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Applying HRA to FLEX – Using IDHEAS-ECA

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ABSTRACT

This report describes the human reliability analysis (HRA) of scenarios involving diverse and flexible coping strategies (FLEX) and associated equipment. The HRA method used for this project is the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA). IDHEAS-ECA has been developed to focus on specific contexts, especially those that involve operator actions taken outside the main control room of a nuclear power plant. The basis for IDHEAS-ECA is "The General Methodology of an Integrated Human Events Analysis System" (IDHEAS-G) which addresses a broad set of contexts. Both industry and the Nuclear Regulatory Commission are beginning to incorporate FLEX strategies into probabilistic risk assessments (PRAs).

This FLEX HRA effort involved the following: 1) plant site visits to better understand FLEX strategies, associated equipment and operator actions; 2) selection and development of credible, HRA/PRA scenarios and associated human failure events; 3) training on IDHEAS-ECA and an associated software tool; 4) a workshop for HRA analysts to perform and/or finalize their HRA quantification using IDHEAS-ECA; and 5) final documentation of results. The results of this FLEX HRA effort will be used by the developers of IDHEAS-ECA to guide future developments.

Key Words
Human reliability analysis (HRA)
FLEX
Probabilistic risk assessment (PRA)

EXCUTIVE SUMMARY

This report describes the human reliability analysis (HRA) method of scenarios involving the nuclear power industry's implementation of diverse and flexible coping strategies (FLEX). The HRA method used for this effort was the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA).

Background

The U.S. Nuclear Regulatory Commission (NRC) and nuclear power industry have been using probabilistic risk assessment (PRA) to identify risk-significant vulnerabilities in plant design and operations and to risk-inform licensing decisions since the 1990s. The 1995 NRC PRA Policy Statement paved the way for the wide-spread use of PRA today. Subsequent rulemaking, regulatory guides (RGs), and NRC reports have reinforced the role of PRA in risk-informed decisionmaking.[1] In turn, the nuclear power industry has taken advantage of NRC's risk-informed guidance (e.g., RG 1.174 for plant-specific changes to the licensing basis, RG 1.177 for risk-informed technical specifications) to make modifications to their plants and operations.

Since the first PRA performed for the nuclear power industry (i.e., the "Reactor Safety Study," or WASH-1400), human reliability analysis (HRA) has been an important part of PRA. In particular, HRA must support PRA models in representing the "as-operated" aspect of nuclear power plants (NPPs). The first HRA method, the "Technique for Human Error Rate Prediction" (documented in NUREG/CR-1278) supported not only the first U.S. PRA but continues to be applied throughout the world for both nuclear and non-nuclear technologies.

However, many dozens of HRA methods have been developed in the intervening years, both in the U.S. and internationally. For example, multiple HRA methods were developed by following design and operational changes made following the Three Mile Island 2 accident in 1981. Other methods, especially internationally, were developed for specific reactor designs (e.g., MERMOS). More recent, or so-called "second generation," HRA methods have been based on more recent advances in cognitive and behavioral science, offering better explanations for "why do humans err?" Examples of two such methods developed by the NRC include "A Technique for Human Event Analysis" (ATHEANA) and the "Standardized Plant Analysis Risk-Human Reliability Analysis" method (SPAR-H). The NRC also has developed context-specific HRA guidance (e.g., *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines*, NUREG-1921 and Supplements 1 and 2) and performed HRA/PRA for regulatory purposes (e.g., rulemaking on pressurized thermal shock) and research (e.g., NRC's Office of Nuclear Regulatory Research site-wide, all hazards Level 3 PRA project). It should be noted that, with a few exceptions, the human error probabilities (HEPs) used in these HRA methods are directly or generally based on THERP.

The Development of IDHEAS-ECA

Improvements to HRA and its application have continued since the flurry of HRA method development in the 1990s and early 2000s. For example, the U.S. NRC Commission, in its staff

[1] Examples of include: NRC's Regulatory Guide 1.205 which supports industry's voluntary transition to the National Fire Protection Standard 805 (NFPA-805) - a risk-informed and performance-based approach to fire protection; and NRC reports such as *The Proposed Risk Management Regulatory Framework,* NUREG-2150; "Recommendations for Enhancing the Reactor Oversight Process," SECY-19-0067)

requirements memorandum (SRM) M061020, directed the Advisory Committee on Reactor Safeguards (ACRS) to, "work with the [NRC] staff and external stakeholders to evaluate different human reliability models in an effort to propose a single model for agency use or guidance on which model(s) should be used in specific circumstances." In response to SRM M060120, the NRC staff evaluated several HRA methods by conducting two international collaborative research projects that compared the results obtained from the HRA methods to simulator experiments. Based on the results of the comparisons, the NRC staff identified areas for HRA improvement and decided to develop an enhanced HRA methodology to integrate the strengths of the existing HRA methods and improve HRA in the areas of application scope, scientific basis, variability, and data. The enhanced HRA methodology is referred to as "The General Methodology of an Integrated Human Event Analysis System" (IDHEAS-G). IDHEAS-G is intended to be a human-centered, general methodology used to develop application-specific HRA methods and consists of two parts: a cognition model of human performance and an HRA process that implements the cognition model.

Several companion documents to IDHEAS-G have been developed or are planned. For example, a cognitive basis framework was developed and documented in NUREG-2114, and the Integrated Human Event Analysis System for Data (IDHEAS-DATA) was created to develop HEPs, using a variety of sources (e.g., psychological literature, NPP simulator exercise). Hence, IDHEAS-G is the first NRC HRA method developed since THERP that has a unique, underlying database.

The Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) has been developed as an extension of "The General Methodology of an Integrated Human Events Analysis System" (IDHEAS-G) to address a broad set of contexts, especially those that involve operator actions taken outside the main control room of a nuclear power plant. In addition, the IDHEAS-ECA guidance is a streamlined version of that for IDHEAS-G, particularly for HRA qualitative analysis and quantification. IDHEAS-ECA address the context of beyond-design-basis external events (BDBEE) and the diverse and flexible coping strategies (FLEX) strategies implemented by the U.S. nuclear power industry.

HRA/PRA Application to FLEX

Both the NRC and industry are beginning to modify PRA models to represent the implementation of FLEX. All of the NRC's Standardized Plant Analysis Risk (SPAR) models have been updated to include FLEX strategies. Also, many utilities have expanded their PRA models to include the use of FLEX equipment. Also, some utilities have requested licensing changes that involve using FLEX strategies or equipment for non-FLEX contexts (e.g., provide additional diesel generator redundancy in loss of offsite power scenarios).

Regarding HRA, specifically, the Electric Power Research Institute (EPRI) issued guidance for FLEX HRA in November 2018 and NRC's Office of Nuclear Regulatory Research (RES) performed an expert elicitation to develop human error probabilities (HEPs) for FLEX scenarios in 2019 (Volume 1 of this report). Although there are several differences between the two reports, both reports lacked certain details regarding how FLEX has been implemented that are important to performing HRA.

As will be discussed later in this report, there are some challenges to modeling FLEX scenarios and non-FLEX scenarios involving FLEX equipment in PRA. For example, the information documenting FLEX implementation may not be directly applicable to HRA/PRA (e.g., timing information may be too conservative or not match a PRA end state, such as core damage).

NRC's FLEX HRA Using IDHEAS-ECA

The main objective of this effort was to perform HRA for credible and detailed scenarios involving FLEX strategies and associated equipment. A secondary objective was to perform this HRA using IDHEAS-ECA (as part of a larger piloting effort). In order to accomplish both of these objectives, this FLEX HRA effort took advantage of several important resources, such as:

1. The participation of both NRC and industry HRA analysts in both scenario development and HRA quantification activities
2. Two plant site visits – one boiling water reactor (BWR) and one pressurized water reactor (PWR) – attended by many of the HRA analysts and supported by several FLEX and operational experts (both plant-specific and industry-wide)
3. Support by FLEX and operational experts throughout the project to develop credible, detailed and PRA-relevant scenarios – one FLEX scenario for a seismic event and two non-FLEX scenarios involving use of FLEX equipment to provide redundant sources of electrical power and feedwater, respectively
4. Input from HRA analysts and FLEX/operational experts to develop qualitative HRA insights that served as a common understanding of FLEX strategies, associated equipment and operator actions
5. A face-to-face, FLEX HRA Workshop that facilitated the ultimate, common understanding of the scenarios and how to apply IDHEAS-ECA

In addition, the NRC's FLEX HRA effort addressed not only a "classic" FLEX scenario for a beyond design basis external event, but also two non-FLEX scenarios (i.e., the initiating event is not an external event) that were of interest to industry.

Summary Results and Lessons Learned from NRC's FLEX HRA Using IDHEAS-ECA

Overall, this FLEX HRA effort was successful in accomplishing its main and secondary objectives. Examples of key accomplishments are:

- Both NRC and industry HRA analysts learned more about FLEX equipment and utility preparations for using FLEX equipment that are important inputs to HRA/PRA.
- The combination of information collection during the site visits, inputs from industry FLEX experts, and traditional HRA/PRA constructs were sufficient[2] to support the development of three scenarios that both NRC and industry analysts agreed were credible:
  - One "classic" FLEX scenario for a seismic event
  - One non-FLEX scenario for a "sunny day" loss of all feedwater (and deployment of a FLEX pump)
  - One non-FLEX scenario for a "sunny day" station blackout (SBO) with a FLEX Plus diesel generator pre-staged while an emergency diesel generator was out-of-service for long-term maintenance
- The participating HRA analysts and NRC's technical team learned important lessons about how to perform HRA for FLEX, regardless of the HRA quantification method. (e.g., how to use industry-wide and plant-specific information about FLEX implementation

[2] Supplemented by some key assumptions.

such as the industry-wide use of common connections, plant-specific FLEX timelines and validations).

- Industry participation (both FLEX experts and HRA analysts) and interaction with NRC staff (both HRA analysts and NRC's FLEX HRA technical staff) throughout the project created a confidence in the process and results.
- The confidence in the scenario development approach also translated into a collegial environment for the workshop.
- Both NRC and industry HRA analysts judged that the IDHEAS-ECA human error probability (HEP) results to be credible and consistent with their qualitative assessment of individual human failure events (HFEs).
- Generally, the HEPs developed by the participating industry and NRC HRA analysts were consistent (within an order of magnitude). There were a few cases for which there were outlier results.

In addition, some important HRA/PRA insights were developed as a result of this effort, such as:

- Timing validation information that was developed to support FLEX implementation can be used but:
    - It may be conservative (and PRA success criteria may require much shorter times for the completion of operator actions)
    - Because FLEX timing information has been developed for site-wide events, this information may represent the time needed to perform actions for more than one unit (whereas most PRAs are performed for a single unit)
    - It may not be directly applicable to PRA because the "success criteria" used for FLEX validation are different than PRA success criteria (e.g., a serious consequence such as core damage or component failure)
- PRA event trees may require additional modeling (e.g., additional branches and end states) to accommodate the use of FLEX equipment, especially if FLEX equipment is being used as backup equipment to front-line, safety systems in non-FLEX PRA scenarios (e.g., FLEX pumps used if all auxiliary feedwater (AFW) pumps fail – both before or after feed-and-bleed criteria have been reached).
- Thermal-hydraulic analyses may not have been performed to support crediting FLEX equipment (e.g., if one AFW pump runs for one hour then all AFW fails, how much more time do operators have until the feed and bleed success criteria are reached, compared to that if all AFW pumps failed at t=0?)
- For non-FLEX scenarios, HRA/PRA credit cannot be given unless appropriate supports for operator actions are provided. For example, modifications to Emergency Operating Procedures (EOPs) to include use of FLEX equipment must have strong and unambiguous guidance for deployment in order to obtain HRA credit (in addition to consideration of adequate time).

Regarding feedback on IDHEAS-ECA and its associated software, resolution of comments from the workshop and survey will be documented and published separately.[3]

[3] At the time of this report's publication, documentation of comment resolution (and associated refinements to IDHEAS-ECA guidance and associated software tool) was still in progress. This documentation will be publicly available in ADAMS.

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The authors would like to thank many groups and individuals who contributed their time, experience, and insights to this report.

Mary Presley (EPRI) offered the support of her organization, facilitating the participation of various members from industry through the Memorandum of Understanding (MOU) between the NRC's Office of Nuclear Regulatory Research (RES) and EPRI. This MOU also facilitated the exchange of information between NRC and industry participants. Mary also provided her insights from EPRI's previous FLEX HRA work and her participation in NRC's expert elicitation for FLEX HRA. In addition, EPRI provided support for one of the industry HRA analysts. Mary also helped to identify other industry HRA analysts who were willing to support this project and served as an observer for the FLEX HRA Workshop.

The authors also appreciate the support from representatives of the Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) Owners Groups (BWROG and PWROG, respectively), including Greg Krueger (BWROG, retired) and Roy Linthicum (PWROG). Both the PWROG and BWROG assisted in identifying nuclear power plant (NPP) sites to host visits from the project team and in identifying FLEX and operational experts to support these site visits and other project activities. Roy Linthicum also provided support as an operational expert.

The authors are grateful for the time and wealth of experience provided by several industry and NRC FLEX and operational experts:

- Phil Amway, Exelon
- Randy Bunt, Southern Company
- Frank Gaber, Arizona Public Service
- Jim Lynde, Exelon
- Josh Miller, NRC's Office of Nuclear Reactor Regulation (NRR)
- Sue Sallade, Exelon (retired)
- William Webster, Dominion

These subject matter experts were essential in helping the project team and HRA analysts to understand key aspects of FLEX strategies, associated equipment, and operator actions. Many of the experts participated in the plant site visits, helping to explain both site-specific and industry-generic features of FLEX. These experts also participated in numerous phone call meetings to support the development of scenarios. A few of these experts attended the FLEX HRA Workshop to provide additional FLEX and/or operational information needed during HRA quantification. Also, some of these experts provided the essential elements of the non-FLEX scenarios that were evaluated in this project.

The authors are also grateful for the time and effort from the industry and NRC HRA analysts who participated in this project:

- Frank Arner, NRC Region I
- Mark Averett, Florida Power & Light
- John Bretti, Entergy
- Scott Freeman, NRC Region II
- Kaydee Gunter, Jensen-Hughes
- Chris Hunter, NRC RES

These HRA analysts participated in phone calls to finalize scenario descriptions and associated HFE definitions, participated in remote training on IDHEAS-ECA, attended the face-to-face workshop at NRC's Headquarters to perform the HRA evaluations, and developed the final HRA analyses and associated documentation. Kaydee Gunter and Chris Hunter also provided specific HRA/PRA details for scenario descriptions (e.g., event trees).

The authors would like to thank additional NRC staff who provided their time and experience to understanding FLEX and related events. In particular, the authors would like to thank Mark King (NRR, Division of Reactor Oversight, Generic Communications and Operating Experience Branch) for searching out relevant operational experience and sharing his own experiences.

Lastly, the authors would like to express a special thanks to the staff at the two plant sites that were visited during this project. Plant managers as well as administrative, training, operations, and PRA staff worked to ensure that the site visits were a success and met project goals. In addition, both sites were gracious and responsive hosts (e.g., providing conference room space, accommodating last-minute requests).

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS

AC	alternating current
ACRS	Advisory Committee on Reactor Safeguards
ADAMS	Agencywide Documents Access and Management System
ADS	automatic depressurization system
AFW	auxiliary feedwater
AO	auxiliary operator; field operator; equipment operator
AOP	abnormal operating procedure
ARP	annunciator response procedure
ASP	Accident Sequence Precursor (program)
ATHEANA	A Technique for Human Event Analysis
ATWS	anticipated transient without scram
BDB	beyond-design-basis
BDBEE	beyond-design-basis external event
BWR	boiling water reactor
BWROG	Boiling Water Reactor Owners Group
CBDT	Cause-Based Decision Tree
CCW	component cooling water
CDF	core damage frequency
CE	Combustion Engineering
CFM	cognitive failure mode
CS	containment spray
CSFST	critical safety function status tree
CT	critical task
CVCS	chemical and volume control system

DC	direct current
DHR	decay heat removal
ECA	events and conditions assessment
ECCS	emergency core cooling system
ED	emergency director
EdF	Electricité de France
EDG	emergency diesel generator
EDMG	extensive damage mitigation guideline
ELAP	extended loss of AC power
EO	equipment operator; auxiliary operator; field operator
EOC	error of commission
EOF	emergency operations facility
EOO	error of omission
EOP	emergency operating procedure
EP	emergency preparedness
EPRI	Electric Power Research Institute
ERF	emergency response facility
ERO	emergency response organization
ESW	essential service water
ET	event tree
FIP	final integrated plan (for implementing FLEX)
FLEX	diverse and flexible coping strategies
FO	field operator; auxiliary operator; equipment operator
FRP	fire response procedure
FSG	FLEX support guideline
HCR/ORE	Human Cognitive Reliability/Operator Reliability Experiment

HCVS	hardened containment vent systems
HEART	Human Error Assessment and Reduction Technique
HEP	human error probability
HFE	human failure event
HMI	human-machine interface
HPI	high pressure injection
HPSI	high pressure safety injection
HPSR	high pressure safety recirculation
HRA	human reliability analysis
HVAC	heating, ventilating, and air conditioning
IAEA	International Atomic Energy Agency
IDHEAS	Integrated Human Event Analysis System
IDHEAS-ECA	Integrated Human Event Analysis System for Event and Condition Assessment
IDHEAS-G	General Methodology of an Integrated Human Events Analysis System
IE	initiating event
INPO	Institute of Nuclear Power Operations
IPE	Individual Plant Examination
JPM	job performance measure
LER	licensee event report
LLOCA	large, loss-of-coolant accident
LOCA	loss-of-coolant accident
LOOP	loss of offsite power
LPI	low pressure injection
LPSD	low power and/or shutdown
LPSI	low pressure safety injection

LPSR	low pressure safety recirculation
LWR	light water reactor
MCR	main control room
MLOCA	medium loss-of-coolant accident
MOV	motor-operated valve
MOU	memorandum of understanding
NARA	Nuclear Action Reliability Assessment
NEI	Nuclear Energy Institute
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NRC-RES	NRC's Office of Nuclear Regulatory Research
NRR	NRC's Office of Nuclear Reactor Regulation
NSSS	nuclear steam supply system
NUREG	Nuclear Regulatory Commission technical report
OMA[4]	operator manual action (typically in response to a fire)
OSC	operational support center
PIF[5]	performance influencing factor
PORV	power-operated relief valve
PRA[6]	probabilistic risk assessment; PSA
PSA[3]	probabilistic safety assessment; PRA
PSF[2]	performance shaping factor
PTS	pressurized thermal shock
PWR	pressurized water reactor

[4] In 10 CFR 50, Appendix R, these are local manual action (outside the MCR). In fire PRA, these may be operator actions added in response to a fire, such as to address spurious indications or alarms.
[5] Often PIF and PSF are used interchangeably.
[6] PRA and PSA are often used interchangeably.

PWROG	Pressurized Water Reactor Owners Group
RASP	Risk Assessment Standardization Project
RCIC	reactor core isolation cooling system
RCS	reactor coolant system
RHR	residual heat removal
RNO	response not obtained
RO	reactor operator
ROP	Reactor Oversight Process
RPS	reactor protection system
RPV	reactor pressure vessel
RT	reactor trip
RWST	refueling water storage tank
SAFER	Strategic Alliance for FLEX Emergency Response
SAMG	severe accident management guideline
SAT	systematic approach to training
SBO	station blackout
SD	shutdown
SE	Safety Evaluation
SG	steam generator
SGTR	steam generator tube rupture
SI	safety injection
SLC	standby liquid control
SLOCA	small loss of coolant accident

SM[7]	shift manager; shift supervisor
SME	subject-matter expert
SPAR	Standardized Plant Analysis Risk
SPAR-H	Standardized Plant Analysis Risk-Human Reliability Analysis method
SRA	senior reactor analyst
SRO	senior reactor operator
SS[4]	shift supervisor; shift manager
SSC	systems, structures, and components
STA	shift technical advisor
SW	service water
TDAFW	turbine-driven auxiliary feedwater
THERP	Technique for Human Error Rate Prediction
TSA	time sensitive action (for FLEX strategies)
TSC	technical support center
U.S.	United States of America
V&V	verification and validation
WOG	Westinghouse Owners Group (now the Pressurized Water Reactor Owners Group, PWROG)

[7] The supervisor in the MCR may be called a shift supervisor or shift manager, depending on the NPP. Also, some NPPs have changed from using "SS" to "SM." Consequently, older event reports (e.g., licensee event reports) may use "SS" to refer to the position now called "SM."

1 INTRODUCTION

The report describes an effort to perform HRA for contexts involving the implementation of diverse and flexible coping strategies (FLEX). The HRA was performed using the NRC's new HRA method, the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) [1], and its associated software tool [2]. The FLEX HRA approach, its results, and its ensuing insights are described in this report.

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC) and nuclear power industry have been using probabilistic risk assessment (PRA) to identify risk-significant vulnerabilities in plant design and operations and to risk-inform licensing decisions since the 1990s. The 1995 NRC PRA Policy Statement [3] paved the way for the wide-spread use of PRA today. Subsequent rulemaking, regulatory guides (RGs), and NRC reports have reinforced the role of PRA in risk-informed decisionmaking.[8] In turn, the nuclear power industry has taken advantage of NRC's risk-informed guidance (e.g., RG 1.174 [8] for plant-specific changes to the licensing basis, RG 1.177 [9] for risk-informed technical specifications) to make modifications to their plants and operations.

Since the first PRA performed for the nuclear power industry (i.e., the "Reactor Safety Study," or WASH-1400 [10]), human reliability analysis (HRA) has been an important part of PRA. In particular, HRA must support PRA models in representing the "as-operated" aspect of nuclear power plants (NPPs). The first HRA method, the "Technique for Human Error Rate Prediction" (NUREG/CR-1278 [11]) supported not only the first U.S. PRA but continues to be applied throughout the world for both nuclear and non-nuclear technologies.

Many dozens of HRA methods have been developed in the intervening years, both in the U.S. and internationally. For example, multiple HRA methods were developed by following design and operational changes made following the Three Mile Island 2 accident in 1979 [12]. Other methods, especially internationally, were developed for specific reactor designs (e.g., MERMOS [13]). More recent, or so-called "second generation," HRA methods have been based on more recent advances in cognitive and behavioral science, offering better explanations for "why do humans err?" Examples of two such methods developed by the NRC include "A Technique for Human Event Analysis" [14,15] and the "Standardized Plant Analysis Risk-Human Reliability Analysis" method [16]. The NRC also has developed context-specific HRA guidance (e.g., *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines*, NUREG-1921 and Supplements 1 and 2 [17, 18, 19]) and performed HRA/PRA for regulatory purposes (e.g., rulemaking on pressurized thermal shock) and research (e.g., NRC's Office of Nuclear Regulatory Research site-wide, all hazards Level 3 PRA project [20, 21]). It should be noted that, with a few exceptions, the human error probabilities (HEPs) used in these HRA methods are directly or generally based on THERP.

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[8] Examples of include: NRC's Regulatory Guide 1.205 [4] which supports industry's voluntary transition to the National Fire Protection Standard 805 (NFPA-805) - a risk-informed and performance-based approach to fire protection [5]; and NRC reports such as *The Proposed Risk Management Regulatory Framework,* NUREG-2150 [6] and "Recommendations for Enhancing the Reactor Oversight Process," SECY-19-0067) [7].

Improvements to HRA and its application have continued since the flurry of HRA method development in the 1990s and early 2000s. For example, the U.S. NRC Commission, in its staff requirements memorandum (SRM) M061020 [22], directed the Advisory Committee on Reactor Safeguards (ACRS) to, "work with the [NRC] staff and external stakeholders to evaluate different human reliability models in an effort to propose a single model for agency use or guidance on which model(s) should be used in specific circumstances." In response to SRM M060120, the NRC staff evaluated several HRA methods by conducting two international collaborative research projects that compared the results obtained from the HRA methods to simulator experiments [23, 24, 25, 26]. Based on the results of the comparisons, the NRC staff identified areas for HRA improvement and decided to develop an enhanced HRA methodology to integrate the strengths of the existing HRA methods and improve HRA in the areas of application scope, scientific basis, variability, and data. The enhanced HRA methodology is referred to as "The General Methodology of an Integrated Human Event Analysis System" (IDHEAS-G) [27]. IDHEAS-G[9] is intended to be a human-centered, general methodology used to develop application-specific HRA methods and consists of two parts: a cognition model of human performance and an HRA process that implements the cognition model.

Several companion documents to IDHEAS-G have been developed or are planned. For example, a cognitive basis framework was developed and documented in NUREG-2114 [28], and the Integrated Human Event Analysis System for data (IDHEAS-DATA) [29] was created to develop HEPs, using a variety of sources (e.g., psychological literature, NPP simulator exercise). Hence, IDHEAS-G is the first NRC HRA method developed since THERP [11] that has a unique, underlying database. Other data-driven methods of note are:

- EPRI's Human Cognitive Reliability/Operator Reliability Experiment (HCR/ORE) method [30, 31] that was developed in the 1980s using simulator experiments
- The Human Error Assessment and Reduction Technique (HEART) method [32] developed in the United Kingdom, also in the 1980s
- Nuclear Action Reliability Assessment (NARA) [33], which is an updated version of HEART, currently owned by Electricité de France (EdF)
- EdF's *Méthode d'Evaluation de la Réalisation des Missions Opérateurs pour la Sûreté (MERMOS)* [13] was created in the 1990s/2000s, originally from simulator data for its N4 reactors

In all cases, the underlying databases for these HRA methods have not been independently peer reviewed and are not publicly available.[10]

In responding to the Great East Japan Earthquake (see, for example, Reference 35) and, more specifically, the event at the Fukushima Daiichi NPP, both the NRC and industry are beginning to modify PRA models to represent the implementation of diverse and flexible coping strategies (FLEX). Regarding HRA, specifically, the Electric Power Research Institute (EPRI) issued guidance for FLEX HRA in November 2018 [36]. Also, in 2018, NRC's Office of Nuclear Regulatory Research (RES) sponsored an expert elicitation project (Volume 1 of this report) [37] to use an expert panel to: 1) estimate benchmarking HEPs for a representative set of FLEX actions, and 2) identify the factors impacting the HEPs. Although there are several differences between the two reports, both reports lacked certain details regarding how FLEX has been implemented that are important to performing HRA. The purpose of the expert elicitation project was to gain an understanding of human performance in implementing FLEX strategies and to

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[9] IDHEAS-G was not available when the HRA documented in this report was performed.

[10] The underlying database for THERP [34] still exists in paper form and was reviewed at the time of THERP's publication. One of the original criticisms of THERP related to this underlying database.

use the expert judgments of the HEPs to inform development of a new FLEX HRA method the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) [1], and its associated software tool [2] for contexts involving the implementation of diverse and flexible coping strategies (FLEX).

1.2 Objectives

The main objectives of this research effort were: 1) perform HRA/PRA for FLEX and non-FLEX scenarios using FLEX strategies and/or equipment, and 2) use IDHEAS-ECA [1, 2] to assess the HFEs within the FLEX and non-FLEX scenarios. This FLEX HRA was performed by a panel of HRA analysts representing both NRC and industry. Draft versions of the IDHEAS-ECA guidance[11] [1] and associated software tool [2][12] were used by the HRA analysts to perform HRA quantification. This trial use of IDHEAS-ECA[13] is intended to provide feedback to the IDHEAS-ECA developers for later improvements.

In addition, there are several underlying objectives:

- To develop a set of credible HRA/PRA scenarios involving the use of FLEX equipment
- To develop sufficiently detailed qualitative HRA analysis inputs for performing HRA quantification
- To facilitate a face-to-face workshop (as well as pre-meetings and follow-on meetings) for the HRA analysts to perform HRA quantification with IDHEAS-ECA
- To obtain feedback from both NRC and industry HRA analysts

1.3 Technical Approach

The technical approach used for NRC's FLEX HRA effort was, to the extent possible, the same as that used to perform any HRA to support PRA. In addition, since NRC's Office of Regulatory Research (RES) and the Electric Power Research Institute (EPRI) agreed to use their Memorandum of Understanding (MOU) [38] as a vehicle to bring in industry resources to support NRC's effort, the resulting technical approach took advantage of these resources, balanced with the need to meet NRC-internal schedules.

The technical approach used for this effort consisted of the following:

- Identification and collection of information on FLEX strategies, equipment and associated operator actions
- Identification of a group of HRA analysts to represent both NRC and industry to participate in this project
- Identification of a group of FLEX and operational experts to assist in the development and assessment of FLEX scenarios and associated operator actions
- Development of a set of credible HRA/PRA scenarios involving the use of FLEX equipment

[11] The reader should be aware that an earlier version of IDHEAS-ECA (i.e., a draft report provided to the FLEX HRA team on October 3, 2019) was used for this analysis. There are a few differences between the October 2019 version and the February 2020 version.

[12] The reader should be aware that both the guidance and software tool were updated following the workshop. However, the authors expect that these updates will not substantially change the results obtained with IDHEAS-ECA.

[13] The authors generally use the term "IDHEAS-ECA" to represent the combination of the IDHEAS-ECA guidance and software tool that was used in this effort. Occasionally, the discussion addresses either the guidance or software, in which case the phrases "IDHEAS-ECA guidance," "IHDEAS-ECA software tool" or the like is used.

- Identification and definition of human failure events (HFEs) associated with using FLEX equipment in each scenario
- Development of qualitative HRA analysis inputs for each HFE that is sufficiently detailed to support HRA quantification (independent of HRA quantification method)
- Support of training of HRA analysts on IDHEAS-ECA prior to the workshop
- Conduct of face-to-face workshop with HRA panelists to use IDHEAS-ECA to perform HRA for FLEX and non-FLEX scenarios[14] and associated HFEs
- Support of HRA analysts in their final HRA quantification HFEs

The first three bullets are expanded upon immediately below. Detailed discussion of the remaining technical approach is provided in later sections of this report. It should be noted that, as for traditional HRA, some tasks were performed iteratively or continuously throughout the project (e.g., whenever new information was collected, the understanding of FLEX strategies and associated scenarios were updated accordingly). Also, all activities were performed with the end goal of providing HRA analysts the necessary inputs to perform HRA quantification, regardless of the HRA approach or method.

1.3.1 Information on FLEX Strategies, Equipment, and Associated Operator Actions

As typical of HRA/PRA, information was collected and interpreted iteratively throughout this effort. Plant-specific and other proprietary information sharing was facilitated by EPRI due to the Memorandum of Understanding between NRC's RES and EPRI. In particular, EPRI provided a file sharing website where both general and plant-specific project information could be stored and shared.

Examples of information sources that the project team either used or were aware of before this project started include:

- Prior studies such as NRC's expert elicitation for FLEX [37] and EPRI's FLEX HRA report [36]
- Various reports on the Great Japan Earthquake (e.g., the Fukushima Daiichi event) (see for example, References 33 and 39)
- NRC's task force on Fukushima [40]
- Reviews of relevant operation experience (e.g., Vogtle loss of offsite power [41])
- NUREG/CR-7256, "Effects of Environmental Conditions on Manual Actions for Flood Protection and Mitigation," Volumes 1 and 2 [42, 43]

After project initiation, there were many more sources of information that were used to inform the development of FLEX-related scenarios. For example, a variety of plant or site-specific information was used, as discussed in Sections 2, 3, and 6. Also, various industry-generic information related to the implementation of FLEX were used (e.g., NEI 12-06 [44], NEI 12-01 [45]).

In addition, information typically used in HRA/PRA (e.g., emergency operating procedures (EOPs) – format, clarity, and content; success criteria and scenario timing information; training quality and frequency) was compared to that for FLEX in order to better understand any operator challenges in implementing FLEX strategies. Comparisons were also made between

[14] Terminology for discussing PRA scenarios involving FLEX strategies and equipment is still evolving. In this report, "FLEX scenarios" are those beyond-design-basis accident scenarios for which FLEX strategies were developed. Also, in this report, "non-FLEX scenarios" are scenarios in which FLEX equipment is used for accident response but not as originally intended by industry's implementation of FLEX strategies.

equipment and associated operational supports for FLEX strategies versus that for early efforts regarding Severe Accident Mitigation Guidelines (SAMGs) and Extensive Damage Mitigation Guidelines (EDMGs). Some of these information sources are discussed later in this report in the context of the plant site visits and scenario development efforts.

1.3.2 HRA Analysts

Unlike a typical HRA/PRA, multiple HRA analysts were needed for this effort. The project team used two criteria to select HRA analysts for participation in this project: 1) HRA/PRA experience, and 2) a balance of NRC and industry analysts. Furthermore, the project team decided that a total number of six (6) analysts was preferable (especially in managing visit to plant sites, face-to-face interactions during the workshop, etc.).

For the NRC analysts, one senior HRA/PRA analyst who is responsible for the Accident Sequence Precursor (ASP) Program (among other responsibilities) was selected from RES. Two other NRC analysts (Senior Reactor Analysts (SRAs) from Regions I and II) were chosen for their experience with the NRC's Significance Determination Process (SDP).

The EPRI project manager asked industry for volunteers to support this effort. Two experienced HRA/PRA analysts who represented different nuclear utilities participated. In addition, EPRI support the participation of a third experienced HRA/PRA analyst from a consulting firm.

The specific tasks assigned to the HRA analysts were:

- Attend plant visits and/or review plant information relevant to scenarios to be addressed FLEX HRA Workshop
- Assist in collecting information and developing qualitative HRA
- Assist in revising HFE definitions and scenario descriptions (to be used as inputs in HRA quantification)
- Participate in training on IDHEAS-ECA
- Perform preliminary HRA assessments of scenarios and associated human failure events (HFEs) using IDHEAS-ECA
- Assist in collecting variations between NPPs on HRA-relevant factors regarding use of FLEX equipment
- Participate in FLEX HRA Workshop to finalize HRA assessments (both qualitative and quantitative)
- Provide any needed follow-on inputs for final results and feedback on IDHEAS-ECA

1.3.3 FLEX and Operational Experts

In a typical HRA/PRA, plant site staff (e.g., engineering, operations) provide the plant-specific information needed to develop and describe scenarios and quantify HFEs. Also, this particular project needed plant-specific information and industry-generic information on FLEX strategies. This information was supplied by several experts on FLEX strategies and FLEX equipment. In addition, as in any HRA/PRA analysis, operational experts for the relevant scenarios were required. In most cases, the FLEX experts who supported this project also were operational experts (e.g., formerly Senior Reactor Operators (SROs)).

One staff member from the NRC who participated in most of the FLEX audits supported this effort on the plant site visits and, as needed, in the scenario development effort.

Industry volunteered many FLEX and operational experts to fill various roles in this effort. Plant-specific experts were provided during the plant site visits for presentations, discussions, tours, and walkdowns. Additional utility and owners group experts participated in the following ways:

- Initial presentations on FLEX
- Subject-matter experts representing various utilities, generally:
    - during plant site visits
    - in understanding FLEX implementation, generally
    - in support of scenario development, generally and for specific scenarios
    - in understanding use of FLEX equipment in non-FLEX scenarios (including changes to plant-specific operations)
    - in support of HRA analyst understanding of scenarios – before and during FLEX HRA Workshop

FLEX and operational experts who supported this project are identified in the Acknowledgements. However, the plant-specific subject-matter experts are not identified to protect proprietary information.

1.4 Scope and Limitations

Three factors influenced the scope and limitations of this research effort:

1. Technical requirements for developing credible HRA/PRA scenarios,
2. Available resources (e.g., calendar time, personnel, existing technical inputs), and
3. Project schedule.

Some key limitations for this project include:

- There were no existing PRAs that were directly relevant to the non-FLEX scenarios developed and the associated plant-specific features and capabilities.
- There were no existing technical calculations to support realistic definitions of some HRA/PRA success criteria (e.g., time available or time required for operator actions).
- A PRA was not developed to support this effort.
- Existing HRA-relevant information for FLEX strategies (e.g., FLEX validation times) was not developed to support PRAs. As a result, some of this information may be conservative for HRA/PRA purposes.
- HRA analysts participating in this effort had limited time outside the FLEX HRA Workshop to perform HRA quantification with IDHEAS-ECA, mostly because of their normal job demands within the project schedule.

In addition, the draft IDHEAS-ECA guidance report that was available to the project team was not as complete as the currently available draft. In particular, guidance for addressing HRA dependency and recovery was not available for the project team. Consequently, the guidance for dependency and recovery was not demonstrated in this effort. Also, timing information that was available for this effort was either too limited or too uncertain to allow for a demonstration of the IDHEAS-ECA method's guidance for human error probability (HEP) contributions from timing concerns.

Project scope decisions were made to compensate for the limitations identified above and to take advantage of available resources. Scope decisions that are expected to be relevant to understanding the technical approach used and the project results include:

- To the extent possible, scenarios were based on relevant previous efforts to develop HRA/PRA scenarios for FLEX (e.g., EPRI's November 2018 report [36], NRC's expert elicitation [37]).
- The scenarios developed represent a single unit (even if the plant site has more than one unit).
- Two (2) U.S. nuclear power plant (NPP) sites – a boiling water reactor (BWR) and a pressurized water reactor (PWR) – were the predominant sources of detailed HRA-relevant FLEX information.
- Information from a small group of PWR Owners Group and BWR Owners Group representatives, and FLEX experts (both NRC and industry) supplemented the plant-specific information from the two plant sites to provide a more generic operational understanding of FLEX strategies and equipment that was used in all scenarios.
- To use IDHEAS-ECA, HRA panelists were asked to assess operator actions in one (1) "classic" FLEX scenario[15], and two (2) non-FLEX scenarios.[16]
- The FLEX scenario was modeled as a seismic event, so no environmental hazards (e.g., effects from external flooding that may impact operator actions) were addressed. Also, debris removal was not explicitly addressed.
- As traditionally done in PRA, a 24-hour mission time[17] was used for all scenarios.
- HRA panelists were asked to assess only those operator actions associated with FLEX strategies and equipment only, and not that already addressed by traditional HRA/PRA.
- FLEX validation timing information was used for all operator actions in the FLEX scenarios. In cases, the timing of operator actions was based on FLEX validation timing results for a site-wide response (e.g., the timing results represent actions for two units), especially if the actions were taken by a single operator and all in the same location.
- Only a few variations of the "base case" scenarios[18] were addressed.
- For the timing of plant behavior and associated parameters in the non-FLEX scenarios, assumptions were made in the absence of relevant thermal-hydraulic calculations.
- For the timing of operator actions in the non-FLEX scenarios, a combination of FLEX validation times and expert judgment[19] was used.
- To the extent possible, HRA-relevant aspects of non-FLEX scenarios were based on actual plant modifications to emergency operating procedures (EOPs) and procedures, training, plant configurations, staffing, and other preparations at a specific plant.

Additional scope limitations and assumptions were made for individual scenarios, as described in Section 3.

[15] This report uses "FLEX scenario" and "classic FLEX scenario" interchangeably to refer to accident scenarios initiated by a beyond-design-basis event for which industry has implemented FLEX strategies.
[16] As already noted, this report defines "non-FLEX scenarios" as scenarios in which FLEX equipment is used for accident response but not as originally intended by industry's implementation of FLEX strategies.
[17] As for traditional PRA scenarios, the authors recognize that there are plant-to-plant differences in design and capabilities (for both installed and FLEX equipment) that result in different plant states at the end of the 24-hour mission time.
[18] In this effort, a "base case" scenario is defined by the HRA analysts. Elements of the base case description are chosen as being important to the HRA. In addition, if resources allowed, changes to a few of these HRA-important elements were selected to define variations on the base case scenario.
[19] In such cases, the "expert" was either a plant-specific, currently licensed Senior Reactor Operator (SRO) or someone else with similar operational experience.

1.5 Intended Audience

The intended audience of this report on FLEX HRA using IDHEAS-ECA is U.S. Nuclear Regulatory Commission (NRC) and members of the nuclear power industry who perform HRA/PRA applications involving FLEX strategies and associated operator actions and equipment.

1.6 Report Structure

This report is organized into the following sections and appendices:

- Section 1 (this section) is the introduction to the report, including the background and scope of this research.
- Section 2 describes visits to U.S. nuclear power plant (NPP) sites and information collected during those visits.
- Section 3 describes the HRA/PRA scenarios and how they were developed.
- Section 4 briefly describes training of IDHEAS-ECA.
- Section 5 briefly describes the FLEX HRA Workshop.
- Section 6 highlights the HRA quantification results obtained using IDHEAS-ECA.
- Section 7 summarizes HRA/PRA lessons learned from this effort.
- Appendix A provides the summary notes from the plant site visits.
- Appendix B describes the FLEX Scenario for a BWR.
- Appendix C describes the Non-FLEX Scenario for a PWR – Loss of All Feedwater.
- Appendix D describes the Non-FLEX Scenario for a PWR – Station Blackout with Pre-Staged Portable Diesel Generators.
- Appendix E documents discussions on scenario variations.

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2 PLANT SITE VISITS

One of the early activities in this effort was visiting two NPP sites – one pressurized water reactor (PWR) design and one boiling water reactor (BWR) design. The two trips were made on September 17 – 19, 2019, and October 2 - 3, 2019.

The plant site visits were instrumental by providing:

- an opportunity to review site-specific FLEX procedures and walkdowns of FLEX strategies, equipment, staging locations, and operator actions – with the support of plant-specific operations staff and input from FLEX experts
- a basis for comparison to operator actions modeled in internal event Level 1 HRA (i.e., traditional HRA), and to other strategies, such as post-core damage response using the initially developed Severe Accident Management Guidelines (SAMGs) and security event response using the initially developed Extensive Damage Mitigation Guidelines (EDMGs)
- confirmation, especially from the HRA perspective, of the importance how FLEX strategies have been implemented (e.g., industry-wide standardization of fittings, color-coding of electrical cables, simple-to-use design of FLEX equipment)
- a vehicle for HRA analysts (both NRC and industry) to form a common understanding of FLEX strategies, equipment, and associated operator actions
- an opportunity for HRA analysts to communicate face-to-face with FLEX experts who have a broader knowledge of FLEX strategies, in order to understand:
    - the underlying basis or purpose of FLEX strategies and how they are implemented
    - what similarities exist between U.S. NPPs with respect to implementation of FLEX
    - what variations exist between U.S. NPPs with respect to implementation of FLEX
    - how to best model operator actions associated with FLEX equipment in HRA/PRA
- a transparent means of collecting and interpreting HRA-relevant information, independent of the HRA quantification method, on FLEX strategies, associated equipment and operator actions

As traditionally done when performing HRA, information collected during the plant site visits (e.g., plant walk-downs, interviews of operators and operator trainers, observations of simulator exercises) served as important input to later tasks in this project. In this project, such later tasks are the development of scenarios and associated HFEs and HRA. The thoroughness of the information collection during these plant site visits (limited by the duration of the visits and other availabilities) was important to establish confidence in the appropriate level of detail for the scenarios developed and the qualitative HRA inputs, both of which were needed to support HRA quantification efforts later, regardless of which HRA quantification method was used. Also, the qualitative HRA – both raw information and its understanding for HRA purposes – that was developed from the plant site visits was intentionally generic in nature (i.e., sufficient and relevant to HRA, regardless of quantification method used).

2.1 Selection of Plant Sites

Industry representatives (e.g., owners group representatives) identified volunteer NPPs for the plant site visits and arranged for the sharing of plant-specific information before, during, and following the site visits. Per the MOU with RES [1], EPRI facilitated the transfer of plant-specific, proprietary information from participating utilities to the FLEX HRA project team.

Two NPP sites were selected for the visits – one PWR and one BWR. Both are two-unit sites. Industry representatives selected the specific sites based on factors such as availability of on-site personnel (e.g., the NPP was not in an outage), and timing of the visit such that project milestones could be met.

It should be noted that plant-specific information from two other PWRs was used to develop two, parallel non-FLEX scenarios. Again, the specific NPPs and associated scenario inputs were provided voluntarily by industry participants in the project using the NRC-RES/EPRI MOU [1] as the conduit to share information. However, because information from these two PWRs was limited, the general insights from the two plant site visits was used to fill in any gaps.

2.2 Objectives of Plant Site Visits

The objectives of the plant site visits were communicated to the owners group representative, the utility hosts, and the HRA analysts who participated in the visits. In particular, the stated purpose of both visits was to better understand and confirm aspects of:

1. operator actions (both decisions and equipment manipulation) taken in response to an external event with extended loss of all AC power that include use of FLEX equipment,
2. operator actions taken in response to other initiating events (not external events) that would lead to use of FLEX equipment, and
3. contexts in which FLEX equipment may be used to provide redundancy or backup to frontline or safety equipment that is unavailable.

The goal of the site visits was to collect information that was readily available and to identify other potential sources of information. Examples of operator action information that are needed for HRA include:

- timing of actions
- procedural support for both decision-making and equipment manipulation
- associated training
- communications and coordination
- tools and equipment
- travel time

Another important objective of the plant site visit was to interview and perform walkdowns with operators and operator trainers. While other plant staff may provide important and useful information, it is important for HRA to reflect what operators know and how operators behave. Consequently, the following personnel supported the plant site visits:

- Staff who were familiar with operations and operator training to provide information on operator actions for using FLEX equipment, including:
    - Decisions and associated procedure paths to using FLEX equipment for both external events that involve Extended Loss of AC Power (ELAP) and non-external events

    - Specific tasks required to deploy FLEX equipment
- Staff who were familiar with procedures (e.g., EOPs, FLEX procedures) and how they are trained on and implemented with respect to use of FLEX equipment.
- Staff who were familiar with or have direct roles in decision-making for use of FLEX equipment (e.g., control room supervisors, Technical Support Center (TSC) decision makers).
- Staff who were familiar with the plant layout and equipment locations to assist, as necessary, the NRC/RES-industry team in performing walkdowns of certain operator actions associated with use of FLEX equipment.
- Staff who were familiar with demonstrations of use of FLEX equipment, including any timing information.
- Staff who were familiar with any "realistic" demonstrations of FLEX equipment (e.g., mini emergency drills (i.e., E-drills) for ELAP).

In all cases, the NPP was assumed to be at full-power at the start of the event and the operators have no prior warning of the event which causes a reactor trip.

2.3 Planning for Plant Site Visits

A significant amount of planning was required to make the plant site visits beneficial to the project. The need for HRA-relevant information was the overriding factor, balanced by the availability of plant site staff to support this need. In addition, both the FLEX experts and plant site staff had information about FLEX strategies and associated equipment that were considered important to share.

Information that was requested before the plant site visits included:

- Procedures relevant to FLEX scenarios, including EOPs (e.g., procedures for SBO) and FSGs
- Site validation plan
- Final integrated plan (FIP)
- Any FLEX PRA information (e.g., HFE evaluations)
- Documentation of any mini E-drills or other "realistic" demonstrations of using FLEX equipment
- Any operational history of using FLEX equipment (including use of FLEX equipment as a source of redundancy)

2.4 HRA Analyst Preparations Prior to Plant Site Visits

The HRA analyst kick-off meeting for this project was conducted via Skype on September 12, 2019 (i.e., less than one week before the first plant site visit). Consequently, the kickoff meeting served as a vehicle for plant site visit prep, as well as an introduction to the project, its objectives, milestones, and key dates. The HRA analysts also were given access to EPRI's file sharing website where general FLEX and plant-specific FLEX information could be found.

In particular, the HRA and scenario development teams did the following prior to the site visits:

- Identified a preliminary list of operator actions for FLEX scenarios
- Defined a preliminary list of assumptions for FLEX and non-FLEX scenarios
- Developed a preliminary description of a "classic" FLEX scenario

- Reviewed materials from the plants (e.g., emergency operating procedures (EOPs,), FLEX Support Guidelines (FSGs), FLEX scenario “scripts” (i.e., accident and operator response timelines)
- Developed a list of questions to ask during operator interviews and walkdowns

The lists and the high-level description of the FLEX scenario noted above represented preliminary results from the scenario development team. The FLEX scenario script was provided by the hosts of both the BWR and PWR plant site visits. HRA analysts were encouraged to provide input to the agendas for the plant site visits and to participate in all interviews and discussion while on-site.

2.5 Agenda and Attendees for Plant Site Visits

As in any plant site visit for HRA, it was important to make best use of the opportunities to talk to and observe plant personnel, and walkdown key operator actions and associated equipment for FLEX strategies. The section summarizes the general agenda for both plant site visits and the attendees for each visit.

2.5.1 Plant Site Visit Agenda

The agenda for each site visit was developed by the NRC project team and the plant site visit host.

In general, the agenda for the plant site visits included the following:

- Day 1:
    - Overview of site/plant and FLEX capability
    - Discussion of scenarios (with and without site personnel)
    - Walkdown of FLEX building (with operator)
- Day 2:
    - Observation and/or discussion of FLEX-relevant simulator training (e.g., the BWR site visit included observation of simulator training in response to a seismic event followed by SBO)
    - Discussion of FLEX training, simulator training, etc.
    - Plant walkdown (e.g., FLEX equipment travel paths, laydown areas)
    - Plant walkdown “inside fence” (e.g., FLEX equipment connections, load shed locations)
    - Summary of day’s activities

The timing and order of activities were flexible, being dependent on when plant personnel (e.g., operators) and resources (e.g., ability to observe simulator exercises) were available and how long it took to get through security checkpoints.

For the BWR plant site visit, the time for security checkpoints was especially important because two escorts and a large group of visitors (e.g., more than 10) participated in walkdowns both inside and outside the plant’s protected area. Also, the BWR plant site visit included an additional half-day meeting to discuss FLEX scenario variations for both BWRs and PWRs.

For the PWR plant site visit, it was not possible to observe simulator training. Instead, a video of a Combustion Engineering (CE) PWR FLEX scenario simulator exercise was viewed and discussed by the NRC project team, HRA analysts, and FLEX and operational experts. Also, the size of the group who participated in the in-plant walkdowns was limited to NRC project team members and HRA analysts, with only a few FLEX experts.

2.5.2 Attendees for BWR Plant Site Visit

Plant site visits are valuable sources of HRA information. Consequently, it was important that the attendees of the plant site visits include some of the HRA analysts who would later perform HRA quantification. The attendance of FLEX experts, who provided additional information (both plant-specific and industry-wide), background, and history on FLEX strategies, represented an information source beyond that which is typical for HRA. In addition, since the NRC team was responsible for developing the scenarios and associated HFEs in collaboration with the FLEX experts, the plant site visit provided a useful vehicle for the FLEX experts to understand modeling HRA/PRA needs.

Attendees for the BWR plant site visit were:

- Susan Cooper (USNRC – project team, technical lead)
- Carmen Franklin (USNRC – project team, project manager)
- Michelle Kichline (USNRC – project management)
- Mary Presley[22] (EPRI – NRC/industry liaison, project manager and observer)
- Phil Amway (Exelon – FLEX expert)
- Randy Bunt (Southern – FLEX expert)
- Frank Gaber (Arizona Public Service – FLEX expert)
- Josh Miller (USNRC – FLEX expert)
- Greg Krueger (NEI/Exelon - BWR Owner's Group)
- Sue Sallade (Exelon – PWR Owner's Group)
- Frank Arner (USNRC – HRA analyst)
- Kaydee Gunter (Jensen-Hughes – HRA analyst)

The roles of the plant site personnel who supported the site visit included:

- Operations (e.g., SROs - both active and management, field operator for walkdowns)
- Operator training and training development
- FLEX strategies

In addition, utility managers offered support for the project and provided additional information at several points during site visit. In particular, a utility manager made it possible for the attendees to observe a simulator exercise for a FLEX scenario during the site visit.

2.5.3 Attendees for PWR Plant Site Visit

As for the BWR plant site visit, the participation of HRA analysts and FLEX experts in the PWR plant site visit was critically important to later project tasks. This plant site visit provided information on some differences between BWR and PWR FLEX strategies, as well as plant-specific details. Also, additional information from and discussion with FLEX experts was beneficial to understanding HRA-relevant aspects of FLEX strategies and to developing scenarios for HRA evaluation.

Attendees for the PWR plant site visit were:

[22] Participated only by phone in discussion of variations on the 3rd day.

- Susan Cooper (USNRC – project team, technical lead)
- Carmen Franklin (USNRC – project team/project manager)
- Michelle Kichline (USNRC – project management)
- Mary Presley (EPRI – NRC/industry liaison, project manager and observer)
- Phil Amway (Exelon – FLEX expert)
- Randy Bunt (Southern – FLEX expert)
- Frank Gaber (APS – FLEX expert)
- Josh Miller (USNRC – FLEX expert)
- Bill Webster (Dominion – FLEX expert/PRA)
- Mark Averett (FP&L – HRA analyst)
- Kaydee Gunter (Jensen-Hughes – HRA analyst)
- Chris Hunter (USNRC – HRA analyst)

The roles of the plant site personnel who supported the site visit included the following:

- Operations (e.g., SROs - both active and management)
- Operator training and training development
- Procedure development
- PRA
- FLEX strategies

In addition, utility managers (e.g., site vice president, licensing) offered support for the project and provided additional information at several points during the site visit.

2.6 Summary of HRA-Related Information Collected During Plant Site Visits

Information collected during the plant site visits played an important role in later project tasks such as scenario development, development of qualitative HRA inputs, and final HRA quantification using IDHEAS-ECA [2]. Also, the information and understanding developed from the site visits led to gathering and interpreting other information that was needed for later HRA tasks. Furthermore, the plant visits provided opportunities for the HRA analysts to communicate with the FLEX experts who also participated in the visits.

In both site visits, information relevant to at-power, internal event Level 1 HRA/PRA and post-core damage (i.e., Level 2 HRA/PRA) was collected and discussed, often to provide a comparison to how operator actions in FLEX strategies were supported by training and experience, procedures, cues and indications, human machine interface (HMI), timing validations, and so on. However, such comparisons are given predominantly in the second site visit notes and overall summary for both site visits.

This section discusses the notes[23] from each of the two plant sites visited. Then, a summary that combines the notes from the two sites visits, as well additional HRA insights, is provided. Appendix A provides more detailed notes on both plant site visits.

[23] Notes on certain proprietary and plant-specific details of each plant site's FLEX strategies have not been documented in this report.

2.6.1 Summary of HRA/PRA-Relevant Notes for Plant Site Visit to a BWR

The first plant site visit for this project was to a BWR NPP. Being the first site visit, this was the first opportunity for the NRC project team and HRA analysts to get in-person information about FLEX strategies, their implementation, and associated equipment. Also, this was the first opportunity to have face-to-face communications with FLEX experts.

Consequently, the first site visit provided probably the largest increase in understanding of FLEX. However, the number of notes taken during this site visit was fewer than that for the later, PWR plant site visit. Later, during the development of the FLEX scenario, additional HRA-relevant insights were captured that are based on this BWR. Therefore, the fewer notes for the BWR plant site visit should not be taken as an indication that less was learned from this site visit.

The notes taken below were developed by the NRC project team. A draft version of the notes was reviewed by the plant site hosts, FLEX experts, and other plant site visit attendees, including the HRA analysts who attended. When finalized, the plant site visit notes were distributed to be used in later steps of the project. The notes from the BWR site visit are presented below in these categories:

- Plant-specific highlights
- Other aspects of FLEX strategies
- Discussion of variations between NPPs

Section A.1 provides more detailed notes for BWR plant site visit.

2.6.2 Summary of HRA/PRA-Relevant Notes for a Plant Site Visit to a PWR

The second plant visit for this project was to a Westinghouse PWR NPP. Based on the success of the first plant site visit, the same general agenda and requests for information and personnel support were used for the second site visit.

Being the second site visit, the NRC project team and HRA analysts were prepared to ask more detailed questions of plant site personnel and the FLEX experts in attendance. Consequently, the number of notes taken for this visit is greater than that for the first site visit.

The notes taken below were developed by the NRC project team. A draft version of the notes was reviewed by the plant hosts, FLEX experts, and other site visit attendees, including the HRA analysts who attended. When finalized, the site visit notes were distributed to be used in later steps of the project.

The notes from the PWR site visit are presented below in these categories:

- Plant-specific highlights
- Overview of FLEX strategies (both plant-specific and, generally, industry-wide)
- Highlights of scenario discussions with plant personnel and FLEX experts
- Highlights from plant walkdowns and associated discussions
- Highlights from video of PWR FLEX simulator exercise and associated discussions

Section A.2 provides more detailed notes for the PWR site visit.

2.6.3 Summary of Combined HRA/PRA-Relevant Notes

The purpose of the combined HRA/PRA-relevant notes is to summarize aspects of FLEX strategies and associated equipment that are important to HRA/PRA. These notes are expected to be important inputs to the development of scenarios (see Section 3) and the HRA quantification using IDHEAS-ECA [2] for both FLEX scenarios and non-FLEX scenarios (see Section 6).

These notes represent insights developed from the BWR and PWR plant sites, supplemented by discussions with FLEX experts on other specific NPP FLEX strategies. However, these insights cannot be considered "complete" on capturing all differences between U.S. NPPs with respect to FLEX strategies and equipment. Also, additional discussions were needed to develop HRA inputs for non-FLEX scenarios. (See Section 3.5 for discussion of non-FLEX scenarios.)

These summary notes capture important aspects regarding the following topics:

- PRA modeling for FLEX strategies
- HRA feasibility assessment for FLEX strategies
- Procedures for implementing FLEX strategies
- Skill-sets, training, and task analysis for FLEX actions
- Timing validations and timelines for FLEX
- Operator actions in FLEX strategies
- Use of FLEX equipment in non-FLEX scenarios
- Additional differences between NPPs with respect to FLEX strategies and equipment

2.6.3.1 PRA modeling for FLEX Strategies

The NRC's Standardized Plant Analysis Risk (SPAR) models are beginning to include some modeling of FLEX. However, there were no existing SPAR PRA models that were directly relevant to support this project. Also, the PWR visited had a PRA but it was not used since the team decided to use a BWR FLEX scenario for analysis. As a result, some PRA modeling needs were identified in this project.

For example, both plant visits included discussions of the success criteria used for FLEX strategies, especially the timing validations for operator actions. Preliminarily, there appears to be a mismatch between the success criteria used for FLEX and that typical for PRAs. Namely, the event tree headings and end states for FLEX strategies do not correspond with core damage. For example, failure to deploy the FLEX DG before DC batteries fail does not equate to core damage. Even if the operator action of "blind feeding the SG" (for PWRs) fails immediately, it will take some time before core damage occurs.

Further investigation and discussions are needed to clarify this potential conservatism. Although this potential conservatism is not within the scope of the FLEX HRA Project, some discussion of this issue will be pursued.

Also, there were no existing PRA models relevant to the two non-FLEX scenarios. In the absence of PRA logic models and associated engineering calculations, certain assumptions had to be made. Sections 3.5.1.2 and 3.5.2.2, respectively, provide the scenario-specific assumptions for each of the two non-FLEX scenarios.

2.6.3.2 HRA Feasibility Assessment for FLEX Strategies

The concept of feasibility was formally defined for HRA/PRA in the "Joint EPRI/NRC-RES Fire HRA Guidelines," NUREG-1921 (July 2012) [3]. This reliability-based definition is based on the deterministic definition provided in NUREG-1852, "Operator Manual Actions" [4], which also addressed fire events. The definition of HRA feasibility was later expanded for main control room abandonment (MCRA) scenarios in fire events with Supplements 1 (August 2017) [5] and 2 (June 2019) [6] to NUREG-1921. The draft IDHEAS-ECA guidance document that was available for this effort did not include HRA feasibility assessment, but it is expected that this concept will be included in later versions.

The important HRA feasibility assessment criteria given in NUREG-1921 and its supplements are:

- HRA feasibility assessment should be made for both individual operator actions and across an entire scenario for all operator actions combined
- at both the individual HFE and scenario level, there must be:
    - sufficient time to perform the operator action(s)
    - sufficient manpower to perform the operator action(s)
    - available and sufficient primary cues
    - procedures and associated training for the operator action(s)
    - an accessible location for performing the operator action(s) (including travel paths)
    - available and accessible tools for performing the operator action(s)
    - operable components for the associated operator action(s)
    - a communication plan
    - a plan for command and control (C&C)

Additional guidance on each of these criteria are given in NUREG-1921 and its supplements.

Based on preliminary reviews of two plant-specific validations of FLEX strategies, it appears that the approach for the development and validation of FLEX strategies generally addresses the above feasibility assessment criteria. Consequently, for the purposes of this project, assumptions have been made that operator actions addressed in the FLEX HRA project are feasible from the perspective of HRA. However, as in any HRA, the issue of HRA feasibility will be considered as a continuous step throughout the analysis.

Also, while operator action feasibility may have been adequately addressed by the definitions used for FLEX, HRA feasibility is different and should be assessed in any plant-specific HRA/PRA. In addition, HRA feasibility for a specific operator action might be evaluated as adequate for a FLEX scenario, but may not be adequate for a non-FLEX scenario involving the same operator action and FLEX because, for example, the timing constraints for PRA success criteria in a non-FLEX scenario may be significantly shorter.

2.6.3.3 Procedures for Implementing FLEX Strategies

As with other aspects, there are some similarities and some differences between NPPs regarding procedural support for FLEX strategies.

All NPPs have FSGs (or at least one FSG). Most commonly, multiple FSGs are used. Also, all NPPs have a procedural link within their EOPs (usually the EOP that addresses station blackout (SBO)) that addresses the decision to declare ELAP and provides an entry point for the FSGs.

And, all NPPs will be following multiple procedures in parallel once the FSGs are entered (e.g., steps in EOPs will continue to be followed with respect to heat removal in parallel with FSGs related to damage assessment, debris removal, FLEX equipment deployment, etc.).

Style guides (that typically address human factors issues that HRA models) are used at NPPs for developing operations procedures (e.g., EOPs). Typically, these same style guides were used to develop FSGs so that there was a continuity in training. The use of procedure writing style guides for the development of FSGs is in stark contrast to the development of other non-EOP procedure sets. For example:

- Fire protection engineers were predominantly responsible for writing fire response procedures (FRPs). In fact, the initial FRPs differed so much in content and format from EOPs that some operators told HRA/PRA analysts that they would not use them. Some NPPs that are transitioning to NFPA-805 [7] have since re-written their FRPs.
- By February 2019, all PWRs updated their Severe Accident Management Guidelines (SAMGs) into a common structure. When SAMGs were first developed, there were differences between NPPs with respect to their content, detail, and formatting. For example, initially, it was not typical for SAMGs to be formatted like EOPs and, with some exceptions, SAMGs for most NPPs did not provide the step-by-step guidance that FSGs contain.

For FLEX scenarios, differences between NPPs that have been identified so far include:

- differences in the procedural logic used for the decision to declare ELAP
- differences in the timing for the decision to declare ELAP (which is, in turn, related to plant-specific battery life and the availability of other power sources)
- differences in how many FSGs are used (e.g., most NPPs have multiple FSGs but there are NPPs that have only one FSG)
- while almost all NPPs have a severe weather procedure that addresses many hazards, some NPPs may have other hazard-specific procedures (e.g., procedure for a seismic event) which may be entered even before a reactor trip and entry in the EOPs and which may have transfers to FSGs

In addition, some BWRs have adopted a BWROG procedure model that includes FLEX equipment directly into EOPs for reasons other than loss of all AC power (e.g., loss of a pump or water source). At present, few if any PWRs have adopted such a strategy. The PWROG is currently working on a similar approach for the PWR EOPs.

2.6.3.4 Skill-Sets, Training, and Task Analysis

The operator actions required to respond to FLEX events involve skill-sets of two types: 1) those that are similar to that represented by human failure events already modeled in PRAs, and 2) those that are significantly different than those typically modeled in PRA.

Traditional PRAs represent mostly MCR operator actions; both decisionmaking and manipulation of equipment are represented. There are some actions taken outside the MCR, mostly involving manipulation of equipment at local plant stations. In SBO scenarios, field operators perform an SBO DC load shed. Similarly, FLEX scenarios include MCR operator actions – both decisions (e.g., deciding on transitions to another procedure) and manipulation of equipment. In addition, many NPPs require a FLEX (or “deep”) DC load shed which involves similar actions but for different DC loads and potentially different locations and associated panels.

Examples of actions that differ from those modeled in traditional PRAs include: 1) the operation of portable equipment such as FLEX pumps and diesel generators (DGs), 2) the removal of debris, and 3) the transport of portable equipment to appropriate laydown areas. Although these actions are discussed later in this section, some key aspects of these actions are important to understand in the context of training and skill-sets:

- Operation of portable equipment – As noted elsewhere in this report, the type of portable equipment selected industry-wide is more robust and simpler to operate than equipment typically operated in NPPs and modeled in PRA. Field operators (or equipment operators[24]) have the responsibility for operating FLEX portable equipment.
- Debris removal – Across the industry, debris removal is performed using large tractors and/or trucks with appropriate attachments. Again, this equipment is robust and simple to operate (and may be similar to trucks and tractors for personal home or farm use). "Hard cards" are provided inside the equipment that explain how to operate this equipment. Consequently, a different, lesser skill-set is needed to operate this equipment and perform debris removal than for operation of permanently-installed or other portable equipment (i.e., field operator qualifications are not needed to perform this action). There are differences between NPPs on whether field operators, security personnel, or other plant staff are responsible for debris removal.
- Transport of portable equipment - Portable equipment is transported to appropriate laydown areas by the same large tractors and/or trucks that are used for debris removal. Also, the same personnel are responsible for transport as for debris removal (although, depending on the site, more personnel may be needed for debris removal than for transport). Again, a different, lesser skill-set is needed to perform these tasks as opposed to that needed to operate permanently-installed or other portable equipment.

Industry has developed operator action supports for these actions that are more unique for FLEX strategies. In particular, NEI 12-06 [8] addresses "Inherent FLEX Attributes That Enhance Human Reliability in the Event of a Beyond Design Basis Event" in Attachment 5 to Appendix E of NEI's report. Attributes that were observed or discussed during the site visits include:

- Use of standardized equipment (i.e., minimal or no specialized equipment)
- Simple, straightforward tasks (i.e., only skill-set needed is that of a "journeyman")
- Clear and color-coded labeling
- Procedures written with sufficient detail for user

NEI 12-06 also identifies the use of the Systematic Approach to Training (SAT) as another attribute for enhancing human reliability. Consequently, most or all U.S. NPPs have developed training for FLEX actions using SAT, which also make training on FLEX actions consistent with how other operator training has been developed and implemented at US NPPs. SAT activities and the details of how to perform SAT originate in reports published by the Institute of Nuclear Power Operations (INPO)[25] and U.S. Department of Energy (DOE), primarily in the 1980s and 1990s. More recently, IAEA has published reports on SAT for use by the nuclear power industry worldwide. For example, IAEA's report, *Nuclear Power Plant Personnel Training and its Evaluation – A Guidebook"* [9] provides the following definition of SAT:

> "SAT is an approach to training that provides a logical progression from the identification of the competencies required to perform a job to the development and

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[24] NPPs differ in how they label non-licensed operators who operate equipment outside the MCR.

[25] These INPO documents provide all of the elements of SAT but describe the approach as the "training system development (TSD) approach." INPO reports are proprietary.

implementation of training to achieve these competencies, and the subsequent evaluation of this training."

Also, a more recent IAEA report [10] on experience in using SAT states that "[SAT] is recognized world-wide as the international best practice for attaining and maintaining the qualification and competence of nuclear power plant personnel."

Both the more recent IAEA reports and the original INPO reports describe SAT as consisting of five activities or phases:

1. Analysis,
2. Design,
3. Development,
4. Implementation, and
5. Evaluation.

While all phases are critical to implementing SAT, the analysis phase is of particular importance to HRA. As described in IAEA's report, *Analysis phase of systematic approach to training (SAT) for nuclear plant personnel* [11], the analysis phase consists of some sort of job analysis. In particular, the Job and Task Analysis (JTA) is the predominant method used in US NPPs, having originated in military applications. According to this IAEA report,

> "[i]n the early 1980s, INPO conducted industry-wide generic JTAs for operations, maintenance, and technical support positions for PWRs and BWRs. These JTAs were then used by the nuclear power plants to develop plant specific analyses."

Consequently, the application of SAT implies that a task analysis has been performed for FLEX actions as part of developing appropriate training for each task. Also, the training development for FLEX actions is consistent with other NPP personnel training (e.g., that need to implement EOP actions), including that for MCR operators as represented in traditional HRA/PRA. This commonality between operator actions directed by EOPs and that for FLEX strategies implies an associated, common expectation of operator reliability.

In addition to the training efforts described above, the NPP industry developed standards for industry-common training that could be used by each site to support response to external events, including those that may exceed the design basis of plants. The working group that developed these standards is comprised of industry, INPO, NEI, and Owners Group personnel with expertise in training, operations, and other technical areas, as well as knowledge of planned industry changes to be made in response to the Fukushima Daiichi event. Products of this working group include:

- National Academy for Nuclear Training e-Learning (NANTeL)[26] Modules
- FLEX Equipment Operating Aids
- Emergency Response Case Studies
- Guidelines for Training and Qualification of emergency response organization (ERO) Personnel
- Decision-making Training for Emergency Responders
- Decision-Making Under Stress Training for Emergency Responders

[26] NANTeL is a nationwide system that delivers nuclear power plant training courses to any computer with internet access.

2.6.3.5 *Important Aspects Related to Timing Validations and Timelines*

Timing information on operator actions is important to HRA/PRA. For example, inputs for the time available and time required for operator actions are important in the determination of the feasibility [27]of operator actions in HRA and are used as direct inputs in certain HRA quantification methods.

In addition, timelines of operator actions can be important to understanding an overall PRA scenario. Also, in certain PRA contexts, such as response to a fire that requires main control room abandonment (MCRA), timelines of multiple operator actions being performed in parallel and in sequence can be an extremely helpful tool for HRA and PRA analysts. NUREG-1921 Supplements 1 and 2 [5, 6] provide examples of such timelines and describe how they are useful to HRA/PRA. Timelines were not explicitly addressed in the draft version of IDHEAS-ECA that was used in this effort. However, later versions are expected to provide such guidance.

All NPPs performed validations of the FLEX actions using industry established guidance based on the required implementation time. In particular, NEI 12-06 [8] provides guidance "…to reasonably assure required tasks, manual actions and decisions for FLEX strategies are feasible and may be executable within the time constraints identified in the Overall Integrated Plan (OIP)/Final Integrated Plan (FIP) or the sequence of events associated with the Mitigating Strategies Flood Hazard Information (MSFHI)." Two processes are described in NEI 12-06:

1. validation process, and
2. verification process.

As described in NEI 12-06,

- "Validation of FLEX strategies consists of validation of the feasibility of individual strategies described in the OIP/FIP using the graded approach as described in this document and in the integrated review of the FLEX strategies. The purpose of the integrated review is to ensure that adequate resources (personnel, equipment, materials) are available to implement the individual strategies to achieve the desired results…."
- Verification is performed prior to validation and consists of verifying "…equipment capability and performance, equipment connections, tooling, plant modifications, and procedures/guidelines…" that were put into place "…as part of existing licensing processes such as the design change process, procurement process, or procedure/guideline development process. Therefore, additional verification is within the scope of this validation process."

The graded approach outlined in NEI 12-06 focuses on:

- Phase 2 of event response[28]
- Actions completed after the start of the event[29]

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[27] It is important to understand that HRA feasibility is defined differently than feasibility in FLEX validations. There is some overlap of concepts but the definition of HRA feasibility is based on criteria, as described in Section 2.6.3.2.

[28] Per NEI 12-06, Phase 2 is the period in which the plant transitions from installed plant equipment to on-site FLEX equipment and consumables to maintain or restore key functions. Phase 1 applies the initial time period when installed plant equipment is relied upon, and Phase 3 applies to the time period when additional capability and redundancy is supplied by off-site FLEX equipment until power, water, and coolant injection systems are restored or commissioned.

[29] NEI 12-06 defines such actions as "reactive actions."

- Time sensitive actions (TSAs) (defined as tasks, manual actions or decisions that are identified as having time constraints in the “Sequence of Events Timeline” in the site’s OIP/FIP).

The graded approach is used to identify the level of validation for TSAs as follows:

- Level A: Used for TSAs started within the first 6 hours
- Level B: Used for TSAs started between 6 and 24 hours after the event
- Level C: Used for other tasks or manual actions in the OIP/FIP that are not TSAs but are labor intensive or require significant coordination

The time required for Level A TSAs is determined using simulations, talkthroughs or walkthroughs, or reasonable judgement using multiple teams. Timing validations for Level B TSAs are accomplished through talkthroughs or walkthroughs, or reasonable judgement without requirements for multiple crews. Validation of Level C TSAs is accomplished using reasonable judgment.

Based on the general descriptions of the validation process and plant-specific results documented in a site’s OIP/FIP, timing information already developed for validating FLEX strategies may be useful for HRA/PRA for FLEX scenarios. For example, the timelines developed for TSAs provide a useful demonstration that HRA feasibility criteria of sufficient time and manpower have been evaluated as satisfied. The validations for specific operator actions may be sufficient as timing inputs to HRA, depending on how the operator actions are defined and what, if any, conservative assumptions[30] were used in performing the validation. Also, there may be operator actions that are taken for the entire site (e.g., actions for both Units 1 and 2 taken by a single operator within a single operator action definition) while the HRA/PRA addresses only a single unit on site.

2.6.3.6 Important Aspects Related to HRA/PRA for Operator Actions in FLEX Strategies

Both plant site visits included discussions of specific operator actions of interest for FLEX strategies and associated equipment. Highlights from those discussions are captured here.

2.6.3.6.1 Debris Removal

Plant site visit walkdowns, interviews, and discussions included the following key aspects with respect to debris removal:[31]

- Debris removal is only required for FLEX scenarios (i.e., is not needed for non-FLEX scenarios).
- Different NPPs will use different equipment, but in all cases this equipment is robust (e.g., large front loader or bulldozer style tractors and ¾ ton or larger trucks).
- In contexts where deploying debris removal equipment might be delayed, such equipment is pre-staged (e.g., might pre-stage equipment to assure accessibility is not impacted with advance warning of a hurricane or flooding).
- Different NPPs have chosen different approaches on what plant staff (e.g., field operators (FOs) versus security personnel) are responsible for debris removal (and often also transport of FLEX equipment).

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[30] The validation may define a time constraint (typically called “time available” in HRA) that is not consistent with an HRA/PRA success criterion.
[31] See also NEI 12-06, Appendix E, Attachment 5.

- In all cases, the timing validations required for FLEX have been performed by NPPs to ensure that adequate personnel are available and knowledgeable to perform the necessary tasks at that time.
- However, commercial grade equipment is used for these tasks because such equipment is easier to operate than might be required for other local operator tasks. Also, “hands on” training is provided and "hard cards" with operating instructions are provided with the vehicles.
- All NPPs performed demonstrations to validate these actions.

While each NPP has performed an assessment of what debris might need to be removed, the amount of debris and associated time to remove it is considered uncertain in most NPP assessments. General guidance was provided on how to perform this assessment, with the expectation that a detailed debris assessment was not needed. The strategy used by many NPPs is to assign the most conservative estimated time for debris that can be tolerated in the overall timing validation. Consequently, there is variation between NPPs on the estimated times for debris removal that are not really related to the amount of debris expected. For example, some NPPs chose a longer time because they had more time available due to longer battery life and larger water resources.

2.6.3.6.2 Decision to Use FLEX Strategies

Plant site visit simulator observations, interviews, and discussions included the following key aspects with respect to deciding to use FLEX strategies:

- For FLEX scenarios (i.e., accident scenarios initiated by an external event), almost all NPPs have proceduralized an explicit "declare ELAP" step.
- A few NPPs initiate actions for damage assessments and engaging offsite resources without declaring ELAP (in order to avoid the consequences of declaring a General Emergency too soon).
- The typical timeframe for “declaring ELAP” is 45 – 60 minutes with outliers as early as 15 minutes and as late as more than an hour.

Differences between NPPs on when this decision must be made are usually driven by plant-specific battery life, time needed to deploy FLEX equipment, when preferred water resources are depleted, and so forth.

There also are differences in the procedural logic for this decision. Many NPPs have procedures with wording such as "if no AC power is restored by 1 hour, declare ELAP and..." initiate certain FLEX Supporting Guidelines (FSGs). Other procedure wording includes, "If no AC power is expected to be restored by 4 hours, declare ELAP by 1 hour."

In all cases, time is a key cue for this decision along with reports from the field on efforts to restore AC power on-site (e.g., successful start of an EDG) and from offsite power sources. Potential differences between NPPs include:

- while most NPPs will make only one attempt to start an EDG from the MCR, the number of attempts to locally start an EDG will depend on the plant-specific design of the EDG (e.g., drain on batteries, limitations on air) and on how many field operators (FOs) or equipment operators (EOs) are available versus other FO responsibilities once FLEX strategies are initiated

- number of power sources beyond typical offsite power and on-site EDGs (e.g., cross-tie to another unit, alignment to dam power source, additional diesel generators (DGs) that are not FLEX DGs)

Because the decision to declare ELAP is embedded in most NPP emergency operating procedures (EOPs), the decision to declare ELAP for a non-FLEX scenario (e.g., a "sunny day Station Blackout (SBO) should be similar for a non-FLEX scenario.

The decision to use other FLEX equipment and associated strategies in non-FLEX scenarios (e.g., "sunny day loss of feedwater " (PWRs)) is different both between BWRs and PWRs (due to Owner's Group developments) and between specific NPPs. This is discussed further under "procedures" and "using FLEX equipment in non-FLEX scenarios."

2.6.3.6.3 DC Load Shed

Per site visit interviews and discussions, most NPPs include a DC load shed in order to extend the life of DC batteries.

However, there are differences between NPPs on such load sheds:

- For most NPPs, EOPs already include a DC load shed as part of the NPP's SBO procedure (i.e., SBO load shed).
- Some NPPs may require an additional DC load shed as part of the FLEX strategy; this load shed is called either a "FLEX DC load shed" or "deep load shed."
- The amount equipment "shed" differs from NPP to NPP, depending on DC battery life and other available power sources.
- The number of electrical panels and locations with electrical panels for a FLEX load shed varies from NPP to NPP.

In most cases, the principal loads remaining after the SBO and FLEX load sheds are necessary instrumentation for operators to monitor important NPP parameters, including that needed to keep the turbine-driven reactor core isolation cooling system (RCIC) pump (for BWRs) or the turbine-driven auxiliary feedwater (AFW) pump (for PWRs) operating and removing decay heat.

Similarities between the two example NPPs include:

- The operator actions required for the FLEX load shed are essentially the same as that already addressed in traditional PRAs for SBO load sheds (i.e., breaker position changes).
- Training is provided for these operator actions.
- All NPPs have provided some type of operator aid for performing load shed. Our plant site visits provided two examples of such aids, i.e.,
    - For one NPP, blue labels in electrical panels indicate which breakers are included in the "FLEX load shed."
    - For the other NPP, the procedure provides a table that mimics the electrical panel, showing which position each breaker should have following load shed. In addition, bolding is used to highlight which breakers must be re-positioned. Operators are trained to self-check the final breaker positions by comparing the bolded boxes in the procedure table to the breakers on the panel.
- Procedures include place-keeping aids (e.g., check boxes). Operators are trained to perform a single breaker re-positioning, followed by checking off the appropriate box in the procedure (as opposed to checking all boxes after all breaker manipulations).

- Timing validations for all aspects of deep load shed (e.g., travel time is included) have been performed.

2.6.3.6.4 Transport and Set-Up of FLEX Equipment

Plant site visit walkdowns, interviews, and discussions indicated that there are some differences between NPPs with respect to transport and set-up of FLEX equipment.

For the two example NPPs:

- A separate FLEX building housed and sheltered FLEX equipment, vehicles for debris removal and transporting FLEX equipment, and related support equipment. The FLEX building is designed to shelter the equipment for all relevant external hazards.
- "Hard cards" were located on or near all of the equipment, providing instructions on how to use the equipment. These hard cards supplemented training on the equipment. (See also the discussion on debris removal since the same equipment is used for both debris removal and transport of FLEX equipment.)
- FLEX equipment is staged in a FLEX building such that the equipment can be transported in the order in which the FLEX strategy specifies.
- Large tractors or heavy duty trucks are used to transport the FLEX equipment. A tractor would first transport the FLEX DG. One a separate trip, the tractor transports the trailer with the needed cables for the FLEX DG. Similarly, the FLEX pump would be transported prior to the trailer with the hoses needed for the FLEX pumps.
- There are two laydown areas, two connection points, and associated paths (a primary and an alternate) for all FLEX equipment.
- Distances from the FLEX building to the laydown areas and connection points are not far. Traffic activity will be very limited, but on multi-unit sites, especially after the first 6 hours, traffic could include 2-3 vehicles.[32] For the majority of sites, there is significant visibility even with anticipated debris fields for travel areas. Also, most of this traffic is moving at 10 to 20 mph, mostly because of the condition of haul roads. For some vehicles, the tires are leak resistant or have been foam-filled which also limits the speeds at which vehicles can travel. Finally, it is expected practice that traffic be coordinated if multiple vehicles are in operation at the same time.
- Lay down areas are marked for each piece of FLEX equipment, outlined in blue paint. The laydown areas must be maintained as accessible.
- After the equipment is positioned, FOs/EOs make the final connections needed. FOs/EOs are trained on making these connections and gaining access to the connection points. The trailers with the cables or hoses have any necessary tools to gain entry to connection points. If necessary, security personnel are available to assist in getting through any security barriers at the entry points.
- FLEX DG cables are color-coded, using an industry standard, to ensure that the proper connections are made.
- FLEX pump hose connections are also standardized.
- Cables and hoses are of the proper length to facilitate deployment.
- Timing validations for all aspects of transport and set-up have been performed.
- For both NPPs visited (and likely for other NPPs), FOs/EOs were responsible to setting up the FLEX equipment.

Some differences between the two NPPs visited and other sites include:

[32] If resources are available, debris removal may continue while FLEX equipment is being transported.

- Not all NPPs have separate FLEX buildings. Some used diverse buildings, and some did not require debris equipment to be in a building. Such differences are based on plant-specific hazards and available resources on site.
- The two NPPs that were visited differed on the personnel used to transport the FLEX equipment. FOs/EOs were used at one NPP, while the other NPP used security personnel to accomplish transport. There are yet other sites that use maintenance personnel for the transport of FLEX equipment. Due to the simplicity of operating the transport vehicles, this difference is not considered to be important for HRA.[33]
- Some NPPs have pre-staged FLEX equipment, so there is no need to transport this FLEX equipment.
- There may be differences between NPPs on how much additional set up (e.g., connection of hoses or cables) is required to ready the FLEX equipment for service. When performing the HRA in these cases, there will be no contribution from transport (and maybe set up) for this FLEX equipment.

2.6.3.6.5 Operating FLEX Equipment in FLEX Scenarios

Once FLEX equipment is transported and set-up, MCR operators must decide on using the equipment, then instructing FOs/EOs to start the equipment. This decision is procedurally directed from the FSGs. If, for example, an NPP's EDG was successfully repaired/restarted before a FLEX DG was put into service, then MCR operators can decide to change the strategy to using the permanently installed EDG. However, for some NPPs, there could be some complications with "backing out" of the FSGs, depending on the electrical lineup following the FLEX load shed.

Finally, FOs/EOs/AOs start the FLEX equipment. In some cases, this is as simple as pushing a button.

2.6.3.7 Important Aspects Related to Using FLEX Equipment in Non-FLEX Scenarios

Some NPPs have or are considering the use of FLEX equipment for non-FLEX scenarios (i.e., initiator is not an external event). Both the NRC and industry recognize that use of FLEX equipment in non-FLEX scenarios could be an enhancement to NPP safety.

Non-FLEX scenarios are included in the scope of the NRC’s FLEX HRA project. Non-FLEX scenarios are discussed in more detail in the next section. However, there are some similarities and differences that can be preliminarily identified. For example:

- If a "sunny day[34]" loss of all AC power occurred, all NPPs should be able to use existing EOPs to transfer to FSGs relevant to using FLEX DGs in such scenarios.
- For "sunny day" losses of other functions (e.g., loss of feedwater for PWRs), the procedural links between EOPs and FSGs may not exist. Some BWRs have incorporated FLEX equipment directly into their EOPs. For these NPPs, the procedural links already exist, and FLEX equipment can be credited in these non-FLEX scenarios.
- For use of FLEX equipment in place of safety equipment during on-line maintenance of the safety equipment, all NPPs can be treated similarly as long as:
    - FLEX equipment is pre-staged,

[33] For both plant sites, there was specific training on operating the debris removal equipment for the personnel responsible.

[34] In other words, the loss of AC power occurs without an external hazard or event.

- Operators are briefed on the use of FLEX equipment (e.g., before every shift),
- Just-in-time training for use of FLEX equipment is provided, and
- Equipment functionality is demonstrated regularly

2.6.3.8 Additional Notes on FLEX Strategies

The sub-sections above have identified various similarities and differences between NPPs with respect to implementing FLEX strategies and associated equipment. The notes in this section capture additional similarities and differences that did not fit under the topic headings above.

For example, U.S. NPPs have similar FLEX strategies that involve use of FLEX equipment. Also, both BWRs and PWRs rely on the use of turbine-driven pumps to provide heat removal until FLEX equipment is running (or offsite power is restored).

Additional differences between NPPs include:

- how many external events must be addressed, and which external event (e.g., seismic event, hurricane or tornado) is considered most likely to result in an extended loss of all AC power (ELAP)
- the timing of when to declare ELAP
- the estimated time for debris removal
- the timing of when FLEX equipment is used
- which FLEX equipment (i.e., FLEX diesel generator (DG) versus FLEX pump) is needed first
- whether FLEX equipment is pre-staged or must be transported before use
- whether DC load shed (both SBO and FLEX) is needed and, if needed, how many loads are shed

These differences are linked to the capabilities and limitation of the NPP's permanently installed equipment (e.g., safety-related systems, batteries). Examples of NPP relevant capabilities are:

- DC battery life
- number of permanently installed emergency diesel generators (EDGs) or other DGs
- number of permanently installed pumps (e.g., auxiliary feedwater pumps for PWRs)
- alternate power sources (e.g., dams)
- whether preferred water sources (e.g., condensate storage tank) are seismically and/or missile protected

Consequently, a NPP's FLEX strategy is inherently linked to its capabilities (i.e., the various aspects of a FLEX strategy should not be "mixed and matched"). For example, an NPP with a relatively short DC battery life might have a FLEX strategy that compensates for a shorter available time by:

- declaring ELAP earlier (e.g., 15 minutes after reactor trip)
- having its FLEX DGs or pumps permanently staged
- storing FLEX connecting cables or hoses at the location where they are needed (instead of in the FLEX building)

2.7 <u>References</u>

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[35] EPRI published the same report in August 2017.
[36] This is EPRI's publication date for this report. A essentially identical version of this report will be published by the USNRC.

3 HRA/PRA SCENARIO DEVELOPMENT

This section describes the process for scenario development and the resulting scenarios and associated HFEs. The majority of this project's effort, both in calendar time and time spent, was devoted to developing credible, sufficiently detailed scenarios for HRA evaluation. The results of this effort, along with that associated with the plant site visits, were important to supporting the HRA quantification performed for FLEX and non-FLEX scenarios using IDHEAS-ECA [1] (see Section 6). In particular, the scenarios were developed and described in enough detail to support HRA quantification, regardless of what HRA quantification method is chosen.

This effort involved development of two different types of scenarios that required somewhat different development approaches:

1. A FLEX scenario that is initiated by an external event and requires implementation of FLEX strategies for successful mitigation.
2. Non-FLEX scenarios that are not initiated by an external event but that incorporate FLEX equipment in accident response

3.1 General Process for Developing Scenarios

Although this project was performed without benefit of a larger PRA study, the general approach to the development of scenarios was similar to that for any HRA/PRA application. However, since the HRA evaluations performed in this project were not part of a larger PRA study, the scenario development efforts needed to include some PRA tasks related to accident sequence development, as well as HRA (therefore, requiring both HRA and PRA expertise). But, since project resources did not allow for the full development of a PRA, or even selected scenarios, this effort relied heavily on existing work, including relevant PRA models (e.g., event trees) that could be used as-is or adapted for the project's purposes. Also, in some cases, assumptions were made in the absence of PRA-relevant information (e.g., success criteria timing information). Despite these limitations, the project still had the overall aim of developing scenario (and associated HFE) information consistent with that needed for traditional HRA/PRA studies and for event analyses using the NRC's SPAR models. Also, the scenario and associated HFE descriptions were intended to be useful and relevant inputs for any HRA quantification method (i.e., not useful only to IDHEAS-ECA [1]). It also should be noted that the draft IDHEAS-ECA guidance document[37] was not available to the HRA analysts during the plant site visits.

The need for an expanded approach to scenario and HFE development was not obvious at the start of this effort. Even though initial efforts were on understanding operational experience (e.g., the only SBO in the U.S. – a site-wide, shutdown event at Vogtle [2]), the next steps taken were aimed at collecting information to populate typical HRA documentation formats. However, two things made it clear that the focus should be on understanding FLEX operationally (rather than being driven by the formats, scope, and terminology of existing HRA methods and documentation protocols):

1. FLEX strategies have been developed with different "end states" than that for a typical PRA (e.g., FLEX "success criteria" do not correlate with PRA system or plant functional success criteria so a FLEX "failure" is not a failure in PRA space), and

[37] A draft of the IDHEAS-ECA guidance document was provided to the HRA analysts on October 3, 2019. There are some differences between this version of the IDHEAS-ECA guidance and the more recent February 2020 report.

2. It was important for HRA analysts to not only understand FLEX operationally, but also compare and contrast FLEX actions with those they were more familiar with in at-power, internal events Level 1 PRAs.

Also, this effort involved development of two different types of scenarios that required somewhat different development approaches:

1. A FLEX scenario that is initiated by an external event and requires implementation of FLEX strategies for successful mitigation.
2. Non-FLEX scenarios that are not initiated by an external event but that incorporate FLEX equipment in accident response.

The NRC project team developed the scenarios with assistance from FLEX experts and other industry experts. The HRA analysts also were involved in scenario development, providing feedback on the credibility of the scenarios, completeness of the scenario descriptions, and priorities for the evaluation of associated HFEs. Development of credible scenarios, which was the most time-consuming portion of this project, essentially started when information collection began and ended during the FLEX HRA Workshop (as additional information or adjustments to understanding FLEX inputs were provided by FLEX experts as needed). The scenario and associated HFE descriptions were not considered "complete" until the HRA analysts agreed that their needs with respect to credibly and level of detail were met.

Additional discussion on how the scenarios were developed is given in the respective sections on the FLEX and non-FLEX scenarios.

3.2 Selection of Scenarios and Associated HFEs

The scenarios and associated HFEs were selected with inputs from the NRC and industry. Those who provided inputs included:

- both the NRC management and project teams
- EPRI project manager and industry liaison[38]
- members of the scenario development team (i.e., industry FLEX and operational experts)
- HRA analysts (both NRC and industry) who participated in the FLEX HRA Workshop

Considerations on the selection of scenario and associated HFEs included:

- project objectives and schedule
- scope and limitations of previous HRA efforts for FLEX scenarios (e.g., EPRI FLEX HRA report [3] and NRC's expert elicitation [4])
- relevance to NRC's and industry's needs with respect to use of FLEX strategies in non-FLEX scenarios

Because selections and reasons for selections were different for the FLEX scenario versus non-FLEX scenarios, further discussion on scenario and associated HFE selection is discussed separately below.

3.2.1 Selection of the FLEX Scenario

A FLEX scenario was included in the scope of this project primarily to compare with and improve upon previous HRA efforts for FLEX scenarios and to be applicable to both BWRs and

[38] In most places, the title "EPRI project manager" is used in this report.

PWRs. In addition, the FLEX scenario was defined to be the same or similar to that used in these previous efforts in order to focus resources on developing more HRA-relevant details for use by the HRA analysts. In order to address these concerns, the FLEX scenario selected is for a BWR NPP such as that described in the EPRI FLEX HRA report [3].

3.2.2 Selection of the Non-FLEX Scenarios

Two non-FLEX scenarios were selected for development. Additional non-FLEX scenarios, or variations on these two scenarios, were proposed. However, this effort addressed only two non-FLEX scenarios due limited resources and the general agreement that the scenarios selected were adequately representative of what both industry and the NRC were interested in with respect to non-FLEX scenarios.

3.3 General Assumptions

There are several assumptions that were used for all three scenarios considered in the FLEX HRA project using IDHEAS-ECA [1]. In some cases, these assumptions are related to the project scope and limitations described in Section 1.4.

In addition, this effort used these general assumptions that consistent with NEI 12-06 [5] and are identified as "boundary conditions in Section 1.3.1 of EPRI's FLEX HRA report [3]:

- All reactors on-site are initially operating at power.
- Each reactor is successfully shutdown when required (i.e., all rods inserted, no anticipated transient without scram (ATWS)).
- On-site staff are at site administrative minimum shift staffing levels.
- There are no independent, concurrent events (e.g., no active security threat).
- All personnel on-site are available to support site response.
- Spent fuel in dry storage is outside the scope of FLEX.

Note that, since the non-FLEX scenarios do not involve an external event, that the list above is not identical to that given in NEI 12-06 [5] and EPRI's FLEX HRA report [3] since these two documents deal with beyond-design-basis external events (BDBEE).

3.4 FLEX Scenario

Development of the FLEX scenario for a BWR involved integrating a variety of inputs and iteration with the HRA analysts to ensure the FLEX scenario description and accompanying material were sufficient to support HRA quantification. Because there was no accompanying PRA effort, this effort "borrowed" some elements of a higher-level PRA in order to adequately describe the scenarios from an HRA perspective. For example, an event tree given in the EPRI FLEX HRA report [3] was used for the FLEX scenario in this effort. Also, to address topics not captured in the draft IDHEAS-ECA report (e.g., HRA feasibility assessment, timeline development, etc.), guidance from other HRA methods was used.

Plant-specific information for the BWR NPP visited during this project also was critically important. Examples of such plant-specific information are:

- EOPs (e.g., the equivalent of E-0, the station blackout procedure)
- FLEX Support Guidelines (FSGs)
- FLEX "script" (i.e., a type of timeline that shows plant behavior, operator responses, and procedure transitions and steps)

- Final Integrated Plan (FIP)
- FLEX staffing study (as represented by a spreadsheet showing an integrated timeline of all required personnel and their actions)
- Plant site visit notes (see Section 2 and Appendix A)

3.4.1 Development of the FLEX Scenario

This section summarizes the development of the FLEX scenario for a BWR – a base case and two variations on this base case. Appendix B provides a more complete description of the FLEX scenario and its variations.

Several information sources were used to describe this scenario for the purposes of the HRA assessments. Before the FLEX HRA Workshop, all HRA analysts were provided with a write-up that identified high-level HFEs, assumptions, references to other materials that were available on the EPRI file sharing site, a discussion of key PSFs (or PIFs) that might be needed for performing HRA quantification, and an example event tree. The materials referenced and used to develop the write-up are the same as those used to develop the scenario, such as:

- Plant-specific FLEX scenario script
- Plant-specific EOPs (e.g., SBO procedure and related attachments)
- Plant-specific FSGs (e.g., deploy FLEX generator)
- Plant-specific FIP
- Plant-specific Validation Plan
- Plant-specific integrated timeline
- Plant-specific site visit notes – both BWR and PWR visits
- Combined plant site visit notes

Because the NRC project team, FLEX experts, and most of the HRA analysts attended the plant site visits, recollections of these visits (e.g., observations of a seismic event response in the plant-specific simulator) aided in scenario discussions. In addition, FLEX experts attended the FLEX HRA Workshop and were able to clarify any questions during discussions of specific scenarios. Following the workshop, one of the FLEX experts provided some additional materials related to containment venting to support HRA quantification of the associated HFE.

3.4.2 Specific Assumptions for the FLEX Scenario

Many of the assumptions adopted in prior FLEX HRA efforts also were considered important to this effort. For example, the traditional PRA scope that limits modeling to the first 24 hours after plant trip was adopted. More general assumptions are given above (see Section 3.3). Also, while the full scenario description starting from reactor trip needs to be understood, the only HFEs considered in this effort are those specifically related to FLEX strategies and equipment (e.g., no operator actions associated with installed plant equipment or Phase 1 per NEI 12-06 [5]).

Additional assumptions used specifically for this FLEX scenario are:

- One of two divisional diesel generators is out-of-service for extensive maintenance (i.e., 10 year rebuild of diesel engine).
- High Pressure Coolant Injection (HPCI) is out-of-service for extensive maintenance and is not available for injection.
- The plant has implemented procedures for FLEX mitigating strategies.
- There are two units on site.

- A large seismic event impacts all units on site.
    - Operators know (from field reports and MCR indications) that there is widespread damage from this external event.
- Only one reactor and its associated response are modeled.
- The initiating event (i.e., seismic event) and reactor trip occur at t=0.
- The second EDG fails to start.
- The initiating event causes a Loss of Offsite Power (LOOP) and subsequent Station Blackout (SBO).
    - There is no recovery of offsite power unit after 24 hours.
- FLEX validation exercises and integrated timeline provide adequate assurance of HFE feasibility.
- FLEX validation exercises and integrated timeline use the same starting point for the "start time" (or time delay) and the "success criteria" (or time available).[39] This starting point is assumed to be t=0 (or reactor trip and time of the initiating event).
- FLEX validation times for operator actions are used as-is, even if they appear to apply to both units on site. (In some cases, it might be possible to separate Unit 1 and Unit 2 timing information. In other cases, it appears that a single operator will perform actions for both units.)
- The HRA/PRA model addresses accident progression out to 24 hours after the initiating event.
- Even if there is some warning prior to the initiating event, there is inadequate time to pre-stage FLEX equipment that requires transportation.
- According to the integrated timelines for the two-unit site, the following plant staff take on roles that are important to HRA:
    - Inside the MCR:
        - Shift Manager (SM)
        - Control Room Supervisor (CRS)
        - Shift Technical Advisor (STA)
        - 2 Reactor Operators (ROs) – 1 per unit
        - Senior Reactor Operator (SRO)
    - Outside the MCR:
        - 6 Equipment Operators (EOs)
        - Other plant staff (e.g. Instrumentation & Control (I&C) technicians, security personnel) assist the EOs in various tasks (e.g., debris removal, helping to deploy hoses).
- Regarding the deployment of FLEX DGs:
    - Vendors do the FLEX equipment testing (i.e., push button).
    - Field operators observe this testing.
    - Only field operators make connections (i.e., not security personnel).
    - The SAT (Systematic Approach to Training) was used to determine type and frequency of training for FLEX (including that for deploying FLEX equipment).
- Regarding environmental influences:
    - Operator actions in the MCR are not directly affected by environmental conditions.

[39] Definitions for FLEX timing terms are different than that for HRA/PRA. Using the timing parameter definitions in NUREG-1921 [7] (i.e., EPRI/NRC-RES Fire HRA Guidelines), "start time" in FLEX is the time when a cue or procedure step occurs to start an operator action. In NUREG-1921, this time is called "time delay" (e.g., the time from t=0 that a cue occurs). Also, FLEX defines the "success criteria" as the time by which an operator action should be performed to be successful. In HRA/PRA, this definition is associated with the term "time available."

- Actions related to debris removal are directly affected by environmental conditions following the seismic event.
- For other actions, alternate travel paths (because of debris) and flashlights (because of SBO) may be needed.

For the base case FLEX scenario, the following was assumed:

- The modeled NPP has a relatively short battery life such that an Extended Loss of AC Power (ELAP) must be recognized at one hour after event initiation.
- There is definitive procedural guidance on the requirement for ELAP at one hour after event initiation.

For two variations on the base case FLEX scenario, the following was assumed:

- Variation #1: The modeled NPP has a longer battery life (e.g., approximately 4 hours; more than 1 hour but less than 12 hours).
    - Procedural guidance is more ambiguous than for the base case, i.e., if AC power cannot be restored within 4 hours, declare ELAP within 1 hour of losing all AC power.
- Variation #2: Same as #1 except that it is less obvious that power that power cannot be restored.

3.4.3 HFEs for the FLEX Scenario

Given the limited resources for this project (e.g., project schedule, HRA analyst availability), the various teams providing inputs to this decision agreed to shorten this list to five to six operator actions for evaluation by HRA analysts. Considerations for selecting this shorter list of HFEs for the BWR FLEX scenario included experience from prior FLEX HRA efforts, relevance to both PWR and BWR FLEX strategies, what HFEs are currently included in SPAR models, and insights from the plant site visits. The resulting list of HFEs for the base case FLEX scenario is:

1. Operators fail to declare ELAP (or perform its equivalent)
2. Operators fail to perform FLEX DC load shed
3. Operators fail to deploy FLEX diesel generator
4. Operators fail to fail to initiate containment venting

Note that this list does not include any actions related to debris removal and refueling. Also, operator actions related to use of a FLEX pump were omitted from the final list of HFEs to be evaluated. Insights from the two plant site visits were used to justify the exclusion of these operator actions. For example, it was agreed that the operator actions associated with using the FLEX pump were similar to that for the FLEX DG. So, no additional HRA/PRA insights would be gained by including both of these HFEs. Regarding actions associated with debris removal, it was agreed that this task, requiring only the skill set of a "journeyman," was not suited for HRA modeling. Also, there is significant uncertainty in what effort (e.g., amount of debris, affected plant areas, time required for removal) would be needed for the task of debris removal. Finally, there was inadequate time and other resources to address refueling actions in this effort.

There was insufficient information and time to address the HFE associated with containment venting during the workshop. However, after FLEX experts provided additional information, some HRA analysts provided an assessment of the containment venting HFE after the workshop.

For the variation on the base case FLEX scenario, the only HFE assessed was “operators fail to declare ELAP.” The HFE is the only HFE that would be affected by the context of the defined variation.

3.4.4 Summary Description of the Base Case FLEX Scenario

At a high level, the FLEX scenario for a BWR is modeled as a beyond-design-basis (BDB) external event that impacts all units at the site (although only one unit is modeled in this effort). More specifically, the FLEX scenario modeled was a station blackout (SBO) (as modeled in a traditional PRA), but specifically caused by a seismic event and with FLEX strategies implemented that provide the plant with additional capabilities (e.g., portable diesel generators and pumps).

The assumptions specific to this BWR FLEX scenario (given above) are important to understanding this scenario and how it progresses (especially with respect to equipment out-of-service at the time of reactor trip).

The write-up provided to the HRA analysts summarizes this FLEX scenario in the following way:

- A seismic event occurs that damages the plant’s switchyard, causing a loss of offsite power.
- Reactor and turbine trips occur; operators enter their Emergency Operating Procedures (EOPs), beginning efforts to stabilize plant conditions.
- One EDG is out-of-service for maintenance and the second EDG fails to start.
- By 15 minutes after reactor trip, operators enter the procedure for the loss of offsite power, performing it in parallel with other EOPs. Also, an equipment operator is dispatched to try to determine why the remaining EDG did not start.
- Within the first hour after reactor trip:
    - The equipment operator attempts to restart the EDG but determines that major repairs are needed.
    - MCR operators start a reactor pressure vessel (RPV) cooldown and try to control RPV water level and pressure.
    - MCR operators initiate containment venting.[40]
    - MCR operators dispatch an equipment operator to perform SBO DC load shed.
    - MCR operators receive reports that offsite power is not restored, and alternate power sources are unavailable.
- At (or before) 1 hour after reactor trip:
    - SBO DC load shed is complete.
    - MCR operators make the procedure transfer (that is the equivalent of declaring ELAP), then proceed to guidance for using FLEX equipment, e.g.,
        - MCR operators dispatch an equipment operator to perform FLEX DC load shed.
        - FLEX guidance for assessing plant damage and travel paths is entered.
        - Debris removal is initiated.
        - Alternate communications are established.
- After 1 hour, plant conditions begin to degrade, e.g.,
    - Building heat up occurs due to loss of ventilation.
    - The suppression pool heats up.

[40] This is the earliest that MCR operators can perform this action. However, the operators have 6-7 hours to do this. The overall objective is to keep the suppression pool temperature below 240^0 F.

- Long-term RCIC operation (i.e., use of turbine-driven pump) is needed to maintain adequate core cooling.
- At 90 minutes, FLEX DC load shed is complete.
- At 2 hours, debris removal is complete.
- At 3 hours, the FLEX DG deployment is started.
- At 5 ½ hours:
  - The FLEX pump deployment is started.
  - Critical electrical loads are fed by the FLEX DG.
- At 6 hours, the ERO is staffed and the Shift Manager turns over the Emergency Director (ED) function to the Technical Support Center (TSC).
- At 12 hours, refueling of FLEX equipment is started.
- At 30 hours, the FLEX pump starts to inject into the RPV.

For each of the HFEs modeled for this scenario, HRA analysts referred to plant-specific procedural guidance, information from plant-specific walkdowns, and timing validation information to perform HRA assessments. The following are examples[41] of information used by the HRA analysts to perform their evaluations:

- HFE – Operators fail to declare ELAP[42]
  The plant-specific procedural guidance for this BWR is contained in the EOP for the loss of offsite power. This procedure consists of several "sheets" of flowcharts. Also, the initial sheet (i.e., Sheet 1) contains transfers to other sheets depending on how many EDGs are "available for operation." Both Sheet 5 and Sheet 6 apply to the case of no EDGs available, with Sheet 6 explicitly labeled "ELAP." In addition, there is a prominent "Note" next to this portion of the flowchart in Sheet 1, that defines "ELAP" as "Extended loss of AC power (ELAP) exists when it is expected that no 4 kV bus will be re-powered within one hour." Discussions during the BWR plant site visit confirmed that training supports this determination. With the procedural guidance and training combined, this guidance in Sheet 1 was judged to be "explicit" with respect to HRA assessments. Sheet 6 (i.e., ELAP) consists of five parallel sections that are to be executed concurrently to address this plant condition (with references made to the relevant FSGs and other procedures needed for implementation). "FLEX Strategies" is one of the five sections (although FSGs are called out in other sections, as well).

- HFE – Operators fail to perform FLEX DC load shed
  FLEX DC load shed is identified in Sheet 6 (ELAP) of the BWR's plant-specific loss of offsite power procedure as a "priority" (red font coupled with a red arrow). A plant-specific FSG provides the procedural guidance for performing FLEX DC load shed. As the procedure shows, almost all of the breaker manipulations are performed in the same room. There are a few breaker manipulations to perform in two other locations. Generally, fewer breaker manipulations are required for FLEX DC load shed, as compared to SBO DC load shed. It was noted in the BWR plant site visit walkdowns that the breakers that require manipulation for FLEX DC load shed are all marked with a "FLEX" blue tag for easy identification. For this reason, the FLEX DC load shed was judged to be similar in difficulty to the SBO DC load shed (and may be simpler due to fewer manipulations and the eye-catching, blue "FLEX" labels).

[41] Other HFEs quantified for this scenario are discussed in Appendix B.
[42] Note that, for this BWR, there is no "actual" declaration of ELAP. Rather, there is an important procedure transition that is tied to the plant-specific definition of ELAP and MCR operators will announce "Exiting Sheet 5, entering Sheet 6 (ELAP)."

Further information on HFEs for the FLEX scenario is provided in Appendix B.

3.4.5 Summary Description of Two Variations on the FLEX Scenario

For the NRC's FLEX HRA workshop using IDHEAS-ECA [1], two variations on the FLEX scenario were considered, both being related to procedure guidance for the HFE of "Operators fail to declare ELAP." Both variations were expected to represent more difficult "decision making" for MCR operators. (Additional discussion on variations for both the FLEX scenario and the two non-FLEX scenarios is provided in Appendix E.)

Specifically, for the first variation, the procedure is assumed to consist of the following:

IF AC power cannot be restored within 4 hours, then declare ELAP

Also, there is a note for the procedure step that states: "The decision to declare ELAP must be made within 1 hour of loss of all AC power."

For the second variation, all conditions (including procedural guidance) are the same as for the first variation except that it is not as obvious that power cannot be restored.

3.5 Development of Non-FLEX Scenarios

Non-FLEX scenarios are scenarios in which FLEX equipment is used as a backup or replacement for permanently installed equipment. Industry FLEX experts volunteered plant-specific non-FLEX implementations of FLEX strategies/equipment. For both non-FLEX scenarios, no scenario-specific HRA/PRA models were provided. Consequently, it was necessary to build PRA event trees and define success criteria for both HRA and PRA. For example, event trees and fault trees from the SPAR models were used to preliminarily describe the accident sequence of one of the non-FLEX scenarios. Also, the development of credible non-FLEX scenarios required making some assumptions (e.g., timing information that would ordinarily be developed in thermal-hydraulic calculations for PRA plant function or system success criteria). The HFEs selected for non-FLEX scenarios were scenario- and plant-specific, depending on the details of how FLEX equipment (and associated procedures) were used in these non-FLEX scenarios.

The basic attributes of the non-FLEX scenarios were based on plant-specific incorporation of FLEX strategies and/or equipment into plant procedures that are beyond that needed for response to a FLEX scenario. Consequently, further descriptions of the scenario development approach are given below for each non-FLEX scenario is separate sections.

3.5.1 Non-FLEX Scenario: "Sunny Day" Loss of All Feedwater

The non-FLEX scenario for a "sunny day" (i.e., no external event) loss of all feedwater was developed through interactions between the project team and industry FLEX experts. Also, HRA analysts provided inputs on whether the scenario seemed credible and could be credited by HRA/PRA. SPAR models for a PWR loss of all feedwater were used as the basis for creating and understanding this non-FLEX scenario.

In addition, a substantial amount of plant-specific information was provided by industry FLEX experts in order to build this non-FLEX scenario. Some assumptions also were needed to complete the scenario. One such assumption for PRA success criteria was for the time when feed-and-bleed (F&B) criteria would be met if a motor-driven AFW pump runs for one hour before failing.

3.5.1.1 Development of the Non-FLEX Scenario: "Sunny Day" Loss of All Feedwater

This section summarizes the development of the non-FLEX scenario for a two-unit, Westinghouse PWR involving a loss of all feedwater *without* an external event (i.e., a "sunny day" loss of all feedwater). Other variations[43] on this non-FLEX scenario were discussed during scenario development, but only one case for this non-FLEX scenario was considered. It should be noted that this non-FLEX scenario is important for a specific NPP due to its design and associated limitations or vulnerabilities. Appendix B provides a more complete description of this non-FLEX scenario (and Appendix E provides additional discussion on variations for both the FLEX scenario and the two non-FLEX scenarios).

Before the FLEX HRA Workshop, all HRA analysts were provided with a write-up that identified high-level HFEs, assumptions, references to other materials that were available on the EPRI file sharing site, a timeline that illustrated the procedure path for the scenario, a discussion of key PSFs (or PIFs) that might be needed for performing HRA quantification, and an example event tree from the SPAR model of a similar PWR. This writeup for the non-FLEX scenario for the "sunny day" loss of all feedwater was much more detailed and lengthier than the writeup for the FLEX scenario.

The materials used to develop this scenario and its associated write-up were mostly plant-specific, such as:

1. Plant-specific EOPs, including:
    a. 1ES-0.1 for Reactor Trip Response, Unit 1
    b. 1FR-H.1, Response to Loss of Secondary Heat Sink, Unit 1
2. Plant-specific FSGs, including:
    a. 1FSG-3, Alternate Low Pressure Feedwater, Unit 1
    b. 0FSG-5, Initial Assessment and FLEX Equipment Staging – both units
    c. 1FSG-5, Initial Assessment and FLEX Equipment Staging, Unit 1
3. An applicable Critical Safety Function Status Tree (CSFST) for Loss of Heat Sink

There also were several discussions between the NRC project team and HRA analysts on this scenario, especially focused on credible and creditable operator actions. In addition, FLEX experts attended the FLEX HRA Workshop and were able to clarify any questions during discussions of specific scenarios.

3.5.1.2 Specific Assumptions for the Non-FLEX Scenario – Loss of All Feedwater

Like the FLEX scenario, many of the assumptions used in traditional PRA studies (e.g., only the first 24 hours after plant trip are modeled) are relevant to this non-FLEX scenario. In addition, any assumptions about FLEX equipment that were developed for the FLEX scenario were assumed to be applicable for this scenario, unless there were scenario-specific changes that the

[43] In particular, use of the FLEX pump to feed the SG after F&B is performed (i.e., restoration of feedwater following successful F&B). However, definition of an associated PRA end state for this scenario was beyond the scope of this effort.

plant has made. Such assumptions would include training for use of FLEX equipment, FLEX human-machine interface (HMI), procedure support for deploying a FLEX pump, and so on.

Because this non-FLEX scenario is quite unique, there are more important assumptions to identify beyond the general assumptions given in Section 3.3. Also, while the full scenario description starting from reactor trip needs to be understood, only one HFE was considered in this effort.

Additional assumptions used in defining this non-FLEX scenario are:

- There are two units on site.
- Only one reactor and its associated response are modeled.
- The initiating event (i.e., loss of all feedwater) and reactor trip occur at t=0.
- All four condensate pumps have failed.
- The NPP has only two motor-driven AFW pumps (and no turbine-driven pumps).
- 1A AFW pump is unavailable for short-term maintenance.
- AFW pumps for Unit 2 are NOT available for use via crosstie (but the crosstie itself is available for a FLEX pump to feed a SG).
- The plant has implemented procedures for FLEX mitigating strategies.
- The plant has modified its EOPs for loss of heat sink to include use of the FLEX pump (including reference to the applicable FSG for deploying the FLEX pump).
- Initial training on the modified FR-H.1 is performed for both MCR operators and field operators.
- The modified FR-H.1 is integrated into the normal MCR operator training cycle that includes simulator training every two years plus classroom training. The simulator training is not integrated with field operator (FO) training (e.g., operator trainers play the role of FO with respect to communications).
- The modified FR-H.1 is integrated into the normal FO training cycle with classroom training plus FLEX training on use of the FLEX pump.
- The guidance in the modified FR-H.1 provides clear and unambiguous instructions, e.g.,
    - There are no instructions in NOTES or CAUTIONS.
    - Any instructions embedded in a CAUTION do not have operators skipping procedure steps.
- FLEX validation exercises and integrated the timeline provide adequate assurance of HFE feasibility in the context of FLEX scenarios.
- Some simulator exercises for this non-FLEX scenario (i.e., loss of all feedwater simulator exercises that involve the use of the FLEX pump) have been performed.
- FLEX validation exercises and the integrated timeline use the same starting point for the “start time” (or time delay) and the “success criteria” (or time available).[44] This starting point is assumed to be whenever the 1B AFW pump fails.
- FLEX validation times for the operator action of interest are used as-is, even though this is a non-FLEX scenario
- There is no pre-staging of FLEX equipment.

Additionally, there were several important assumptions made about timing. Some of these assumptions are consistent with that used in other HRA/PRAs (e.g., the average number of

[44] Definitions for FLEX timing terms are different than that for HRA/PRA. Using the timing parameter definitions in NUREG-1921 76] (i.e., EPRI/NRC-RES Fire HRA Guidelines), “start time” in FLEX is the time when a cue or procedure step occurs to start an operator action. In NUREG-1921, this time is called “time delay” (e.g., the time from t=0 that a cue occurs). Also, FLEX defines the “success criteria” as the time by which an operator action should be performed to be successful. In HRA/PRA, this definition is associated with the term “time available.”

minutes per step that operators take to move through EOPs). Other assumptions relate to the fact that there was no larger PRA study to support timing information about plant conditions that are typically generated by thermal-hydraulic calculations. Examples of these timing assumptions are:

- 1-2 minutes per procedure step is generally assumed, unless the procedure explicitly indicates that operators need to perform tasks quickly (e.g., the caution in FR-H1 about performing F&B steps quickly). In cases when operators are expected to perform steps quickly (e.g., initial steps in E-0, F&B steps), approximately 1 minute or less per step is assumed.
- One (i.e., 1B AFW) AFW pump is assumed to run successfully for 1 hour after reactor trip due to loss of feedwater.
- It is assumed that it takes 20 minutes to satisfy that the red path criteria heat sink is met (in the Critical Safety Function Status Tree (CSFST)) <u>after</u> the 1B AFW pump fails to run (i.e., 80 minutes after reactor trip).
- After the 1B AFW pump fails to run, operators will try **only once** to re-start an AFW pump locally (and spend not more than about 10 minutes from dispatch to reporting back that the re-start did not work).
- The Shift Manager (SM) who decides to use the FLEX pump to feed an SG takes no more than about 15 minutes after reaching Step 3 in FR-H.1 (where a CAUTION states that the AFW crosstie with FLEX pump deployment should be used if feedwater restoration is not “timely”).
- Training reinforces the need for the SM to make a timely decision so that the FLEX pump can be deployed before F&B criteria are met.
- It is assumed that the decay heat removed while 1B AFW pump runs in the 1st hour after reactor trip is such that feed-and-bleed criteria are not reached until after the time needed to deploy the FLEX pump (including time needed to get to relevant steps in FR-H1.
    - Specifically, the criteria for F&B conditions are reached later than 78 minutes after FR-H1 is entered (i.e., more than 158 minutes after reactor trip).
- It is assumed that deploying a FLEX pump for feeding a SG from the RWST takes one hour to perform from the time of dispatch.

Since some of these assumptions are critical to this non-FLEX scenario, they will be re-capped, as needed, in the non-FLEX scenario summary (Section 3.5.1.4) below.

3.5.1.3 HFEs for Non-FLEX Scenario – Loss of All Feedwater

Due to project resource constraints, both scenario developers and HRA analysts agreed to focus on the operator action to decide to use the FLEX pump in this non-FLEX scenario, rather than operator actions needed to deploy the FLEX pump.

Consequently, there was only one HFE evaluated for this scenario with a single critical task: Operators fail to recognize need for FLEX pump (using the modified FR-H1). This HFE represents the cognitive portion only of a larger HFE that the team originally defined: Operators fail to initiate use of FLEX pump. Although there are some differences between deploying a FLEX pump for a FLEX scenario and this loss of all feedwater scenario, the HRA analysts agreed that the HRA assessment would be similar in both cases. Consequently, the execution portion of the larger HFE was not addressed in this effort.

The success criteria for the larger HFE which represents all operator actions, both cognitive and execution, are completed before F&B criteria are reached. This time to when F&B criteria is reached is plant-specific, depending on a variety of factors including how long the AFW pump runs before failing. (The modeling assumptions given above define the timing used in this effort.) Consequently, the HFE for the cognitive portion must be completed such that there is adequate time to deploy the FLEX from the time of FO dispatch.

3.5.1.4 Summary Description of the Non-FLEX Scenario – Loss of All Feedwater

At a high level, the non-FLEX scenario for a PWR is modeled as a loss of all feedwater scenario *without* an external event (i.e., a "sunny day" loss of all feedwater) that affects only one unit at the plant site. More specifically, this non-FLEX scenario modeled was a loss of heat sink scenario, but with EOPs (specifically, FR-H.1) modified to include the option of using a FLEX pump to feed SGs.

The assumptions specific to this PWR non-FLEX scenario (given above) are important to understanding this scenario and how it progresses (especially with respect to equipment out-of-service at the time of reactor trip).

Appendix C provides a more detailed description of this scenario, including the specific procedure path that operators are expected to take. The following is a high-level summary of this non-FLEX scenario in timeline form:

- T=0 — Reactor trip due to a transient, including loss of feedwater with 1B AFW pump start on auto-signal. Operators enter E-0.
- T= 2-5 minutes — Operators reach Step 4 in E-0, then transfer to ES-0.1 (Reactor Trip Response). Per training, operators start monitoring the Critical Safety Function Status Tree following transition out of E-0.
- T=5-60 minutes — Operators continue implementing ES-0.1. The SM arrives about 5 minutes after reactor trip and the STA arrives 10 minutes after reactor trip.
- T=60 minutes — 1B AFW pump stops (e.g., fails to run).
- T= 80 minutes — Operators enter FR-H1 via red path on loss of heat sink in Critical Safety Function Status Tree.
- T= 81-82 minutes — Operators reach Step 2 in FR-H1. F&B criteria are NOT met, so operators go to the Response Not Obtained (RNO) column. In the RNO column, operators are directed to monitor for F&B conditions and go to Step 3.
- T= 82 minutes — Operators go to Step 3. A caution between Step 3 directs operators to proceed to Step 5 to establish FW via AFW crosstie (and FLEX pump) if restoration of feed flow to any SG is not expected to be timely. The SM is responsible for deciding when/if the AFW crosstie and FLEX pump will be used. He/she

begins assessing efforts to restore 1B AFW pump, as well as SG levels.

At FR-H.1 Step 3, sub-step i, the operators will be in the RNO column with adequate feed flow NOT verified. The RNO directs operators to Step 4 – Stop all RCPs (in order to reduce RCS heat input).

- T=83–98 minutes — Operators continue to work through FR-H.1, reaching Step 5. The SM completes his assessment of feed flow restoration efforts and decides that the AF crosstie and FLEX pump should be used. Operators go to Step 5, complete Steps 5a-5c, including dispatching field operator to implement FSG-3 to deploy the FLEX pump to feed an SG.
- T=98 minutes — Operators reach Step 5, complete steps 5a-5c, including dispatching a field operator to implement FSG-3 to deploy the FLEX pump
- T=158 minutes — FSG-3 and FSG-5 are implemented and FLEX pump is in operation, supplying feed flow to a SG (1 hour after operator dispatch in caution before Step 3 in FR-H1).

3.5.2 Non-FLEX Scenario: "Sunny Day" Station Blackout with One EDG Out-of-Service for Maintenance

The non-FLEX scenario for a "sunny day" (i.e., no external event) station blackout (SBO) was developed similarly to that for the other non-FLEX scenario (e.g., through interactions between the project team and industry FLEX experts, with inputs from the HRA analysts on the credibility of the scenario).

Although a good amount of plant-specific information was used to develop this non-FLEX-scenario, some effort was made to make this scenario less plant-specific (and more generally applicable to other NPPs). For example, certain procedural guidance was assumed to be available for operator response to the SBO that the actual NPP does not have.

3.5.2.1 Development of Non-FLEX Scenario: "Sunny Day" Station Blackout with One EDG Out-of-Service for Maintenance

This section summarizes the development of the non-FLEX scenario for a two-unit, Combustion Engineering (CE) PWR involving a loss of all AC power or Station Blackout (SBO) *without* an external event (i.e., a "sunny day" SBO). Only one case for this non-FLEX scenario was considered. It should be noted that this non-FLEX scenario is important for a specific NPP due to a specific plant configuration as well as its design and associated capabilities. Appendix D provides a more complete description of this non-FLEX scenario.

Before the FLEX HRA Workshop, all HRA analysts were provided with a write-up that identified high-level HFEs, assumptions, references to other materials that were available on the EPRI file sharing site, a timeline that illustrated the procedure path for the scenario, and a discussion of key PSFs (or PIFs) that might be needed for performing HRA quantification. This writeup for the non-FLEX scenario for the “sunny day” SBO contained some very detailed and specific assumptions, some of which were plant-specific and some that the HRA analysts thought were necessary to have a viable scenario to credit with HRA/PRA.

The materials referenced and used to develop the write-up are the same as those used to develop the scenario, such as:

1. Plant-specific EOPs, including:
    - Standard Post-Trip Actions (i.e., E-0)
    - Station Blackout procedure
2. Other procedures, including plant-specific FSGs:
    - Operations Maintenance Activities – Appendices C and D
    - Conduct of Operations
    - A “contingency plan” specific to using FLEX DGs in the specific plant configuration used for this scenario
    - FSGs related to operation of FLEX DGs
3. Communications with industry FLEX experts and Owners Group representatives with respect to the use of a “contingency plan.”

There also were several discussions between the NRC project team and HRA analysts on this scenario, especially focused on credible and creditable operator actions. A conference call with the NRC team, HRA analysts, and industry FLEX experts was crucial to getting agreement on how HRA could credit a “contingency plan.” FLEX experts attended the FLEX HRA Workshop and were able to clarify any questions during discussions of specific scenarios.

3.5.2.2 Specific Assumptions for the Non-FLEX Scenario – SBO with One EDG Out for Maintenance

Like the FLEX scenario, many of the assumptions used in traditional PRA studies (e.g., only the first 24 hours after plant trip are modeled) are relevant to this non-FLEX scenario. In addition, any assumptions about FLEX equipment that were developed for the FLEX scenario were assumed to be applicable for this scenario, unless there were scenario-specific changes that the plant had made. Such assumptions would include general training for use of FLEX equipment, FLEX human-machine interface (HMI), procedure support for deploying a FLEX diesel generator, etc.

Because this non-FLEX scenario is quite unique, there are more important assumptions to identify beyond the general assumptions given in Section 3.3. Also, while the full scenario description starting from reactor trip needs to be understood, only one HFE was considered in this effort.

Additional assumptions used in defining this non-FLEX scenario are:

- There are two units on site.
- Only Unit 1 and its associated response are modeled.
- This NPP has a very long battery life.
- The initiating event (i.e., loss of offsite power) and reactor trip occur at t=0.
- 1B EDG is out-of-service for long-term repairs.
- The remaining EDG A fails to start very shortly after offsite power is lost
- There is initial success of the turbine-driven auxiliary feedwater (AFW) pump.
- The pressurizer power-operated relief valve(s) (PORV(s)) successfully reclose given a demand.

- The reactor coolant pump (RCP) seals remain intact.
- Three portable diesel generators (4.16 kV – FLEX Plus)[45] are deployed to their FLEX pad to ensure the ability to bring Unit 1 to cold shutdown in the event of a LOOP during the extended period that the Unit 1 train B EDG is inoperable.
  - The three portable diesel generators are deployed and physically connected to the Unit 1 train B 4.16 kV AC FLEX connection box for the duration of the extended EDG B outage time.[46]
  - A test run is performed to demonstrate parallel operation of the three portable DGs after equipment is staged.
  - Routine inspections (start of shift and normal operator rounds during shift) of the portable DGs are performed by operations personnel to ensure normal standby conditions are maintained.
- Because the pre-staged FLEX Plus DGs have a different configuration than that for response to an external event, the timing validations and associated staffing plan that the utility developed have limited applicability to this scenario.
- The FLEX Plus DGs are connected when they are pre-staged with the exception of closing breakers to connect to the bus. Additional time is needed to sync the DGs.
- The total time elapsed from reactor trip until when connections between the FLEX Plus DGs and 4160 V bus are completed and the FLEX Plus DGs started and synched is less than 1 hour[47]
- Battery life is very long (e.g., 14 hours or more)
- If FLEX Plus DGs are successfully put into service in the timeframe expected, ELAP would not need to be declared.
- "Normal," lower voltage FLEX DGs remain available throughout the scenario, housed in the FLEX building.
- The SM arrives in the MCR at 5 minutes after reactor trip. The STA arrives in the MCR 10 minutes after reactor trip, as required.
- A contingency plan was developed to put the pre-staged portable DGs into operation in the case of a potential loss of offsite power, coupled with failure of the Unit 1 EDG A.[48]
- Training, briefings, and walk downs are provided to the operators responsible for operating the portable DGs as part of the preparation for use of the generators.
  - Operations crews are briefed on the implementing procedure.
  - Designated operators will be familiar with instructions for starting and operating the portable DGs.
  - Operations staff have received classroom training for FLEX strategies, which included the use of the portable DGs.
  - Also, instructions for operating the FLEX Plus DGs are given on a "hard card" that is stored with the FLEX Plus DGs.

Key details of the plant's contingency plan for the using the pre-staged FLEX Plus DGs are:
- The contingency plan is written like a procedure with specified entry conditions (including cues) and instructions. For example, the contingency plan is written such that:

[45] These specific FLEX DGs are not those typically available for FLEX. Rather, these portable DGs are like the SAFER DGs that would be brought on-site in Phase 3 of FLEX (per NEI 12-06 [5]). Consequently, the plant's ability to respond to an external event that requires FLEX strategies is not affected by deployment of the FLEX Plus DGs.
[46] This configuration, as well as the associated equipment, is different than that used in response to a FLEX scenario.
[47] Information is provided by plant-specific AOs.
[48] Contingency plans (or standing orders) are typically used for plant configurations that are not normal.

    - The criteria for implementation include an “AND” statement (i.e., there are multiple criteria that must be satisfied before the plan should be implemented).
    - There are no “NOT” statements.
    - Direction for implementation is typical of that in EOPs (i.e., IF criteria for implementation are satisfied, THEN implement the plan); there are no judgments needed for implementation (e.g., there are no statements such as “Consider implementing…).
- The contingency plan is stored in the MCR.
- There is an extra[49] reactor operator (RO) in the MCR that is designated[50] to implement the contingency plan which includes dispatch of an Auxiliary Operator (AO) to start the FLEX Plus DGs.
- The additional RO designated to implementing the contingency plan is located in the MCR at all times, 24 hours a day.
- There is no automatic actuation of any of the installed FLEX equipment. All FLEX Plus DGs would be manually started and operated, if required, by a designated AO.
- Specific cues for this contingency plan that the designated RO will be monitoring are:
    - Reactor trip
    - Indications of loss of offsite power (e.g., trouble alarm for 4.16 kV switchgear)
    - Out-of-service “tag”[51] for U1 DG B
    - Indications that U1 DG A fails to start
- All MCR operators are briefed at every shift turnover on the contingency plan and associated plant configuration with the pre-staged FLEX Plus DGs.
- Upon reactor trip, the MCR operators will perform immediate actions, as trained.
- In general, operators are trained on the strategies and hierarchy of procedures for LOOP that specify use of alternate power sources, including the portable DGs.
- In parallel with the performance of immediate actions, the designated RO will implement the contingency plan (if needed).
- The designated RO will dispatch the designated AO to perform the actions described in the contingency plan,[52] which include several breaker manipulations and electrical connections, in addition to start of the FLEX Plus DGs.
- The designated AO is available 24 hours per day, although he/she may be assigned other duties when not needed to operate the FLEX Plus DGs. Also, a designated AO is available 24 hours per day on all shifts to perform necessary refueling operations.
- Starting from when dispatched, the time needed for the AO to perform tasks associated with putting the pre-staged FLEX Plus DGs into service is assumed to be 30 minutes, including required travel time to performance locations after dispatch.

Since some of these assumptions are critical to this non-FLEX scenario, they will be re-capped, as needed, in the non-FLEX summary (Section 3.5.2.4) below.

[49] “Extra” means that there are more operators in the MCR than is required for minimum staffing.
[50] The U.S. NPP industry generally refers to operators with such duties as “designated.” The distinction between “designated” and “dedicated” depends on how much time is available to take the action.
[51] For this plant, a paper tag is used. Some plants may use magnets.
[52] For this hybrid scenario, the specific steps that the AO must take are in the procedure “Operation Maintenance Activities,” specifically in the section on the FLEX DGs. This procedure is on EPRI’s file share site.

3.5.2.3 HFEs for Non-FLEX Scenario -SBO with One EDG Out for Maintenance

Although other HFEs were identified and briefly discussed, there was only one HFE evaluated for this scenario: Operators fail to connect and operate pre-staged portable FLEX Plus DGs.[53] This HFE consists of both cognition and execution aspects. The cognition portion of the HFE represents the responsibilities of the extra RO in the MCR. The execution portion represents the responsibilities of the designated AO.

The success criteria for this HFE for operators to put the FLEX Plus DGs into successful operation before ELAP would need to be declared.

3.5.2.4 Summary Description of Non-FLEX Scenario Description: SBO with One EDG out for maintenance

Based on modeling assumptions typically used in HRA/PRA, the most likely core damage case for this non-FLEX scenario is a grid-related loss of offsite power (LOOP) initiating event and subsequent station blackout (SBO) due to the failure of all the EDGs.

The assumptions specific to this CE PWR non-FLEX scenario (given above) are important to understanding this scenario and how it progresses (especially with respect to equipment out-of-service and pre-staged at the time of reactor trip).

Appendix D provides a more detailed description of this scenario, including the specific procedure path that operators are expected to take. The following is a high-level summary of this non-FLEX scenario in timeline form:

- T=0 — Reactor trip due to a "sunny day" LOOP (no ATWS); operators enter Standard Post Trip Actions (SPTA) procedure (i.e., E-0)
- T=0-1 minutes — 1A EDG fails to start (and 1B EDG is out-of-service for long-term maintenance).
- T=0-5 minutes — Operators reach Step 3 in E-0 and recognize that there are no EDGs running. The SM arrives in the MCR.
- T=5-8 minutes — In parallel with MCR operators implementing steps in the SPTA, an AO will be dispatched to try to start 1A EDG locally. Also, in parallel, the designated RO for the contingency plan follows the progress of the other MCR operators to Step 3 and notes that the 4.16 kV Switchgear Annunciator in combination with other entry conditions for the contingency plan. The designated RO begins implementing the contingency plan, including dispatch of the designated AO to perform necessary actions to put the FLEX Plus DGs into service.
- T=10-14 minutes — Operators reach Step 10 in E-0, then use the Diagnostic Actions flow chart. The second diamond in the flow asks if there is AC and DC power to at least one train. Since there is no AC power, operators follow the "no" path. The next question is

[53] We decided to eliminate "adding loads" to our discussions because we had inadequate information on the procedure guidance for this and how this would be implemented (including what steps would be taken by the AO and what the MCR operators would need to do).

whether at least one vital DC power train have power. Because the batteries have not depleted yet, there is DC power. The flow chart recommends that operators consider using the Blackout procedure then moves on to checking other critical parameters.

- T=15 minutes — Operators enter Blackout procedure and perform its steps in parallel with EOP steps.
- T=38-40 minutes — Designated AO completes actions to put FLEX Plus DGs into operation; 4.16 kV bus is re-energized.
- T=40 min — Operators exit Blackout procedure per Exit Conditions,[54] Step 3a (At least one vital 4.16 kV bus is energized….).
- T= 40+ min — Operators continue in EOPs to safety shutdown the reactor.

3.6 References

1. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. U.S. Nuclear Regulatory Commission, Loss of Vital AC Power and the Residual Heat Removal System During Mid-Loop Operations at Vogtle Unit 1 on March 20, 1990, NUREG-1410, June 1990.

3. Electric Power Research Institute, Human Reliability Analysis (HRA) for Diverse and Flexible Mitigation Strategies (FLEX) and Use of Portable Equipment, EPRI 3002013018, November 2018.

4. U.S. Nuclear Regulatory Commission, *Utilization of Expert Judgment to Support Human Reliability Analysis of Flexible Coping Strategies (FLEX) – Volume 1*, (to be published with this report), December 2020.

5. Nuclear Energy Institute, *Diverse and Flexible Coping Strategies (FLEX) Implementation* Guide, NEI 12-06, Rev. 5, April 2018.

6. U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines – Final Report*, NUREG-1921/ EPRI 1023001, July 2012.

[54] "Exit Conditions" would be applied as a continuous step.

4 IDHEAS-ECA TRAINING

Prior to the FLEX HRA Workshop, training on the draft IDHEAS-ECA guidance [1] and software tool [2] was provided. All training materials can be found in the NRC's Agencywide Documents Access and Management System (ADAMS) library on the public side ADAMS (see Reference [3]).

4.1 Training Format and Logistics

IDHEAS-ECA training was provided after the plant site visits and approximately one month before the FLEX HRA Workshop during which IDHEAS-ECA was to be used. The training was scheduled to meet project deadlines so that information on IDHEAS-ECA was available in time for HRA quantification activities. The principal targets for this training were the NRC and industry HRA analysts. However, other project team members, including the FLEX experts, were invited to take the training.

Each HRA analyst was provided with an electronic copy of the draft IDHEAS-ECA Guidance report [1] and software [2] on October 30, 2019. Prior to the training sessions, the HRA analysts were asked to:

- review the draft IDHEAS-ECA guidance report
- download the IDHEAS-ECA software tool
- review a Loss of Component Cooling Water scenario and the crew-by-crew simulator performance for this scenario from the US HRA Empirical Study (NUREG-2156) [4]

The NRC hosted a virtual training via Skype on IDHEAS-ECA on November 6 and 14, 2019. For scheduling purposes, the training was offered on two days to allow the analysts flexibility to attend either session. Each session was four hours and was facilitated by IDHEAS-ECA guidance author, Jing Xing and the IDHEAS-ECA software tool developer, James Chang. A follow-up Skype Meeting was offered on November 19, 2019 for any follow-up questions.

4.2 Training Content

The IDHEAS-ECA training materials were prepared in four parts. The first half of the training course (Parts I and II) provided an introduction of the IDHEAS-ECA HRA method, step-by-step guidance and walk-through of the IDHEAS-ECA process. The second half of the training was conducted using IDHEAS-ECA itself to demonstrate certain features of the associated software tool.

More specifically, the high-level agenda for Parts I and II of the training included:

- The high level of detail needed to analyze and organize the three scenarios
- Illustrations of how the method aligns with software using the IDHEAS-ECA Worksheets for the qualitative analysis and the HEP quantification completed using the software tool
- Demonstrations of how IDHEAS-ECA models human failure through context of the HFEs, critical tasks and the five cognitive failure modes (CFMs) and performance influencing factors (PIFs).
    - As implemented in the software, the training displayed the PIFs affecting each CFM and addressed how to assess each PIF

- A breakdown of the 6-step IDHEAS-ECA process[55] and a description for each step (This process supports the information used to draft the qualitative worksheets.)

To supplement Parts I and II, Part III was a walk-through of the IDHEAS-ECA process with a Loss of Component Cooling Water and Reactor Coolant Pump Sealwater example scenario. This scenario was used in the US HRA Empirical Study [4]. It was designed to have multiple concurrent component and control failures to increase the operator's workload and to distract the operator's attention to prevent a reactor coolant pump seal failure. This information from the US HRA Empirical Study [4] was used to explain the features and functionality of the IDHEAS-ECA guidance (especially its worksheets that are used to guide and document the HRA) and the associated software tool.

Part IV consisted of training materials discussing the functions and features of the software tool. Training slides included screenshots of the following:

- Software tool design functions
- Visual interfaces for each response and display field (Fields requiring a user action versus those used for information display only were distinguished.)
- How to properly execute and identify actions within the software tool.

4.3 References

1. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. U.S. Nuclear Regulatory Commission, *IDHEAS-ECA Software Tool,* v.1.1, 2020.

3. U.S. Nuclear Regulatory Commission, "IDHEAS-ECA ToolTraining Materials," ML20150A422, May 29, 2020.

4. U.S. Nuclear Regulatory Commission, The U.S. HRA Empirical Study: Assessment of HRA Method Predictions Against Operating Crew Performance on a U.S. Nuclear Power Plant Simulator, NUREG-2156, June 2016.

[55] In the October 3, 2019 draft report, the IDHEAS-ECA process included six (6) steps. The February 2020 version of the report includes eight (8) steps. The two new steps are: 7) calculate the overall HEP by adding the contributions from the CFMs and the uncertainties in timing, and 8) analyze the uncertainties in the HRA results and perform sensitivity analysis, if needed. This effort did calculate the overall HEP, facilitated by the IDHEAS-ECA software too. This effort did not address uncertainties or perform sensitivity analysis.

5 FLEX HRA WORKSHOP USING IDHEAS-ECA

On December 3 – 5, 2019, the NRC hosted the FLEX HRA Workshop. The workshop was attended by the HRA panelists,[56] FLEX experts, and the EPRI project manager. NRC project staff served various roles including host, facilitator, IHDEAS-ECA author, and project management.

5.1 Purpose of Workshop

The purpose of the workshop was to support the HRA analysts in performing HRA quantification of scenarios involving FLEX strategies and equipment, using IDHEAS-ECA [1][57] and its associated software tool [2]. In addition, this was a face-to-face opportunity to clarify or modify any scenario and associated HFE descriptions. FLEX experts were in attendance to answer any questions regarding the scenarios and to provide realistic information for any needed modifications.

The workshop and follow-on conference calls on the HRA quantifications performed were intended to be the basis for HRA analysts using IDHEAS-ECA guidance [1] and the associated software tool [2].

5.2 Pre-Workshop Activities

Prior to the workshop, HRA analysts participated in weekly teleconferences to review and develop scenario and associated HFE descriptions. A set of combined plant visit notes (with HRA insights), scenario descriptions, and related materials were provided. In addition, a common HRA qualitative analysis was developed for each scenario and provided to HRA analysts. This qualitative analysis was based on information collected throughout the project.

Ultimately, the HRA qualitative analysis was the basis for inputs to HRA quantification. Examples of such qualitative HRA results are:

- Key features of FLEX equipment and strategies (e.g., as documented in plant site visit notes)
- Descriptions of scenarios, including timelines, event trees, scenario scripts, procedure paths, key assumptions (especially in the absence of a larger PRA study)
- Descriptions of HFEs, associated procedural guidance, cues, timing, and other performance shaping factors

Although the NRC staff collected, interpreted, and documented this information, FLEX experts reviewed it for accuracy and completeness. Then, prior to the workshop, HRA panelists reviewed and discussed this information for its suitability for HRA quantification, regardless of the HRA quantification method or approach. The HRA panelists reached a consensus that this information was adequate for using IDHEAS-ECA.

[56] Two HRA analysts participated by phone.
[57] The HRA analysts used an October 3, 2019 version of IDHEAS-ECA that is largely the same as the February 2020 version. However, there are some differences.

5.3 Workshop Logistics

The workshop was held in the training facility at NRC's headquarters office. The room was arranged so that HRA analysts could see all of the other analysts, as well as NRC project staff and FLEX experts. A projector and screen were used throughout the workshop to display relevant information for workshop discussions (e.g., plant-specific procedures).

The NRC technical lead served as the facilitator for the workshop. Although the workshop was not an "expert elicitation" like some prior efforts for FLEX HRA (see Volume 1 of this report [3]), the same principles and concerns (e.g., controlling bias) were considered and addressed in the workshop.

All materials needed to describe the scenarios were available. For example, electronic files on EPRI's file sharing site were available via an NRC laptop and associated NRC-internal internet access. Electronic files could be projected on a large screen.

Any additional notes, questions, or assumptions that were identified were captured in notes (e.g., flipchart notes). A whiteboard and other typical conference room or classroom amenities also were used, as needed.

5.4 Summary of Workshop

A few of the HRA analysts did some of the HRA quantification work prior to the workshop. Other analysts did their first HRA quantification work during the workshop. In almost all cases, analysts used the workshop as an opportunity to refine their understanding of the scenarios and associated HFEs.

Over the 2 ½ day workshop, each of the three scenarios and associated HFEs were discussed. In general, the format for scenario discussion included:

- Review of the scenario and associated HFEs (Section 3 provides summary descriptions while Appendices B, C, and D provide full descriptions.)
- More lengthy discussions, as needed, to adequately describe the scenario, its variations, and associated HFEs
- If needed, supporting materials, such as plant-specific procedures, were consulted
- When needed, FLEX experts provided additional information on FLEX equipment, operations and procedures, and overall strategies
- HRA analyst independently selected items within the software tool (either from prior work or in real-time at the workshop), such as:
    - Identification of "critical tasks"
    - Selection of CFMs
    - Selection of PIFs
    - HEPs
- HRA analyst evaluations using IDHEAS-ECA [1] were discussed, including reasons why certain choices were made.
- If needed, HRA analysts could make alterations to their analyses if new information, a different interpretation of information, or different guidance on how to use IDHEAS-ECA [1] or its software tool [2] was provided.
- When needed, attending FLEX experts provided additional information on FLEX equipment, operations and procedures, and overall strategies.

The workshop provided an opportunity for the analysts to have in-depth explanations supporting the logic of their evaluations, and to explain how specific critical tasks were evaluated and why certain PIFs and attributes were selected for each scenario. Within these discussions, it provided clarity and an opportunity for analyst to bridge any gaps or misunderstandings of the base scenarios and compare how each scenario was evaluated among the panelist and compare results. Also, the workshop included discussions of possible scenario variations that could result in the development of different HEP values with IDHEAS-ECA [1] and its software tool [2]. Subject matter experts participated in the workshop to provide the necessary information needed for analyst to complete their analyses.

At the beginning of the workshop, the facilitator attempted to lead the HRA analysts through how to fill out Worksheet A (and, to some extent, Worksheet B) in the IDHEAS-ECA guidance [1] which is similar to, but not the same as, the general HRA qualitative analysis provided in the scenario descriptions. After spending some time on Worksheets A and B, the rest of the workshop was devoted to the equivalent of Worksheets C and D in the IDHEAS-ECA guidance [1] (which parallels the input fields in the associated software tool [2]).

The author and developer of the IDHEAS-ECA guidance [1] and software tool [2] were also readily available during the workshop to assist analysts with questions. Although some analysts were inclined to change their IDHEAS-ECA input selections based on the group discussion, it was encouraged to capture the original selections and justify why the original selections were made and if they believed the HEP calculated were valid.

Some HRA analyst feedback on IDHEAS-ECA [1] was provided during workshop discussions. A survey on IDHEAS-ECA [1] and its software tool [2] was provided at the end of the workshop.

5.5 Workshop Results

The principal results of the workshop were:

- HRA quantification results using IDHEAS-ECA [1, 2] (See Section 6 for a summary of these results.)
- Survey responses and informal feedback during discussions

High-level HRA results were captured by the workshop facilitator on a flipchart. These notes documented key scenario assumptions (especially new assumptions that were not developed prior to the workshop) and preliminary HRA results that were used by analysts to develop final documentation of their HRA quantification. In addition, detailed collaborative and individual results were noted throughout the workshop by the NRC technical support staff and EPRI project manager.

Some analysts were not able to complete the survey before the end of the workshop. These responses were supplied after the workshop. Resolution of comments from the surveys and informal discussions will be documented and published separately.[58]

[58] At the time of this report's publication, documentation of comment resolution (and associated refinements to IDHEAS-ECA guidance and associated software tool) was still in progress. This documentation will be publicly available in ADAMS.

5.6 References

1. U.S. Nuclear Regulatory Commission, Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. U.S. Nuclear Regulatory Commission, *IDHEAS-ECA Software Tool,* v.1.1, 2020.

3. U.S. Nuclear Regulatory Commission, *Utilization of Expert Judgment to Support Human Reliability Analysis of Flexible Coping Strategies (FLEX) – Volume 1*, (to be published with this report), December 2020.

6 FLEX HRA RESULTS USING IDHEAS-ECA

This section provides the HRA analysts' results for the three scenarios evaluated using IDHEAS-ECA. The development of the results includes, Worksheets A-E referenced in IDHEAS-ECA guidance report [1], IDHEAS-ECA software tool [2] output reports, and notes from the workshop discussion which elaborates on the information captured in Section 3.

6.1 High-Level Description of IDHEAS-ECA Guidance and Software Tool

The IDHEAS-ECA software tool [2] which produces HRA quantification results is based on the IDHEAS-ECA guidance report [1]. Consequently, a short description of IDHEAS-ECA [1] is given here, focusing on the terminology that is needed to develop HEPs with IDHEAS-ECA.

The IDHEAS-ECA HRA method [1] represents human actions in a PRA (i.e., human failure events (HFE)) using five macro cognitive functions: *detection, understanding, decisionmaking, action execution, and inter team coordination.* These macro cognitive functions are based on the cognitive basis for HRA, which was published as NUREG-2114 [3]. In IDHEAS-ECA, the failure of a macro cognitive function is defined as the cognitive failure mode (CFM) (e.g., failure of *detection*, failure of *understanding*).

IDHEAS-ECA [1] also incorporates the 20 performance influencing factors (PIFs) discussed in the IDHEAS-G [4] methodology framework. In the IDHEAS-ECA methodology, PIFs are used to model the conditions, or context, that affect human performance of an action within this HRA method. IDHEAS-ECA also identifies associated "attributes" which are characteristics of PIFs. The attributes describe the way the PIFs represent a challenge to macro cognitive functions (or activating the CFM) for a critical task, thereby increasing the likelihood of error in the affected macro cognitive function(s). Within the IDHEAS-ECA software tool, the PIFs and attributes are provided in a drop-down list with associated boxes for the user to select. In the IDHEAS-ECA HRA quantification results shown below, the CFM, PIF and PIF attributes are shown to document the basis for the resulting HEP.

There are base values for each CFM built into the software tool. Using the software tool, analysts must select which CFMs are judged to be important or relevant to the specific operator action and/or critical task. Only the CFMs that are selected make a contribution to the overall human error probability (HEP); CFMs that are not selected do not make any contribution to the overall HEP. Within each CFM, the analyst must determine if there are any performance influencing factors (PIFs) or attributes that are relevant to the operator action and/or critical task. When there are no PIFs or attributes selected, the base HEP value of the CFM selected will be used to calculate the overall HEP. The base HEP values of each CFM are shown in Table 6-1.

Table 6-1 Base HEP values for Cognitive Failure Mechanisms

Failure of Detection	1.00E-04
Failure of Understanding	1.00E-03
Failure of Decision Making	1.00E-03
Failure of Action Execution	1.00E-04
Failure of Teamwork	1.00E-03

6.2 High-Level Description of IDHEAS-ECA Results

HRA results are shown in Sections 6.3, 6.4, and 6.5, respectively, for each of the three scenarios identified and described in Section 3. For the FLEX scenario, multiple HFEs were identified and quantified. In contrast, only one HFE was quantified for each of the two non-FLEX scenarios. In the discussions below, there is a results table for each HFE addressed.

Within each table, results are shown for each of the HRA analysts who participated in the NRC's FLEX HRA project.[59] The HRA analysts are identified as "Subject A," "Subject B," and so on, consistently throughout the results tables.

For each table presenting the HRA quantification results, the following information is provided for each analyst:

- the cognitive failure modes selected,
- the performance influencing factors and attributes within the selected cognitive failure mechanism, and
- the overall human error probability of that HFE and any justification for PIF selections, if provided.

Timing data, Pt, was discussed during the workshop, but was not consistently used when applying IDHEAS-ECA. In particular, for some operator actions, the relevant timing parameters were not clearly defined or known for the scenarios.

Table 6-2, below, provides a roadmap to the results and associated tables that are given in subsequent sections. Table 6-2 also shows the scenario and associated HFE(s) that are addressed and the critical tasks for each HFE. For reader convenience, the specific table numbers for the HFE quantification results are shown.

Table 6-2 Roadmap for FLEX Scenario HFE Quantification Results

Scenario	HFEs Evaluated	Critical Tasks	Variations	Table #
FLEX[60]	Fail to declare ELAP	No breakdown[61]	Case 1	6-3
			Case 2	6-3a
			Case 3	6-3b
	Fail to perform FLEX DC Load Shed	No breakdown[62]	None	6-4
	Fail to deploy FLEX DG	a.Transport DG	None	6-5a
		b. Connect, start, and load DG		6-5b
	Fail to perform containment venting	Recognize, decide and execute	None	6-6

[59] While six HRA analysts participated in this project, only five analysts provided complete HRA quantification results.
[60] For this analysis, debris removal was assumed to be successful and not modeled explicitly.
[61] For this analysis, this HFE was not broken down into critical tasks.

Table 6-2 Roadmap for FLEX Scenario HFE Quantification Results				
Scenario	**HFEs Evaluated**	**Critical Tasks**	**Variations**	**Table #**
		containment venting		
Non-FLEX: Sunny Day Loss of All Feedwater	Fail to recognize need for FLEX pump	Recognize need for FLEX pump and initiate pump deployment	None	6-7
Non-FLEX: Sunny Day SBO	Fail to understand need for, connect and start FLEX Plus DG	Recognize need for FLEX Plus DG, connect and start pre-staged DG to energize plant safety bus	None	6-8

6.3 Results for FLEX Scenario – Large Seismic Event and SBO

Section 3.4 and Appendix B provide a detailed description of the FLEX scenario for a BWR, involving a large seismic event and subsequent SBO. This section also identified many key scenario-specific assumptions and four HFEs to quantify for this FLEX scenario:

1. Operators fail to declare an extended loss of all AC power (ELAP)
2. Operators fail to perform FLEX DC load shed
3. Operators fail to deploy FLEX DG
4. Operators fail to perform containment venting

Each of these HFEs for the FLEX scenarios are addressed below.

6.3.1 Results for FLEX Scenario: Base Case HFE1 – Operators fail to declare ELAP

For the first HFE in this scenario, operators fail to declare ELAP, Section 3.4.2 provides the following key assumptions for a "base case" FLEX scenario:

- The modeled NPP has a relatively short battery life such that an Extended Loss of AC Power (ELAP) must be recognized at one hour after event initiation.
- There is definitive procedural guidance on the requirement for ELAP at one hour after event initiation.

Table 6-3 provides the IDHEAS-ECA HRA quantification results for the HFE "operators fail to declare ELAP" for the base case FLEX scenario. Except for Subject B, the analysts provided generally consistent results in the 1E-3 range.

Table 6-3. FLEX Scenario: CASE 1, HFE1 – Operators fail to declare ELAP				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject A	Detection	No Impact; No PIF selection Only base value used	No justification provided	**1.10E-3**
	Decision Making	No Impact; No PIF selection Only base value used		

Table 6-3. FLEX Scenario: CASE 1, HFE1 – Operators fail to declare ELAP				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject B	Understanding	No Impact; No PIF selection Only base value used	Shift manager has as much info as possible about the status of the LOSP recovery and availability of another offsite power source. There is no penalty for declaring ELAP early, but they would rather not have to "undo" load shedding if power restoration is expected momentarily.	**1.41E-01**
	Decision Making	**Task Complexity** competing or conflicting goals (C25)	Analyst wants to capture the issue that operators will try multiple ways to recover power. There is an uncertainty in how much time operators would spend waiting for additional information.	
Subject C	Detection	No Impact; No PIF selection Only base value used	Operators can acknowledge the situation that there is no power to any of the 4 safety buses	**1.1E-3**
	Understanding	No Impact; No PIF selection Only base value used	Operators understand that during evaluation of loss of all AC power, the 1-hour time frame is set in stone and cannot be deviated from due to the importance of getting a FLEX generator deployed and started.	
Subject D	Detection	No Impact; No PIF selection Only base value used	The cue is based on the expectation that AC power to any 4.16 kV bus cannot be restored	**1.10E-3**
	Decision Making	No Impact; No PIF selection Only base value used	A decision must be made.	
Subject E	Detection	**Multitask, Interruption, Distraction** Distraction by other on-going activities that demand	No justification provided	**2.69E-3**

Table 6-3. FLEX Scenario: CASE 1, HFE1 – Operators fail to declare ELAP				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
		attention (Moderate Effect Level) (**MT1; level 5)		
	Understanding	**Multitask, Interruption, Distraction** Distraction by other on-going activities that demand attention (**MT1; level 1)	No justification provided	
	Decision Making	No Impact; No PIF selection Only base value used	No justification provided	

6.3.2 Results for FLEX Scenario: Variation Cases for HFE1 – Operators fail to declare ELAP

Section 3.4.2 also provides the following key assumptions for the two variations on the base case FLEX scenario:

- Variation #1:
  - The modeled NPP has a longer battery life than that for the base case (e.g., approximately 4 hours; more than 1 hour but less than 12 hours).
  - Procedural guidance is more ambiguous than for the base case, i.e., IF AC power cannot be restored within 4 hours, declare ELAP within 1 hour of losing all AC power.

- Variation #2:
  - The assumptions are the same as for Variation #1, except that it is less obvious that power cannot be restored.

Consequently, HRA analyst evaluation of the two variations on the base case FLEX scenario included consideration of these different scenario parameters, which resulted in the selection of different influencing factors than for the base case scenario. Tables 6-3a and 6-3b show the results for these two variations, including how the overall HEP is altered. It should be noted that the alphabetical identifier in parenthesis are the PIF codes used in the software tool.

For Variation #1, the principal difference between this variation and the base case is the more ambiguous procedural guidance (i.e., IF AC power cannot be restored within 4 hours, declare ELAP within 1 hour of losing all AC power). The results for this variation are shown below in Table 6-3a. For this variation, Subject C calculated the same result as for Case 1 (or the base case). The rest of analysts produced HEP results that were higher than the base case. However, two of the four analysts produced HEPs that were still in the 1E-3 range while the other two analysts produced substantially higher results (e.g., 1E-2 range).

Table 6-3a. FLEX Scenario: CASE 2, HFE1 – Operators fail to declare ELAP				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject A	Decision Making	**Info Completeness and Reliability** Information is unreliable or uncertain (**INF2; Level 2)	No justification	**3E-2**
Subject B	Decision Making	**Info Completeness and Reliability** Information is unreliable or uncertain (**INF2; Level 2)	For this variation I would select PFI INF2 and the level would vary depending on details of what the procedure guidance would say. Level would range from 3 to 5 given the example presented to the team.	**3E-2**
Subject C	Decision Making	No Impact; No PIF selection Only base value used	No justification provided	**1.1E-3**
Subject D	Decision Making	**Procedure and Guidance** Procedure requires judgement (PG2)	No justification provided	**1.73E-3**
	Detection	No Impact; No PIF selection; Only base value used		
Subject E	Decision Making	No Impact; No PIF selection; Only base value used	No justification provided	**2.1E-3**
	Understanding			

Table 6-3b shows the results for variation #2 which is the same as Variation #1 except that it is less obvious that power cannot be restored (e.g., little damage onsite and reports on offsite damage are incomplete). For this case, all analysts produced HEP results that are significantly higher than Case 1 (or the base case). These HEP values range from low 1E-2 range to 0.1.

Table 6-3b FLEX Scenario: CASE 3, HFE1 – Operators fail to declare ELAP				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject A	No Information provided			
Subject B	Decision Making	**Information Completeness and Reliability**	No justification provided	**8E-2**

		Information is unreliable or uncertain (**INF2; Level 3)		
		Procedure and Guidance Procedure requires judgement (PG2)		
Subject C	Understanding	**Scenario Familiarity Unpredictable dynamics in known scenarios (SF1)**	No justification provided	**3.82 E-2**
	Decision Making	**Task Complexity** Decision criteria are intermingled; ambiguous or difficult to assess (C32)		
		Information Completeness and Reliability Information is unreliable or uncertain (INF2) Level 1		
		Procedure and Guidance Procedure requires judgement (PG2)		
Subject D	Detection	No Impact; No PIF selection; Only base value used	No justification provided	**1.6E-2**
	Decision Making	**Procedure and Guidance** Procedure requires judgement (PG2) **Task Complexity** Decision criteria is ambiguous or difficult to assess (C32) .	No justification provided	
Subject E	Understanding	**Task Complexity** Ambiguity associated with assessing the situation (C15)	No justification provided	**1.02E-1**
	Detection	No Impact; No PIF selection; Only base value used		
	Decision Making	**Procedure and Guidance** Procedure requires judgment (PG2)		

6.3.3 Results for FLEX Scenario: HFE2, HFE3, and HFE4

Tables 6-4 through 6-6 show the results for the other three HFEs evaluated with IDHEAS-ECA [1,2] for the FLEX scenario.

Table 6-4 shows the results for the second human failure event performed per the plant-specific FLEX procedure for FLEX DC load shed. For the specific BWR considered, all of the breakers that need to be manipulated have special FLEX labels that make them stand out from regular plant labels. Also, all of the breakers are in the same area, but at several different panels. The plant-specific procedure clearly identifies which breakers require manipulation and there are very few breakers to manipulate on each panel. As expected for such FLEX operator actions, there is no peer checker available for this action, but self-check is relatively easy to perform because there are so few manipulations required. All analysts produced HEP results in the 1E-3 range.

Table 6-4 FLEX Scenario: HFE2 - Operators fail to perform FLEX DC load shed

Analyst	CFM Selection	PIF and Attribute Selection	Justification	Overall HEP
Subject A	Action Execution	**Scenario Familiarity** Infrequently performed scenarios (**SF3) **Task Complexity** Straightforward procedure execution with many steps (C31) **Time pressure** Due to perceived time urgency (MF2)	No justification provided	**6.00E-03**
Subject B	Action Execution	**Task Complexity** Straightforward procedure with many steps (C31)	No justification provided	**2.2E-03**
		Environmental Poor lighting for reading info or execution (ENV4)	Very small breakers that require operators to use a flashlight to read the breaker IDs	
		T**raining and Experience** Inadequate training frequency or refreshment (**TE1; level 5)	Selected this based on the definition of infrequent training. Analyst does not believe there is an issue with only training on this action once every couple of years	
Subject C	Action Execution	**Scenario Familiarity** Infrequently performed scenarios (**SF3; level 1) **Staffing** Lack of backup or peer check or cross-checking **(**STA2) **Time pressure** Due to perceived time urgency (MF2)	No justification provided	**3.1E-03**
Subject D	Action Execution	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31)	No justification provided	**2.00E-03**

Table 6-4 FLEX Scenario: HFE2 - Operators fail to perform FLEX DC load shed				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject E	Action Execution	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31)	No justification provided	**2.00E-03**

The third HFE modeled for the FLEX scenario is "Operators fail to deploy the FLEX DG." This HFE does not include debris removal (which would be modeled as a separate HFE) or the task of determining the best transportation and staging path (which also would be modeled in a different HFE, if at all). Therefore, it is assumed that the primary staging location is used. It also is assumed that a vendor normally tests the FLEX equipment, but the operators transport the equipment for the vendors for testing. In the workshop, the HRA analysts elected to quantify this HFE in two critical tasks: 1) operators fail to transport the FLEX DG, and 2) operators fail to connect and start[62] the FLEX DG. Tables 6-5a and 6-5b show the results of the third human failure event of deploying the FLEX diesel generator for these two critical tasks, respectively. For the first critical task, all analysts produced HEP results in the 1E-3 range. For the second critical task, all but one analyst produced results in the 1E-3 range. The outlier result for the second critical task was 1.2E-2 which is an order of magnitude greater than the lowest results of 1E-3.

Table 6-5a FLEX scenario: Critical Task 1 - Fail to transport/HFE3 - Operators fail to deploy FLEX DG				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject A	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1)	No justification provided	**1.0E-3**
Subject B	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Training and Experience** Inadequate training frequency or refreshment (**TE1; level 1)	No justification provided	**1.0E-3**
Subject C	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1)	No justification provided	**1.0E-3**
Subject D	**Teamwork**	No Impact; No PIF selection; Only base value used	No justification provided	**1.0E-3**
Subject E	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios;	No justification provided	**3.0E-3**

[62] Two HRA analysts also addressed FLEX DG "load" but those results are not reported here.

		(**SF3; level 1) **Mental, Fatigue, Stress and Time Pressure** Time pressure due to perceived time urgency (MF2)		

Table 6-5b FLEX Scenario: Critical Task #2 – Connect, start, and load/ HFE3 - Operators fail to deploy FLEX DG				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject A	**Decision Making**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1)	This was selected for the main control room coordinating implementation	**1.2E-2**
	Action Execution	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31)	No justification provided	
Subject B	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31)	No justification provided	**2E-3**
Subject C	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31) **Mental, Fatigue, Stress and Time Pressure** Time pressure due to perceived time urgency ((MF2)	No justification provided	**6E-3**
Subject D	**Action Execution**	**Task Complexity** Straightforward procedure execution with many steps (C31)	No justification provided	**1E-3**
Subject E	**Action Execution**	**Scenario Familiarity** Infrequently performed scenarios; (**SF3; level 1) **Task Complexity** Straightforward procedure execution with many steps (C31) **Mental, Fatigue, Stress and Time Pressure**	No justification provided	**6E-3**

Table 6-5b FLEX Scenario: Critical Task #2 – Connect, start, and load/ HFE3 - Operators fail to deploy FLEX DG				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
		Time pressure due to perceived time urgency (MF2)		

Table 6-6 shows the results of the fourth HFE – Operators fail to perform containment venting. For this HFE, the analysts chose to model only one critical task that encompassed failures of recognizing the need, deciding to perform, and executing containment venting. Also, this HFE was addressed after the workshop, because additional information was needed by the HRA analysts, and only two analysts provided results for this HFE. Note that only three analysts provided HEP results for this HFE, with two analysts calculating 2.72E-2 and the third analysts calculating a result about a factor of 10 smaller.

Table 6-6 FLEX Scenario: HFE4 - Operators fail to perform containment venting				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
Subject B	Detection	No Impact; No PIF selection; Only base value used	Detection – C4, SF0: no impact. Monitoring of containment pressure is very straightforward and simple. PG0 – No impact – procedure guidance is clear.	**2.10E-3**
	Decision Making	No Impact; No PIF selection; Only base value used		
	Action Execution	**Task Complexity** Straightforward Procedure execution with many steps (C31)	Execution – SF0, ENV0, PG0 – All no impact, C31 Straightforward procedure with many execution steps.	
Subject C	Detection	No Impact; No PIF selection; Only base value used	No justification provided	**2.72E-2**
	Understanding	**Scenario Familiarity** Infrequently performed scenarios (**SF3)		
	Decision Making	No Impact; No PIF selection; Only base value used		
	Action	**Scenario Familiarity** Infrequently performed scenarios (**SF3) **Task Complexity** Straightforward Procedure execution with many steps (C31) **Procedure and Guidance**		

Table 6-6 FLEX Scenario: HFE4 - Operators fail to perform containment venting				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
		Procedure design less than adequate (PG1) **Mental Fatigue, Stress and Time Pressure** Time pressure due to perceived time urgency (MF2)		
	Teamwork	**Task Complexity** Coordinate activities of multiple diverse teams or organizations (C44)		
Subject D	Detection	No Impact; No PIF selection; Only base value used		**2.72E-2**
	Understanding	**Scenario Familiarity** Infrequently performed scenarios (**SF3)	No justification provided	
	Decision Making	No Impact; No PIF selection; Only base value used		
	Action Execution	**Scenario Familiarity** Infrequently performed scenarios (**SF3) **Task Complexity** Straightforward Procedure execution with many steps (C31) **Procedure and Guidance** Procedure design less than adequate (PG1) **Mental Fatigue, Stress and Time Pressure** Time pressure due to perceived time urgency (F2)	No justifications provided	
	Teamwork	**Task Complexity** Coordinate activities of multiple diverse teams or organizations (C44)	Operators must communicate the local evacuation of Reactor Building and SBGTS Filter Train area. Operators must coordinate with Chemistry to determine release rates.	

6.4 Results for Non-FLEX Scenario – Sunny Day Loss of All Feedwater

As stated in Section 3.5.1.3, there was only one HFE evaluated for this non-FLEX scenario: Operators fail to recognize need for FLEX pump (using a modified loss of heat sink procedure, FR-H1). This HFE represents the cognitive portion only of a larger HFE that the team originally defined for the FLEX scenario: Operators fail to initiate use of FLEX pump. Although there are some differences between deploying a FLEX pump for a FLEX scenario and this non-FLEX loss of all feedwater scenario, the HRA analysts agreed that the HRA assessment of the execution portion of this HFE would be similar in both cases (i.e., the actions required for transporting and putting the FLEX pump are the same, regardless if it is a BDBEE FLEX scenario or a non-FLEX, "sunny day" loss of feedwater). Consequently, the execution portion of the larger HFE was not addressed in this effort.

Section 3.5.1.2 identified many key assumptions for this scenario. It is important to note that the HRA results, regardless of HRA method, for this HFE would be very different without these key assumptions.

Table 6-7 documents the IDHEAS-ECA [1, 2] results for this HFE. There were no variations on this scenario that were addressed. Note that the HEP results for this HFE are split among the analysts. Two analysts calculated HEPs in the 1E-2 range while the other three analysts calculated the HEP to be in the 1E-3 range.

Table 6-7 Non – FLEX, loss of FW: Operators fail recognize need for FLEX pump

Analyst	CFM Selection	PIF and Attribute Selection	Justification	Overall HEP
Subject A	Detection	**Scenario Familiarity** Unpredictable dynamics in known scenarios (SF1)	No justification provided	**3.26E-3**
	Understanding	No Impact; No PIF selection; Only base value used	No justification provided	
	Decision Making	**Procedure and Guidance** The procedure requires some judgement (PG2)	No justification provided	
Subject B	Detection	**Task Complexity** Detection is moderately complex (C2) **Mental Fatigue, Stress, Time Pressure** Time pressure due to perceived time urgency (MF2)	The shift manager must make a timely decision to deploy the FLEX equipment. The crew needs to recover feedwater before the conditions for feed and bleed.	**1.59E-02**
	Understanding	No Impact; No PIF selection; Only base value used	Operators are routinely trained on scenario	
	Action Execution	**Scenario Familiarity** Infrequently performed scenarios (**SF3) **Task Complexity** straightforward procedure execution with many steps (C31)	FLEX is a new strategy at the plant and training which involves moving the equipment may not be routinely trained on.	
	Teamwork	No Impact; No PIF selection; Only base value used	There should be some longer-term team work between the main control	

Table 6-7 Non – FLEX, loss of FW: Operators fail recognize need for FLEX pump				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
			room and the local operators to start and control the FW pump and level.	
Subject C	Detection	**Task Complexity** Detection demands for high attention (C3)	No justification provided	**4.19E-3**
	Understanding	**Procedure and Guidance** Procedure requires judgement (PG2)		
	Decision Making	**Procedure and Guidance** Procedure requires judgement (PG2)		
Subject D	Detection	No Impact; No PIF selection; Only base value used	No justification provided	**1.3E-2**
	Understanding	No Impact; No PIF selection; Only base value used		
	Decision Making	**Task complexity** Procedure transfer (multiple strategies to choose) (C22)		
Subject E	Decision Making	**Procedure and Guidance** Procedure requires judgement (PG2)	No justification provided	**1.69E-3**

6.5 Results for Non-FLEX Scenario – Sunny Day SBO

Table 6-8 shows the results of the non-FLEX scenario in which a station blackout (SBO) occurs with the following key configuration:

- one EDG is out of service for an extended maintenance outage
- three FLEX Plus DGs are pre-staged to back up the remaining EDG in case it fails.

In this scenario, as described in Section 3.5.2.4, a “sunny day” loss of offsite power (LOOP) occurs, followed by the failure of the remaining EDG. There are several key and very plant-specific features of this scenario that are described in Section 3.5.2.4 and in Section 3.5.2.2 where key assumptions are documented. For example, a unique procedure, referred to as a “contingency plan”, was developed in order to use the pre-staged, portable DGs. In order to credit use of the contingency plan (in parallel with normal main control room response using EOPs), a particularly key assumption is that there is an extra RO designated to implement this contingency plan in order to energize the emergency buses using the FLEX Plus DGs. The extra RO in the MCR is designated to identify the need to implement the contingency procedure, using control room indications, then to implement the procedure and dispatch a designated AO to put the FLEX Plus DGs into service.

Table 6-8 documents the IDHEAS-ECA [1, 2] results for this HFE which includes: 1) understanding the need for the FLEX Plus DGs, and 2) connecting and starting the pre-staged FLEX Plus DGs. There were no variations on this scenario that were addressed. It is important to note that the HRA results, regardless of HRA method, for this HFE would be very different without thee key assumptions identified in Section 3.5.2.2.

Table 6-8 Non – FLEX, SBO: Operators fail to connect and start three FLEX Plus Diesel Generators

Analyst	CFM Selection	PIF and Attribute Selection	Justification	Overall HEP
Subject A	Detection	No Impact; No PIF selection Only base value used	No justification provided	**3.13 E-3**
	Decision Making	No Impact; No PIF selection Only base value used		
	Action Execution	**Task Complexity** Straightforward Procedure Execution (C31) **Scenario Familiarity** Infrequently Performed Scenarios (**SF3; level 1)	No justification provided	
Subject B	Decision Making	**Scenario Familiarity** Infrequently performed scenarios (**SF3; level 1)	No justification Removing PG3, HEP decreases to 1.36E-2. This was a variation captured from Subject B.	**2.5E-2**
		Procedure and Guidance Procedure lacks details (PG3)		
	Action Execution	**Scenario Familiarity** Infrequently performed scenarios (**SF3; level 1) **Task Complexity** Straightforward procedure execution (C31) Procedure and Guidance	No justification provided	
	Teamwork	**Task Complexity** Complexity of information communicated (**C41) level 1 **Mental Fatigue, Stress, Time Pressure** Sustained(>30mins) high demanding cognitive activities requiring continuous attention	No justification provided	
Subject C	Detection	No impact; No PIF selection Only base value used	No justification provided	**4.09E-3**
	Understanding	No impact; No PIF selection Only base value used		
	Decision Making	No impact; No PIF selection Only base value used		
	Action Execution	**Task Complexity** Straightforward Procedure Execution (C31) **Scenario Familiarity** Infrequently Performed Scenarios (**SF3) level 1		
Subject D	Detection	No impact; No PIF selection		**4.69E-3**

Table 6-8 Non – FLEX, SBO: Operators fail to connect and start three FLEX Plus Diesel Generators				
Analyst	**CFM Selection**	**PIF and Attribute Selection**	**Justification**	**Overall HEP**
		Only base value used		
	Understanding	No PIF selection Only base value used		
	Decision Making	No PIF selection Only base value used		
	Action Execution	**Scenario Familiarity** Infrequently Performed scenario (**SF3; level 1) **Task Complexity** Straightforward Procedure Execution (C31) **Human System Interface** Similarity in Elements (HS18) **Staffing** Lack of backup; lack of peer check (STA2)		
Subject E	Detection	No Impact; No PIF selection Only base value used	No justification provided	**1.1E-3**
	Action Execution	**Task Complexity** Straightforward Procedure execution with many steps (C31)		

The following comments were captured in notes for quantification of this HFE:

- Most analysts agreed that the HEP result would be higher if there was not an extra RO in the MCR designated to implement the contingency procedure. However, the analysts did not think that the task would always fail (HEP of 1.0) without an extra, designated MCR operator. Some thought the biggest affect would be on timing if there was no designated AO.
- An additional HFE or critical task would be needed for loading the FLEX DG.
- All the analysts thought their results were reasonable (although HEP results range from 1.1E-3 to 2.5E-2, with four out of five analysts providing results in the 1E-3 range).

6.6 Conclusions

Overall, the HRA analysts stated that they thought the IDHEAS-ECA [1, 2] results were "reasonable[63]" and within their understanding given the scenario descriptions and assumptions. For some HFEs (e.g., "operators fail FLEX DC load shed"), there were only slight differences in the overall HEP values. For other HFEs (e.g., "operators fail to declare ELAP"), there were greater differences in assessed HEPs across the HRA analysts. Preliminarily, the variations between analysts in their selections of PIFs and attributes appears to depend on a number of factors, including:

- the analysts' comprehension and interpretation of the event and the details within the event

[63] In this instance, "reasonable" is interpreted qualitatively (e.g., logically consistent with the facts) rather than by any specific quantitative metric.

- the analysts' ability to translate their understanding of the scenarios and associated HFEs into the appropriate inputs for the IDHEAS-ECA HRA method [1]

The NRC is continuing its testing of IDHEAS-ECA and is investigating why analyst-to-analyst variations in using IDHEAS-ECA occur.

6.7 References

1. U.S. Nuclear Regulatory Commission, Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. U.S. Nuclear Regulatory Commission, *IDHEAS-ECA Software Tool,* v.1.1, 2020.

3. U.S. Nuclear Regulatory Commission, *Cognitive Basis for Human Reliability Analysis*, NUREG-2114, January 2016.

4. U.S. Nuclear Regulatory Commission, The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G), Draft NUREG-2198, ML20238B988, June 2020.

5. Gertman, D.I., Blackman, H.S., Byers, J., Haney, L., and Marble, J., *The SPAR-H Method*, NUREG/CR-*6883*, August 2005.

7 HRA/PRA LESSONS LEARNED AND NEXT STEPS

As noted in the previous section, this effort provided some initial feedback on the use of IDHEAS-ECA [1, 2] in FLEX contexts. In addition, this effort provided some lessons learned and insights regarding HRA and PRA modeling of FLEX and non-FLEX scenarios. Such lessons learned and insights could be beneficial to future related efforts regarding HRA/PRA for FLEX.

7.1 Overall Observations

At a high level, this effort provided several benefits to both the NRC and industry. Examples of such benefits are:

- Both NRC and industry HRA analysts learned more about FLEX equipment and utility preparations for using FLEX equipment that are important inputs to HRA/PRA. Examples of such important inputs are:
    - Have additional measures (e.g., FLEX-specific labels, strengthened place-keeping aids in procedures) been taken to support the reliability of FLEX operator actions (which are trained less frequently than similar EOP-based actions (e.g., SBO DC load shed))?
    - Is there evidence of a consensus on how long operators will wait for restoration of an EDG that initially failed to start before moving on to other power restoration options?
    - Is there evidence of a consensus understanding on how much time operators have before they must declare ELAP?
- HRA/PRA can represent the positive affect (e.g., lower assigned HEPs) of improvements in how FLEX strategies are implemented (e.g., better procedural support for the decision to declare ELAP) that have occurred since initial HRA efforts to address FLEX [3, 4].
- HRA/PRA is shown to be able to address the use of FLEX equipment in non-FLEX scenarios. However, non-FLEX scenarios require collaboration of FLEX and HRA/PRA experts for their development. (see Section 7.2 below on HRA and PRA modeling insights.)
- The combination of information collection during the site visits, inputs from industry FLEX experts, traditional HRA/PRA constructs, and several key assumptions were sufficient to support the development of three scenarios (1 FLEX, 2 non-FLEX) that both NRC and industry analysts agreed were credible.
- The HEPs developed by the participating industry and NRC HRA analysts were consistent (within an order of magnitude) for several HFEs. However, there was some variation in calculated HEPs between analysts despite having developed a common understanding of the scenarios.
- Industry-wide and plant-specific information about FLEX implementation (e.g., industry-wide use of common connections, plant-specific FLEX timelines and validations) and background information on why these choices were made (e.g., SAT was used to develop training for FLEX actions in order to be consistent with other operator actions) provided a basis for how to assess associated operator actions from the HRA perspective.

- Industry participation (both FLEX experts and HRA analysts) and interaction with NRC staff (both HRA analysts and the NRC's FLEX HRA technical staff) throughout the project created a confidence in the process and results.
- The confidence in the scenario development approach also translated into a collegial environment for the workshop.
- The human error probabilities (HEPs) generated by IDHEAS-ECA were considered to be generally credible by both NRC and industry HRA analysts for the NPPs that were evaluated.[64]
- Informal feedback from the NRC HRA analysts indicates that they are more open to using a new HRA tool than they might have been at the start of the project.

One important caution regarding the HRA modeling of scenarios involving FLEX strategies and equipment is that recent events involving difficulties in starting and operating FLEX equipment are critically important to FLEX HRA. For example, assumptions underlying the HRA documented in this report are based on the assertion that FLEX equipment is robust and simple to operate, therefore, not requiring the same level of training required to permanently installed equipment. If such assumptions about FLEX equipment reliability and operability cannot be supported, then the HRA results would be different.

7.2 Insights for HRA and PRA Modeling

Several important insights resulted from this effort related to HRA and PRA modeling. Three of the most important insights applied to both FLEX and non-FLEX scenarios. Namely:

1. The two plant site visits and associated industry materials on FLEX implementation allowed the HRA analysts to better understand how FLEX strategies were expected to be implemented by industry. However, HRA/PRA analysts will need to confirm that FLEX implementation for another NPP is similar to the two NPPs visited in this project.
2. Having a relatively large number of industry and NRC experts participate in the on-site visits (including FLEX walkdowns) was invaluable in developing a common understanding of the qualitative analysis required to support FLEX HRA.
3. The level of detail in the developed scenarios was likely greater than that typical of some HRA/PRAs (e.g., HRA documentation in Accident Sequence Precursor (ASP) analyses). However, this level of detail was important for the HRA analysts to consider the scenarios as credible.
4. By design, the HRA analysts in this project were provided with the equivalent of the HRA qualitative analysis for each HFE (i.e., they did not need to develop their own qualitative understanding). Consequently, the principal variations between analysts were related to how individual analyst interpreted the qualitative analysis into the inputs required by IDHEAS-ECA [1, 2] for quantification. Previous studies (e.g., HRA Benchmarking studies [5, 6, 7, 8] have shown that differences in qualitative understanding can be an important source of analyst-to-analyst variability.

[64] However, it should be noted that HRA dependency, recovery, and uncertainty was not evaluated in this effort.

Some insights that are principally relevant to FLEX scenarios include:

- The definition of "success criteria" used for FLEX implementation (for example, see NEI 12-06 [9]) is different than that used in PRA. Consequently, PRAs for BDBEE FLEX scenarios would need to develop the appropriate success criteria (e.g., a serious consequence such as core damage or component failure).
- The timing validations for FLEX implementation may be conservative as compared to the timing information typically used in PRA.
- Because FLEX validation times are typically developed for site-wide events, these times may represent operator actions for more than one unit. If the FLEX PRA models only one unit, the HRA/PRA analyst will need to either separate timing contributions for each unit or accept a certain amount of conservatism in this timing input.
- The quantitative FLEX HRA results need to be strongly supported by plant-specific inputs and walkdowns. Without this type of detailed information, there is a large potential for uncertainty among analysts, resulting in potentially conservative HEPs. This is supported by the relatively lower HEPs for FLEX scenario HFEs in this effort versus that in previous efforts (e.g., NRC's expert elicitation effort [4]) for which less information was available.

Similarly, there are a few insights that are specifically related to the development of non-FLEX scenarios. For example:

- Non-FLEX scenarios are likely to be very plant-specific, including:
    - What initiating event and what failed plant function or system is important
        - Importance likely will be determined by NPP-specific strengths or vulnerabilities in capability for event response
- In order to best represent what are considered safety improvements (e.g., modifying EOPs to include use of FLEX equipment) for non-FLEX scenarios, FLEX experts and HRA/PRA experts should work together in order to ensure that such modifications are effective in reducing plant risk, e.g.,
    - procedural modifications should be feasible (e.g., adequate time, sufficient cues and staffing) and reliable from the HRA perspective
    - pre-staged FLEX equipment reliability should be considered (e.g., is there adequate testing that the equipment has been properly staged?)
- FLEX timing validation information may be insufficient for non-FLEX scenarios because the timeframe of response is shorter than that for a BDBEE, e.g.,
    - The typical timeframe for deploying FLEX equipment (without consideration of preliminary tasks such as debris removal) is an hour or more.
    - Most traditional PRA scenarios require response in less than an hour. For example, the two non-FLEX scenarios addressed in this report had the following timing constraints:
        - The FLEX pump must be deployed before the F&B criteria was reached. In traditional PRAs, this time is about 45 minutes. The scenario that this report addressed was specifically designed to provide more time for deploying the pump.

- The FLEX DGs needed to be operating before criteria for declaring ELAP were met. The scenario that this report addressed included pre-staging of the FLEX DGs in order to have FLEX DGs operating in enough time.

- Thermal-hydraulic (T-H) analyses may not have been performed to support crediting FLEX equipment in non-FLEX scenarios (e.g., if AFW pump runs for one hour then fails, how much more time do operators have until F&B success criteria are reached than if the AFW pump failed at t=0?)

7.3 Potential Areas for Future Work

The insights mentioned above indicate some potentially beneficial areas for future work, such as development of:

- Additional IDHEAS-ECA guidance on the selection of appropriate CFMs and PIFs.
- Full documentation of the HRA implications of "ideal" FLEX implementation[65] (building on the plant site visit notes documented in Section 2).
- Checklists or other tools that NRC HRA analysts could use to determine how close to "ideal" a specific NPP is in order to evaluate HFEs for that plant.
- Additional guidance for intended IDHEAS-ECA users on how to translate an operational understanding of a FLEX or non-FLEX scenario into the IDHEAS-ECA terminology.
- Guidance on the differences between FLEX and non-FLEX scenarios and how they should be treated in HRA/PRA.
- Additional examples of IDHEAS-ECA [1, 2] application, including recommended PSF/PIF assessments for specific HFEs and scenario contexts (which would guide analysts to context-specific concerns and help in maintaining analyst-to-analyst consistency).

7.4 References

1. U.S. Nuclear Regulatory Commission, Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. U.S. Nuclear Regulatory Commission, *IDHEAS-ECA Software Tool,* v.1.1, 2020.

3. Electric Power Research Institute, Human Reliability Analysis (HRA) for Diverse and Flexible Mitigation Strategies (FLEX) and Use of Portable Equipment, EPRI 3002013018, November 2018.

4. U.S. Nuclear Regulatory Commission, *Utilization of Expert Judgment to Support Human Reliability Analysis of Flexible Coping Strategies (FLEX) – Volume 1*, (to be published with this report), December 2020.

[65] For example, how should HRA assess an operator action (e.g., FLEX DC load shed) that is similar to an EOP action (e.g., SBO load shed) when: 1) operators train less frequently on the FLEX action than for the EOP action, and 2) the FLEX action is better supported than the EOP action (e.g., there are FLEX-specific labels for the breakers that need to be manipulated for the FLEX action).

5. U.S. Nuclear Regulatory Commission, International HRA Empirical Study – Phase 1 Report: Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Performance Data, NUREG/IA-0216, Volume 1, November 2009.

6. U.S. Nuclear Regulatory Commission, International HRA Empirical Study – Phase 2 Report: Results from Comparing HRA Method Predictions to Simulator Data from STGR Scenarios, NUREG/IA-0216, Volume 2, August 2011.

7. U.S. Nuclear Regulatory Commission, International HRA Empirical Study – Phase 3 Report: Results from Comparing HRA Method Predictions to HAMMLAB Simulator Data from LOFW Scenarios, NUREG/IA-0216, Volume 3, December 2014.

8. U.S. Nuclear Regulatory Commission, The U.S. HRA Empirical Study: Assessment of HRA Method Predictions Against Operating Crew Performance on a U.S. Nuclear Power Plant Simulator, NUREG-2156, June 2016.

9. Nuclear Energy Institute, *Diverse and Flexible Coping Strategies (FLEX) Implementation* Guide, NEI 12-06, Rev. 5, April 2018.

APPENDIX A
SUMMARY NOTES FROM THE PLANT SITE VISITS

This appendix provides the summary notes from the two plant site visits conducted for this project.

A.1 Summary of HRA/PRA-Relevant Notes for the Plant Site Visit to a BWR

As stated in Section 2.6.1, the first plant visit for this project was to a BWR NPP. Section 2.6.1 also stated that the first site visit provided probably the largest increase in understanding of FLEX but had fewer notes taken during this visit than that for the later, PWR plant site visit. However, the fewer notes for the BWR plant site visit should not be taken as an indication that less was learned from this visit. In addition, the BWR plant visit was the source of many of the HRA/PRA-relevant insights that are documented in Section 2.6.3.

The notes taken below were developed by the NRC project team. A draft version of the notes was reviewed by the plant hosts, FLEX experts, and other site visit attendees, including the HRA analysts who attended. When finalized, the site visit notes were distributed to be used in later steps of the project. The notes from the BWR visit are presented below in these categories:

- Plant-specific highlights
- Highlights from observing a BWR simulator exercise for a seismic event and SBO
- Other aspects of FLEX strategies

The BWR plant visit also included a discussion of scenario variations, mostly for FLEX scenarios. Highlights of this discussion are given in Appendix E.

A.1.1 Overall Plant-Specific Highlights

The following items were considered key takeaways from the BWR plant site visit:

1. Because of industry improvements, the decision to declare an extended loss of AC power (ELAP) (e.g., how transfers to FLEX Support Guidelines (FSGs) are incorporated into EOPs, wording of procedural guidance, FLEX scenario-specific training) is better supported than those decision that previous FLEX HRA efforts have addressed.
2. In a FLEX event (i.e., an external event that involves an extended Station Blackout (SBO)), keeping the turbine-driven pump in the reactor core isolation cooling (RCIC) system running is key. If operators can keep the RCIC running, then heat can be removed from the reactor and core uncovery can be prevented. The needed indications for monitoring RCIC operation are not lost in DC load sheds.
3. From the whole body of walkdowns and interviews, FLEX strategies and equipment, associated procedures and training, design (e.g., human factoring of interfaces such as the use of universal electrical connections across the U.S. NPP industry), are much more robust than that originally put into place for the response to security events (e.g., B.5.b equipment and associated Extensive Damage Mitigation Guidelines (EDMGs)).
4. As an additional resource in non-FLEX scenarios, the NPP's B.5.b pump is sheltered and located across the alley from plant buildings. Only hoses to connect to the pump are required to provide water. However, this pump is not protected from external hazards.
5. The BWR has installed a hardened vent as an additional way to remove decay heat.

6. The control room crew for both units is similar to that modeled for internal events Level 1 PRA (e.g., 1 Shift Manager, 2 Control Room Supervisors, 3 Reactor Operators, 1 Shift Technical Advisor).
7. Noted from walkdowns:
    a. Universal connectors make connecting easy.
    b. For FLEX DC load shed:
        i. Blue tags are used to identify which breakers must be manipulated.
        ii. Although there are multiple breakers and multiple cabinets that need to be manipulated, the total number of breakers is few.
        iii. Operators can tell when a breaker is in the correct position; there is a “feel” to the endpoint.
    c. Field operators are adequately familiar with FLEX equipment and vehicles used to transport equipment because of training and other practice.

A.1.2 Highlights From Observing a BWR Simulator Exercise for a Seismic Event and SBO

During the BWR plant visit, the FLEX HRA team had the unique opportunity to observe a simulator exercise for a beyond-design basis external event (BDBEE), including the use of FLEX procedures. The particular initiator was a seismic event followed by an SBO (which lead to using a seismic event for the FLEX scenario in this FLEX HRA effort – see Appendix B). Overall, this was a very valuable experience for the HRA analysts for see how operators respond to a FLEX scenario.

Plant visit attendees not only observed the simulator exercise but were provided with explanations and insights on the exercise, as it progressed, from the plant escort and FLEX/operations experts. The simulator exercise was “frozen” at some point and the site visit attendees were invited onto the simulator floor to more closely view the EOP flowcharts being used and ask questions.

Examples of insights gained from observing this FLEX scenario in the BWR simulator are:

- Operators are very comfortable using flowchart EOPs
- Communications in the control room between operators were well-controlled (even if a lot of alarms were annunciating)
    - Crew briefs were performed to make certain everyone knew what the plant conditions were and what procedures were currently in use
    - Protocols were used to gain the attention of the whole crew for crew briefs
- Communications from the field (e.g., reports of damage from the seismic event) and offsite sources (e.g., reports on offsite power restoration) that are important inputs to the decision to declare ELAP were demonstrated
- Incorporation of the transition to FSGs for an SBO (i.e., declare ELAP) was accomplished easily and seamlessly
    - Operators systematically worked through the use of the flowcharts for an SBO
    - Operators worked methodically to obtain necessary information (e.g., how many EDGs are running) to make the proper choices within the flowcharts, including transition to FSGs (i.e., “declare ELAP” is not explicit with these procedures; this decision is implied by transition to FSGs)

A.1.3 Highlights From Discussions About FLEX Strategies

To supplement the plant walkdowns and simulator observations, the BWR plant visit included considerable discussion on FLEX strategies, generally, and features of the site-specific implementation. Because this was the first face-to-face meeting for the various members (e.g., HRA analysts, FLEX experts, NRC technical staff) of the NRC's FLEX HRA project, the discussion ranged from basic descriptions of how the industry has implemented FLEX to details of site-specific design and operations that incorporate FLEX.

For example, there was considerable discussion about the BWR's specific EOPs and FSGs. These discussions included:

- Regarding BWR EOPs, generally:
  - How BWR EOPs are constructed (e.g., flowcharts)
  - How BWR EOPs are implemented by the control room operators (e.g., what does the shift supervisor do? How many operators are needed to implement EOPs? What do board operators do? What is the role of the Shift Technical Advisor (STA)?)
  - How do operators communicate while implementing BWR EOPs (both generally and for the specific BWR)?
- Regarding the site-specific EOPs and how FSGs are incorporated:
  - What are the entry points into FSGs?
  - When in the FLEX scenario are FSGs entered (and are there differences depending on the type of external event)?
- Regarding the operator's decision to declare ELAP:
  - What is the procedural guidance for this decision (e.g., specific columns and notes in the flowchart)?
  - What kinds of information will the control room crew receive to make the decision?
  - What would be the timing of this information?
  - Would operators wait for information (i.e., delay or hesitate) rather than make the decision?

The following additional observations were made during the BWR plant visit:

- Transition to FLEX Support Guidelines (FSGs) has been incorporated into EOPs.
- Extended loss of AC power (ELAP):
  - The SBO procedure and operator training are consistent in that, after 1 hour in an SBO condition, ELAP is declared.
  - No actual declaration of ELAP is required; transition from the SBO procedure to FSGs is the equivalent.
- The "success criteria" identified in the FLEX Final Integrated Plans (FIPs) does not have the same basis as PRA success criteria:
  - FLEX "success criteria" is tied to natural circulation and not core damage.
  - FLEX validations (e.g., timing of operator actions) were not done with respect to core damage.
  - Timing information in FIPs could be useful to HRA/PRA for FLEX but could be conservative in some cases (because FLEX "success criteria" is not tied to core damage).
- This NPP does not take credit for the BWR equivalent (e.g., blind feeding with RCIC) of a PWR "blind-feeding" steam generators (SGs).

A.2 Summary of HRA/PRA-Relevant Notes for the Plant Site Visit to a PWR

As discussed in Section 2.6.2, the second site visit for this project was to a Westinghouse PWR NPP. Section 2.6.2 also noted that there are more notes for this visit because the experience of the first site visit made the NRC project team and HRA analysts more prepared to ask detailed questions of plant personnel and the FLEX experts in attendance. Consequently, the number of notes taken for this visit is greater than that for the first site visit. Also, like the BWR visit, the PWR visit was the source of HRA/PRA-relevant insights that are documented in Section 2.6.3.

The notes taken below were developed by the NRC project team. A draft version of the notes was reviewed by the plant hosts, FLEX experts, and other site visit attendees, including the HRA analysts who attended. When finalized, the site visit notes were distributed to be used in later steps of the project.

The notes from the PWR visit are presented below in these categories:

- Plant-specific highlights
- Overview of FLEX strategies (both plant-specific and, generally, industry-wide)
- Highlights of scenario discussions with plant personnel and FLEX experts
- Highlights from plant walkdowns and associated discussions
- Highlights from the video of the PWR FLEX simulator exercise and associated discussions

A.2.1 Plant-Specific Highlights

The following items were considered key takeaways from the PWR plant visit:

1. From discussion on the first day of the site visit:
    a. Security personnel remove debris and move FLEX equipment.
2. From walkdowns:
    a. Panels for FLEX load shed are mimicked in the procedure.
    b. Confirmed that the operator would check off breaker manipulations one-at-a-time, as they are performed.
    c. Confirmed that the operator would use the procedure's bolded boxes around "OPEN" breaker positions as a self-check on the correct positioning of the breakers.
    d. Connection points are accessible and have some similarities to what we saw in the BWR plant site visit.
    e. When asked about any "challenging operator actions, the "SRO escort did not identify any.
    f. When asked to compare FLEX actions to SBO or other EOP actions, the SRO escort again did not identify any challenges and said that FLEX actions are easier but are trained on less frequently.
3. Failure to strip all loads in a FLEX load shed may not significantly change battery life.
4. This PWR does not credit blind feeding the SG in SBO PRA scenarios.

A.2.2 Overview of FLEX Strategies

During the PWR plant visit, the following information was presented by plant personnel and supplemented by more general information from FLEX experts on implementing FLEX strategies:

1. FLEX equipment is construction industry grade that requires less training and skills than needed for equipment operators (EOs).

2. The systematic approach to training (SAT) (see, for example, References 1 and 2) was used to define training population, methods, and frequencies for FLEX.[66]
3. Typical PWR FLEX scenario:
    a. NPPs may have an external event/severe weather procedure that will have steps to initiate plant assessment[67]
    b. Most Westinghouse PWRs have multiple FSGs[68]
    c. ECA-0.0 (SBO procedure):
        i. The immediate action page provides conditions where initiation of FSGs may be directed
        ii. Includes an initial DC load shed (for this PWR, there are lots of panels, but the actions are not complicated and are well-trained)
        iii. Battery life is site-specific. Some sites have performed additional calculations for SBO load shed[69] using more realistic assumptions, resulting in additional time for the functionality of batteries beyond the typical SBO load shed calculation (e.g., 6 hours versus 4 hours of battery life). This PWR uses 4 hours as battery life after SBO load shed.
    d. ELAP - many NPPs must do this by 60 minutes after reactor trip
        i. FSG-4 directs FLEX (or deep) DC load shed
        ii. For this PWR, FLEX load shedding involves cross-tying batteries, shedding all loads except for one train of instrumentation
4. For this PWR, the critical timeline in a FLEX event is to establish a backup source of electricity
    a. After successfully performing FSG-4 for FLEX deep DC load shed, there should be 14 hours of battery life remaining
    b. FLEX electrical connections are color-coded per the industry standard for FLEX
    c. The phase rotation meter provides indication of a correct connection
    d. There is standardized rotation on connections
    e. This PWR did testing to make sure that phase rotation is correct

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[66] The use of SAT in developing operator supports for implementing FLEX strategies is generally industry-wide.

[67] Plant assessment is performed for any event with consequences (i.e. the station will send out operators to assess the condition of the plant following the event like assessing the EDGs to see if they can be started and loaded which is the primary objective in ECA 0.0). The plant assessment to determine clear paths for implementing FLEX strategies is contained in FSG-5 for most PWRs. In addition to FSGs, the plant assessment for damaged conditions will be initiated by certain Abnormal Operating Procedures depending on the event.

[68] This is the list of FSGs that PWRs use, based upon PWROG guidelines. They are initiated from ECA-0.0, LOSS OF AC POWER, or ARG-4, LOSS OF ALL AC POWER WHILE ON SHUTDOWN COOLING. ARG-4 and FSG-14 were added later under a separate project for shutdown ELAP.
FSG-1, Long Term RCS Inventory Control
FSG-2, Alternate AFW/EFW Suction Source
FSG-3, Alternate Low Pressure Feedwater
FSG-4, ELAP DC Load Shed/Management
FSG-5, Initial Assessment And FLEX Equipment Staging
FSG-6, Alternate CST Makeup
FSG-7, Loss Of Vital Instrumentation Or Control Power
FSG-8, Alternate RCS Boration
FSG-9, Low Decay Heat Temperature Control
FSG-10, Passive RCS Injection Isolation
FSG-11, Alternate SFP Makeup And Cooling
FSG-12, Alternate Containment Cooling
FSG-13, Transition From FLEX Equipment
FSG-14, Shutdown RCS Makeup

[69] Per NRC endorsed guidance on extended battery life calculations for batteries ML13241A188 [3].

   f. Dust covers protect the color coding on the connections (which may appear duller in color than the actual connections)
   g. This PWR has "glow-in-the-dark" labels that are reflective; many sites have "glow-in-the-dark" labels
5. Generally, FLEX events are not modeled beyond 24 hours in PRA. (SAFER equipment is expected to arrive by 72 hours after event start.)
6. Communications capability is addressed
7. A staffing assessment was done
8. Heat removal for FLEX scenario:
   a. Phase I: Turbine-driven auxiliary feedwater (TDAFW) pump
      i. Can control (i.e., start and stop) the TDAFW pump from the MCR
      ii. For this PWR, there is no local indication of SG level; EOs must communicate with the MCR or auxiliary shutdown panel[70]
   b. Phase 2: transition to FLEX
      i. BDB (beyond design basis) pump uses water from the settling pond[71] to supply the AFW system
      ii. Also, the pump can provide makeup to the spent fuel pool
   c. The TDAFW pump can operate only to ~350 lbs., after which there is inadequate steam pressure.
9. RCS injection
   a. Need water after 16 hours (before reflux boiling/loss of natural recirculation)
   b. Core damage is calculated to occur at approximately 30 hours if no injection is provided
   c. The PRA for this PWR assumes 24 hours for core damage (i.e., no failure within 24 hours)
   d. Phase 2: Two BDB pumps take suction from the RWST and link up to the RCS T_{hot} connection
10. Containment cooling - need cooling within 1 week
11. Spent Fuel Pool – 12 hours to boiling

A.2.3 Highlights of Scenario Discussions

By the second site visit, the scenario development team had made some decisions about addressing both FLEX and non-FLEX scenarios in this project. During this visit, there was an opportunity to have face-to-face discussions about scenario development. Plant personnel who were available during these discussions offered additional, relevant plant-specific information.

The following are highlights from the scenario discussions on FLEX scripts, FLEX strategies and equipment:

1. FLEX strategies apply to the entire site (e.g., for this PWR, both Units 1 and 2 are addressed at the same time).
   a. For three-unit sites, the most compromised unit is addressed first.

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[70] One FLEX expert noted that most NPPs have local indications for SG level.
[71] This PWR's Safety Evaluation (SE) prioritizes available water sources by cleanliness. The settling pond is one of the cleanest.
The Phase 2 FLEX strategy for reactor core cooling and decay heat removal provides an indefinite water supply for feeding the SGs by deploying the beyond-design basis (BDB) high capacity pump to take suction from the settling pond or the circulating water discharge canal. SG water injection using a portable BDB AFW pump is available through both primary and alternate connection locations when the TDAFW pump becomes unavailable.

    b. Site-wide staffing is per Emergency Plan (E-plan) requirements (see NEI 10-05 [4] which provides the E-plan requirements for staffing)
2. There are variations from site to site regarding the transport of FLEX equipment. At this PWR, security personnel are responsible for debris removal and moving FLEX equipment. (At the BWR plant, equipment operators had this responsibility.)
3. Regarding debris removal and its associated assessment:
    a. For this PWR, the assessment (FSG-5) is done by the 3rd SRO and an RO:
        i. This FSG is shared in the MCR (i.e., 1 procedure for both units)
        ii. The first priority is debris removal on site
        iii. Other local roads (e.g., main access roads to the site) are cleared later. (Such roads could be cleared in parallel with on-site debris removal, if there is extra equipment that is not used for transferring FLEX equipment.)
4. Regarding FLEX diesel generators (DGs):
    a. Generally, Westinghouse NPPs just have 480V FLEX DGs
    b. Generally, it is not the size of the electrical source that's important; it is what plant functions are being restored
    c. This PWR uses:
        i. 120 V power directly (i.e., without going through battery chargers), then controls AFW locally
        ii. 480V power feeds battery chargers so instruments are powered via DC current
5. Generally, the TDAFW is a slow-moving system
    c. It can be "set," then very little tweaking is needed; it is easy to adjust (e.g., ¼ turn, then wait about 15 minutes for feedback)
    d. If the TDAFW has been running, it is easy to re-start (i.e., just turn 1 valve)
    e. Starting the TDAFW from "scratch" is more difficult
6. FSG-4: powers instruments in the MCR
7. FSG-7: powers the remote shutdown panel
8. Operator actions for FLEX scenarios:
    a. SRO/Operations - Once operators enter E-0, they "sigh" because they "know where they are" (i.e., EOPs are a "comfort zone" for most operators)
    b. SRO/Operations and FLEX experts – communications are much simpler in FLEX scenarios[72]
        i. Once you enter ECA-0.0, there are no maintenance activities
        ii. It will be much quieter in the MCR (e.g., there will be ~12 calls to the MCR for people to say where they were when they stopped their work; then there will be no more calls)
        iii. Without power to the plant, not much is going on (i.e., plant activities have stopped)
        iv. Human/resource requirements in FLEX are easier than day-to-day business requirements
    c. FLEX experts: The FLEX procedure structure makes water preferences known; the procedure directs which to use
    d. FLEX training:
        i. INPO looked at training for FLEX[73]

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[72] SRO/Operations – Most operators consider the worst scenario to be loss of instrument air

[73] INPO reviews site performance related to training:

a. Personnel responsible to perform emergency response duties have the knowledge, skills, and proficiency to execute their emergency response roles in accordance with established procedures and guidelines.

   ii. For this PWR, some things are trained on every 3 years, and some are trained on every 4 years. Plus, there are bits and pieces of actions that are trained on more frequently.
   iii. Across the U.S. NPPs, everyone had initial FLEX training[74]
   iv. For this PWR, FLEX equipment is moved out of buildings yearly (by security). Also, the trucks are swapped out, so the fuel stays good and the truck tires do not rot.

e. Regarding DC load shed:
   i. ECA-0.0 has entry into FSG-4 (each unit will have an FSG-4)
   ii. Actual load shedding is performed by 1 equipment operator (EO), using an attachment to the procedure
   iii. For this PWR, the procedure for FLEX DC load shed mimics the panel layout with respect to columns of breakers.
      1. For this PWR, procedure writers/operations intentionally made these procedures different (e.g., "ON" positions for breakers are bolded)
      2. Also, operators are trained on procedure place-keeping (e.g., do step, THEN sign off on the step in the procedure)
   iv. Having five times more breakers does not mean five times the HEP; because the procedure for this PWR has been designed to support these operator actions.
   v. Generally, there are standard conventions for breakers being ON/OFF.
   vi. Typical training will reinforce operators to "take their time."
   vii. For this PWR, the expected time for operator action performance is not included in procedures. (It was included in the BWR's procedure.)
   viii. For this PWR, the FLEX DC load shed procedural guidance has the operators going back to certain panels to flip more breakers (i.e., the same panels as those in the SBO DC load shed).
      1. This is done to make sure the distribution is even between batteries (i.e., keep DC loads even on batteries).
   ix. The loads that are shed might not be live loads. The load shed might be done in order to prevent equipment from operating later.
      1. The loads that are shed are mostly instruments.
      2. Battery life calculations include potential valve strokes, etc. that would occur if such loads were not preemptively shed.
   x. Also, if the operator fails to shed a load, the operators can still recover (e.g., if equipment starts, there is time to trip equipment)
      1. If the operator flips "off" something that should be "on," there will be lost instruments in the MCR (and MCR operators will see this).
      2. Operators are trained to <u>not</u> correct an incorrectly positioned breaker. Instead, the operator needs to check with the MCR to confirm that it is ok to flip the breaker back "on."
      3. FLEX experts – "Failures" to strip load in load shed probably will not change battery life significantly.
   xi. At some NPPs, the load shed may include stripping the batteries for the EDGs.
   xii. As loads are shed, operators can see and will monitor battery voltage:

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b. Drills, exercises, and tabletops are integrated in conjunction with training to prepare personnel to execute their assigned emergency response duties and sustain high levels of performance.

[74] There is a NANTel course on FLEX Basic and FLEX advanced.

            1. There are indications in the MCR on what loads are on/off.
      xiii. FLEX experts:
            1. For a non-FLEX scenario, the FLEX DC load shed probably will not be needed.
            2. Even for a FLEX scenario with minimum debris removal, only an SBO load shed probably would be needed.
      xiv. Deploying FLEX DG 480V is addressed in another procedure attachment
            1. The EO gets the attachment from the MCR
            2. The operators have hours to deploy the FLEX DG
            3. Once the FLEX DG is working, battery chargers and inverters will be working again (and some loads will be re-started)

9. On water sources:
    a. A tornado impact on the storage tank does not mean all the water is gone
        i. Some NPPs credited their storage tank; but some NPPs do not have protected condensate storage tanks (CSTs) so they will need alternate sources of water sooner.
    b. For some NPPs, AFW pumps already have fire water as a backup water source
    c. Most NPPs have more water than they are crediting in their FLEX validation studies
10. Scenarios to address include:
    a. FLEX (i.e., scenarios for which FLEX strategies have been developed - “classic”)
    b. “Sunny day” loss of function
        i. Many BWRs have already incorporated FLEX equipment explicitly in EOPs
        ii. In general, PWRs do NOT do this (but the PWORG is planning to do this too, using BWR experience as a model)
            1. However, operators know that FSGs are available for implementation
        iii. NEI 12-06 [5] (e.g., Section 11.6) - contains procedure diagrams
            1. FSGs are a tool set for use with SAMGs and EOPs
            2. Loss of all FW (including AFW) is analyzed (i.e., red path in FR-H.1)

A.2.4 Highlights from Plant Walkdowns and Associated Discussions

The following are highlights from the plant-specific walkdowns and associated discussions of FLEX strategies and equipment:

1. From the walkdown of the FLEX building:
    a. Tractors are staged so they can be driven out of both doors (on opposite sides of the building), with “buckets” attached (and other grappling attachments are located near the edge of the dome).
    b. There are lots of portable lights available in the FLEX building.
    c. There are many similarities to the BWR’s FLEX building with respect to the type and quantity of FLEX equipment and the staging of FLEX equipment.
2. From discussions after the FLEX building and outside fence walkdowns:
    a. Security personnel are responsible for operating the tractors to move FLEX equipment.
        i. For this PWR, it is assumed that 2 hours is needed for debris removal following a FLEX event.
        ii. Security personnel are typically local residents and/or farmers (who already know how to operate tractors and, therefore, were insulted by the requirement to be trained on how to use tractors).

        iii. There are “hard cards” on how to operator tractors with the equipment.
    b. EOs are responsible for supervising laydown of FLEX equipment.
    c. EOs are responsible for operating FLEX equipment.
    d. The industry-wide requirement for timing validations (e.g., based on NEI 12-06 [5]) is to do a demonstration using multiple crews if the time margin is less than 20%.
    e. Regarding staffing for a FLEX event, it is expected that there are no concurrent fire or security events.
    f. The FLEX Staffing Study requirements in NEI 12-01 [6] are based on NEI 10-05 [4]:
        i. The FLEX staffing study uses the same format and structure
        ii. The FLEX staffing study is identical for some aspects, so these aspects do not have to be done again
    g. The FLEX Validation document may have relevant information for HRA regarding:
        i. Performance shaping factors
        ii. Estimated (or demonstrated) timing of operator actions[75]
        iii. Different hazards
    h. For this PWR, most of the discharge fittings are the same size; suction sittings can be different sizes, but adapters are available.
3. From walkdowns inside the fence with a PWR SRO, the SRO confirmed that:
    a. Panels for the FLEX DC load shed are mimicked in the procedure
    b. The operator would check off breaker manipulations one-at-a-time, as they are performed (i.e., good placekeeping)
    c. The operator would use the procedure’s bolded boxes around “OPEN” breaker positions as a self-check on the correct positioning of the breakers
    d. The operator would need to check with the MCR before correcting an incorrectly positioned breaker
    e. Connection points are accessible and have some similarities to what were seen during the BWR plant site visit
    f. There were no “challenging operator actions”
    g. FLEX actions are generally easier than EOP actions but are trained on less frequently.

A.2.5 Highlights from Video of PWR FLEX Simulator Exercise and Associated Discussions

During the PWR plant site visit, it was not possible to observe simulator exercises. In place of such observations, a video of a simulator exercise for an external event requiring FLEX strategies was viewed, then discussed by the host plant’s operational experts, the NRC project team, and the attending HRA analysts and FLEX experts. Because the simulator exercise video was for a Combustion Engineering (CE) PWR, there were some differences between that NPP and the visited Westinghouse PWR (e.g., procedure formats and names, number of FSGs developed for implementing FLEX strategies, redundancy of equipment in certain safety and support systems).

The following are highlights from the discussion of the simulator video, with comparisons to the PWR and BWR NPPs visited during this project:

[75] However, some timing validations represent operator actions for all units on site, whereas HRA/PRA typically models a single NPP.

1. The video shows that the CE PWR and the BWR NPP are similar on how "updates" are done among the MCR operators (e.g., the MCR operator announces "Update!" then everyone in the MCR holds up their hands to acknowledge that they are listening; after the updated information is provided, "end of update" is announced)
2. For Westinghouse PWRs (and the specific PWR visited):
    a. Once done with E-0 initial steps and the first step in ECA-0.0 (which are focused on verifying reactor and turbine trips), the operators then started focusing on why the EDGs were not working, e.g.,
        i. ECA-0.0 directs operators to try to start of one EDG; if it does not start, then operators are instructed to move on to trouble-shooting
    b. The operators will continue to work through steps and other options in ECA-0.0. (If there are enough equipment operators, then they will continue to trouble-shoot why the EDG did not start. For the PWR visited, there probably would not be enough operators if they only have the minimum number of staff because they will be needed elsewhere)
        i. The staffing study for the PWR visited shows that more staff available will be available after 30 mins for EDG trouble-shooting
3. According to one FLEX expert, at some sites, they have "re-programmed" operators on the timing of FSGs 4 and 5 in SBO training to make certain that they start implementing these FSGs within an hour.
    a. This training relates to not having "confidence" that EDGs will be restored in 4 hours
4. Regarding ELAP:
    a. For this PWR, the procedure step is: "*Step 20, check if AC power is restored within **<u>45</u>** minutes" (e.g., has offsite power been restored, EDGs started, or other sources been aligned?)
        i. "*" means continuous step
        ii. If the answer is "no," then the operators go to the Response Not Obtained (RNO) column on the righthand side:
            1. declare ELAP, initiate FSG-4 (load shed), initiate FSG-5 (initial assessment and FLEX equipment staging)
        iii. To determine whether power is restored, call the system operator; they are mandated to call at 35 minutes (i.e., the auxiliary operator calls using Satellite phone, as stated in the FLEX staffing study)
        iv. A plant-specific operations expert states that "you don't have a choice" on declaring ELAP at 45 minutes
5. What do operators do if offsite power is restored after FLEX equipment is already in use?
    a. For this PWR, the FLEX DC load shed includes stripping the 4 kV protection; FSG-13 provides instruction on how to restore offsite power
    b. However, once the FLEX DGs are working, operators would use the TSC to help in re-loading using offsite power
    c. Generically, guidance for this situation says that it is "not preferable to power FLEX loads/trains with offsite power"
        i. Also, you cannot "mix and match" power sources and loads
        ii. A plant-specific operations and PRA expert stated that the procedural direction is: FSG-13, Step 2 – "Check with TSC"
    d. The earlier you get back offsite power, the easier it is to restore. Also, if operators have progressed far into implementing FSGs with FLEX equipment

working, then the plant state is stable and there is time to “back out” of FLEX equipment use

e. Generally, FSGs are focused on providing power to one 480V bus with FLEX DGs
f. Later, when SAFER equipment arrives, this equipment would power other buses/divisions

6. Notes on the severity of declaring ELAP:
    a. Many sites declare ELAP (i.e., make the decision that the plant is in an SBO) at the same time that a “General Emergency” is declared (i.e., the highest level of alert which is generally associated with the need to perform evacuations and with potential deaths)
    b. This PWR has a new, not yet implemented procedure that changes the criteria for declaring a “General Emergency” from just declaring ELAP to ELAP plus a red path (in critical safety function tree) for core cooling
        1. As a result of this procedure change, the conditions for declaring a “General Emergency” would never be reached for a non-FLEX event that involves a loss of coolant accident (LOCA)

A.3 References

1. International Atomic Energy Agency¸ Experience in the Use of the Systematic Approach to Training (SAT) for Nuclear Power Plant Personnel, IAEA-TECDOC-1057, Vienna, December 1998.

2. International Atomic Energy Agency¸ Analysis Phase of Systematic Approach to Training (SAT) for Nuclear Plant Personnel, IAEA-TECDOC-1170, Vienna, August 2000.

3. U.S. Nuclear Regulstory Commission, “Battery Life White Paper Endorsement,” ML13241A182, September 18, 2013.

4. Nuclear Energy Institute, *Assessment of On-Shift Emergency Response Organization Staffing and Capabilities*, NEI 10-05, Rev. 0, June 2011.

5. Nuclear Energy Institute, *Diverse and Flexible Coping Strategies (FLEX) Implementation* Guide, NEI 12-06, Rev. 5, April 2018.

6. Nuclear Energy Institute, *Guideline for Assessing Beyond Design Basis Accident Response Staffing and Communications Capabilities*, NEI 12-01, ML12044A009, March 2012.

APPENDIX B
FLEX SCENARIO FOR A BWR

This appendix captures the description of the FLEX scenario for a BWR that was assessed using the IDHEAS-ECA HRA method.

There were several pieces of information that were provided to the HRA analysts in order to perform HRA quantification. This appendix provides the following:

- FLEX scenario description
- HRA/PRA modeling for the FLEX scenario
- Key modeling assumptions
- Key timing information (including a FLEX scenario script)
- Illustrative assessments of plant site visit notes into preliminary IDHEAS-ECA assessments

The HRA analysts also were asked to consider the understanding of FLEX summarized in the plant site visit notes, especially the combined notes, that are given in Section 2.

B.1 FLEX Scenario Description

With a BWR at 100 percent power, a Beyond Design Basis (BDB) seismic event occurs that results in the loss of all offsite power.

At the time of the seismic event and subsequent reactor trip, the plant was in a normal full power lineup with equipment operable/functional with the following exceptions:

1. One of two divisional diesel generators is out-of-service for extensive maintenance (i.e., a 10 year rebuild of the diesel engine).
2. The high pressure coolant injection (HPCI) system is out-of- service for extensive maintenance and not available for injection.

The plant has implemented procedures for FLEX mitigating strategies.

This event is identical to a Station Blackout (SBO) event except that FLEX strategies have been implemented that provide the plant with additional capabilities (e.g., portable diesel generators and pumps).

In summary:

- A seismic event occurs that damages the plant’s switchyard, causing a loss of offsite power.
- Reactor and turbine trip occur; the operators enter their Emergency Operating Procedures (EOPs), beginning efforts to stabilize plant conditions.
- One Emergency Diesel Generator (EDG) is out of service for maintenance and the second EDG fails to start.
- By 15 minutes, the operators enter the procedure for the loss of offsite power, performing it in parallel with the EOPs. Also, an equipment operator is dispatched to try to determine why the EDG did not start.
- Within the first hour:

    - The equipment operator attempts to restart the EDG but determines that major repairs are needed.
    - Main Control Room (MCR) operators start a reactor pressure vessel (RPV) cooldown and try to control RPV water level and pressure.
    - MCR operators initiate containment venting.
    - MCR operators dispatch an equipment operator to perform SBO DC load shed.
    - MCR operators receive reports that offsite power is not restored, and alternate power sources are unavailable.
- At (or before) 1 hour after reactor trip:
    - The SBO DC load shed is complete
    - MCR operators declare ELAP, then proceed to procedural guidance for using FLEX equipment, e.g.,
        - MCR operators dispatch an equipment operator to perform FLEX DC load shed.
        - FLEX guidance for assessing plant damage and travel paths is entered.
        - Debris removal is initiated.
        - Alternate communications are established.
- After 1 hour, plant conditions begin to degrade, e.g.,
    - Building heat up occurs due to loss of ventilation
    - The suppression pool heats up
    - Long-term RCIC operation (i.e., use of turbine-driven pump) is needed to maintain adequate core cooling
- At 90 minutes, the FLEX DC load shed is complete.
- At 2 hours, debris removal is complete.
- At 3 hours, start deploying FLEX DG.
- At 5 ½ hours:
    - Operators start deploying FLEX pump
    - Critical electrical loads are supported by the FLEX DG.
- At 6 hours, the ERO is staffed and the Shift Manager turns over Emergency Director (ED) function to the Technical Support Center (TSC).
- At 12 hours, operators start refueling FLEX equipment.
- At 30 hours, operators start using the FLEX pump to inject into the RPV.

B.2 HRA/PRA Modeling

This FLEX scenario is an extension of the typical PRA modeling for an SBO in which the FLEX strategy and associated equipment is credited.

B.2.1 PRA Modeling

For the purposes of this analysis, the event tree shown in Figure 1-6 of EPRI's "Human Reliability Analysis (HRA) for Diverse and Flexible Mitigation Strategies (FLEX) and Use of Portable Equipment" report [1] is generally applicable. This figure is replicated as Figure B-1 in this report.

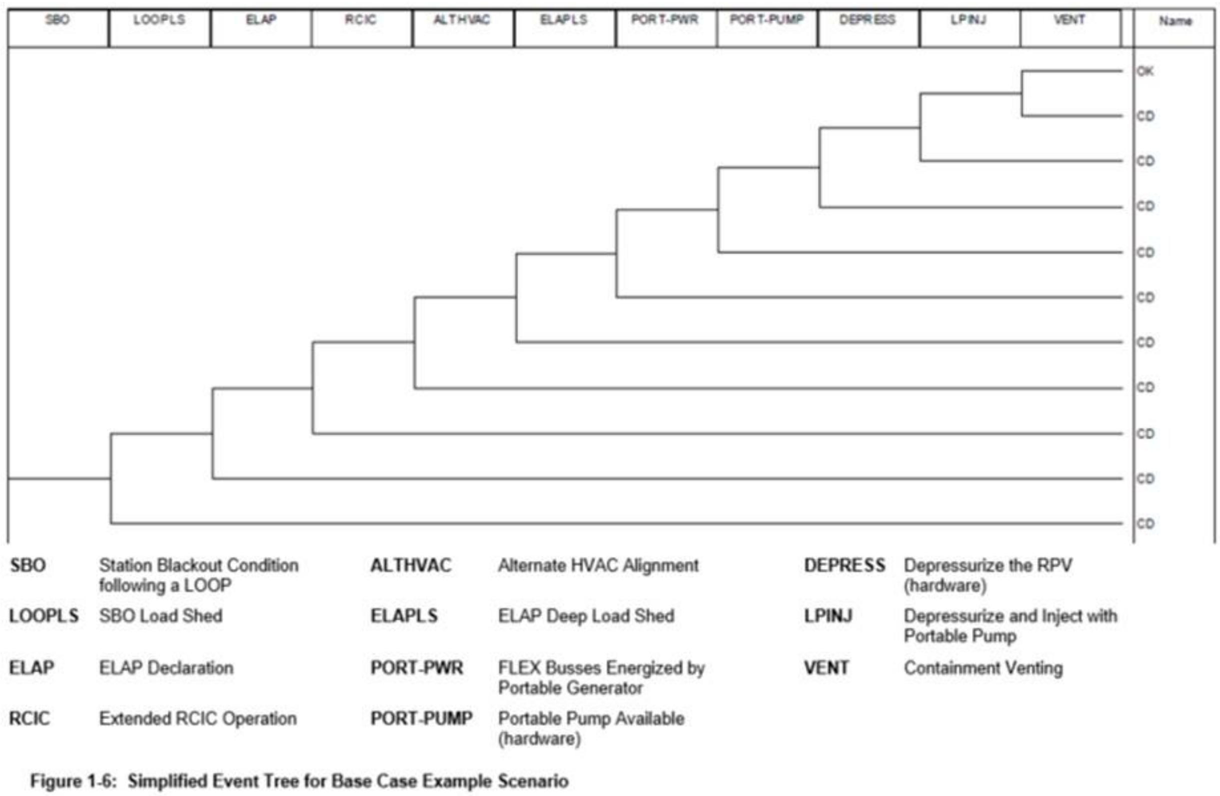

Figure B-1 FLEX Scenario Event Tree from EPRI's FLEX HRA report [1]

B.2.2 HRA Modeling

As stated in Section 3.4.3, the list of HFEs addressed for the base case FLEX scenario is:

1. Operators fail to declare ELAP (or perform its equivalent)
2. Operators fail to perform FLEX DC load shed
3. Operators fail to deploy the FLEX diesel generator
4. Operators fail to fail to initiate containment venting

A longer list of HFEs was originally considered for the FLEX scenario. However, given the limited resources for this project (e.g., project schedule, HRA analyst availability), the various teams providing inputs to this decision agreed to shorten this list to 5-6 operator actions for evaluation by HRA analysts. Considerations for selecting this shorter list of HFEs for the BWR FLEX scenario included experience from prior FLEX HRA efforts, relevance to both PWR and BWR FLEX strategies, what HFEs are currently included in SPAR models, and insights from the plant site visits. Also, some aspects of FLEX operator actions (e.g., transportation of FLEX equipment) was considered to be similar with respect to HRA concerns.

As noted in Section 3.4.4, HRA analysts referred to BWR plant-specific information (e.g., procedural guidance, information from plant-specific walkdowns, and timing validation information) to perform HRA assessments for each of the HFEs modeled for this scenario. However, virtually all of the plant visit notes given in Section 2 played a role in the HRA analyst assessments. Considerable time and effort were put into developing the notes, including reviews by both FLEX experts and HRA analysts for accuracy and consensus. Given the amount of time devoted to understanding the operator action-related aspects of the FLEX scenario, there was little formal documentation of HFE descriptions.

The following are examples of summary information used by the HRA analysts to perform their evaluations:

- HFE – Operators fail to declare ELAP[76]
  The plant-specific procedural guidance for this BWR is contained in the EOP that specially addresses the loss of offsite power. This procedure consists of several "sheets" of flowcharts. Also, the initial sheet (i.e., Sheet 1) contains transfers to other sheets depending on how many EDGs are "available for operation." Both Sheet 5 and Sheet 6 apply to the case of no EDGs available, with Sheet 6 explicitly labeled "ELAP." In addition, there is a prominent "Note" next to this portion of the flowchart in Sheet 1, that defines "ELAP" as "Extended loss of AC power (ELAP) exists when it is expected that no 4 kV bus will be re-powered within one hour." Discussions during the BWR site visit confirmed that training supports this determination. With the procedural guidance and training combined, this guidance in Sheet 1 was judged to be "explicit" with respect to HRA assessments. Sheet 6 (i.e., ELAP) consists of five parallel sections that are to be executed concurrently to address this plant condition (with references made to the relevant FSGs and other procedures needed for implementation). "FLEX Strategies" is one of the five sections (although FSGs are called out in other sections, as well).

- HFE – Operators fail to perform FLEX DC load shed
  FLEX DC load shed is identified in Sheet 6 (ELAP) of the BWR's plant-specific loss of offsite power procedure as a "priority" (red font coupled with a red arrow). A plant-specific FSG provides the procedural guidance for performing FLEX DC load shed. As the procedure shows, almost all of the breaker manipulations are performed in the same room. There are a few breaker manipulations to perform in two other locations. Generally, fewer breaker manipulations are required for the FLEX DC load shed, as compared to the SBO DC load shed. It was noted in the BWR site visit walkdowns that the breakers that require manipulation for FLEX DC load shed are all marked with a "FLEX" blue tag for easy identification. For this reason, the FLEX DC load shed was judged to be similar in difficulty to the SBO DC load shed (and may be simpler due to fewer manipulations and the eye-catching, blue "FLEX" labels).

- Operators fail to deploy FLEX diesel generator
  Deploying the FLEX DG involves: 1) transport of the DG from the FLEX Building to the appropriate laydown area via FSG-10, 2) AC electrical alignment via FSG-13, and 3) installation, starting, and adding of loads. At the BWR site, field operators are used for all three tasks (while security personnel are used for transporting FLEX equipment at the PWR site. In all cases, field operators are responsible for doing electrical alignment, then installing, starting and loading. Electrical connections are standardized for FLEX and the FLEX DG is supposed to be easy to operate (e.g., push button), by design. Field operators are trained on all actions. The training content and frequency requirements were developed via the Systematic Approach to Training (SAT). Vendors perform the testing of FLEX DGs, while field operator observe the testing.

[76] Note that, for this BWR, there is no "actual" declaration of ELAP. Rather, there is an important procedure transition that is tied to the plant-specific definition of ELAP and MCR operators will announce "Exiting Sheet 5, entering Sheet 6 (ELAP)."

- Operators fail to fail to initiate anticipatory containment venting
  The purpose of anticipatory containment venting is to prevent core damage and preserve RCIC operation. Following the hardened containment vent systems (HCVS) vent path procedures, operators will enter T-102, Primary Containment Control EOP, when drywell pressure reaches 2 psig. Containment pressure cannot be maintained below 2 psig because there is no power to Standby Gas Treatment as a result of declaring ELAP. Once containment pressure exceeds 2 psig AND pressure reduction is required to restore and maintain adequate core cooling (required for RCIC preservation strategy), then the operators are instructed to vent containment using procedure, T-200. The operator is guided to the preferred vent path for ELAP: T-200J. The operators work through T-200J to steps for bursting the rupture disc, opening the containment vent values, and monitoring vent status.

B.3 Key Modeling Assumptions

Sections 3.3 and 3.4.2 provide the general and FLEX scenario-specific assumptions, respectively.

In the materials provided before the FLEX HRA workshop, the HRA analysts were asked to focus on the following assumptions[77] as being particularly significant to the modeling of this FLEX scenario:

1. The initiating event and reactor trip occur at t=0.
2. The initiating event impacts all units on site.
3. The reactor is at-power at the time of the initiating event.
4. The reactor successfully shuts down (i.e., no ATWS).
5. The spent fuel pool is outside the scope of analysis.
6. There are no independent, concurrent events (e.g., no security threat).
7. The staffing level is the minimum required.
8. FLEX validation exercises and associated timelines provide adequate assurance of HFE feasibility (e.g., time required and time available for operator actions). (This assumption applies to the base scenarios considered, as well as some of the scenario variations.)
9. FLEX validations exercises and associated timelines use the same starting point for the “start time” (or time delay) and the “success criteria” (or time available).
10. FLEX validation times for operator actions are used as-is, even if they appear to apply to both units on site. (In some cases, it might be possible to separate Unit 1 and Unit 2 timing information. In other cases, it appears that a single operator will perform actions for both units.)
11. The HRA/PRA model addresses accident progression out to 24 hours[78] after the initiating event.
12. Even if there is some warning prior to the initiating event, there is inadequate time to pre-stage FLEX equipment that requires transportation, etc.

[77] Many of these assumptions are the same or similar to that in EPRI’s FLEX HRA report [1].
[78] 24 hours is the traditional PRA mission time. There will be plant-to-plant differences on what FLEX actions are needed within 24 hours.

In addition, for the base case FLEX scenario, it is assumed that the operators know that there is widespread damage from the external event[79]

B.4 Scenario Timing Information

There are several sources of scenario timing information that can be useful to HRA/PRA. For example, the description of the FLEX scenario given in Section B.1 outlines the key events as the FLEX scenario progresses. In addition, each NPP has developed an integrated timeline[80] for FLEX that shows all key actions, and the associated plant staff who perform these actions, throughout the FLEX scenario. Also, as part of implementation of FLEX strategies, each NPP has performed time validations for time sensitive actions. Finally, scenario scripts are another way to present how the scenario unfolds, but with additional plant behavior and operational details. The next subsections discuss and/or present some of the timing information used by the HRA analysts in using IDHEAS-ECA.

B.4.1 Excerpts from Plant-Specific Integrated Timeline

According to the integrated timeline for the two-unit site, the following plant staff take on roles that are important to HRA;

- Inside the MCR:
    - Shift Manager
    - Control Room Supervisor (CRS)
    - Shift Technical Advisor (STA)
    - 2 Reactor Operators (ROs) – 1 per unit
    - Senior Reactor Operator (SRO)/RO
- Outside the MCR:
    - 6 Equipment Operators (EOs)

Other plant staff (e.g., Instrumentation and Control (I&C) technicians, security personnel) assist the EOs in various tasks (e.g., debris removal, helping to deploy hoses).

B.4.2 FLEX Scenario Script

Using the BWR's plant-specific FLEX scenario script, the scenario script shown in Table B-1 was developed. The scenario script was, in turn, used as the basis for the summary description of the FLEX scenario. A scenario script, such as that shown in Table B-1, can be an especially important information source if there is no opportunity to observe relevant simulator exercises.

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[79] One variation on the base case FLEX scenario is that there is less damage and less widespread damage.
[80] These timelines are extensions of the integrated timelines developed for main control room abandonment scenarios for fire HRA/PRA that are described in NUREG-1921 Supplements 1 and 2 [2, 3].

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
1 T=0	A BDB seismic event occurs, causing significant damage to plant switchyard resulting in damage to off-site power feeds and main generator output that is not readily recoverable.	1. Turbine trip on load reject (automatic) 2. Reactor Scram on Turbine Trip (automatic)	• Rapid loss of condenser vacuum • MSIV closure • RPV Pressure cycling on SRV setpoint • RPV level drop due to void collapse
2 T= 0 – 5 minutes	Reactor Core Isolation Cooling (RCIC) system automatically starts on low reactor water level and injects into the RPV from the Suppression Pool suction.	1. Operator at the controls provides scram report 2. Enter T-101 on low Rx water (+1”) level/high pressure (1085 PSIG) 3. Report of seismic event called into MCR. 4. Report of switchyard damage; enter seismic procedure in parallel with EOPs 5. Initial plant stabilization a. Confirm Reactor S/D by observing all control rods fully inserted b. Stabilize RPV pressure using Safety Relief Valves (SRVs) below 925 PSIG Restore/maintain RPV level using RCIC in a band of +5 to +35 inches	

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
3 T= 0-15 minutes	Standby Emergency Diesel Generator fails to start and load respective bus. Loss of all AC power.	1. Enter SE-11 Attachment 1 for loss of offsite power 2. Continue use of EOPs in parallel 3. Dispatch operator to the EDG that failed to start to determine cause of start failure (SE-11 Attachment B) 4. Dispatch operator for damage assessment (FSG-001) 5. Shift Manager recognizes Emergency Action Level (EAL) condition, declares Site Area Emergency (SAE)/activates Emergency Response Organization (ERO)	SAE declaration begins process of obtaining off-site support/staffing ERO.
4 T = 15 – 60 minutes	While attempting local manual D/G start, Equipment Operator reports loud knocking noise and large oil leak from one Emergency D/G and unsuccessful start of the second Emergency D/G.	1. Local manual start attempt is made, loud knocking noise and large oil leak observed, EDG emergency shutdown 2. RO reports that local manual start attempts of the EDG are unsuccessful, major oil leak on one EDG 3. Unit Supervisor (US) continues with SE-11 Attachment 1 actions	SBO and ELAP response is functionally the same for the initial actions.
5 T= 20 minutes	Decay heat maintains high RPV pressure requiring SRV actuation	Commence RPV cooldown to 500 PSIG then maintain 200 to 300 PSIG at 100°F/hour	Not time critical but consistent with SBO strategy. Maintaining pressure at 200 to 300 PSIG preserves RCIC operation.
6 T = 15 - 45	Battery chargers are no longer maintaining battery charge due to the loss of all AC power.	Use SE-11 Attachment T to commence SBO DC Load Shed.	Prolong safety related battery life. Completion time is time sensitive.

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
6 15 – 45 minutes	SRV actuation complicates RPV level control, other plant conditions threaten continued operation of RCIC	1. US assigns actions to defeat RCIC trips using T-225 and T-229 • High RPV Water Level • Low RPV Pressure 2. Start/complete opening RCIC Room doors SE-11 Attachment U	RCIC preservation
7 T = 60 minutes	SBO DC Load Shed started at T =15 minutes	SBO DC Load Shed is complete	• Extends battery life • RCIC preservation
8 T= 60 minutes	SBO DC load shed is complete but not sufficient for ELAP conditions	1. Declare ELAP/Enter SE-11 Sheet 6 2. Start ELAP DC Load Shed	• Allows deep DC load shed • Extends battery life
9 T= 60 minutes	Limited pneumatic supply for SRVs, building heat up from loss of normal ventilation, RCIC heat up of Suppression Pool challenges long term RCIC operation	1. Start equipment deployment assessment (FSG-001) 2. Start debris removal (FSG-002) 3. Start Alternate Radio Antenna deployment (FSG-020) 4. Start RB natural circulation (FSG-033) 5. Start Alignment of N_2 to automatic depressurization system (ADS) SRVs (T-261 or FSG-044) 6. Line up to vent Containment (T-200, T-200J)	• FLEX deployment • Communications • Equipment qualification • Long term pressure control • RCIC preservation
10 T= 60 minutes or when Containment Pressure reaches 2 PSIG	Suppression Pool temperature rise from RCIC operation challenges RCIC operation	If RCIC is needed for adequate core cooling and Containment Pressure exceeds 2 PSIG, vent containment (T-200, T-200J)	Maintain Suppression Pool temperature less than 240°F to preserve RCIC operation

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
11 T = 60 – 90 minutes	Long term RCIC operation is needed to maintain adequate core cooling	Defeat additional RCIC trips using FSG-043 • Exhaust valve isolation • Torus Suction valve isolation • RCIC steam supply valve closure • RCIC min flow valve closure • RCIC Turbine Trips	Maintain RCIC injection
12 T = 90 minutes	ELAP DC Load Shed started at T+60	ELAP DC Load Shed is complete	Extends battery life
13 T = 120 minutes (2 hours)	Debris removal necessary to support deployment of FLEX equipment	Complete debris removal	FSG-001 used to select best pathway with minimum debris removal
14 T = 180 minutes (3 hours)	Batteries have limited availability, source of power to inverters, instrumentation and control power	Start deployment of 480 volt AC FLEX D/G to supply selected loads (FSG-010)	Maintain power to critical equipment needed for long term coping
15 T = 195 – 270 minutes (3¼ - 4½ hours)	Loss of normal ventilation results in battery room heat up, battery charging results in production of hydrogen	Start establishing Battery Room ventilation (FSG-031). Complete at T+270	Maintain equipment qualification/prevent hydrogen buildup
16 T = 330 minutes (5½ hours)	Loss of cooling results in heat up of Control Room	Start establishing Control Room ventilation (FSG-039)	Maintain Control Room habitability
17 T = 330 minutes (5½ hours)	RCIC is the sole source of RPV makeup	Commence deployment of portable FLEX pump (FSG-040)	Backup to RCIC Makeup to Torus
18 T = 330 minutes (5½ hours)	FLEX D/G deployment started at T+180	Supply critical electrical loads with 480 volt AC FLEX D/G	Recharge batteries Maintain power to vital equipment, controls and indications

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
19 T = 360 minutes (6 hours)	ERO staffed Typical ERO staffing time is less than 60 minutes but assumed 6 hours per NEI 12-01	1. Shift Manager turns over ED function to TSC. Turnover checklist includes: • Plant status and trends • ERO Command and Control 2. Corporate ED briefs TSC	• ERO Command and Control to TSC ➢ Objective is to reduce administrative burden from Control Room staff • Command and Control of plant retained by Control Room using Operating Procedures
20 T = 390 minutes (6½ hours)	RCIC heat load raises RCIC room temperatures with loss of normal ventilation	Complete RCIC Room ventilation using FSG-032 and FSG-033	Preserve RCIC operation, maintain room temperature below 150°F
21 T = 720 minutes (12 hours)	Fuel oil consumption will require that FLEX equipment be refueled on a periodic basis	Commence refueling FLEX equipment (FSG-050)	Fuel oil tanks are maintained at greater than ¼ full. The typical fuel oil tank volume contains enough fuel for 10 to 12 hours of operation at full load. 12 hours is considered he earliest that refueling would be required.
22 T = 1800 minutes (30 hours)	Prolonged RCIC operation and containment venting result in loss of Suppression Pool water inventory	Start injection to Torus (FSG-042)	Provides long term water supply for indefinite coping.
Break in Scenario – Plant has long term stability in this condition, but the scenario continues with the transition to the portable FLEX pump			

Table B-1 FLEX Scenario Script			
Sequence	**Condition**	**Action**	**Notes**
23 T = 1800 minutes (30 hours)	RCIC trips and cannot be restarted. RPV water level continues to lower. FLEX pump is lined up for injection and RPV pressure has been reduced to about 150 PSIG	1. Unit Supervisor enters alternate level control strategy 2. US directs operator to inhibit the automatic depressurization system (ADS) 3. US directs RPV blowdown 4. US directs RPV injection using FLEX portable pump to maintain RPV water level.	• Transition from RCIC to low pressure FLEX pump. • FLEX pump discharge capability is <150 PSIG • RPV blowdown is required to allow FLEX pump injection • Plant is stable with injection using the FLEX portable pump and the FLEX generator suppling essential electrical loads.
End of Scenario			

B.4.3 HFE Timing Information and Plant-Specific FLEX Final Integrated Plan

Standard HRA terminology for timing parameters (see, for example, Section 4.6.2 in NUREG-1921 [4]) is used here, e.g.,

- Start time (T_0) (or t=0). Typically, the start of the event, such as when reactor trip occurs.
- System time window (T_{sw}). The time from the start of the event until the action is no longer beneficial (typically, when irreversible damage occurs, such as core or component damage).
- Delay time (T_{delay}). The time from the start (typically the initiating event) until the time at which the operators acknowledge the cue.
- Time available (T_{avail}). The time available for operator action(s); $T_{avail} = T_{sw} – T_{delay}$
- Time required (T_{reqd}). The time needed to complete the operator action(s), both cognitive and execution contributions.

The plant's validation results are used as timing inputs. Consistent with NEI 12-06 [5], the plant used a graded approach for performing validations of "time sensitive actions" (TSAs) (i.e., there is a "time constraint" on the maximum amount of time in which the action can be performed successfully), where:

Level A Used for TSAs started within the first 6 hours

Level B: Used for TSAs started between 6 and 24 hours after the event initiation

Level C: Other tasks or manual actions in the OIP/FIP that are labor intensive or require significant coordination

The FIP uses the following titles for documenting the NPP's validations along with how HRA analysts should interpret these titles into the timing parameters identified above:

- Start time – This heading appears to be equivalent to the delay time.
- Time constraint – This heading appears to be equivalent to the system time window.
- Success criteria – This heading appears to be equivalent to the time available.
- Results – This heading appears to be equivalent to the time required.

The analyst should be cautioned that interpreting the timing results for a plant's validation plan may be complicated if the site is multi-unit. The validation plan results may be for both units, while this analysis is focused on a single unit. In some cases, unit-specific results may be available. In other cases (especially if a single field operator is performing both Unit 1 and Unit 2 actions), the timing data cannot be separated for a single unit. As noted in the "Key Assumptions" section, this analysis will use the final results reported in the NPP's FIP (which is typically for both units on site).

<u>Perform debris removal</u>
The plant's validation plan does not identify this action as time sensitive. In addition, the event timeline in the plant's validation plan shows that this is action is not time constrained.

<u>Initiate Containment Venting</u>
This action is identified as a Level A TSA in the plant's validation plan. For Level A TSAs, a simulator or timed walkthrough is performed to develop results.

The time available (identified as "success criteria" in the validation results) is 45 minutes from t=15 minutes. The time required (identified as "results") is approximately 42 minutes.

<u>Declare ELAP.</u>
This action is identified as a Level A TSA in the plant's validation plan. For Level A TSAs, a simulator or timed walkthrough is performed to develop results.

The time available (identified as "success criteria" in the validation results) is 60 minutes (or 1 hour) from t=0. The time required (identified as "results") is 40 minutes.

<u>Perform FLEX DC Load Shed (or "deep load shed")</u>
This action is identified as a Level A TSA in the plant's validation plan. For Level A TSAs, a simulator or timed walkthrough is performed to develop results.

The time available (identified as "success criteria" in the validation results) is 30 minutes from t=15 minutes (when the EO is dispatched). The time required (identified as "results") is about 14 minutes.

<u>Deploy FLEX diesel generators (DGs) (including transportation, installation, starting)</u>
This action is identified as a Level A TSA in the plant's validation plan. For Level A TSAs, a simulator or timed walkthrough is performed to develop results.

The time available (identified as "success criteria" in the validation results) is 4 hours, with EOs being dispatched to start this action at t=3 hours (i.e., action must be complete by t=7 hours). The time required (identified as "results") is about 2 hours and 16 minutes.

Deploy FLEX pump (including depressurization, if needed, transportation, etc.)
This action is identified as a Level A TSA in the plant's validation plan. For Level A TSAs, a simulator or timed walkthrough is performed to develop results.

However, the particular action addressed in the plant's validation plan is for feeding the spent fuel pool, which is not an action that is addressed in this report.

Refuel FLEX DG
This action is not explicitly addressed in the plant's validation plan.

Refuel FLEX pump
This action is not explicitly addressed in the plant's validation plan.

B.5 Preliminary IDHEAS-ECA evaluations

The NRC technical team provided the HRA analysts with examples of how to interpret the site visit notes (Section 2) into the terminology used in IDHEAS-ECA [6]. The notes shown below are that illustrative work.

B.5.1 Mapping Relevant HRA Information on FLEX to IDHEAS-ECA "Context"

IDHEAS-ECA [6] discusses different "contexts" as part of applying this HRA method. Below are illustrative examples of how FLEX information, collected as part of the FLEX HRA project, could be "mapped" to these different types of "contexts" in IHDEAS-ECA. However, the HRA analysts participating in the FLEX HRA project were asked to perform their own analyses.

Environmental context. Operator actions performed in the MCR are not directly affected by environmental conditions. Operator actions performed outside of the MCR may be influenced by debris. Operator action for debris removal will be directly affected. For other actions, alternate travel paths may be needed, and flashlights will be needed.

System context. Initially, there will several calls to the MCR from field operators to report what work was stopped by the seismic event and associated loss of all AC power. After those calls, the MCR environment will be less busy than usual since, without AC power, most systems will not be running. The turbine-driven RCIC pump and associated indications will be the focus of MCR operators along with dispatch and communication with field operators who are clearing debris and deploying FLEX equipment.

Field operators will be outside the plant dealing first with debris removal, then deploying FLEX equipment. Operator actions performed inside the plant (e.g., DC load sheds) will require flashlights to see equipment to operate.

Personnel context. For MCR operators, the crew has worked as a cohesive crew for a long time. The MCR crew is experienced. The NPP's Conduct of Operations is followed, EOPs are being used, and FSGs are embedded in the EOPs for easy entry. Station Blackout (SBO) scenarios are practiced frequently in the simulator.

The field operators are trained on all operator actions required for this scenario (which are principally in the plant's FSGs). Debris removal and transportation of FLEX equipment do not require extensive training, like actions that may typically be called out in EOPs.

Task context. For MCR operators, SBO scenarios are practiced frequently. Also, after SBO and FLEX DC load sheds (after which there is no other running equipment and few indications), the principal responsibilities of the MCR operators is to keep the RCIC pump running and support the field operators in their actions.

For field operators, many of the operator actions (e.g., remove debris, transport FLEX equipment), required relatively unskilled labor. Other actions (e.g., FLEX DC load shed) are similar to actions that are practiced more frequently and may have associated job performance measures (e.g., SBO load shed). Also, FLEX actions have been supported by industry-wide efforts to make FLEX actions simple (e.g., color coding of electrical connections, common FLEX pump connections). Further, this NPP has added FLEX-specific tags on the breakers to be manipulated in the FLEX DC load shed action.

B.5.2 HFE Characterization and Performance Influencing Factors

The HRA analysts participating in the FLEX HRA project were asked to use the site visit notes to identify relevant influencing factors[81] for each of the HFEs identified above. The following performance influencing factors are considered by IDHEAS-ECA[82] (see Reference [6], Table 2-1, page 2-3) under the high-level headings of “Environment and situation,” “System,” “Personnel,” and “Task,” respectively:

1. Work location, accessibility, and habitability,
2. Workplace visibility,
3. noise in workplace and communication pathways,
4. heat/cold/humidity,
5. resistance to physical movement,
6. system and I&C transparency to personnel,
7. human-system interfaces,
8. equipment and tools,
9. staffing,
10. procedures, guidelines, and instructions,
11. training,
12. teamwork and organizational factors,
13. work processes,
14. information availability and reliability,
15. scenario familiarity,
16. multi-tasking, interruptions and distractions,
17. task complexity,
18. mental fatigue,
19. time pressure and stress, and
20. physical demands.

[81] The HRA analysts were told that the plant site visit notes (which were developed to be independent of HRA methods) contained discussions of performance shaping factors (PSFs) that may differ in definition from those described in the IDHEAS-ECA guidance [6] and associated software tool [7].
[82] It should be noted that the draft IDHEAS-ECA report that was available for this effort had a slightly different list of PIFs.

B.6 References

1. Electric Power Research Institute, Human Reliability Analysis (HRA) for Diverse and Flexible Mitigation Strategies (FLEX) and Use of Portable Equipment, EPRI 3002013018, November 2018.

2. U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines – Qualitative Analysis for Main Control Room Abandonment Scenarios*, NUREG-1921, Supplement 1/EPRI 3002009215, January 2020.[83]

3. U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines – Quanfication Guidance for Main Control Room Abandonment Scenarios*, NUREG-1921, Supplement 2/EPRI 3002013023, June 2019.[84]

4. U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines – Final Report*, NUREG-1921/ EPRI 1023001, July 2012.

5. Nuclear Energy Institute, *Diverse and Flexible Coping Strategies (FLEX) Implementation* Guide, NEI 12-06, Rev. 5, April 2018.

6. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

7. U.S. Nuclear Regulatory Commission, *IDHEAS-ECA Software Tool,* v.1.1, 2020.

[83] EPRI published the same report in August 2017.
[84] This is EPRI's publication date for this report. A essentially identical version of this report will be published by the USNRC.

APPENDIX C
NON-FLEX SCENARIO FOR A PWR: LOSS OF ALL FEEDWATER

This appendix captures the description of the non-FLEX scenario involving the loss of all feedwater for a PWR that was used for the FLEX HRA project using IDHEAS-ECA [1].

There were several pieces of information that were provided to the HRA analysts in order to perform HRA quantification. This appendix provides the following:

- Non-FLEX scenario description
- HRA/PRA modeling for the non-FLEX scenario
- Key modeling assumptions
- Scenario timelines (for two cases)
- Preliminary assessment of influencing factors
- Procedure path (for two cases)
- Any additional notes made during the FLEX HRA Workshop that are relevant to HRA

The HRA analysts also were asked to consider the understanding of the use of FLEX strategies and equipment (as summarized in the plant site visit notes given in Section 2) that may be relevant to this non-FLEX scenario.

C.1 Non-FLEX Scenario Description: Loss of All Feedwater

With a Westinghouse PWR at 100 percent power, a loss of all feedwater occurs with 1A Auxiliary Feedwater pump out of service for maintenance.

C.1.1 Background

With the plant at 100 percent power, the 1A AFW pump was undergoing monthly surveillance testing. During the test, the 1A AFW pump experienced a mechanical failure and tripped. Operators responded to alarms and identified physical damage to the 1A AFW pump. The control room staff immediately declared the 1A AFW pump inoperable. The plant continued to operate at 100% power and there were no automatic or manual safety system responses initiated as a result of the failure. No other systems were impacted.

The licensee initiated an investigation to determine the cause and subsequent corrective actions required for the failure. As part of the investigation, a damage assessment identified that repairs could be made to the 1A AFW pump within the allowed outage time (AOT). Repair activities were initiated.

In addition, the licensee recently modified its loss of heat sink procedure, FR-H1, to provide guidance on the use of a FLEX pump to provide steam generator (SG) makeup.

C.1.2 Hypothetical Transient Event

With the plant configuration and conditions described above, a hypothetical transient event occurs.

C.2 HRA/PRA Modeling

This non-FLEX scenario is an extension of the typical PRA modeling for a loss of all feedwater with:

- one of two auxiliary feedwater pumps out of service for maintenance
- successful reactor trip/turbine trip
- remaining AFW pump (1B) fails
- Unit 2 AFW pump via crosstie is unavailable
- no consequential loss-of-coolant accident (LOCA) occurs from either RCP seals or stuck-open PORV
- modifications to the loss of heat sink procedure (FR-H.1) to include the use of a FLEX pump

C.2.1 PRA Modeling

A loss of main feedwater event tree from NRC's SPAR models was used for the purposes of this project. This project also used a feedwater fault tree, modified to include FLEX pump credit following failures after 1 hour of operation of the motor-driven AFW pump. The event tree and fault tree are shown in Figures C-1 and C-2, respectively.

In addition, two different cases which respect to the timing of the AFW pump failure can be considered, both of which include use of FR-H1 modified to include use of a FLEX pump to provide feedwater from the refueling water storage tank (RWST):

- Case #1: The 1B AFW pump fails to start with entry into the loss of heat sink procedure, FR-H1, from E-0 (reactor trip/safety injection procedure), and
- Case #2: The 1B AFW pump fails to run (i.e., pump is assumed to fail 1 hour after reactor trip) with entry into FR-H1 via the Critical Safety Function Status Tree, red path for loss of heat sink.

The implications of the two different cases are:

- Case #1: When the 1B AFW pump fails immediately, the FLEX pump will be available for injection AFTER the criteria for feed and bleed (F&B) is reached, and operators perform F&B, and
- Case #2: When the 1B AFW pump fails after 1 hour, there is more time available after entering FR-H1 to deploy the FLEX pump before F&B criteria are met. In this case, FW is restored by the FLEX pump, so F&B does not need to be performed.

For the FLEX HRA project, only Case #2 was evaluated.

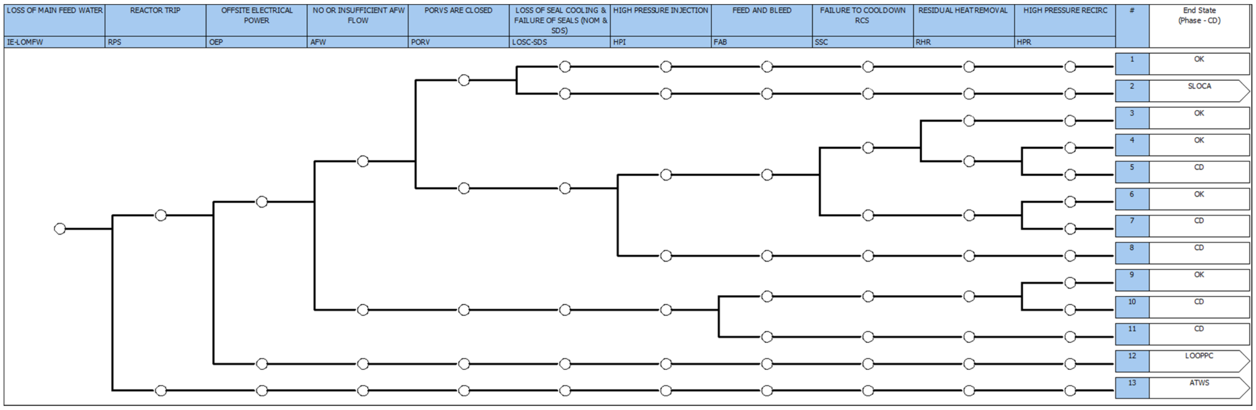

Figure C-1. Loss of Main Feedwater Event Tree – SPAR model

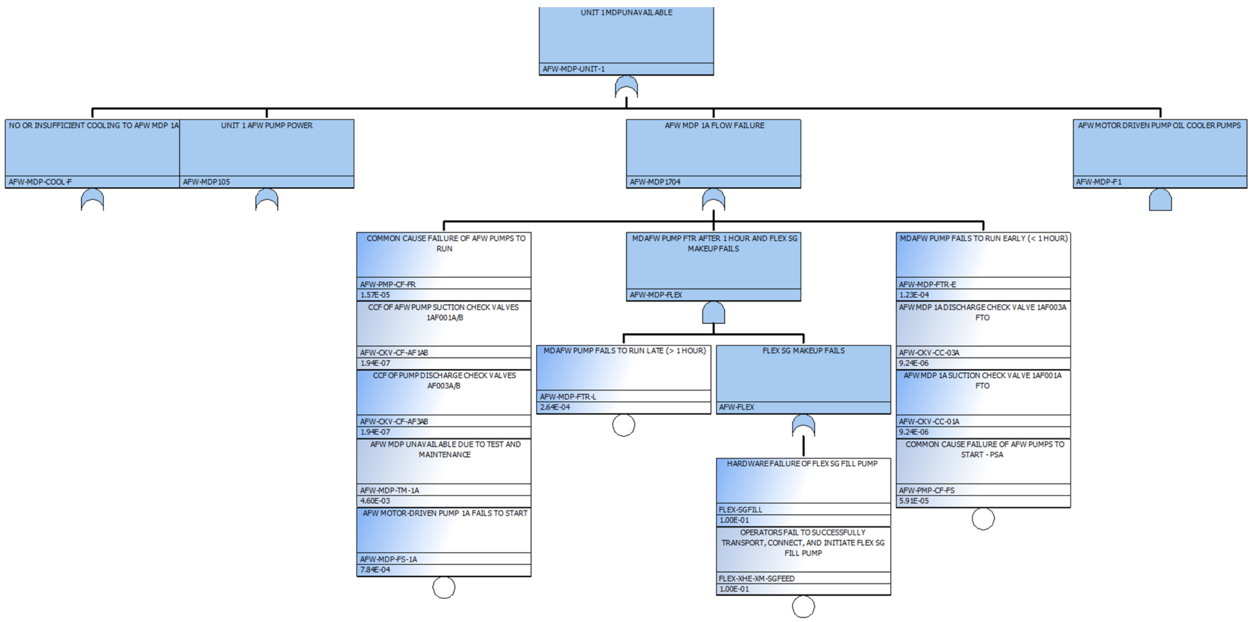

Figure C-2. Potential fault tree model - FLEX pump feed to SG after motor-driven AFW pump fails at 1 hour.

C.2.2 HRA Modeling

For both cases discussed above, the following additional basic events and associated fault tree logic are needed to credit the FLEX pump:

1. Operators fail to deploy the FLEX pump (post-initiator HFE)
   a. (Cognitive contribution) (MCR) Operators fail to initiate use of FLEX pump via FR-H1
   b. (Execution contribution) (Equipment or local) Operators fail to transport, set up, and start FLEX pump via FSG-3 (and FSG-5 per Step 2 of FSG-03)
2. FLEX pump fails to start (equipment reliability)
3. FLEX pump fails to run (equipment reliability)

So, there is only one HFE to model but with cognitive and execution contributions. The execution contribution should be identical to that for a FLEX scenario, except that there is no debris removal and, since a FLEX diesel generator is not needed for this scenario, the FLEX pump is the only equipment that needs to be deployed. Consequently, the only HFE contribution to assess is: Operators fail to initiate use of the FLEX pump.

The success criteria for the HFE is different depending on which scenario case is considered. (See Scenario Timeline below.)

Critical Tasks – Operators fail to initiate use of FLEX pump (cognitive contribution)
The critical tasks for this HFE are developed based on the expected procedure path (which is given below):

- Operators reach Step 3 and read this CAUTION above Step 3:
  If at any time it has been determined that restoration of feed flow to any SG is untimely or may be ineffective in heat sink restoration, then the AF crosstie should be implemented per Step 5.
- In parallel with other operator actions to implement FR-H1, the Shift Manager (SM) determines that restoration of feed flow to any SG will be untimely or ineffective, then transfers to Step 5 of FR-H1. This assessment would be based on an understanding of the current plant conditions, the AFW pump and other failures that have occurred, the status of efforts to restore feedwater, and the expected evolution of plant conditions in the future.
- Step 5, FR-H1 is implemented:
  a. SM has determined that restoration of feed flow will be untimely or ineffective.
  b. Check if the AF pump crosstie (to Unit 2) is available
  c. Dispatch field operator to “align AF crosstie per 1FSG-3, Alternate Low Pressure Feedwater

Critical Tasks – Operators fail to initiate use of FLEX pump (contribution from execution)
The execution contribution to this HFE is not developed; the critical tasks and associated performance influencing factors (PIFs) should be similar to that developed for the “classic FLEX scenario.” If time allows, HRA assessment of this HFE contribution could be performed as a variation on that for the “classic FLEX scenario” since different NPPs underlie the two different scenarios.

C.3 Key Modeling Assumptions

The following assumptions were determined to be significant to the modeling of this event:

- The NPP has only two AFW pumps (neither of which are turbine-driven), and any cross-ties to AFW pumps on a second unit are unavailable.
- The 1A AFW pump is unavailable for short-term maintenance.
- The AFW pump for Unit 2 is NOT available for use via crosstie.
- All four condensate pumps have failed.
- 1-2 minutes per procedure step is generally assumed, unless the procedure explicitly indicates that operators need to perform tasks quickly (e.g., the caution in FR-H1 about performing F&B steps quickly). In cases when operators are expected to perform steps

quickly (e.g., initial steps in E-0, F&B steps), approximately 1 minute or less per step is assumed.

- In the Case #1 scenario:[85]
  - the time to satisfying the criteria for the red path on heat sink in the Critical Safety Function Status Tree is assumed to be 10 minutes after reactor trip (since the 1B AFW pump fails to start at t=0).
  - the time to satisfying the criteria for F&B (i.e., low SG levels) after entering FR-H1 is about 40 minutes.
  - the time to steam generator dry out is greater than the time needed to deploy the FLEX pump (including time needed to get to relevant steps in FR-H1); consequently, the FLEX pump can be used to inject water in the SG after successful F&B.
- In Case #2:
  - the time to satisfying the criteria for the red path on heat sink in the Critical Safety Function Status Tree is assumed to be 20 minutes after the 1B AFW pump fails to run (i.e., 80 minutes after reactor trip).
  - the decay heat removed while 1B AFW pump runs in the 1st hour after reactor trip is such that feed-and-bleed criteria are not reached until after the time needed to deploy the FLEX pump (including time needed to get to relevant steps in FR-H1; specifically, F&B conditions are not reached until greater than 78 minutes after FR-H1 is entered (i.e., more than 158 minutes after reactor trip).
- The SM needs a minimum of ~7-8 minutes upon reaching Step 3, and the associated caution, in FR-H1 to assess feed flow restoration efforts and decide to use the AF crosstie and FLEX pump to feed a SG. This time is used for Case #1. For Case #2, fifteen (15) minutes is used.
- Deploying a FLEX pump for feeding a SG from the RWST takes one hour to perform from the time of dispatch.
- Initial training on the modified FR-H.1 is performed for both MCR operators and field operators.
- The modified FR-H.1 is integrated into the normal MCR operator training cycle that includes simulator training every two years plus classroom training. The simulator training is not integrated with FO training (e.g., operator trainers play the role of FO with respect communications).
- The modified FR-H.1 is integrated into the normal FO training cycle with classroom training plus FLEX training on use of the FLEX pump.

C.4 Non-FLEX Scenario Timeline

There are two scenario timelines to consider - one each for the two cases described above.

C.4.1 Non-FLEX Scenario Timeline for Case #1: AFW pump trips at t=0

For this case, the success criteria for the HFE – Operators fail to initiate use of FLEX pump – is that all operator actions, both cognitive and execution, are completed before the steam generators dry out. This time will be plant-specific. However, the FLEX pump could be used to re-establish feedwater to a SG (before it assumed that the SG has not reached dry out conditions), but this would be AFTER feed and bleed (F&B) is performed.

[85] This case was not evaluated in this project.

Note: Per the event tree shown in Figure C-1, this case is typically not addressed (i.e., if F&B is successful, the subsequent event tree headings and end states do not address restoration of FW). Consequently, it is not immediately apparent what PRA credit could be obtained by using the FLEX pump if typical PRA modeling is used. However, additional PRA modeling could be performed to show such potential credit.

- T=0 — Reactor trip; operators enter E-0. Auto-start signal for 1B AFW pump occurs, but pump fails to start.

- T=2-5 minutes — Operators reach Step 4 in E-0, then transfer to ES-0.1 (Reactor Trip Response). Per training, operators start monitoring the Critical Safety Function Status Tree following transition out of E-0. The Shift Manager (SM) arrives in the MCR about 5 minutes after reactor trip.

- T= 5-10 minutes — In parallel with implementation of ES-0.1, Operators recognize that, without any FW pumps running (i.e., all AFW pumps are failed), they will be on the red path for heat sink in the Critical Safety Function Status (CSFS) tree. Steam generator (SG) levels are dropping. Without FW, operators will be anticipating transition to FR-H1. The Shift Technical Advisor (STA) arrives (as required) and takes over his/her responsibilities, including monitoring the CSFS tree.

- T= 10 minutes — SG levels drop below 10% narrow range (and less than 500 gpm AFW flow); conditions for red path on heat sink are met. Operators transition immediately to FR-H1.

- T=11-12 minutes — Operators reach Step 2 in FR-H1. Since the F&B criteria are NOT met, they continue to monitor for F&B conditions, trip all RCPs, and proceed to Step 3.

- T=12 minutes — Operators reach Step 3 in FR-H1. A caution between Step 3 directs operators to proceed to Step 5 to establish FW via AFW crosstie (and FLEX pump) if restoration of feed flow to any SG is not expected to be timely. The SM is responsible for deciding when/if the AFW crosstie and FLEX pump will be used. He/she begins assessing efforts to restore 1B AFW pump, as well as SG levels.

- T=13-21 minutes — Operators continue working through FR-H1. The SM completes the assessment of feed flow restoration efforts and decides that the AF crosstie and FLEX pump should be used. Operators go to Step 5, complete Steps 5a-5c, including dispatching field operator to implement FSG-3 to deploy the FLEX pump to feed an SG.

- T=50 minutes — F&B criteria are met; operators immediately proceed to Step 15 to implement F&B (including the caution before Step 15 for implementing Steps 15 – 18 quickly).

- T= 51-55 minutes Operators implement Steps 15 – 18 for F&B.

- T= 81 minutes FSG-3 and FSG-5 are implemented and FLEX pump is in operation, supplying feed flow to an SG (1 hour after operator dispatch in caution before Step 3 in FR-H1).

C.4.2 Non-FLEX Scenario Timeline for Case #2: AFW fails to run after 1 hour of operation

For this case, the success criteria for the HFE – Operators fail to initiate use of FLEX pump – is that all operator actions, both cognitive and execution, are completed before F&B criteria are reached. The time to when F&B criteria is reached is plant-specific, depending on a variety of factors including how long the AFW pump runs before failing. (See Key Modeling Assumptions above.

Note: This case can be addressed in PRA by using modified fault trees (FTs) such as that shown in Figure C-2. PRA credit for using the FLEX pump and associated revised EOPs by comparing results of the modified FTs versus the original FTs (that do not include the FLEX pump).

- T=0 Reactor trip; operators enter E-0. AFW pump starts on auto-signal.

- T= 2-5 minutes Operators reach Step 4 in E-0, then transfer to ES-0.1 (Reactor Trip Response). Per training, operators start monitoring the Critical Safety Function Status Tree following transition out of E-0.

- T=5-60 minutes Operators continue implementing ES-0.1. The SM arrives about 5 minutes after reactor trip and the STA arrives 10 minutes after reactor trip.

- T=60 minutes 1B AFW pump stops (e.g., fail to run)
-
- T= 80 minutes Operators enter FR-H1 via red path on loss of heat sink in Critical Safety Function Status Tree.

- T= 81-82 minutes Operators reach Step 2 in FR-H1. F&B criteria are NOT met, so operators monitor for F&B conditions, trip RCPs, and go to Step 3.

- T= 82 minutes Operators go to Step 3. A caution before Step 3 directs operators to proceed to Step 5 to establish FW via AFW crosstie (and FLEX pump) if restoration of feed flow to any SG is not expected to be timely. The SM is responsible for deciding when/if the AFW crosstie and FLEX pump will be used. He/she begins assessing efforts to restore 1B AFW pump, as well as SG levels.

  At Step 3, sub-step I, the operators will be in the RNO column with adequate feed flow NOT verified. The RNO directs operators to Step 4 – Stop all RCPs (in order to reduce RCS heat input).

- T=83–98 minutes — Operator continue working through FR-H1. The SM completes his assessment of feed flow restoration efforts and decides that the AF crosstie and FLEX pump should be used. Operators go to Step 5, complete Steps 5a-5c, including dispatching field operator to implement FSG-3 to deploy the FLEX pump to feed an SG.
-
- T=98 minutes — Operators reach Step 5, complete steps 5a-5c, including dispatching a field operator to implement FSG-3 to deploy the FLEX pump

- T=158 minutes — FSG-3 and FSG-5 are implemented and the FLEX pump is in operation, supplying feed flow to an SG (1 hour after operator dispatch in caution before Step 3 in FR-H1).

C.4.3 Non-FLEX Scenario - Potential Variations

Hypothetical variations on Case #1 that could result in PRA credit are:

- Case #1, Variation #1 – FLEX pump must be deployed in less than 38 minutes:
    - The FLEX pump is pre-staged soon after the 1A AFW pump is declared inoperable.
    - Standing orders/temporary procedure for starting the FLEX pump are put into place with an HRA-credited mechanism for implementation with E-0.
    - The standing orders/temporary procedure are part of every shift turnover.
    - The caution before Step 3 in FR-H1, and associated training, are modified such that an evaluation of feed flow restoration is not needed; instead, the SM dispatches field operators to complete final connections for the pre-staged FLEX pump in parallel with efforts to re-start the 1B AFW pump. Awareness of the time available (i.e., less than 38 minutes) is included in training for the SM and field operators. This potentially changes the task complexity (see discussion below) to NOT complex because SM/operators would be trained that there is no consequence to starting the process of deploying the FLEX pump. If normal AFW is restored before the FLEX pump is operated, there are no irreversible steps to overcome.
    - Timing validations (e.g., walk-throughs) are performed for the field operator actions required to complete set-up and operation of the pre-staged FLEX pump.

Depending on plant-specific thermal hydraulic calculations, the timing in Scenario #2 also may require revision to obtain PRA credit. In such cases, it may be possible to meet the plant-specific timing requirements by implementing only one of the strategies suggested above (e.g., pre-staging the FLEX pump, further modifying FR-H1 and associated training) for Case #1.

C.5 Non-FLEX Scenario and HRA Influencing Factors

There are some different influencing factors for each of the HFEs identified above. The following performance influencing factors are considered by the IDHEAS-ECA guidance[86] (see Reference

[86] It should be noted that the draft IDHEAS-ECA report that was available for this effort had a slightly different list of PIFs.

[1], Table 2-1, page 2-3) under the high-level headings of “Environment and situation,” “System,” “Personnel,” and “Task”:

1. Work location, accessibility, and habitability,
2. Workplace visibility,
3. noise in workplace and communication pathways,
4. heat/cold/humidity,
5. resistance to physical movement,
6. system and I&C transparency to personnel,
7. human-system interfaces,
8. equipment and tools,
9. staffing,
10. procedures, guidelines, and instructions,
11. training,
12. teamwork and organizational factors,
13. work processes,
14. information availability and reliability,
15. scenario familiarity,
16. multi-tasking, interruptions and distractions,
17. task complexity,
18. mental fatigue,
19. time pressure and stress, and
20. physical demands.

The discussion below is preliminary and illustrative of how particulars of the scenario and associated actions would be assessed with the factors above.

<u>HFE: Operators fail to deploy FLEX pump (cognitive contribution)</u>
This action is performed in the main control room (MCR) so there are no environmental conditions of concern. Similarly, MCR design features important to this action are the same as those considered in typical HRAs (and, therefore, the analysts concluded that, for this case, there are no concerns with respect to human-machine interface, no requirements for equipment, no fitness concerns). Similarly, because operator actions are performed in the MCR and there are standard protocols for controlling calls to the MCR and physically entering the MCR, there are no unusual requirements for multi-tasking, and no interruptions or distractions. Also, since communications and command and control are unchanged from that typically addressed by HRA/PRA, the analysts concluded that there was no need to explicitly model these PIFs for this effort.

The following PIFs were assessed further by the analysts: scenario familiarity, task complexity, key cues and indications, time availability/urgency, staffing, training and experience, and procedures.

Scenario familiarity. MCR operators routinely train on F&B scenarios in the simulator. All operators would be trained initially on the modified FR-H1. Following initial training, the frequency of MCR operator training for on FR-H1 is assumed to be every 2 years. Specific training on a loss of all FW scenario with use of a FLEX pump is probably less frequent. As part of implementing FLEX strategies, all field operators received initial training on deploying a FLEX pump. Field operators will continue to train on deploying FLEX equipment once every four years.

Task complexity. Under the current conditions, task complexity could be assessed as “complex” since the SM has to understand previous plant condition history, including AFW pump failures and efforts to start the AFW pump.

Key cues and indications. The key MCR indications for entering FR-H1 on the red path for heat sink in the Critical Safety Function Status Tree are: 1) the loss of FW (i.e., no feed flow to any SG) and 2) dropping SG levels (via narrow range indicators). The key indications and procedural cues for deploying the FLEX pump are:

- Step 2 in FR-H1, check if F&B is required, and associated SG WIDE RANGE level indications
- The caution before Step 3 in FR-H1 about using the AF crosstie (go to Step 5) if feed flow cannot be restored.
- Indications of loss of feedwater, decreasing SG levels, reports (e.g., calls from field operators) on unsuccessful attempts to start AFW pump.
- Instructions in Step 5 in FR-H1, crosstie Train A AF from Unit 2 (via FLEX pump):
    a. Decision by SM that ”…heat sink restoration efforts are not available or are untimely”
    b. AF crosstie available (e.g., Unit 2 does not need AF pump)
    c. Align AF crosstie per 1FSG-3, Alternate Low Pressure Feedwater

Time availability/urgency. MCR operators are trained to be aware of the urgency to complete steps related to F&B. For example, the caution before Step 15 (Establish RCS Feed Path) in FR-H1 states: Steps 15 through 18 must be performed QUICKLY to establish RCS heat removal by RCS feed and bleed. If operators are trained similarly on making the decision to deploy the FLEX pump, there should be a similar awareness of time and urgency. (Note: This is a potential example of another variation.)

Staffing. Typical MCR staffing is expected for this event. The key is whether or when the SM arrives in the MCR since he/she must make an expeditious decision on whether to go to Step 5 in FR-H1 and use the AF crosstie with the FLEX pump providing feedwater to an SG.

Training and experience. Prior to modification of FR-H1 to incorporate the FLEX pump, operators were trained once every 2 years on F&B scenarios. Also, MCR and field operators received initial training on use of FLEX equipment in FLEX scenarios. Similarly, MCR operators received initial training on the modified FR-H1 and will receive continuous training on the new procedure.

Procedures. The key procedures/guidance for these scenarios are:

- E-0, Reactor Trip or Safety Injection
- ES-0.1, Reactor Trip Response
- ST-3, Heat Sink, Critical Safety Function Status Tree
- FR-H.1
- 1FSG-3, Alternate Low Pressure Feedwater Unit 1
- 0FSG-5 & 1FSG-5, Initial Assessment and FLEX Equipment Staging – site wide and specifically for Unit 1

1FSG-3 provides the steps needed to put the FLEX pump into service, including an instruction to dispatch a field operator to use 1FSG-5, Initial Assessment and FLEX Equipment Staging, Attachment C. Both of these FSGs are principally related to the execution portion of the HFE.

C.6 <u>Non-FLEX Scenario – Procedure Paths</u>

In order to credit this non-FLEX scenario in HRA/PRA, a clear path through existing procedures must exist, along with supporting cues and indications. Procedure paths for both cases are given below (although only Case #2 was evaluated).

C.6.1 Non-FLEX Scenario – Procedure Path for Case #1

The procedure path for Case #1 is the same as it would be for a F&B scenario, except that the modified FR-H1 contains steps and a caution that serve as entry conditions to using the FLEX pump to feed a SG.

For Case #1, The procedure path that operators will take is:

- Enter E-0 on reactor trip
- Operators reach Step 4 in E-0, then transfer to ES-0.1 (Reactor Trip Response).
- In parallel, operators start monitoring the Critical Safety Function Status Tree.
- When plant conditions satisfy criteria for the red path on heat sink in the Critical Safety Function Status Tree; enter FR-H1
- FR-H1:
    - Step 1: Check if secondary heat sink is required: YES (got to step 2)
    - Step 2: Check if Bleed and Feed is required:
      NOTE: Onset of natural circulation (indicated by rising loop delta T) may cause RCS pressure to rise……
        - Response Not Obtained (RNO) (at least not yet)
            - Monitor for B&F
            - IF B&F condition occurs, then…Step 15 (not yet)
            - Continue with Step 3

              Operators continue to monitor for F&B conditions and will transfer directly to Step 15 when the F&B criteria are met.
  - Step 3: Try to establish AF flow to at least one SG:
    CAUTION: If at any time it has been determined that restoration of feed flow to any SG is untimely or may be ineffective in heat sink restoration, then AF crosstie should be implemented per Step 5. …
    a. …(several substeps trying to establish feed flow)
    b.
    c. …
    d. …
    e. …

    i. Check AF pumps – BOTH RUNNING; Response Not Obtained (RNO) column:
       - IF NEITHER pump will start, THEN dispatch an operator to start one pump per.….Local control of safe shutdown equipment
       - IF at least one AF pump can NOT be started, THEN GO TO Step 4
  - Step 4: Reduce RCS heat input
    a. Stop all RCPs
  - Step 5: Crosstie Train A AF from Unit 2:
    CAUTION: The AF crosstie should be implemented per Step 5 if other attempts to restore feed flow to the SG(s) will not prevent initiation of feed and bleed. Use of the AF crosstie requires invoking 50.54x.

NOTE: Aligning the AF crosstie will make the 2A AF pump inoperable when Unit 2 is in Modes 1, 2, or 3.
NOTE: If adequate AF flow becomes available then establish AF flow from the affected unit and secure the crosstie.

a. Shift Manager has:
   - Determined other heat sink restoration efforts are not available…
   - Has implemented 10 CFR 50.54 (x)
   - Approved implementation of 1BFSG-3, Alternate low pressure feedwater for AF crosstie

     Initially, the SM may not have made this decision. If not, then the RNO directs operators to Step 6.

     When the SM decides that feed flow will be untimely or ineffective, the operators will return to this step.

b. Check AF crosstie – AVAILABLE
   - 2A AF pump – not required for heat sink
   - 2A AF pump - available….

     This step is to ensure that the crosstie feed path is available.
c. Align AF crosstie per 1BFSG-3
d. Narrow range level in at least one SG – greater than 10%: NO
   - Verify adequate feed flow: NO….
   - …
   - If adequate feed blow can NOT be verified, then go to Step 6

- Step 6: Prepare FW system for restoration:
  a. Check CD/CB pumps – at least one running: NO
     - …
     - If no CD/DB pumps are running, then go to Step 13. Observe caution and notes prior to Step 13.

       At this point in the procedures, operators are directed to Step 13 to use low pressure feed flow with the FLEX pump.
       However, it is possible that the SM made the decision to go to this strategy via the NOTE before Step 3 before operators work through FR-H.1 to this step. The timeline for Case #1 has the SM making this decision at 21 minutes after t=0.
- Step 13: Try to establish feed flow from any available low pressure source to at least one SG:

  CAUTION: Following block of auto SI,….
  NOTE: Main steam isolation will occur….
  NOTE: Low pressure feedwater source should not be used unless other sources are unavailable.
  NOTE: Bleed and feed should not be initiated due to low level in SGs being depressurized, unless core exit temperatures are above 557° F and rising. Steps 15 thru 18 should be performed if core exit temperatures rise.
  NOTE: If an additional SG feed source restores another SG narrow range level above 10% and feeding with low pressure source is no longer necessary to remove decay heat, then the low pressure source should be isolated from the feed line and steam flow from the associated SG should be stopped.

  a. Shift Manager has:
     - Implemented 10CFR50.54 (x)
     - Authorized implementation of:

- 1BFSG-3, Alternate Low Pressure Feedwater
  OR
- EDMG-1, Extensive Damage Mitigation Guideline, Attachment 15

  If the SM has NOT made the decision (RNO), then the operators continue to Step 14.
  However, the RNO also directs operators to return to Step 13 WHEN the SM makes this decision.

  The timeline for Case #1 has the SM making this decision at 21 minutes after t=0. When the decision is made, operators proceed to Step 13b (immediately below).

b. Align one of the following feedwater sources with the final isolation valve closed
c. Check low pressure feedwater source – READY TO PROVIDE FLOW

   It has been assumed that 60 minutes are needed to implement Step 13. The RNO states that "WHEN low pressure available and ready to provide flow, THEN RETURN TO Step 13a.
   GO TO Step 14.

-

- Step 14: Check for loss of secondary heat sink:
  - WIDE RANGE level in any THREE SGs – LESS THAN 27%
  - CETCs – GREATER THAN 557° F AND RISING
    - SG wide range level less than 27% is the F&B criteria. If it is met, operators go on to Step 15 to perform F&B.
    - [skipped steps]
    - If not, RNO directs operators to go back to Step 1 in FR-H.1.
    - [skipped steps]
    - Whether F&B criteria are met now or after returning to Step 1, the F&B criteria will be met before the FLEX pump is ready to provide flow. So, operators will end up at Step 15, performing F&B.

- Step 15: Establish RCS feed path
- Step 16: Verify RCS feed path
- Step 17: Establish RCS bleed path
- Step 18: Verify adequate RCS bleed path
- ….

  Next steps in FR-H.1 are aimed at verifying equipment status, instrument air, etc.

- Step 26: Try to establish AF to at least one SG:

  AF pumps are still failed. RNO for Step 26f directs operators to go to Step 27
- Step 27: Prepare FW system for restoration

  This will not work either. The RNO for Step 27a directs operators back to Step 26.
  When the FLEX pump is ready, the operators will return to Step 13a. Until then, operators will continue performing Steps 26 and 27.

C.6.2 Non-FLEX Scenario – Procedure Path for Case #2

For Case #2, the procedure path starts off similarly to Case #1, but the procedure path ends differently for Case #2:

- Enter E-0 on reactor trip
- Operators reach Step 4 in E-0, then transfer to ES-0.1 (Reactor Trip Response).
- In parallel, operators start monitoring the Critical Safety Function Status Tree.
- Operators will work their way through ES-0.1 until the 1B AFW pump fails
- Operators will continue to follow ES-0.1 in parallel with trying to restore the 1B AFW pump
- When plant conditions satisfy criteria for the red path on heat sink in the Critical Safety Function Status Tree (20 minutes after the 1B AFW pump fails); enter FR-H1
- FR-H1:
    - Step 1: Check if secondary heat sink is required: YES (got to step 2)
    - Step 2: Check if Feed and Bleed is required:
      NOTE: Onset of natural circulation (indicated by rising loop delta T) may cause RCS pressure to rise……
        - Response Not Obtained (RNO) (at least not yet)
            - Monitor for F&B
            - IF F&B condition occurs, then…Step 15 (not yet)
            - Continue with Step 3

              Operators continue to monitor for F&B conditions and will transfer directly to Step 15 when the F&B criteria are met.
  - Step 3: Try to establish AF flow to at least one SG:
    CAUTION: If at any time it has been determined that restoration of feed flow to any SG is untimely or may be ineffective in heat sink restoration, then AF crosstie should be implemented per Step 5. …
    f. …(several substeps trying to establish feed flow)
    g.
    h. …
    i. …
    j. …

    j. Check AF pumps – BOTH RUNNING; RNO column:
       - IF NEITHER pump will start, THEN dispatch an operator to start one pump per ….Local control of safe shutdown equipment
       - IF at least one AF pump can NOT be started, THEN GO TO Step 4
  - Step 4: Reduce RCS heat input
    a. Stop all RCPs
  - Step 5: Crosstie Train A AF from Unit 2:
    CAUTION: The AF crosstie should be implemented per Step 5 if other attempts to restore feed flow to the SG(s) will not prevent initiation of feed and bleed. Use of the AF crosstie requires invoking 50.54x.
    NOTE: Aligning the AF crosstie will make the 2A AF pump inoperable when Unit 2 is in Modes 1, 2, or 3.
    NOTE: If adequate AF flow becomes available then establish AF flow from the affected unit and secure the crosstie.
    a. Shift Manager has:
       - Determined other heat sink restoration efforts are not available…
       - Has implemented 10 CFR 50.54 (x)

- Approved implementation of 1BFSG-3, Alternate Low pressure feedwater for AF crosstie

  Initially, the SM may not have made this decision. If not, then the RNO directs operators to Step 6.

  When the SM decides that feed flow will be untimely or ineffective, the operators will return to this step.

b. Check AF crosstie – AVAILABLE
   - 2A AF pump – not required for heat sink
   - 2A AF pump - available….

     This step is to ensure that the crosstie feed path is available.

c. Align AF crosstie per 1BFSG-3
d. Narrow range level in at least one SG – greater than 10%: NO
   - Verify adequate feed flow: NO….
   - …
   - If adequate feed blow can NOT be verified, then go to Step 6

- Step 6: Prepare FW system for restoration:
  a. Check CD/CB pumps – at least one running: NO
     - …
     - If no CD/DB pumps are running, then go to Step 13. Observe caution and notes prior to Step 13.

       At this point in the procedures, operators are directed to Step 13 to use low pressure feed flow with the FLEX pump.
       However, it is possible that the SM made the decision to go to this strategy via the NOTE before Step 3 before operators work through FR-H.1 to this step. The timeline for Case #1 has the SM making this decision at 21 minutes after t=0.

- Step 13: Try to establish feed flow from any available low pressure source to at least one SG:

  CAUTION: Following block of auto SI,….
  NOTE: Main steam isolation will occur….
  NOTE: Low pressure feedwater source should not be used unless other sources are unavailable.
  NOTE: Bleed and feed should not be initiated due to low level in SGs being depressurized, unless core exit temperatures are above 557° F and rising. Steps 15 thru 18 should be performed if core exit temperatures rise.
  NOTE: If an additional SG feed source restores another SG narrow range level above 10% and feeding with low pressure source is no longer necessary to remove decay heat, then the low pressure source should be isolated from the feed line and steam flow from the associated SG should be stopped.

  a. Shift Manager has:
     - Implemented 10CFR50.54 (x)
     - Authorized implementation of:
       - 1BFSG-3, Alternate Low Pressure Feedwater
         OR
       - EDMG-1, Extensive Damage Mitigation Guideline, Attachment 15

         If the SM has NOT made the decision (RNO), then the operators continue to Step 14.

However, the RNO also directs operators to return to Step 13 WHEN the SM makes this decision.

The timeline for Case #1 has the SM making this decision at 21 minutes after t=0. When the decision is made, operators proceed to Step 13b (immediately below).

b. Align one of the following feedwater sources with the final isolation valve closed
c. Check low pressure feedwater source – READY TO PROVIDE FLOW

It has been assumed that 60 minutes are needed to implement Step 13. The RNO states that "WHEN low pressure feedwater source is ready to provide flow, THEN RETURN TO Step 13c.

Otherwise, GO TO Step 14.

- Step 14: Check for loss of secondary heat sink:
  - WIDE RANGE level in any THREE SGs – LESS THAN 27%
  - CETCs – GREATHER THAN 557° F AND RISING
    - Wide range SG level less than 27% is the F&B criteria. In this case, the F&B criteria are not met.
    -
    - The RNO directs operators back to Step 1.
    -
    - Eventually, the FLEX pump will be ready, and operators will return to Step 13a to use FLEX pump to feed a SG. The F&B criteria will never be reached (if the FLEX pump operation is successful).

Execution Contribution – Operators fails to deploy FLEX pump
This action is identical to that for implementing FLEX strategies in response to an external event except no external event has occurred (so environmental factors were judged to be not a concern and no debris removal is required).

Factors important to this contribution to the HFE are:

- Field/equipment operators are trained on equipment operations, generally, on a once every two year basis. All field operators are given initial FLEX equipment training, then refresher training every 4 years.
- FLEX equipment is simpler to operator than other (e.g., nuclear-grade) equipment. So, while training may be less frequent, the FLEX equipment is easier to operate.
- FLEX connections have been standardized, US NPP industry-wide.

C.7 Additional Notes Made During the FLEX HRA Workshop

The information documented above was provided to the HRA analysts prior to the workshop.

During the workshop, the HRA analysts identified these additional assumptions as being important to this scenario and associated HFE:

- Operators will try **only once** to re-start 2nd AFW pump locally
- No instructions in NOTES or CAUTIONS

- Instructions in “CAUTION” do not have operators skip steps
- Time to implement Step 3f is about 10 minutes to dispatch

C.8 References

1. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

APPENDIX D
NON-FLEX SCENARIO FOR A PWR: STATION BLACKOUT WITH PRE-STAGED PORTABLE DIESEL GENERATORS

This appendix captures the description of the non-FLEX scenario involving a station blackout (SBO) with an emergency diesel generator (EDG) out-of-service for long-term maintenance, and three FLEX Plus diesel generators (DGs) pre-staged to replace the EDG.

There were several pieces of information that were provided to the HRA analysts in order to perform HRA quantification. This appendix provides the following:

- Non-FLEX scenario description
- HRA/PRA modeling for the non-FLEX scenario
- Key modeling assumptions
- Scenario timelines (for two cases)
- Potential variations
- Preliminary assessment of influencing factors
- Any additional notes made during the FLEX HRA Workshop that are relevant to HRA

D.1 <u>Non-FLEX Scenario Description: SBO with One EDG Out-Of-Service and Three Pre-Staged FLEX Plus DGs</u>

With a Combustion Engineering PWR at 100 percent power and three FLEX Plus diesel generator (DG) pre-staged to replace an emergency diesel generator (EDG) that is out-of-service, an SBO occurs.

D.1.1 Background

With the plant at 100 percent power, the 1B emergency diesel generator (EDG) experienced a significant mechanical failure during the performance of a regularly scheduled monthly surveillance test. The Unit 1 control room staff immediately declared the 1B EDG inoperable. The plant continued to operate at 100% power and there were no automatic or manual safety system responses initiated as a result of the failure. No other systems were impacted.

Operators responded to alarms and identified physical damage to the 1B EDG based on oil and metal debris on the room floor. The main control room (MCR) staff immediately declared the 1B EDG inoperable.

The licensee later investigated the cause and subsequent corrective actions required for the EDG failure. As a result, the licensee determined that repairs to the 1B EDG could not be completed within the technical specification (TS) allowed outage time (AOT).

In addition to the analysis and evaluations used to extend the allowed outage time (AOT), several pieces of FLEX equipment, namely: three (3) FLEX Plus (i.e., three AC portable diesel generators and their connections to the Train “B” FLEX 4.16 kV AC connection box) related equipment were deployed, hooked up, tested and placed into standby conditions ready to be operated if required on a loss of offsite power (LOOP) during the entire repair time.

Details of the pre-staging and associated contingency plan are given in Section D.1.3.

D.1.2 Hypothetical SBO

With the plant configuration and conditions described above, a hypothetical SBO occurs.

D.1.3 FLEX Equipment Pre-Staging and Contingency Plan

Three portable diesel generators (4.16 kV – FLEX Plus) are deployed to their FLEX pad to ensure the ability to bring Unit 1 to cold shutdown in the event of a LOOP during the extended period that the Unit 1 train B EDG is inoperable. The three portable diesel generators operate in parallel as a set. The result is that the three portable diesel generators are sufficient to enable a cold shutdown of Unit 1 in the event of a LOOP with a single failure during the extended time period while the Unit 1 train B EDG is inoperable. The three portable diesel generators are deployed and physically connected to the Unit 1 train B 4.16 kV AC FLEX connection box for the duration of the extended EDG B outage time. This configuration, as well as the associated equipment, is different than that used in response to a FLEX scenario (see FLEX Support Guidelines (FSGs)).

The conditions described below are maintained during the entire duration of the Unit1 EDG B outage for repair and restoration.

Operation of the FLEX DGs locally
A test run was performed to demonstrate parallel operation of the three portable DGs after equipment is staged. In particular, the staged FLEX Plus DGs were connected up and started with their output breakers open and paralleled to ensure that they would load share in parallel. Routine inspections (start of shift and normal operator rounds during shift) of the portable DGs are performed by operations personnel to ensure normal standby conditions are maintained including lubrication and fuel levels, standby temperatures, and general equipment condition.

There is an extra[87] reactor operator (RO) in the MCR that is designated[88] to implement the contingency plan, including dispatch of an Auxiliary Operator (AO) to start the FLEX Plus DGs. There is no automatic actuation of any of the installed FLEX equipment. All FLEX Plus DGs would be manually started and operated, if required, by a designated AO. The designated AO is available 24 hours per day, although he/she may be assigned other duties when not needed to operate the FLEX Plus DGs. Also, a designated AO is available 24 hours per day on all shifts to perform necessary refueling operations.

Training, briefings, and walk downs are provided to the Operators responsible for operating the portable DGs as part of the preparation for use of the generators. Operations crews are briefed on the implementing procedure. Designated operators will be familiar with instructions for starting and operating the portable DGs. Operations staff has received classroom training for FLEX strategies, which included the use of the portable DGs. Also, instructions for operating the FLEX DGs are given on a “hard card” that is stored with the FLEX Plus DGs.

MCR response for pre-staged FLEX Plus DG configuration
In order to put the pre-staged FLEX Plus DGs into operation, a contingency plan was developed for the potential loss of offsite power, coupled with failure of the U1 DG A. Contingency plans (or standing orders) are typically used for plant configurations that are not normal.

[87] “Extra” means that there are more operators in the MCR than is required for minimum staffing.
[88] The U.S. NPP industry generally refers to operators with such duties as “designated.” The distinction between “designated” and “dedicated” depends on how much time is available to take the action.

Key details of the plant's contingency plan for the using the pre-staged FLEX Plus DGs are:

- The contingency plan is written like a procedure with specified entry conditions (including cues) and instructions.
- The contingency plan is stored in the MCR.
- The contingency plan calls for the dispatch of a designated AO who is responsible for starting the FLEX Plus DGs.
- Specific cues for this contingency plan are:
  - Reactor trip
  - Indications of loss of offsite power (e.g., trouble alarm for 4.16 kV switchgear)
  - Out-of-service "tag"[89] for U1 DG B
  - Indications that U1 DG A fails to start
- A reactor operator (RO) is designated to implement the contingency plan.
- The designated RO is additional staff (i.e., above the minimum staff requirement for the MCR).
- All MCR operators are briefed at every shift turnover on the contingency plan and associated plant configuration with the pre-staged FLEX Plus DGs.
- Upon reactor trip, the MCR operators will perform immediate actions, as trained.
- In general, operators are trained on the strategies and hierarchy of procedures for LOOP that specify use of alternate power sources, including the portable DGs.
- In parallel with the performance of immediate actions, the designated RO will implement the contingency plan (if needed).
- The designated RO will dispatch the designated AO to perform the actions described in the contingency plan,[90] which include several breaker manipulations and electrical connections, in addition to start of the FLEX Plus DGs.

D.2 HRA/PRA modeling for the non-FLEX scenario

This non-FLEX scenario is an extension of the typical PRA modeling for a grid-related loss of offsite power (LOOP) initiating event and subsequent station blackout (SBO) due to the failure of all the EDGs. In general, this loss of all AC power scenario involves the following key events:

- 1B EDG out-of-service for long-term repairs
- Successful reactor trip/turbine trip
- Remaining EDG (1A) fails to start very shortly after loss of offsite power
- Initial success of the turbine-driven auxiliary feedwater (AFW) pump
- Pressurizer PORV(s) successfully reclose given a demand
- Reactor coolant pump (RCP) seals remain intact

D.2.1 PRA Modeling

Although this scenario is similar to an SBO scenario, this project did not use an SBO event tree and associated fault trees. Because of the contingency plan to use pre-staged FLEX Plus equipment, the SBO event tree would need to be modified to represent the new operator actions and equipment.

[89] For this plant, a paper tag is used. Some plants may use magnets.
[90] For this hybrid scenario, the specific steps that the AO must take are in the procedure "Operation Maintenance Activities," specifically in the section on the FLEX DGs.

It should be noted that, for a complete risk-informed analysis, there should be consideration of the potential for damage to the FLEX Plus DGs while pre-staged (since they will not be in the FLEX building and protected from an external event) and of the potential unavailability of portable DGs for use in implementing FLEX strategies should an external event occur. However, for this specific NPP, the FLEX Plus DGs used in this scenario are not the same as portable DGs (e.g., so-called "normal" FLEX DGs that are lower voltage) used in response to a FLEX event. This NPP has both "normal," lower-voltage FLEX DGs as well as higher-voltage, FLEX Plus DGs.

D.2.2 Operator Actions and Human Failure Events

The following additional basic events are needed to credit the FLEX Plus DGs:

1. Operators fail to properly stage FLEX Plus DG (treated similarly to a pre-initiator of failing to restore equipment to service following test or maintenance)
2. Operators fail to dispatch auxiliary operator (AO) to perform steps for starting FLEX DGs[91] (post-initiator)
3. Operator fails to manually start FLEX Plus DG (post-initiator HFE)
4. Hardware failures, such as:
    a. FLEX DG fails to start (equipment reliability)
    b. FLEX DG fails to run (equipment reliability)
    c. Breakers fail to switch

Note that there are only three human failure events (HFEs) to address:

1. (Pre-initiator; outside main control room (MCR)) Operators fail to properly stage FLEX Plus DGs
2. (Post-initiator; in MCR) Operator fails to dispatch AO to perform steps for starting FLEX Plus DGs
3. (Post-initiator; outside MCR) Operator fails to manually start FLEX Plus DGs[92]

This analysis does not explicitly address the decision to pre-stage FLEX equipment or the transport of FLEX equipment. Also, refueling of FLEX equipment is not addressed in this analysis.

Critical Tasks.
In principle, critical tasks need to be identified for each of the three HFEs identified. However, the pre-initiator HFE could be similar to that for setting up the FLEX DGs for an external event (which is addressed in the "classic FLEX scenario"). So, critical tasks are identified for the two post-initiator HFEs only.

Critical tasks for the HFE defined as "Operator fails to dispatch AO to use maintenance procedure for starting FLEX Plus DGs" are:

- Designated RO fails to recognize "cues" for entry into contingency plan for using pre-staged FLEX Plus DGs

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[91] In this specific scenario description, we are assuming that the contingency plan has all of the instructions needed. However, we also are using some plant-specific information. For example, there are specific steps for breaker manipulations, electrical connections, and starting the FLEX DGs that are found in a plant-specific maintenance activities document.

[92] We decided to eliminate "adding loads" to our discussions because we had inadequate information on the procedure guidance for this and how this would be implemented (including what steps would be taken by the AO and what the MCR operators would need to do).

- Designated RO fails to dispatch AO to align and start FLEX Plus DGs

Critical tasks for the HFE, defined as "Operator fails to properly align and manually start FLEX Plus DGs" are:

- Designated AO fails to properly align breakers and make other electrical connections
- Designated AO fails to start FLEX Plus DGs

D.3 Key Modeling Assumptions

The following assumptions were determined to be significant to the modeling of this event:

- 1B EDG is out-of-service for repair.
- 1A EDG fails to start after reactor trip due to grid-related LOOP.
- Reactor and turbine trip are successful, and no other significant failures occur.
- Because the pre-staged FLEX Plus DGs have a different configuration than that for response to an external event, the timing validations and associated staffing plan that the utility developed have limited applicability to this scenario.
- The FLEX Plus DGs are connected when they are pre-staged with the exception of closing breakers to connect to the bus. Additional time is needed to sync the DGs.
- The total time elapsed from reactor trip until when the connections between the FLEX Plus DGs and 4160 V bus are completed, FLEX Plus DGs started and synched is less than 1 hour[93]
- Battery life is very long (e.g., 14 hours or more)
- If FLEX Plus DGs are successfully put into service in the timeframe expected, ELAP would not need to be declared.
- The additional RO designated to implement the contingency plan is located in the MCR at all times, 24 hours a day.
- The SM arrives in the MCR at 5 minutes. The STA arrives in the MCR at 10 minutes, as required.
- There is a designated AO for performing tasks associated with putting the pre-staged FLEX Plus DGs into service. However, this AO can be assigned other duties so will not necessarily be located where the FLEX Plus DGs are staged when the AO is dispatched.
- Starting from when dispatched, the time needed for the AO to perform tasks associated with putting the pre-staged FLEX Plus DGs into service is assumed to be 30 minutes, including required travel time to performance locations after dispatch. (See Footnote 2.)
- The contingency plan is written such that:
  - The criteria for implementation include an "AND" statement (i.e., there are multiple criteria that must be satisfied before the plan should be implemented).
  - There are no "NOT" statements.
  - Direction for implementation is typical of that in EOPs (i.e., IF criteria for implementation are satisfied, THEN implement the plan); there are no judgments needed for implementation (e.g., there are no statements such as "Consider implementing…..)
- Operator training is on a 4-year cycle for FLEX. Also, AOs tour FLEX buildings and talk through all of the FLEX equipment, including associated cables.

[93] Information provided by plant-specific AOs.

D.4 Scenario Timeline

The sequence of events for the pre-staged, FLEX Plus DGs in a LOOP is:

- T=0 — Reactor trip due to a “sunny day” LOOP (no ATWS); operators enter Standard Post Trip Actions (SPTA) procedure (i.e., E-0)
- T=0-1 minutes — 1A EDG fails to start (and 1B EDG is out-of-service for long term maintenance)
- T=0-5 minutes — Operators reach Step 3 in SPTA and recognize that there are no EDGs running. The SM arrives in the MCR.
- T=5-8 minutes — In parallel with MCR operators implementing steps in the SPTA, an AO will be dispatched to try to start 1A EDG locally. Also, in parallel, the designated RO for the contingency plan follows the progress of the other MCR operators to Step 3, then notes that the 4.16 kV Switchgear Annunciator is in alarm. This annunciator is alarming in combination with other entry conditions for the contingency plan. The designated RO begins implementing the contingency plan, including the dispatch of the designated AO to perform necessary actions to put the FLEX Plus DGs into service.
- T=10-14 minutes — Operators reach Step 10 in the SPTA, then use the Diagnostic Actions flow chart. The second diamond in the flow asks if there is AC and DC power to at least one train. Since there is no AC power, operators follow the “no” path. The next question is whether at least one vital DC power train has power. Because the batteries have not depleted yet, there is DC power. The flow chart recommends that operators “consider” Blackout procedure then move on to checking other critical parameters.
- T=15 minutes — Operators enter Blackout procedure and perform its steps in parallel with EOP steps.
- T=38-40 minutes — Designated AO completes actions to put FLEX Plus DGs into operation; 4.16 kV bus is re-energized.
- T=40 min — Operators exit Blackout procedure per Exit Conditions,[94] Step 3a (At least one vital 4.16 kV bus is energized….).
- T= 40+ min — Operators continue in EOPs to safety shutdown the reactor.

D.5 Potential Variations

Some potential variations to the described scenario above that could be evaluated with HRA are:

[94] “Exit Conditions” are applied as continuous steps.

- Additional "cues" for the RO designated to the contingency plan and board operator, such as a color-coded magnet "tag" by the 1A EDG that reminds operators that the FLEX Plus DGs are pre-staged[95]
- Additional human factoring of the contingency plan (formatting, logic)
- Added human factoring of the procedure for performing breaker manipulations and electrical connections
- Plant modifications to simplify electrical connections

D.6 Preliminary Assessment of HRA Influencing Factors

There are some different influencing factors for each of the HFEs identified above. The following performance influencing factors are considered by the IDHEAS-ECA Tool[96] [1] (see Table 2-1, page 2-3) under the high-level headings of "Environment and situation," "System," "Personnel," and "Task":

21. Work location, accessibility, and habitability,
22. Workplace visibility,
23. noise in workplace and communication pathways,
24. heat/cold/humidity,
25. resistance to physical movement,
26. system and I&C transparency to personnel,
27. human-system interfaces,
28. equipment and tools,
29. staffing,
30. procedures, guidelines, and instructions,
31. training,
32. teamwork and organizational factors,
33. work processes,
34. information availability and reliability,
35. scenario familiarity,
36. multi-tasking, interruptions and distractions,
37. task complexity,
38. mental fatigue,
39. time pressure and stress, and
40. physical demands.
41. time pressure and stress.

<u>Pre-Initiator: Operators fail to properly connect up FLEX Plus DG</u>
Factors important to this pre-initiator HFE are:

- Field/equipment operators are trained on equipment operations, generally, on a yearly basis. All field operators are given initial FLEX equipment training, then refresher training periodically afterward.
- Training, briefings, and walk downs are provided to the operators responsible for operating the portable DGs as part of the preparation for use of the generators.
- A test run was performed to demonstrate parallel operation of the 3 FLEX Plus DGs after the equipment was staged.

[95] If there is an additional "cue" for the board operator, then the HRA could credit the board operator in the detection of the alarm, in addition to the dedicated RO.
[96] It should be noted that the draft IDHEAS-ECA report that was available for this effort had a slightly different list of PIFs.

In particular, the effectiveness of a functional test prior to restoring equipment to a stand-by condition is one of the most important factors in assigning an HEP for a pre-initiator HFE.

The analysts judged that environmental factors should not be a concern for this pre-initiator.

<u>Post-initiator: Operator fails to dispatch AO to perform steps for starting FLEX Plus DGs[2]</u>
Because this action is performed in the MCR, is typical of other highly practiced operator actions, is performed by a designated RO, and is assumed to have more than adequate time for performance, the analysts concluded that following PIFs are expected to be negligible in contribution: multitasking, staffing, environment, equipment and fitness needs, communications, teamwork and command and control, time pressure and stress.

The analysts concluded that other PIFs are relevant, such as:

- Scenario familiarity and training, as it relates to preparations to use the contingency plan
- Task complexity, as it relates to how to enter the contingency plan and how to use the contingency plan
- Key cues and indications, as it relates to how the designated RO enters the contingency plan
- Time available/urgency - unknown
- Procedures, as it relates to pre-determined or assumed features of the contingency plan
- Training and experience, as it relates to pre-job briefings, shift turnover briefings, and other training related to the contingency plan.
- Human-machine interface, as it relates to the cues (e.g., alarms, EDG tag-outs) for entering the contingency plan

<u>Post-initiator HFE: Operator fails to manually start FLEX Plus DGs[2]</u>
For this specific context, the designated RO in the MCR dispatches the designated AO, then the AO establishes communications locally and starts the FLEX Plus DG(s). Unlike the context for an external event initiator, the FLEX Plus DG has already been transported.

Since this scenario does not involve an external event, is performed by a designated AO, and uses typical communications, the analysts concluded that the following PIFs are not considered to be important: multitasking, staffing, environment, equipment and fitness needs, communications, teamwork and command and control, time pressure and stress.

HMI issues for setting up and operating the FLEX Plus DG are NOT the same as for FLEX scenarios. The configuration of the pre-staged FLEX Plus DGs is different than that used in a FLEX scenario. As such some of the industry-wide measures[97] to simplify the use of FLEX equipment may not apply to this HFE.

The analysts concluded that other PIFs are relevant, such as:

- Scenario familiarity and training, as it relates to preparations to use the contingency plan[2]

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[97] Examples of such measures are:

- FLEX equipment is simpler to operator than other (e.g., nuclear-grade) equipment. So, while training may be less frequent, the FLEX equipment is easier to operate.
- FLEX connections have been standardized, US NPP industry-wide. Also, color-coding is used for FLEX DG connections to ensure that correct connections are made.

- Task complexity, as it relates to how to use the contingency plan and the number and kind of steps that need to be performed[2]
- Key cues and indications, such as how the contingency plan is entered
- Time available/urgency, such as what operators are trained on and briefed daily
- Procedures, as it relates to pre-determined or assumed features of the contingency plan[2]
- Training and experience, as it relates to pre-job briefings, shift turnover briefings, and other training related to the contingency plan
- Human-machine interface, as it relates to the electrical panels and associated breakers and the electrical connections needed for the specific configuration with the pre-staged FLEX Plus DGs

The analysts also concluded that there were other HRA-relevant factors, including:

- There is NO automatic actuation of any of the installed FLEX equipment. All FLEX equipment would be manually started and operated, if required, by the designated operations personnel. Also, a test run of the FLEX Plus DG was performed as part of deploying the equipment.
- Routine inspections (start of shift and normal operator rounds during shift) of the portable DGs are performed by operations personnel to ensure normal standby conditions are maintained including lubrication and fuel levels, standby temperatures, and general equipment condition.
- At the beginning of every shift, training, briefings, and walk downs are provided to the operators responsible for operating the portable DGs as part of the preparation for use of the generators. Operations crews are briefed on the implementing procedure. Designated operators will be familiar with instructions for starting and operating the portable DGs. Operations staff have received classroom training for FLEX strategies, which included the use of the portable DGs.

D.7 Additional Notes Made During the Workshop

The information documented above was provided to the HRA analysts prior to the workshop. Several aspects of this scenario and associated HFEs were modified in the workshop.

For example, the modeling of operator actions was simplified to address these critical tasks:

- Implement contingency plan
- AO implements Appendix D

Also, the FLEX experts at the workshop clarified that the specific portable DGs used in this scenario are similar to the SAFER equipment, rather than the typical FLEX DGs addressed in FSGs. In addition, the particular NPP represented in this scenario has both the SAFER-like portable DGs and the typical FLEX DGs.

As a result of the workshop discussion, it was decided to eliminate “adding loads” to the HRA assessment. The HRA analysts thought that there was inadequate information on the procedure guidance for this task and how an AO would implement such guidance (including what steps would be taken by the AO and what the MCR operators would need to do, either separately or in coordination).

D.8 References

1. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

APPENDIX E
VARIATIONS ON SCENARIOS

Throughout this project, potential scenario variations were discussed. Although a few variations were addressed in this project, most variations that were discussed were not addressed (mostly due to inadequate resources). This appendix captures some of those discussions of potential scenario variations.

E.1 Variations in FLEX and Non-FLEX Scenarios

Previous FLEX HRA efforts have recognized variations in FLEX scenario details can be an important impact on HRA results. Consequently, this effort continued consideration of potentially important scenario variations. In fact, the identification of variations was embedded in the effort to develop scenarios.

This section summarizes three categories of variations:

1. Scenario-specific variations addressed in the NRC's FLEX HRA project using IDHEAS-ECA [1],
2. Scenario-specific variations identified (but not addressed) in the FLEX HRA project, and
3. More generalized variations.

E.1.1 Identified Scenario-Specific Variations

As stated above, the development of scenarios for this project naturally led the project team, FLEX experts, and HRA analysts to consider scenario variations. In all cases, iterations on defining scenarios for consideration involved discussion of variations such as:

- Different plant conditions
- Different plant configurations
- Different timing of plant conditions
- Different procedural guidance

Examples of scenario variations that were identified (but not addressed) include:

- FLEX scenario:
    - Seismic event with minimal or moderate damage to plant site
- Non-FLEX scenario – "Sunny Day" Loss of all feedwater
    - All AFW pumps are failed at t=0 and no FLEX pumps are pre-staged (i.e., there is inadequate time to deploy the FLEX pump before F&B criteria are reached)
    - All AFW pumps are failed at t=0 and one FLEX pump is pre-staged
- Non-FLEX scenario – "Sunny Day" Station Blackout
    - Additional "cues" for the RO designated to the contingency plan and board operator, such as a color-coded magnet "tag" by the 1A EDG that reminds operators that the FLEX DGs are pre-staged[98]
    - Additional human factoring of contingency plan (e.g., procedure formatting and logic optimization with respect to HRA credit)
    - Added human factoring of the procedure for performing breaker manipulations and electrical connections
    - Plant modifications to simplify electrical connections for FLEX DGs

[98] If there is an additional "cue" for the board operator, then the HRA could credit the board operator in the detection of the alarm, in addition to the dedicated RO.

E.1.2 Addressed Scenario-Specific Variations

Due to limited resources, there were only two scenario variation addressed in this effort. Those variations were for the FLEX scenario and related to short versus long battery life and the associated procedural guidance for declaring ELAP. See Sections 3.4.5 and 6.3.2 for further details on these scenario variations.

E.2 Discussion of FLEX Scenario Variations Between NPPs

Most attendees for the BWR plant site visit participated in an additional 1/2-day discussion on variations between U.S. NPPs with respect to FLEX strategy implementation. Both HRA analysts and FLEX experts participated in this discussion, and Mary Presley (EPRI) participated by phone.

The starting point for the discussion was the list of variations provided in Table 1-1 in EPRI's FLEX HRA report [2]. Additional variations that were discussed included:

- Different NPPs do different DC load sheds, e.g.,
    - Some NPPs do both SBO and FLEX (or "deep") DC load sheds
    - Some NPPs do FLEX DC load shed only
    - Some NPPs do SBO load shed only
- Different consequences due to FLEX DC load shed (e.g., more trains of instruments are unavailable with more loads shed)
- There can be a lot of conservatism in the battery life calculations. Some plants refined these calculations and other plants have not.
- NPPs can vary as to whether FLEX strategies for water, electricity, or containment venting are needed first. However, generally, electric power restoration is the first need.
- Differences between NPPs regarding on-site and offsite power resources, e.g.,
    - This NPP has four (4) Emergency Diesel Generators (EDGs) shared between two units, three (3) offsite power sources, and an alternate power line
- Differences between NPPs regarding "declare ELAP" include:
    - Some NPPs explicitly "declare ELAP"
    - Some NPPs do not explicitly "declare ELAP" but make equivalent procedure transitions or take equivalent actions
    - There are differences in the procedure logic for declaring ELAP, e.g.:
        - Declare ELAP if NPP does not have AC power back by 1 hour (or similar other time)
        - By 1 hour, if operators do not have confidence that power will be restored by 4 hours, declare ELAP
- Different NPPs have different policies on how much diesel fuel is in the FLEX diesel generator (DG) tanks, e.g.,
    - This NPP keeps the FLEX DG tank 50-75% full (so refueling is not required for 10-12 hours) and have regular tests for degraded fuel
    - Another NPP keeps the FLEX DG fuel tank only 5% full due to fuel degradation concerns
- Are there NPPs that cannot reverse or "back out" of FLEX procedures once they are started?
    - This NPP definitely could "reverse" before FLEX DC load shed; if offsite power was restored after FLEX DC load shed, operators would need support from the Technical Support Center (TSC)

- All PWRs have a deviation document that identifies how that NPP has deviated from the standard FSGs.
- Some NPPs may use hardened containment vent systems (HCVS) for RCIC preservation (anticipatory venting) [not sure if there are any challenges unique to FLEX]
    - Are there other actions for RCIC preservation?
- Regarding communications equipment and other "support" functions:
    - Some NPPs need to deploy portable fans for room cooling for switch gear and batteries. And, these actions must be done early so the batteries do not fail.

E.3 Categorizing and Characterizing Scenario Variations

Follow-on discussions on scenario variations led to the idea of further categorizing or characterizing the variations. For example, would it be helpful to group NPPs by: 1) time when load shed is needed to extend battery life? 2) ease/number of steps to FLEX DC load shed? 3) how long to deploy FLEX equipment?

To this end, Table E-1 was developed to illustrate a potential way of organizing scenario variations, both FLEX and non-FLEX. This table should be viewed as a "work in progress."

Table E-1 HRA for FLEX Project: Organizing variations within scenarios

Scenarios[99]	High-level scenario variations	Next level scenario variations	Required operator actions[100]	Notes
BDBE FLEX scenario	Large external event with extensive damage onsite & offsite	Significant damage is evident both onsite & offsite.	1. Declare ELAP 2. Load shed[101] 3. Remove debris[102] 4. Deploy, install and operate FLEX DG[103] 5. Deploy, install, and operate FLEX pump[101] 6. Refuel FLEX equipment[104] 7. More….	Most extensive damage with associated largest amount of debris removal.
	Less serious external event	• Key damage is offsite[105] • Key damage is onsite		Less damage and associated debris.
Any non-FLEX initiating event	Loss of all AC power	Damage is offsite[106] Damage is onsite	1. Declare ELAP[107] 2. Load shed[102] 3. Deploy, install and operate FLEX DG[104]	No debris.

[99] All scenarios are assumed to start with the NPP at-power.
[100] Note that there are plant-to-plant variations on what and how many operator actions are required within the first 24 hours after the initiator.
[101] Note that there are plant-to-plant differences on load shedding.
[102] Note that the HRA is not expected to model this activity.
[103] There will be various plant-to-plant differences on what is needed for this operator action (e.g., some plants may have pre-staged FLEX equipment).
[104] There will be plant-to-plant differences on when and how much refueling is needed for FLEX equipment (e.g., some plants will start event with almost full fuel tanks while others may start with only 5% full tanks).
[105] This variation may not pose a challenging context for operators to decide to "declare ELAP" and use FLEX equipment. Consequently, this level of decomposition may not be important, except to recognize the possibility.
[106] Scenario developers and HRA analysts should explore whether these differences are important. It may be similar to the less severe FLEX scenario.
[107] "Declare ELAP" is placeholder for how operators would decide to use FLEX equipment in this scenario.

Scenarios[99]	High-level scenario variations	Next level scenario variations	Required operator actions[100]	Notes
			4. Refuel FLEX DG[105]	
	Internal flooding			Debris or other environmental concerns that require plant staff to address and/or require additional time to address.
	Fires			Debris or other environmental concerns that require plant staff to address and/or require additional time to address.
	Loss of injection or feedwater	Loss of injection Loss of other cooling systems (e.g., FW)	1. Decide to use FLEX pump[108] 2. Remove debris 3. Deploy, install, and operate FLEX pump[101] 4. Refuel FLEX equipment[102] OR[109] 1. Decision to use EDMG/B.5.b pump 2. Align B.5.b pump 3. Start B.5.b pump	Depending on the initiator, there may be debris to contend with or other environmental hazards that require plant staff to address and/or require additional time address.
	Loss of heat sink	Loss of service water Loss of cooling for frontline systems Loss of cooling for support systems		
	Other?			
Use of FLEX equipment during on-line maintenance of front-line equipment (hypothetical trip with a demand on system supported by FLEX equipment)	FLEX generator staged to serve as redundant DG + FLEX DG operation	Context for some sort of reportable incident that would be addressed, for example, by an SDP	1. Operators fail to properly stage FLEX DG[110] (latent human error or pre-initiator HFE) 2. Operators fail to start/operate FLEX DG	
	FLEX pump staged to serve as redundant pump + FLEX pump operation		1. Operators fail to properly stage FLEX pump (latent human error or pre-initiator HFE) 2. Operators fail to start/operate of FLEX pump	

[108] Operators will need some sort of proceduralized way to decide on using a FLEX pump in this scenario.
[109] May be out-of-scope for this effort. (But, the same HRA process and principles would be applicable.)
[110] There are likely to be plant-specific differences on the details of these operator actions, depending on how FLEX equipment is staged, if there is a functional test after staging, when and how final connections are made, etc.

E.4 References

1. U.S. Nuclear Regulatory Commission, *Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)* – DRAFT, RIL-2020-02, ML20016A481, February 2020.

2. Electric Power Research Institute, Human Reliability Analysis (HRA) for Diverse and Flexible Mitigation Strategies (FLEX) and Use of Portable Equipment – Examples and Guidance, 3002013018, November 2018.