew availability	• Provide guidance on developing a detailed, integrated timeline, and how to deal with uncertainty in timing estimates, particularly when multiple paths are available. • Also provide clarifying guidance on how to deal with timing in the analysis, including what actions the HCR/ORE method is and isn't applicable to, OR use same correlation with guidance on how to develop appropriate sigmas for different types of actions applicable to FLEX.	The HCR/ORE methodology is available in the HRAC and the inputs required to quantify the HFEs can theoretically be collected, but it is not clear that the HCR/ORE data is representative of some FLEX-like applications. This item overlaps with ongoing research on MCR Abandonment.

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
High Priority			
High	**Execution – Many Steps**	Complete development of IDHEAS[5] [19] Complex Execution decision tree as a method to evaluate these actions (see Appendix B). Benchmark numerical answers against THERP results.	For FLEX applications, most plants will have a streamlined approach in which the number of critical steps is minimized such that use of THERP could provide reasonable results. For cases where there are less developed strategies, it is possible that more work may be required and the number of implementation steps could drive the execution contribution to a high value. THERP is not limited by the number of steps in an execution, but for actions with a large number of steps, the results may be unrealistically high. This may be due to a number of factors, including the difficulty in identifying all failure paths and the appropriate recovery factors for each of the steps. The IDHEAS tree focuses analyst on evaluating blocks of execution actions delineated by recovery opportunities and identifying unrecoverable failures. This item overlaps with ongoing research on MCR Abandonment.

[5] *An Integrated Decision-Tree Human Event Analysis System (IDHEAS)* [19]. The IDHEAS method is currently under development through a joint project between EPRI and the NRC. This method is founded on the most current psychological literature as well as lessons learned from plant operating experience. While this method is geared towards internal events actions, it is considered applicable to any well proceduralized set of actions. Appendix B provides an excerpt of the complex execution decision tree from the draft report.

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
		Medium Priority	
Medium	**Effect of changes to physical environment of command and control location**	TBD.	Being investigated via the fire HRA research on MCR abandonment.
Medium	**Procedures:** Crediting FLEX when there is no explicit procedural link	Guidance on crediting knowledge-based actions.	Feedback from the PRA group to tell the procedure writers that entry conditions need to be provided for certain cases should ensure adequacy of procedures such that this is not a prevalent issue. Modeling knowledge-based actions is not just a FLEX issue, but FLEX has the added complexity of needing to have a cue in advance to set up the equipment.
		Low Priority	
Low	**Complex Control Actions**	Model cognitive and execution failures to start control action using existing methods, consistent with current HRA practice.	While the FLEX actions for many plants will require some kind of complex control action, the same is true for FPIE models (for example, ATWS level control) and the weaknesses in the HRA methods to model them have been overlooked. However, some of these FLEX actions may be more challenging in that may require potentially complex coordination and execution, may take place in a very physically challenging environment, and have impacted or limited instrumentation (for example, raw water intake cell levels).

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
Low Priority			
Low	**Performance of non-operations personnel:** • Timing • Training	Ad hoc approach to apply rule from THERP to double timing estimates; also can investigate the use of the "novice" category in THERP. If all the utilities do training/exercises on these actions, it may be possible to collect the aggregated data as a base distribution to understand and inform the variation in timing.	Having a fully practiced scenario to provide a timing estimate for a FLEX action may not be common. However, there will probably be few cases where this is true for time sensitive actions.
Low	**Regional Response Center Interaction:** • Deployment time • Prioritization	TBD.	Phase 3 FLEX actions not anticipated to be normally credited in FPIE Level 1 PRA, but may be an SDP or Level 2 issue.
On Hold (ad hoc methods sufficient for now)			
On Hold	**Miscellaneous Simple Execution Actions:** • Place portable fan • Prop open door	THERP EOM currently used as ad hoc approach, and should be sufficient for these simple, miscellaneous actions.	Consistent with modeling similar actions in, for example, Fire PRA.

Table 5-2 (continued)
Proposed HRA Research Priorities

Priority	Gap	Proposed Approach	Comments
On Hold (ad hoc methods sufficient for now)			
On Hold	**Errors of Commission**	N/A.	Generic PRA issue. Can search for unrecoverable failures as part of task analysis.
On Hold	**Errors in Calculation**	Verify it is appropriate to use existing THERP method.	This also links to SAMG actions for Level 2/LERF.

5.2 Data Analysis

The data analysis review indicated that the main gap is the availability of applicable generic/industry data for equipment reliability and common cause failures. It will take some time to accumulate adequate plant specific reliability data for use in the data analysis. Therefore, research or analysis should be done to develop appropriate reliability data, until enough experience is obtained throughout the industry. Common cause data is more problematic due to the amount of experience needed to develop realistic common cause failure probabilities. Unavailability data can be estimated based on expected maintenance and test plans, until enough data is accumulated to quantify unavailability based on plant-specific experience. Repair frequency and duration times may be extrapolated from existing data, and plant-specific or industry repair time data will need to be collected for portable equipment.

One potential approach for developing reliability distributions is based on the ASME/ANS PRA Standard supporting requirement DA-D2 [2]:

> If neither plant-specific data nor generic parameter estimates are available for the parameter associated with a specific basic event, USE data or estimates for the most similar equipment available, adjusting if necessary to account for differences…

Since data is not directly available for the portable equipment, expert elicitation [20] may be used to develop adjustment factors that can be applied to existing data distributions for similar equipment (for example, from NUREG/CR-6928 [3]) to create generic distributions for use industry-wide for various types or classes of FLEX equipment. The expert elicitation process could leverage the studies performed by EPRI's Nuclear Maintenance Applications Center (NMAC) to develop the mechanisms and causes of degradation for a variety of FLEX-type equipment [21, 22]. Additionally, experience accumulated through testing of equipment at the Regional Response Centers may provide additional information for generic portable equipment reliability. These generic distributions could then be used in the PRA and Bayesian-updated using plant-specific experience as it becomes available. However, as noted in Chapter 4, challenges exist with this approach, as the existing data available to calibrate experts is sparse and highly dependent on the frequency of use and maintenance of that equipment.

FLEX equipment is currently expected to be in long term storage, with less than 10 hours of run time per year. The preventative maintenance strategies for this equipment, as defined in references [21, 22], are based on that expectation, and many failure modes were discounted as not being expected to be experienced due to the limited run time. If a plant uses the FLEX equipment for other means, beyond mitigation of Beyond Design Basis scenarios, such that they are operating outside of the governing assumptions (for example, equipment used greater than 100 continuous hours of operation or an aggregate of 100 hours in any one 12 month period), then they may need to reconsider the applicable failure modes and maintenance strategies. When developing the generic distributions, the assumptions behind the distributions (for example, low duty cycle v. high duty cycle, maintenance frequency and strategy, and so on) should be careful documented. Similarly, when analysts apply the new generic distribution, they must ensure the assumptions match the site's implementation of FLEX.

It may be appropriate to include in the adjustment factors used to construct the generic distributions the failure contribution due to transportation and installation so they would not need to be assessed separately as part of a human reliability assessment. If this approach is taken, however, care must be exercised when updating the distributions using failure data, as that failure data may not be representative of the conditions and failure modes that would be expected to drive the failure contribution due to transportation and installation. If this approach is taken, guidance would need to be provided on how to update the distribution using test or maintenance data.

6
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A
FLEXIBLE MITIGATION STRATEGY SURVEY RESULTS

A.1 Introduction

This appendix provides results of a survey that was distributed to support the development of this report. Table A-1 provides a copy of the survey that was provided to the BWROG, PWROG, and a few international utilities. The results are summarized in Section A.2.

Table A-1
Survey Questions

1. Are you planning to implement credit for FLEX equipment and related components in the following plant PRA models?		
a. Internal Events PRA	☐ Yes When?	☐ No Why Not?
b. Internal Fire PRA	☐ Yes When?	☐ No Why Not?
c. Seismic PRA	☐ Yes When?	☐ No Why Not?
d. Other Hazard Group PRA (Specify)	☐ Yes When?	☐ No Why Not?
2. Have you begun implementation of FLEX equipment in the PRA models?	☐ Yes	☐ No
If the response to Question #2 is “No”, proceed to Question #10 on next page.		
3. If applicable, what reference sources have you used for FLEX equipment?	(Specify references below.)	
a. Component Reliability Data		
b. Common Cause Factors		
c. Test and Maintenance Unavailability		
4. Have you come across unique data needs?	☐ Yes	☐ No
Specify Unique Data Need(s):		

Table A-1 (continued)
Survey Questions

5. If applicable, what HRA methods have you used for FLEX equipment?	(Specify references below.)	
a. Pre-Initiator HFEs		
b. Post-initiator HFEs		
c. HRA Dependency Analysis		
6. For any credited FLEX capabilities, if known, please characterize some of the attributes of the associated training.	(Provide characterization of training below.)	
a. Hands on, or classroom only?		
b. All operations personnel, some subset of that group, or other groups?		
c. What is the frequency of training?		
7. Have you come across unique HRA needs?	☐ Yes	☐ No
Specify Unique HRA Need(s):		
8. During implementation of the FLEX equipment in the PRA models, were there any risk or operational insights that were gained? If yes, was feedback provided to the FLEX implementation team at the site?	☐ Yes (If yes, please specify below)	☐ No
9. If FLEX is incorporated, have you used the model in any regulatory applications (NOED, SDP, and so on)	☐ Yes (If yes, please specify below)	☐ No
10. Do you have any draft (or final) FLEX implementation procedures that you can share with the EPRI team?	☐ Yes (If yes, please attach in e-mail response.)	☐ No
11. Are there any other difficulties or issues associated with implementing FLEX in PRA models that you would like the EPRI team to know about?	☐ Yes (If yes, please specify below)	☐ No

A.2 Survey Results

Surveys were sent to all U.S. nuclear utilities and several non-U.S. plants. Survey respondents represent 10 utilities, 29 sites, 51 units (36 PWR; 15 BWR) in three countries. An additional two utilities, representing two additional countries, did not provide survey responses but did provide lessons learned or other information regarding their application of FLEX in PRA. Of the survey respondents, most plants have not yet incorporated FLEX into their PRAs, although many intend to in the future. Currently, final FLEX designs are still in progress and most sites do not have FLEX procedures so FLEX cannot be incorporated into a PRA to represent the as-built and as-operated plant.

Based on the survey results, most utilities and plants that intend to incorporate FLEX into their PRAs will do so for all hazards that are modeled. The majority of the utilities responding to the survey intend to incorporate FLEX into one or more of their PRAs. The remaining utilities have not ruled out incorporating FLEX into their PRAs, but do not have current plans for it. Sites that do not intend to include FLEX in the PRA model of record, plan to credit equipment that is deployed to reduce risk in certain configurations and in the reactor oversight process.

Some issues identified in the surveys include:

- The likelihood of successful implementation of FLEX is expected to be dominated by organizational performance, such as the emergency response organization. This type of human performance is not a good fit for current HRA methods, so quantifying the HRA may require some new techniques (see Section 3).
- Since FLEX is being designed for Extended Loss of AC Power (ELAP) events, the plant procedures may not provide for adequate timing to use FLEX for other events.
- FLEX may not provide much benefit in traditional PRA tasks or processes. It may only be worthwhile crediting it in unique situations, such as a performance deficiency (for example, Significance Determination Process).
- During the FLEX implementation phase, other plant changes may be occurring (for example, abnormal system line-ups and/or cross-ties) and it will be a challenge to know in advance what those changes will be. The challenge here is that is there are various potential entry conditions that the plant could be in when it’s time to implement FLEX. For example, what set of failures got you to need FLEX. Had other alternate strategies already been tried, or had changes to the plant been made to cope with other failures before needing FLEX. I think the problem is that implementing FLEX is most likely not a time-zero action, so the plant will be in an undefined state.
- Modeling of equipment recovery will still be a challenge.

Additionally, some U.S. utilities indicated the need for clarification from the regulator prior to deciding whether they intend to credit FLEX in their PRA, particularly with respect to interface with the Significance Determination Process (SDP) and Maintenance Rule.

B
EXCERPTS FROM IDHEAS

B.1 Introduction

The Integrated Decision-Tree Human Event Analysis System (IDHEAS) method [19] is currently under development through a joint project between EPRI and the NRC. This method is founded on the most current psychological literature as well as lessons learned from plant operating experience. While this method is geared towards internal events actions, it is considered applicable to any proceduralized set of actions. The method provides a comprehensive framework and guidance for the evaluation of HFEs both qualitatively and quantitatively within the context of an accident sequence. The following extract provides a brief description of the general quantitative approach from IDHEAS [19]:

> The quantitative approach is a cause-based approach. The HEPs are assessed on the basis of explanations of why the HFE might occur (for example, crew dismisses relevant information that results in their failure to achieve the required response). These explanations are informed by and consistent with the work done to identify cognitive failure mechanisms (for example, bias), the consequences of those mechanisms (proximate causes of failure – that is, a phenomenological description of the way the error is manifested such as dismissing relevant information), and the characteristics of the performance influencing factors (PIFs) that enable those mechanisms to result in errors (for example, for the PIF "training", a specific characteristic relevant to bias could be the focus of the training on a scenario with a different but similar signature). In addition, since there may be opportunities for the crew to correct an error within the time window for success in response, these explanations also address whether and why such an opportunity is feasible or not. The explanations are called crew failure scenarios.
>
> The crew failure scenarios are grouped in terms of the characteristic crew failure mode (CFM) …[f]or each CFM… a decision tree (DT) is created. The branches of the DT represent the PIFs that have been determined to be relevant to determining the likelihood of the CFM occurring. Each path represents a different combination of the status of the PIFs, and represents a high level description of a crew failure scenario.…Which path through the DT is chosen for a specific HFE is determined by the specific characteristics of those PIFs that are determined by the context for the HFE. Thus in documenting the crew failure scenario for a particular CFM, the analyst will not only identify the path through the DT, but also the specific PIF characteristics that dictated the choice of that path.

While the IDHEAS method [19] provides a more comprehensive list of potential CFMs, there are two specific CFM DTs referenced in the recommendations of this report: Complex Execution and Inappropriate Strategy. These two trees have been identified to potentially fill select gaps in the evaluation of HRA for FLEX and are described here. These trees are still under development, and this appendix provides an excerpt of the from the draft report [19].

B.2 Excerpt of Complex Execution CFM

This section provides a description of the Complex Execution CFM DT from IDHEAS. While the PIFs considered are quite general, this tree was developed for internal events type actions; to use this tree for FLEX type actions, branch points may need to be added (for example, environmental factors), modified, or further guidance provided on how to interpret the branch points in the context of FLEX. This tree is still under development, and probabilities are not currently assigned for all branch points.

The remainder of this section describes the Complex Execution CFM, and is quoted here verbatim from [19]:

> A complex task is one which includes a significant number of manipulations or involves challenging cognitive activities that have to be completed successfully for overall success of the mission. Further, for a complex task, the manner in which it is performed can have a significant effect on its success. This decision tree is intended to cover a range of complex tasks, and the reasons for complexity can vary between tasks.

In order to use this DT for quantifying failure to correctly execute a complex action, the following assumptions are made:

- This CFM, in accordance with the definition, is dependent on the operators having identified the correct response and begun to execute it. In other words, they know what function they are dealing with and what the expected outcome should be.
- In order to use this DT, it is assumed that all of the actions are directed and covered by a written procedure (including ex-control room actions). While some of the basic actions may be skill-of-the-craft, the key actions are directed by procedure. If the actions are not covered by procedure, they cannot be quantified with this tree without additional justifications as to why a written procedure is not necessary.
- If the scenario is such that substantially adverse environmental conditions resulting for example from flooding, fires or seismic events, then those actions cannot be quantified with this DT. Either the actions must be quantified with another approach (for example, NUREG-1921 for fire conditions) or the actions must be assigned an HEP of 1.0.
- The DT is intended to distinguish between HFEs where the conditions are optimal and those where they are not.

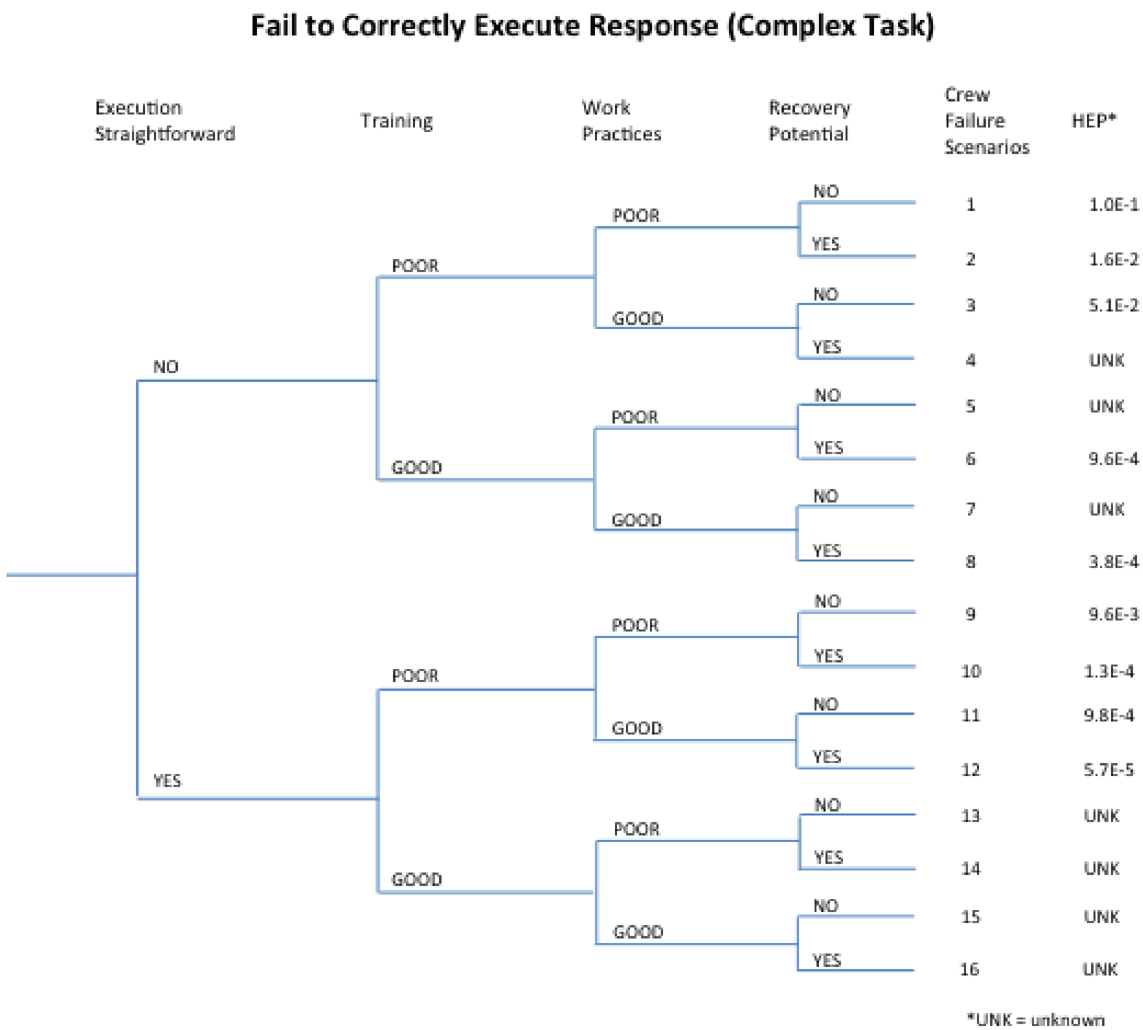

Figure B-1
Complex Execution Crew Failure Mode Decision Tree

<u>Branch Point 1: Execution Straightforward</u>

Definition: Although there may be multiple tasks involved or other characteristics that make the actions complex, the individual actions (sub-tasks) themselves would be straightforward for any licensed operator or other professional plant personnel that would be asked to perform the actions. In other words, there is nothing inherently unusual or difficult involved in performing the specific subtasks. This branch is used to distinguish between tasks that, even though they are complex or are performed outside the MCR, can be expected to be performed reliably, and those for which there are task characteristics that can be conducive to error.

Explanation: Complexity, if measured either in terms of the number of steps that are needed or along other dimensions, does not necessarily translate to the actions being performed unreliably. The list below represents the characteristics of a complex task or ex-control room task that may be assumed to be performed reliably. If these conditions cannot be established, it is assumed that there are opportunities for error.

To address this branch point, the analyst should assess the following:

1. The task does not require skillful coordination of multiple manipulations.
2. The task may be completed at a reasonable pace with ample opportunity for checking instead of having to be done expeditiously.
3. There are no steps that if reversed could cause a failure of the response (for example, by damaging equipment).
4. There is nothing unusual or inherently difficult about the sub-tasks that would normally cause any problems for those executing the actions.

➔ If any of these statements are not true, take the NO branch; otherwise, if all statements apply, take the YES branch.

It will be expected that, in addressing this question, the analyst will have identified the specific characteristics of the task that create the opportunities for error, and also understand the consequences of the errors. This information will be used later in the assessment of the potential for recovery. There may be more than one opportunity but if they have the same consequence, they may be considered together for recovery.

<u>Branch Point 2: Training</u>

Definition: This branch point is intended to determine whether training is sufficient to minimize the opportunities for error for tasks with some inherently complex aspects.

Explanation: Training is an important factor in ensuring that the responses are carried out correctly. The issue of concern here is whether the crew is well trained on this evolution and that any difficult aspects are addressed clearly and thoroughly during training such that a complex task and/or ex-control room task would be straightforward for trained personnel using procedures.

To address this branch point, the analyst should assess the following:

1. Has the crew been properly trained to understand how the scenario may evolve?
2. Are complex tasks and/or ex-control room tasks covered in training?

➔ If the answer to both is No, take the POOR branch. If Yes to either, take the GOOD branch.

<u>Branch Point 3: Work Practices</u>

Definition: This branch point is intended to determine whether, either as a result of standard work practices or by procedure, there are factors that enhance the likelihood that the task, even though complex, can be performed reliably.

Explanation: There are certain work practices that can be credited with increasing the likelihood that tasks are performed reliably. For example, there could be intermediate checks upon completion of some of the individual steps to confirm that the correct manipulation has been performed.

To address this branch point, the analyst should answer the following:

1. Does the procedure include hold points at critical stages to check that, for example, system realignment has been performed correctly?
2. Is it standard work practice for the performer to verify his or her action at each step or another individual is there to check the actions?

➔ Note that these questions should be answered by taking into account the specifics of the task that are conducive to error. If the answer is No to any of these questions, take the POOR branch. Otherwise, take the GOOD branch.

<u>Branch Point 4: Recovery Potential</u>

The assessment of whether credit can be taken for recovery is discussed in general terms in Section 5.15 (of Reference [19]). The following is additional guidance specific to this CFM. This branch point addresses the possibility that, if the action has not been completed successfully, it may be possible to revisit the response and correct any errors made in the manipulation. To address the potential for recovery, the first issue is whether there is an immediate indication of the success of the action via a direct measurement of some plant parameter that reflects the success of the function, for example, water level, pressure (pump flow may not necessarily indicate the water is going to the correct place)? Furthermore, the procedure should require confirmation that the action has been completed successfully. In general this ought to be the case, since there will typically be a step in the procedure to verify that flow has been established. Secondly, it will be necessary to determine that there is enough of a time margin, given the time taken to perform the manipulations in the normal manner, that the failure of the execution could be diagnosed and there is still time to recheck each step to prevent the HFE from occurring. Note that this recovery potential is not intended to apply to control action failures since they are continuous actions and any corrections would be made as part of the evolution.

To address this branch point, the analyst should answer the following: Does the procedure allow for an unsuccessful action error to be identified? This is most significant for the case where the indication of success is indirect (for example, measurement of water level rather than flow).

1. In such a case, does the indication occur in sufficient time to allow the error to be corrected?
2. Does the error identified in the first branch point preclude the possibility of success?

➔ If the answer to all of the questions is No, take the NO branch. Otherwise, take the YES branch. NOTE: This would not apply to control action failures since they are continuous actions and any corrections would be made as part of the evolution.

B.3 Excerpt of Inappropriate Strategy CFM

This section provides a description of the Inappropriate Strategy CFM DT from IDHEAS. While the PIFs considered are quite general, this tree was developed without specific application; to use this tree for FLEX type actions, branch points may need to be added, modified, or further guidance provided on how to interpret the branch points in the context of FLEX. This tree is still under development, and probabilities are not currently assigned for any branch points.

The remainder of this section describes the Inappropriate Strategy CFM, and is quoted here verbatim from [19]:

> For this CFM, the crew has entered the correct procedure and is presented with more than one alternative for how to proceed. The crew chooses the wrong alternative, leading to the HFE. This CFM assumes the crew has the correct mental model for the scenario up until this point (that is, knows what function(s) needs/need to be restored).

Applicability

This CFM is applicable where the crew has choices in a procedure for how to execute their response. Furthermore, it assumes that a deliberate choice is made. This CFM also covers cases where there is judgment left to the operator (for example, external events, implementation of SAMGs). Alternatively, a decision to try to restart a system and fail to transition to a guaranteed success path in time would not be treated under this CFM; rather, it would be treated under the CFM for 'delay implementation'. For example, Westinghouse functional restoration procedure FR H-1 includes steps to try to restore feedwater until the cue for initiation of feed and bleed is reached. To apply the delay response, the operators know which the correct strategy is, but choose to hold off. This CFM, on the other hand, is an incorrect choice of strategy.

Strategy choices may be quite common, although they can be of different types. For example, the BWR procedures frequently say something like: "provide make up using one of the following systems…". In this case, as long as the systems are operable, any one of them would lead to success and, while there is a preferred order that is emphasized in training, it wouldn't matter to the PRA if the order were not strictly followed. The crew might be more comfortable using one system rather than another because it's more controllable (RCIC rather than HPCI for example when the conditions allow it). If, however, the scenario progresses such that the choice of one system over the other causes failure of the response required by the PRA scenario, then that would be covered under this CFM.

Other choices may involve methods of controlling a function, such as cooldown and depressurization where choosing a specific rate of cooldown can be identified as a specific strategy. Usually, when a rapid cooldown is required the procedure would give guidance to exceed the "normal" cooldown rate. A reluctance to do this would be a problem if, by not using the accelerated rate, a failure of the required response would result, that is, the HFE occurs. The qualitative analysis of the HFE would have to identify this as a potential failure if it were indeed the case. For this case, one could postulate that the most relevant PIF would appear to be reluctance associated with the fact that rapid cooldown is not good for the plant in general.

Another example occurs in PWR SAMGs in which the feeding of a hot, dry SG may result in a tube rupture with a potential for consequent releases. Therefore, restoring secondary cooling may be at the expense of sacrificing a release barrier. The operators may be reluctant to restore SG feed even though it would be a better strategy in the long term. This CFM may not be used often during full power, internal events Level 1 PRAs, but will likely be more relevant in Level 2 PRAs and more complex analyses such as those involving the use of SAMGs.

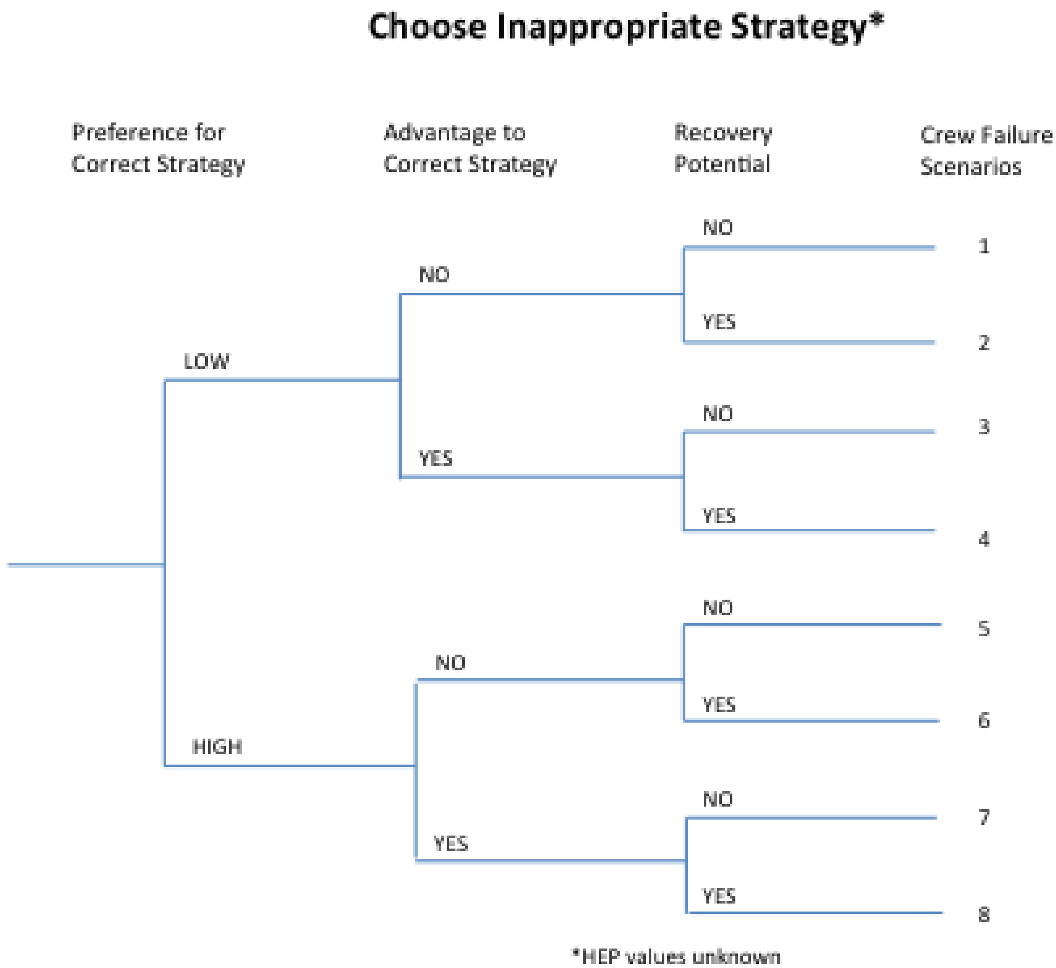

Figure B-2
Inappropriate Strategy Crew Failure Mode Decision Tree

<u>Branch Point 1: Preference for Correct Strategy</u>

The branch point ascertains if the crew has a strong preference to choose one option (the incorrect one) over the correct alternative. The preference for one solution will be influenced by the crew's comfort level in performing the response. A higher level of comfort with the correct response would lead the crew to choose that option over the other alternatives presented. This CFM assumes that the crew has the correct plant status assessment and knows what critical safety functions need to be addressed. Therefore, a big factor in choosing one option over another will be the comfort the operators feel in applying that option. For example, if the crew has less training on, or experience in, applying the correct response, they may exhibit reluctance and a lack of confidence in their ability to apply it over the alternative response.

To address this branch point, the analyst should answer the following:

1. Is the correct response trained more regularly or experienced more often so that the crew would exhibit a preference to enact it when given the choice between the alternatives?
2. Are the operators trained in the correct strategy that emphasizes its significance despite any negative consequences? This is particularly true for those cases where not adopting the strategy could be regarded as a violation, for example, not cooling down at the maximum rate.
3. Is the correct response no more complicated to apply than the incorrect response?

➔ If the answer to all of these questions is Yes, take the HIGH branch. Otherwise, take the LOW branch.

<u>Branch Point 2: Advantage to Correct Strategy</u>

The purpose of this branch point is to determine whether there are considerations related to the correct response that interfere with the operators choosing that response. For example, if the strategy that is required for success (by the PRA success criteria) has a downside, such as it could have financial ramifications for future restart, or indeed is counter-intuitive in that it bypasses one of the primary boundaries (for example, containment venting, although that decision would involve more than the control room crew), then the crew might be hesitant to choose that strategy.

To address this branch point, the analyst should answer the following:

1. Are there competing priorities that make the correct response appear less attractive to the operators?
2. Is there a downside to the correct option that would bias the operators to choosing the incorrect alternative?
3. Is there a mismatch between the procedures, policies and practice such that the correct response is biased against?

➔ If the answer to any of these questions is Yes, the NO branch should be taken. Otherwise, take the YES branch.

<u>Branch Point 3: Recovery Potential</u>

The assessment of whether credit can be taken for recovery is discussed in general terms in Section 5.16 (of Reference [19]). The following is additional guidance specific to this CFM. Recovery of this CFM is possible if the crew monitors the response following initiation of the action and recognizes that the strategies need to be reassessed.

B.4 Excerpt of Delay Implementation CFM

This section provides a description of the Delay Implementation CFM DT from IDHEAS. This CFM is related to the Inappropriate Strategy CMF in that it is one specific type of inappropriate strategy – to knowingly delay one action in favor of pursing another. While the PIFs considered are quite general, this tree was developed for internal events type actions; to use this tree for

FLEX type actions, branch points may need to be added (for example, environmental factors), modified, or further guidance provided on how to interpret the branch points in the context of FLEX. This tree is still under development, and probabilities are not currently assigned for all branch points.

The Delay Implementation CFM DT is described here and is quoted verbatim from [19]:

> The crew, having formed a correct plant status assessment in terms of understanding the nature of the plant disturbance and the critical safety functions that need to be controlled or restored, and knows what action needs to be taken, delays the implementation of the action to the extent that the response is not successful (that is, the HFE occurs).

Applicability

As indicated by the definition, this CFM is applicable when the successful response is the initiation of the appropriate action at or before a critical point (which may be dictated by time or by a specific parameter value, for example, CST level). Note that the PRA success criterion for the response requires initiation before a critical state is reached, often related to the onset of core damage, and this may well be beyond the state corresponding to the parameter value given in the procedure. One of the critical subtasks of such a response involves monitoring the parameter that provides the final cue to begin initiation. There is often some margin built into the procedural guidance. A failure to follow this guidance, if performed willfully, would be a violation of a strict compliance with a procedure, even though the operators might feel they could justify it.

While the two CFMs associated with monitoring have the same effect in that they result in the initiation of the response being delayed beyond the time at which it is successful, this CFM is distinguished from “Critical Data not Checked with appropriate frequency” because the underlying cognitive mechanism is different, and therefore the PIF characteristics that enable this CFM are different. This particular CFM represents a deliberate delay rather than missing the cue. The boundary condition for this CFM is that the crew has successfully monitored the parameter and knows that the critical value specified in the procedure has been reached to perform the action, but there is perceived to be margin such that the action can be delayed to pursue another course of action.

This CFM is meant to capture those crew failure scenarios that result from: (1) delaying an action because it is hoped it can be avoided since, for example, it is an action for which the economic consequences are unfavorable and/or (2) incorrectly assessing the time to complete the action or the time available (for example, believing that there is a margin of available time relative to the procedural directions).

Development of Decision Tree

The DT is developed on the basis that the following are reasons for delaying implementation of the action. One reason for delaying implementation would be believing that the respective function can be achieved by recovery of a system that normally performs that function without resorting to the action (for example, believing AFW can be restored in time to prevent going to feed and bleed). The analyst needs to identify whether there are alternate, more desirable success paths for the HFE. Note that the existence of alternate potential success paths is also addressed in the CFM “Critical data not checked with appropriate frequency” although its impact is different in that it is considered to be a factor that distracts from the monitoring activity. For the current CFM, this is related to the crew's belief that, even though they have reached the point where they should be taking this action, they are on the brink of success with the alternate approach. An important consideration here might be the belief that they have some margin, even at the "last" minute according to the procedure.

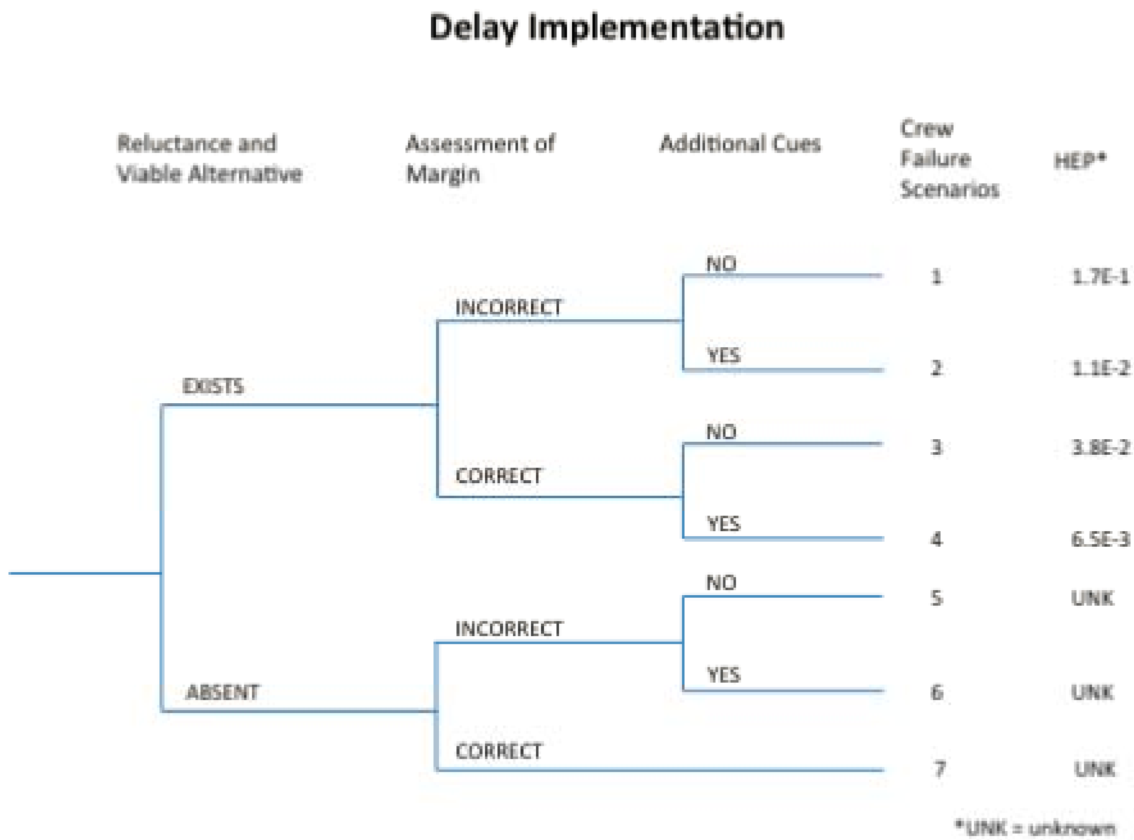

Figure B-3
Delay Implementation Crew Failure Mode Decision Tree

Branch Point 1: Reluctance and Perceived Viable Alternative

Definition: This branch point is concerned with whether there could be a reason for the operators not to want to perform the response as required.

Explanation: Some required responses are considered last ditch responses and are detrimental to the restoration of the plant to full power operation. Such responses include initiation of SLC (BWRs), initiation of F&B (PWRs), or makeup with non-pure water sources (for example, SW or Fire water). This branch addresses whether the response is of this nature. However, since it is a valid, proceduralized response (consistent with the ground-rules adopted for this version of the model) the crew would have no reason to delay implementation unless they believed there was another viable alternative to taking this action. One of these is the recovery of a primary means of achieving the function. If the plant philosophy with respect to procedure following is to carry out the required actions without delay, the analyst may assume that there is no reluctance by the crew. However, if this philosophy does not exist or is not emphasized, then the analyst must consider if the crew felt there was a downside to the response (for example, economically because of prolonged downtime) or if there is an expectation that recovery is imminent.

To address this branch point, the analyst should answer the following:

1. Does the plant philosophy allow operators to exercise discretion in the pace with which they carry out procedures (as opposed to requiring operators to carry out required actions without delay)?
2. Is there a downside to the response, for example, economically because of prolonged downtime or damage to the plant? (Reluctance)
3. Is there a perceived viable alternative (that is, an expectation that recovery is imminent)?

➔ If the answer to all three points (a, b, and c) is Yes, then follow the EXISTS branch. Otherwise, take the ABSENT branch.

<u>Branch Point 2: Assessment of Margin</u>

Definition: This branch point questions whether the crew has an incorrect assessment of the operational margin (for example, as measured or indicated by pressure, level, temperature) so that they think they can delay implementation longer than they actually can.

Explanation: In addition to reluctance, another factor that could play into delaying implementation is the crew thinking they have more time to complete the response than they actually do. In other words, the crew have an incorrect assessment of the time margin based on their understanding of the scenario knowing that, if the point of implementation is tied to a specific parameter value, the procedure would have been designed to provide adequate margin. However, there may be some plant conditions for which the crew’s knowledge base does not lend itself to the correct assessment. The PIFs addressed here are those related to the circumstances under which an incorrect assessment of time margin is possible. The crew’s knowledge base derives from training and, to a lesser extent, experience. However, actions in EOPs are typically only included if they are feasible. Thus, it is expected that adequate time is generally available and usually the lower branch (that is, ‘correct assessment’) should be taken. Therefore, if the scenario is incompatible with the training such that either the training does not adequately prepare the crew in understanding the time margin related to the procedural directions or the specific scenario involves a time margin that is significantly less than those trained on, the upper branch would be taken in this tree. This is more likely to be a significant factor when combined with a reluctance to take the action reinforced by the possibility of avoiding taking the action, that is, the upper path from the prior branch point. A strict compliance with the procedures reduces the significance of this factor considerably.

To address this branch point, the analyst should answer the following:

1. Is this scenario incompatible with those addressed in training and does the training fail to extend to understanding the (time) margin incorporated in the procedural directions?
2. Does the specific scenario involve a time margin that is significantly less than those typically trained on?

➔ If the answer to either of these questions is Yes, the INCORRECT branch should be taken. Otherwise, the CORRECT branch should be taken.

<u>Branch Point 3: Additional Cues</u>

Definition: This branch questions whether there are additional cues that refocus the crew on the need to begin the execution expeditiously.

Explanation: The existence of an alarm related to the initiation of the action can act as a potential recovery for all paths through the trees by redirecting the crew's attention. Also, another crew member responsible for oversight (for example, following the CSFSTs) might reinforce the need for immediate initiation. An example of an additional cue is where the "low" level might be the primary cue for a given action, but there is an additional alarm on "low, low" that would remind the crew.

Note that the amount of credit afforded to this alarm could be different for the path encompassing a reluctance to carry out the action as compared to no reluctance but the incorrect assessment of time margin path because the reluctance involves a cognitive mechanism that could prevent recovery.

Apart from the alarm, no explicit recovery is modeled here because, by definition, the delay has to be significant enough that the function has failed.

To address this branch point, the analyst should answer the following:

1. Is the alarm or additional cues salient?
2. Is the alarm (or other cue) and its importance emphasized in training?
3. Is the philosophy of the plant to respond immediately to this alarm or cue?

➔ If Yes to any of the questions, then the YES path should be taken. Otherwise, the NO path should be taken.

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