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Human Reliability Analysis of See-and-Flee Actions Using the Integrated Human Event Analysis System for Events and Condition Assessment (IDHEAS-ECA) Method

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Disclaimer

Abstract

This report demonstrates the use of the Integrated Human Events Analysis System for Events and Condition Assessment (IDHEAS-ECA) human reliability analysis method to estimate the reliability of administrative Items Relied on for Safety (IROFS). Specifically, this study estimated the reliability of see-and-flee IROFS in three different scenarios (contexts) to demonstrate the breadth and depth of IDHEAS-ECA in incorporating performance influencing factors' effects to estimate the reliability of IROFS. This capability of IDHEAS-ECA is essential for assessing the reliability of IROFS, such as see-and-flee, reliably and with sound technical basis. However, NUEG-1520's guidance on integrated safety analysis does not have this capability. As a result, IDHEAS-ECA can be added to the Office of Nuclear Material Safety and Safeguards' (NMSS) tool set to assess administrative IROFS' reliability and supplement the guidance in NUREG-1520. This report also demonstrates that IDHEAS-ECA can identify dominant reliability drivers. The information in this report will be useful for licensees to effectively use limited resources to improve reliability, and for the NRC staff to evaluate the impacts of the reliability.

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Acknowledgments

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Dr. April Smith, who was a Reliability and Risk Analyst in the Office of Nuclear Material Safety and Safeguards, Division of Fuel Management, provided the see-and-flee scenarios and helped the authors understand and build in analyst assumptions. Dr. Smith was instrumental in coordinating with the Office of Nuclear Regulatory Research (RES) management to facilitate this project.

The authors also appreciate Dr. Y. James Chang, who was a Risk and Reliability Engineer in the Human Factors and Reliability Branch of RES' Division of Risk Analysis, advised the authors in using IDHEAS-ECA to perform the analysis. Dr. Chang is a developer of the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) method and software app.

1 IDHEAS-ECA Developmental Background

The Commission issued Staff Requirements Memorandum (SRM) M061020 directing the Advisory Committee on Reactor Safeguards (ACRS) to “work with the [NRC] staff and external stakeholders to evaluate the different Human Reliability models in an effort to propose either a single model for the agency to use or guidance on which model(s) should be used in specific circumstances” (Ref. 1). This SRM direction led to the development of the Integrated Human Event Analysis System (IDHEAS) suite of human reliability analysis (HRA) methods, including IDHEAS for event and condition assessment (IDHEAS-ECA). IDHEAS-ECA aims to solve the variability issues that motivated the issuance of SRM-M061020, including analyst-to-analyst variability (different analysts using the same HRA method generates significantly different results) and method-to-method variability (the same analysts using different HRA methods generate significantly different results). In the significance determination process (SDP) of the NRC’s reactor oversight program, the differences could result in different regulatory decisions.

The NRC staff began development of the IDHEAS suite methods by performing a large-scale psychological literature review to establish a cognitive basis (NUREG-2114) followed by the development of a generic methodology (IDHEAS-G) for performing HRA (Ref. 2 and 3). The IDHEAS-ECA HRA method (Research Information Letter RIL-2020-02) was developed based on IDHEAS-G to perform HRA for probabilistic risk assessment (PRA) applications, including event and conditional assessment (ECA) in SDP, accident sequence precursor, and baseline PRA (Ref. 4). The staff developed a software app to facilitate the IDHEAS-ECA implementation. NRR, Region offices, and RES staff applied IDHEAS-ECA in ECA and ASP and concluded significant improvement in reducing analyst-to-analyst variability. The Electric Power Research Institute and US nuclear industry evaluated the IDHEAS-ECA method with positive feedback.

In 2021, ACRS wrote a letter (ML21076A421) which provided recommendations to the Commission addressing SRM-M060120 (Ref. 5). Some of the ACRS’ recommendations are:

- IDHEAS-G meets the primary intent of the 2006 Commission SRM, as a single HRA model for the agency to use.
- The derived detailed application methods are expected to meet the intent of the Commission direction in the SRM for “guidance on which model(s) should be used in specific circumstances.”
- IDHEAS-ECA provides a specific derived application. It should be updated periodically to reflect user feedback and to synchronize with model and guidance refinements. Peer review is needed.

The staff conducted a public meeting (ML21096A176) to collect public comments on the IDHEAS suite methods (Ref. 6). The staff has addressed all public comments. The NRC contracted Pacific Northwest National Laboratory to peer review the IDHEAS’ data basis. The review comments are addressed in periodic IDHEAS updates.

Currently, fuel facilities use the integrated safety analysis (ISA), as described in NUREG-1520, “Standard Review Plan for Fuel Cycle Facilities License Applications”, to assess the risk of various hazards such as criticality, chemical, fire, and natural phenomena (e.g., floods, high winds, tornadoes, and earthquakes) (Ref. 7). The administrative IROFS in ISA are about the human and organizational actions to prevent initiating events from propagating to exceed the consequence thresholds specified in 10 CFR 70.61. ISA uses the risk-indexing method to assess the reliability of administrative IROFS. The IROFS' reliability is represented by the failure probability index number (FPIN). NUREG-1520, Rev.2 provides limited instruction on assessing the administrative IROFS' FPIN, including, (1) FPIN is -1 or -2 for an administrative IROFS in response to a rare unplanned demand, and (2) FPIN is -2 or -3 for an enhanced administrative IROFS or an administrative IROFS for routine planned operations. Such instructions aim for quick assessment and tend to be conservative. Situations could arise which need a detailed analysis that ISA does not have instructions for. In such situations, IDHEAS-ECA can be used. In addition, ISA requires assessing the degree of dependence between IROFS. However, NUREG-1520 provides little instruction in assessing the dependence. IDHEAS-ECA's dependence model can assess the dependence with a sound technical basis.

This report provides a demonstration of using IDHEAS-ECA to assess the reliability of the see-and-flee administrative IROFS. The see-and-flee IROFS occurs when a worker needs to promptly leave the workplace and go to a safe location after seeing or sensing the presence of uncontrolled hazardous material (e.g., Uranium Hexafluoride) in the workplace. Depending on the context of the event requiring see-and-flee action, the probability of a successful see-and-flee could vary significantly. NUREG-1520's instruction is insufficient to assess the see-and-flee reliability in different contexts, and the assessed results may not be conservative. This report demonstrates the use of IDHEAS-ECA to perform detailed analyses to assess the see-and-flee reliability in three different contexts (confined space, large space, and outdoor area). The demonstration shows IDHEAS-ECA's ability to calculate the reliability with consideration of the effects of a wide spectrum of factors which could influence human reliability. As a result, IDHEAS-ECA can support ISA reviewers to perform a detailed analysis or to determine the proper FPIN.

Section 2 provides a concise purpose statement for this report. Section 3 discusses the HRA process of applying IDHEAS-ECA, using the IDHEAS-ECA app.

2 Purposes

The two purposes of this report are (1) to make the IDHEAS-ECA method known to NMSS so they can identify the areas of their regulatory responsibilities in which IDHEAS-ECA may be useful, and (2) for NMSS to provide user feedback to improve IDHEAS-ECA for fuel facility applications.

To achieve these purposes, this report estimates the reliability of the see-and-flee IROFS in three different contexts, using IDHEAS-ECA. The exercise demonstrates that IDHEAS-ECA is applicable to assess the administrative IROFS' reliability. In addition, the demonstration shows the ease of implementing the IDHEAS-ECA method (using the IDHEAS-ECA app) and the ability to perform detailed analyses to estimate the administrative IROFS' reliability in different contexts.

IDHEAS-ECA does not aim to replace the risk-indexing method currently used for ISA, instead it aims to supplement the risk-indexing method when a detailed analysis is needed to assess the administrative IROFS' reliability. Section 4 discusses the see-and-flee events and the three different contexts of the event in this study.

3 IDHEAS-ECA HRA Process

IDHEAS-ECA specifies eight steps to perform an HRA that are briefly described below (Ref. 4). Steps 1 through 8 present an overview of the IDHEAS-ECA process and the flow of information.

(1) Step 1: Analyze the event scenario. Analyzing an event includes developing the scenario narrative and timeline, determining the scenario context, and identifying the human action (administrative IROFS), e.g., see-and-flee, to be modeled. The administrative IROFS may contain several critical tasks, which are the human cognitive and physical activities critical to the success of the administrative IROFS. IDHEAS-ECA calculate the reliability of each critical task to calculate the reliability of the administrative IROFS.

(2) Step 2: Analyze the administrative IROFS. This includes defining the administrative IROFS and identifying the critical tasks. The administrative IROFS' definition should discuss its failure impacts on the worker, environment, and public safety as specified in Part 70.61. The critical tasks are used in the latter steps to calculate their reliabilities, which, in turn, are used to calculate the reliability of the administrative IROFS In this report, the reliabilities of critical tasks and of administrative IROFS are represented by human error probabilities (HEPs), which is the failure probability of performing the critical tasks or administrative IROFS.

(3) Step 3: Model the failure of the critical tasks (identified in Step 2). This includes characterizing the critical tasks, identifying cognitive activities required to achieve the critical tasks, and subsequently identifying the cognitive failure modes (CFMs) applicable to the critical tasks. IDHEAS-ECA classifies five CFMs: failure in information detection, failure in understanding the situation, failure in decisionmaking, failure in action execution, and failure in interteam coordination.

(4) Step 4: Assess the performance influencing factors (PIFs) applicable to every CFM. The CFM and PIFs are identified based on the results of scenario analysis (Step 1), Administrative IROFS definition (step 2), and critical tasks characterization (step 3).

(5) Step 5: Calculate the P_c. P_c is the probability of cognitive error of performing the administrative IROFS. The calculation assumes that there is sufficient time available to complete the IROFS. The failure probability caused by time insufficiency is calculated in Step 6. IDHEAS-ECA use a hierarchical structure that includes the following elements: critical tasks, CFMs, and PIFs to calculate P_c (see figure 3-1). The P_c of the administrative IROFS is the probabilistic sum of the P_c of the critical tasks. The P_c of a critical tasks is a function of the CFMs, PIFs and PIF Attributes applied to the critical task. Figure 3-2 shows the graphical user interface of IDHEAS-ECA app to identify the applicable CFMs, PIFs, and PIF Attributes applicable to a critical task.

(6) Step 6: Calculate the P_t. P_t is the failure probability of implementing the administrative IROFS simply because the time available to perform the IROFS is insufficient. Calculating P_t assumes the individual(s) performing the IROFS as trained. IDHEAS-ECA calculates P_t based on two distributions: time-required and time available. P_t is the probability that the time-required exceeds the time-available. IDHEAS-ECA calculates P_t by looking at performing the administrative IROFS as a whole. IDHEAS-ECA does not calculate P_t for each individual critical task.

(7) Step 7: Calculate the administrative IROFS' HEP. The administrative IROFS' HEP is the probabilistic sum of P_c and P_t of the administrative IROFS. That is, $\text{Administrative IROFS' HEP} = 1 - (1 - P_c)(1 - P_t)$, as shown in figure 3-1. The IDHEAS-ECA software calculates the overall HEP automatically using the results from steps 5 and 6.

(8) Step 8: Analyze uncertainties in the HRA, perform sensitivity and dependency analyses, and document the results.

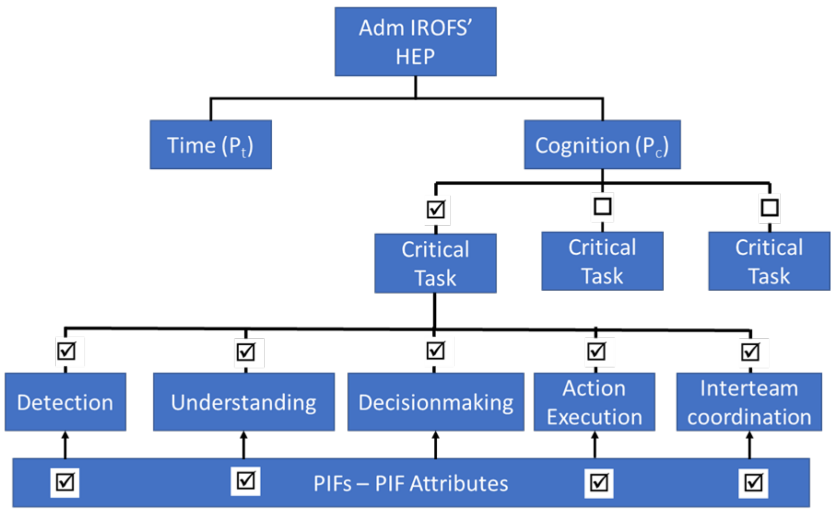

Figure 3-1 HEP quantification structure of an administrative IROFS

3.1 Using IDHEAS-ECA App to Calculate P_c

IDHEAS-ECA models five macrocognitive functions. Failures of these macrocognitive functions correspond to the five CFMs for calculating the HEPs. These five macrocognitive functions are:

- *Detection* (D) is noticing cues or gathering information in the work environment.
- *Understanding* (U) is the integration of pieces of information with a person's mental model to make sense of the scenario or situation.
- *Decisionmaking* (DM) includes selecting strategies, planning, adapting plans, evaluating options, and making judgments on qualitative information or quantitative parameters.
- *Action Execution* (E) is the implementation of the decision or plan to change the course of the scenarios, typically by changing the status of physical components or systems.
- *Interteam Coordination* (T) focuses on how various teams interact and collaborate with each other.

The first four macrocognitive functions (D, U, DM, and E) may be performed by an individual or a team, and Interteam Coordination is performed by multiple groups or teams that are not usually trained together. CFMs are failures of the macrocognitive functions.

IDHEAS-ECA uses PIFs and PIF Attributes to represent the context and calculate the HEP. A PIF attribute is an assessable characteristic of a PIF and describes a way that the PIF challenges the macrocognitive functions and, therefore, increases the likelihood of error in performing the macrocognitive functions. That, in turn, increase the error probabilities of critical tasks and IROFS. The PIF attributes were identified from cognitive and behavioral studies, as well as human error data from various sources.

Appendix A in this report shows the CFMs' base HEPs and PIF weights of each PIF attribute. The base HEPs represent the failure probability of performing the macrocognitive function in an optimal condition (i.e., no negative factors affecting performance) and under a teamwork environment. The values in appendix A represent the percentage change with the effect of the PIF attribute. For example, a PIF weight of 1.1 represents a 10-percent increase in HEP. The bases of the values shown in appendix A are documented in the draft Integrated Human Event Analysis System for Human Reliability Data (IDHEAS-DATA) report (Ref. 8). Below, figure 3-2 shows a screenshot of the IDHEAS-ECA app for selecting PIF attributes.

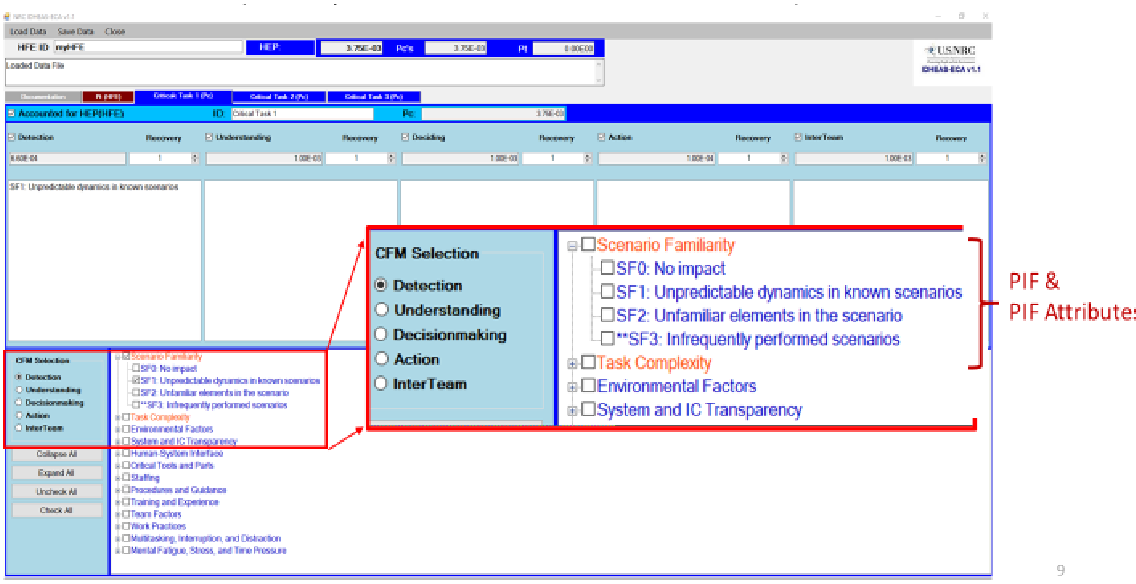

Figure 3-2 Critical task, CFMs, PIF, and PIF Attributes in the IDHEAS-ECA app

3.2 Using IDHEAS-ECA App to calculate P_t

IDHEAS-ECA defines P_t as the probability that personnel could not complete a required human action because of not having sufficient time. The IDHEAS-ECA app provides a graphical user interface (see figure 3-3) for the analysts to specify the uncertainty distributions of the time-required and the time-available to calculate P_t. The IDHEAS-ECA app uses a Monte Carlo sampling technique to take one million data points from each of the two distributions to calculate the P_t. IDHEAS-ECA also provides a constant (fixed) value option (instead of a distribution) for the time-available. If the constant value is selected for the time-available, the P_t is calculated directly by using the time-required distribution and the constant time-available, instead of using Monte Carlo sampling.

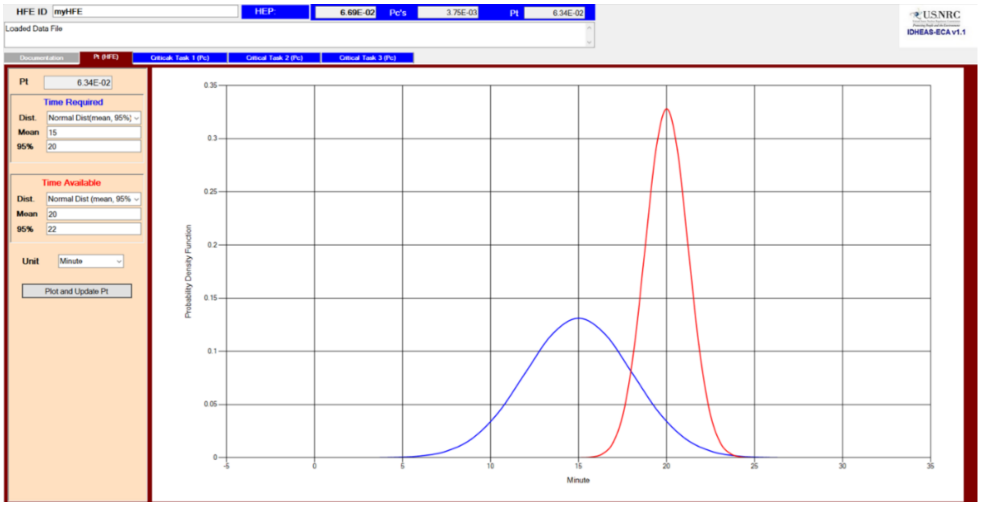

Figure 3-3 Calculate Pt using IDHEAS-ECA app.

4 Scenarios

This study evaluates three see-and-flee scenarios, in which the see-and-flee actions take place in either a confined space, large space, or outdoor area of a hypothetical fuel cycle facility. In a release event, workers are expected to recognize (see) the release, leave (flee) the area immediately, and actuate a release alarm. For all three scenarios, this analysis assumes that the worker will see a white cloud within 10 seconds of a UF_6 release. The definition of a successful see-and-flee event, is when the worker takes no longer than 1 minute to flee to a safe area, starting from the occurrence of the release event. There are release alarms in various locations around the facility. When actuated, the alarm accesses all announcement systems in the facility and emits a klaxon siren, alternating with a recorded voice that announces a release has occurred and issues evacuation instructions. The following presents the work-spaces for each of the three see-and-flee scenarios (confined space, large space, and outdoor area):

(1) Confined Space: A release of UF_6 occurs in a room that is 50 cubic meters (m^3) in volume. The worker is 1 meter from the release and 3 meters from the nearest door. To open the door, the worker must press a large, red button that is on a wall 0.5 meters from the door. After the button is pressed, the door takes approximately 2 seconds to open. Outside of the door is a release alarm that the worker can hit. In the event of a loss of offsite power, the area will lose lighting for 3 seconds before emergency lighting is restored.

(2) Large Space: A release of UF_6 occurs in a room that is 50,000 m^3 in volume. Three workers are 1 meter from the release and 30 meters from the nearest door. To open the door, the worker must slide their badge through a card reader. After the worker slides their badge through the card reader, the door takes approximately 4 seconds to open. Inside the room, approximately 0.3 meter from the door is a release alarm. In the event of a loss of offsite power, the area will lose lighting for 3 seconds before emergency lighting is restored. For the large area, assume there are two other workers, and they are working within 2 feet from each other.

(3) Outdoor Area: A release of UF_6 occurs from a cylinder in a tank farm. The worker is in the tank yard, 1 meter from the release and 30 meters from the tank farm gate. To open the gate, the worker must pick up and slide a 20-pound, large, metal vertical L-pin through a metal well. The L-pin is 2 meters tall and must be lifted 0.5 meter to clear the metal well. A release alarm is located on the wall of a building 30 meters from the tank farm gate. At night, lights provide adequate visibility under normal and emergency (e.g., loss of offsite power) conditions. Workers are discouraged from working in the tank farm during inclement weather (e.g., fog, rain, snow, etc.). However, depending on business needs, a worker may still choose or be directed to carry out duties in the tank farm.

The following additional factors which may affect the worker's performance when implementing see-and-flee actions are listed below:

TRAINING

- The licensee trains workers once every 6 months. The training consists of instructing workers on the following:
  - recognizing what a UF_6 release might look like
  - tripping the nearest release alarm
  - knowing which facility components may be involved in a UF_6 release
  - knowing the nearest exit
  - knowing the consequences of not immediately evacuating the area
  - knowing to leave the area within 1 minute
- Once every 2 years, the licensee holds a drill that simulates a UF_6 release in the main process building.

SEE

- When a UF_6 release occurs, hydrogen fluoride is produced. Hydrogen fluoride is irritating at low concentration but is not sensed at high concentration.
- Released UF_6 may react with airborne moisture to produce hydrofluoric acid which has a noxious odor and uranyl fluoride which is visible as white airborne particulate matter.
- Workers wear personal protective equipment, which includes safety glasses, coveralls, hard hats, and steel-toed boots.
- Workers may detect a release via sound, smell, skin irritation, hearing an alarm, or seeing fog or perhaps a spray.
- All work areas are well lit.

FLEE

- A large release may impair a worker's ability to see.
- The workspace may present a variety of obstacles. The following obstacles apply for each scenario:
  - Confined Space: There are no trip hazards on the floor. The room has a large pipe 1.5 meters above the ground that runs through the middle of the room. At 3 meters from the door, the worker may be behind the pipe.
  - Large Space: The room contains a variety of components and equipment, including pipes, valves, conveyor belts, tanks, and computer workstations. There are alleys approximately 1-meter wide between major pieces of equipment and indicators on the wall for the nearest exit. The floor is known to be slippery.
  - Outdoor Area: The cylinders in the tank farm are stored in racks that are 1.5 meters tall. There are 1-meter-wide alleys between storage racks. The ground is asphalt, and small potholes have formed in most walkways. These potholes are up to 10 centimeters wide.

The analysis incorporated several assumptions made by the analysts in response to the parameters listed above and the information provided by NMSS staff based on their knowledge of see-and-flee response to UF_6. Appendix B gives the full list of questions and answers provided by NMSS staff for consideration and clarification for the see-and-flee scenarios. One notable assumption that was relevant in the analysis was that if the activity, which the worker was performing in each scenario before detecting the release of UF6, were left undone, then the facility could potentially be in an unsafe condition.

5 Operating Experience

Uranium hexafluoride (UF_6) is a colorless gas or a white sand-like solid that emits radioactive particles which can be harmful when inhaled or if they penetrate the skin. UF_6 is also a highly corrosive chemical that can burn skin upon contact and irritate the nose, throat, and lungs, causing coughing, wheezing, and shortness of breath if inhaled (Ref. 9). The NRC issued the information notice 2007-22 "Recent hydrogen fluoride exposures at fuel cycle facilities" (ML071410230) to raise awareness of UF_6 hazards in fuel processing facility (Ref. 10).

NUREG-1198, "Release of UF_6 from a Ruptured Model 48Y Cylinder at Sequoyah Fuels Corporation Facility: Lessons-Learned Report," issued June 1986 (Ref. 11), documented a UF_6 release event that occurred on January 4, 1986, which resulted in one death and several injuries. A cylinder grossly overfilled with UF_6 ruptured due to hydraulic overpressurization. The rupture occurred because the UF_6 changed states from solid to liquid after being heated in a steam chest. The released UF_6 reacted with airborne moisture to produce hydrofluoric acid which has a noxious odor and uranyl fluoride which is visible as white airborne particulate matter. The release filtered through the ventilation system, and, within minutes, the entire building became uninhabitable. The lessons-learned report stated that there was a potential delay in identifying a UF_6 release. There were no monitors for detecting airborne or waterborne UF_6 releases at the facility, even though ionization and conductivity detectors were commercially available. Breathing apparatuses were not readily available for workers leaving the affected areas. In addition, all emergency equipment was lost during this incident.

The International Atomic Energy Agency issued a 1996 report, “Significant Incidents in Nuclear Fuel Cycle Facilities” (Ref. 12), that addressed other high-level historical trends of release and contamination incidents since the 1950s. In 1970, a French facility accidentally released UF_6 when a cylinder valve was broken, causing a leak. Six workers were injured from burns on their hands and feet from the UF_6 release that was combined with carbon dioxide. This report also describes two other release events that directly affected workers, but they were not UF_6 releases.

6 Technical Approach

This study was achieved through collaboration between the staff of the NMSS Division of Fuel Management, who provided three see-and-flee scenarios with specific context, and the staff of the Office of Nuclear Regulatory Research’s (RES) Division of Risk Analysis (DRA), Human Factors and Reliability Branch (HFRB), who applied the IDHEAS-ECA methodology to calculate the HEPs of the see-and-flee IROFS in three different scenarios.

6.1 Human Reliability Analysis Qualitative Analysis

IDHEAS-ECA steps 1 to 3 are for HRA qualitative analysis (i.e., systematically collecting and organizing information that affects human performance). The qualitative analysis includes analyzing the event scenario, identifying and defining the administrative IROFS, and identifying and analyzing the critical tasks of the administrative IROFS. To perform the qualitative analysis, the RES staff first analyzed the information provided by Dr. April Smith (NMSS staff) for each scenario (i.e., see-and-flee in Confined Space, Large Space, and Outdoor Area). The scenarios were discussed in depth with Dr. Smith, who also answered the RES staff’s questions about the scenarios. The questions and answers help specifying clear assumptions for this analysis. Appendix B provides the questions and answers.

The see-and-flee IROFS in this study is modeled with a critical task, which contains four CFMs: detection, understanding, decisionmaking, and action execution. Detection means detecting the abnormality by seeing the cloud of smoke created by UF6 contacting with moisture, and skin irritation. Understanding means correctly interpreting that the abnormal situation requires a prompt evacuation from the workplace. Decisionmaking means deciding to put the work at hand aside and leave the workplace immediately. Action execution means to promptly exit the workplace. The success criterion for the see-and-flee IROFS in this study is for the worker to evacuate the workplace within one minute after the abnormality starts. The worker’s activities in the three scenarios (confined space, large space, and outdoor area) are identical at high-level, but differences exist in the details (e.g., the evacuation path and distance).

6.2 Cognitive Failure Modes Analysis

To calculate the P_c, the analysts used available information to choose the CFMs and PIF attributes applied to the critical task. Every member of the analysis team performed their own separate analysis for each scenario, then met to discuss the justifications for each PIF attribute chosen in their analyses. Based on these discussions, a consensus was reached on what to include in the final analysis for each scenario. The results from the final analysis of each scenario are presented in section 7 of this report.

The critical task of seeing and fleeing has four applicable CFMs:

(1) CFM1: Failure of Detection: The worker fails to detect the signs of the release.

(2) CFM2: Failure of Understanding: Given a successful detection of the sign of a release, the worker fails to assess and understand that the release is toxic and requires an immediate evacuation.

(3) CFM3: Failure of Decisionmaking: The worker fails to make the decision to flee as quickly as possible although he or she detects the signs and correctly assesses the situation. The worker may decide to finish the work at hand before evacuating from the workplace. Wrapping up the task in hand could take longer than the worker expected and resulting in an evacuation delay.

(4) CFM 4: Failure of Action Execution: The worker fails to flee away the site within the time available even though he or she makes the correct decision of fleeing. The worker needs to navigate through the evacuation path and open the door to exit the workplace.

(5) CFM 5: Failure of Interteam Coordination, is not applicable because the critical task is performed individually and does not require team coordination.

6.3 Timing Analysis

IDHEAS-ECA uses the time-available and the time-required for a timing analysis. The time-available in this study is set to be one minute, a constant value. That is the workers need to leave the workplace within one minute to succeed the see-and-flee IROFS in all scenarios. The time-required is the actual time that the workers took to leave the workplace. The time-required is treated as a distribution in this study. The time-required distribution represents the uncertainty caused by various factors that affect the workers' time to see-and-flee. This study did not collect the time-required data on site. Instead, the authors of this report estimated the lower bound and upper bound values of the time-required for each scenario. The estimates were performed by each author independently, as shown in the example in table 6.3-1.

Table 6.3-1 Example of Time-Required Estimates Chosen for Final Analysis Based on Individual Analyses

	Shortest time required estimate (s)	Longest time required estimate (s)
Teammate 1	12	52
Teammate 2	10	44
Teammate 3	17	31
Value used in analysis	10	52

Due to a lack of information about the most appropriate distribution to represent the time-required uncertainty, the authors decided to use normal distribution. For the normal distribution, the mean was calculated based on the average of the minimum lower bound estimate and the maximum upper bound estimate of the three authors. The lower bound and upper bound are interpreted as about the 5th percentile and 95th percentile. There are about four standard deviations between the 5th percentile and 95th percentile (The exact values should be the 4.8th percentile and 95.2th percentile). As a result, the standard deviation is calculated by the maximum upper bound estimate minus the minimum lower bound estimate then divided by 4. An example of the calculations used for the mean and standard deviation of the normal distribution based on the estimates in table 6.3-1 are shown below:

$$\text{Mean} = \frac{(Max\ upper\ bound\ time\ estimate + Min\ lower\ bound\ time\ estimate)}{2} = \frac{(52+10)}{2} = 31\ \text{s}$$

Range = Max upper bound estimate – Min lower bound estimate = 52 – 10 = 42 s

$$\text{Standard Deviation Used} = \frac{Range}{4} = \frac{42}{4} = 10.5\ \text{s}$$

Finally, a constant of 60 seconds was used as the total allowable time (time-available) in each scenario based on the description in section 4. A normal distribution with the specified mean and standard deviation for the time-required and the constant time-available were input into the IDHEAS-ECA app to calculate P_t (see figure 6-1). Alternatively, Equation (3.8) in NUREG-2256 can be used to calculate P_t using these same parameters (i.e., a normal distribution for time-required and a constant value for time-available). The P_t in this case can also be calculated using the following equation in Microsoft Excel:

P_t = 1 - NORM.DIST(time-available, Mean, Standard Deviation, true)

P_t = 1 - NORM.DIST(60, 31, 10.5, true) = 2.87E-3

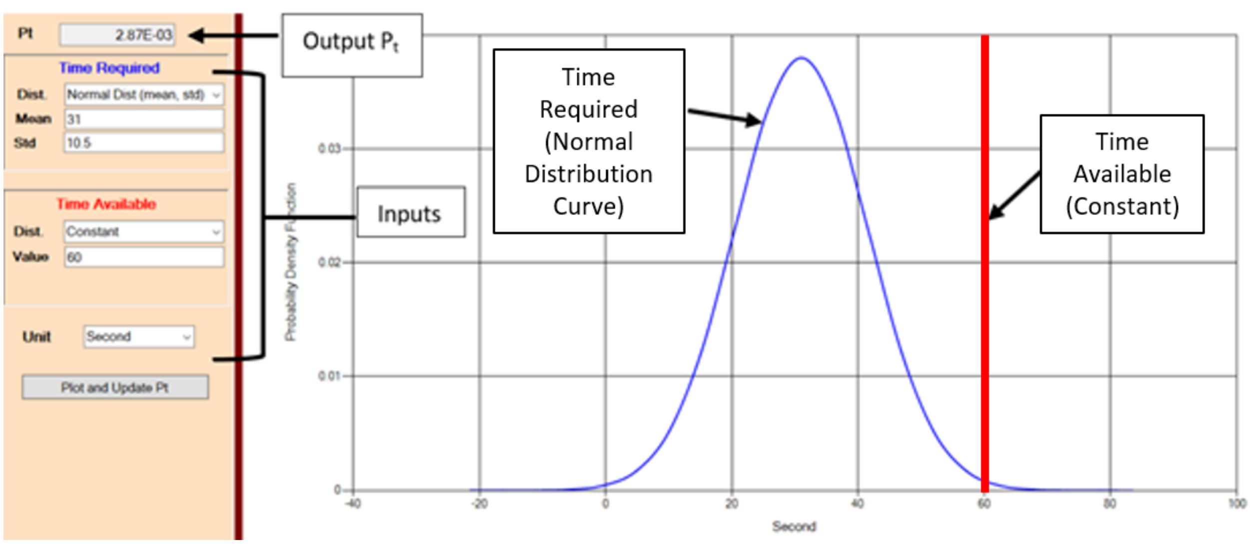

Figure 6-1 IDHEAS-ECA App P_t interface

6.4 Sensitivity Analysis

The P_t is a leading contributor to the failure probability of see-and-flee IROFS. Section 7.4 documents a sensitivity analysis on P_t. Two sensitivity analyses were performed. The first sensitivity analysis varies the time-required to assess the effects on P_t while the time-available remains constant (one minute). The time-required variation is based on the estimates of the analysts. The second sensitivity analysis varies the time-available while the time-required distribution remains the same. The details are discussed in Section 7.4.

7 Results for See-and-Flee Analysis

This section provides the HRA results for the three scenarios evaluated using the IDHEAS-ECA guidance report (Ref. 4). The HEPs were calculated by using the IDHEAS-ECA app. This section addresses IDHEAS-ECA steps 4 to 8.

7.1 Confined Space Scenario

7.1.1 HEP Calculation

Table 7.1-1 defines the HFE and critical task for the Confined Space scenario, then gives every PIF attribute selection for each CFM and the justification for each selection. The table also shows the calculated HEP for each CFM (P_{CFM}) and the total P_c for the entire Confined Space scenario. Note that the table only lists the PIFs that impact task performance (i.e., at least one attribute of the PIF is applicable to the CFM). The table does not list the remaining PIFs because they were assessed as having no impact on the CFMs. All base HEPs and PIF weights can be found in Appendix A of this report.

Table 7.1-2 gives the estimated values for the timing analysis of the Confined Space scenario, including the estimated max upper bound time estimate, minimum lower bound time estimate, the ranges, and mean times (all in seconds) for completing the see-and-flee IROFS. The table also shows the standard deviation of the time-required and total time-available used in the analysis and the calculated P_t for the Confined Space scenario.

Figure 7-1 shows the normal distribution curve for the time required on the same plot as the total available time. To create this curve, the overall mean time and standard deviation of the time required, and total (constant) time available from table 7.1-2 were input into the IDHEAS-ECA app, which calculated the P_t.

Table 7.1-3 shows the total P_c and P_t again, along with the overall HEP calculated for the Confined Space scenario.

Table 7.1-1 Confined Space CFM Analysis (P_c)

CONFINED SPACE: CFM Analysis (P_c)			
HFE: Fail to flee confined space in 1 minute **Critical Task:** Flee confined space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
Failure of Detection	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-3)	The worker is experienced, has adequate training, but has never performed actual scenario	1.02E-02
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 10)	The worker is working alone	
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.2)	The worker is performing a routine task	
Failure of Understanding	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.20E-02

CONFINED SPACE: CFM Analysis (P_c)			
HFE: Fail to flee confined space in 1 minute **Critical Task:** Flee confined space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 1.1)	The worker is working alone	
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.1)	The worker is performing a routine task	
Failure of Decisionmaking	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.78E-01
	Task Complexity: C25: Competing or conflicting goals (Base HEP = 0.14)	If the worker does not complete their routine task, the facility could be left in an unsafe condition. Worker needs to decide whether to finish the routine task or flee the area.	

CONFINED SPACE: CFM Analysis (P_c)			
HFE: Fail to flee confined space in 1 minute **Critical Task:** Flee confined space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 1.1)	The worker is working alone	
	Mental Fatigue, Stress, and Time Pressure: MF2: Time pressure due to perceived time urgency (PIF weight factor = 1.1)	The worker knows they need to leave the room within 1 minute according to training	
Failure of Action Execution	**Mental Fatigue, Stress, and Time Pressure: MF2:** Time pressure due to perceived time urgency (PIF weight factor = 3)	The worker knows they need to leave the room within 1 minute according to training	3.00E-04
Total P_c			1.97E-01

Table 7.1-2 Confined Space Timing Analysis (P_t)

CONFINED SPACE: Timing Analysis (P_t)			
Macrocognitive Function	Estimated Time (s)	Range (s)	Mean Time (s)
Detection	1–10	9	5.5
Understanding	0–7	7	3.5

CONFINED SPACE: Timing Analysis (P_t)			
Macrocognitive Function	Estimated Time (s)	Range (s)	Mean Time (s)
Decisionmaking	2–15	13	8.5
Action Execution	7–20	13	13.5
Overall	10–52	42	31
Standard deviation used = 10.5 seconds			
Total time-available = 60 seconds			
Total P_t = 2.87E-03			

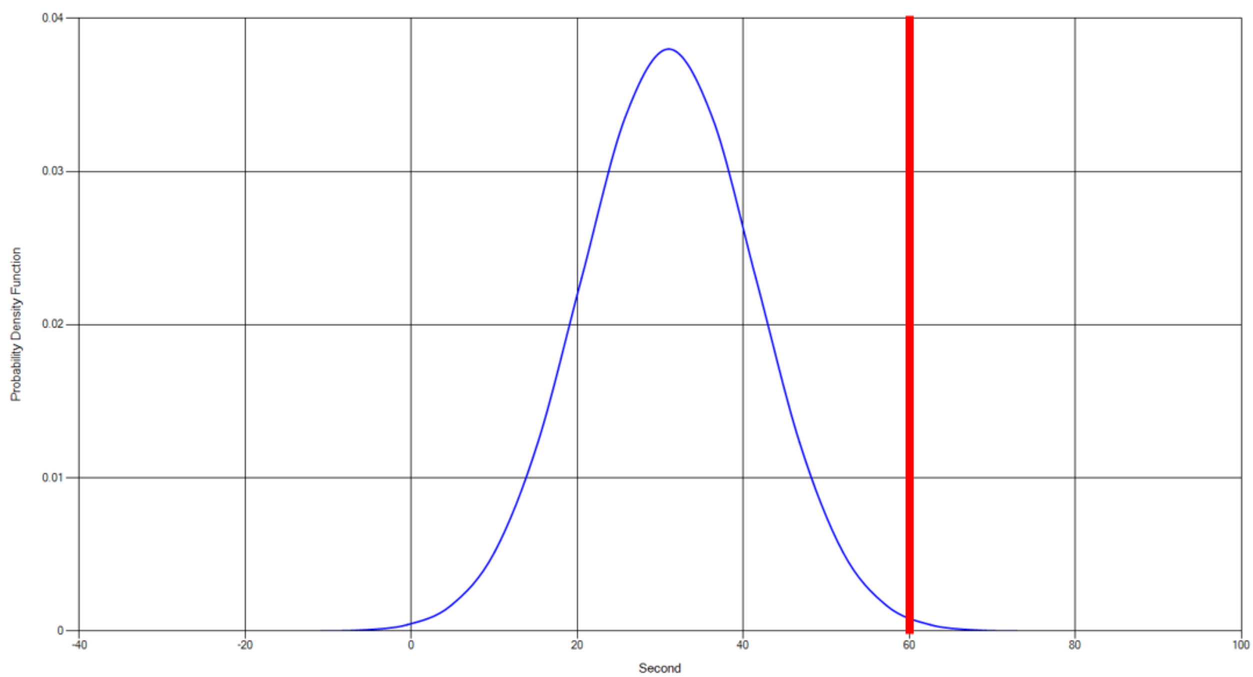

Figure 7-1 Normal distribution of the estimated time-required (curve) and the total time available (60 seconds, shown by the thick line) for Confined Space scenario

Table 7.1-3 Overall HEP for see-and-flee in Confined Space Scenario

CONFINED SPACE: Overall HEP = 1 - (1 - P_c) (1 - P_t)	
Total P_c	1.97E-01

CONFINED SPACE: Overall HEP = 1 - (1 - P_c) (1 - P_t)	
Total P_t	2.87E-03
Overall HEP	1.99E-01

Table 7.1-4 Leading Contributors to P_c Analysis

CONFINED SPACE: Leading P_c Contributor			
Lead Contributor	HEP from the Lead Contributor	P_c without Leading Contributor	Overall HEP without Leading Contributor
Decisionmaking: Task Complexity: Competing or Conflicting Goals	1.40E-01	3.41E-02	3.69E-02

7.1.2 Leading HEP Contributors

In the Confined Space scenario, the leading contributor to the overall HEP value of 1.99E-01 was Failure of Decisionmaking on making the decision to flee from the area. The main driver was the Task Complexity PIF, specifically, the PIF Attribute “Competing or conflicting goals,” which adds a base HEP of 1.40E-01 to the overall HEP. The HEP of 2.87E-03 from the P_t analysis was not a leading contributor to the overall HEP. As described in section 6, the P_t analysis was based on time estimates for performing each macrocognitive function, and not on real data. Table 7.1-2 shows the estimates used in this analysis. The leading time estimate that influenced P_t was the time required for Action Execution to flee from the area. The Action Execution time estimate considers the size of the room, the large pipe 1.5 meters above the ground that runs through the middle of the room, the worker being 3 meters from the exit door, the worker pressing a button on a wall and is 0.5 meters from the exit door, and the approximately 2 seconds needed to open the door. For Task Complexity, the analysis assumed that the worker was performing some type of routine activity before the release. For all three scenarios, NMSS staff stated that there were some activities, though routine, that if left undone may put the facility into an unsafe condition. However, workers are trained to drop everything they are doing and leave the area immediately. The attribute “Competing or conflicting goals” under the Task Complexity PIF has a base value of 1.40E-01 (0.14) in IDHEAS-ECA. This translates to 86 percent of workers deciding to flee the confined space once the UF_6 release is detected, and 14 percent of workers in this scenario deciding to complete the routine task rather than flee the area immediately. Removing this PIF would reduce the probability of workers staying in the confined space when there is a release.

7.2 Large Space

7.2.1 HEP Calculation

Table 7.2-1 defines the HFE and critical task for see-and-flee IROFS of the Large Space scenario and gives every PIF Attribute selection for each CFM and the justification for each selection. The table also shows the calculated P_c for each CFM and the total P_c for the entire see-and-flee IROFS. Note that the table only lists the PIFs that impact task performance (i.e., at least one PIF Attribute is applicable to the CFM). The table does not list the remaining PIFs because they were assessed as having no impact on the CFMs.

Table 7.2-2 gives the estimated values for the timing analysis of the Large Space scenario, including the estimated lower bound and upper bound values of the time-required, the range, and mean (all in seconds) for completing the macrocognitive functions and for the overall analysis. The table also shows the standard deviation and total time available used in the analysis, and the calculated P_t for the Large Space scenario.

Figure 7-2 shows the normal distribution curve on the same plot as the total available time. To create this curve, the overall mean time, standard deviation, and total time available from table 7.2-2 were plugged into the IDHEAS-ECA app, which calculated the P_t.

Table 7.2-3 shows the total P_c and P_t again, along with the overall HEP calculated for see-and0flee in the Large Space scenario.

Table 7.2-1 Large Space CFM Analysis (P_c)

LARGE SPACE: CFM Analysis (P_c)			
HFE: Fail to flee large space in 1 minute **Critical Task:** Flee large space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
Failure of Detection	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-3)	The worker is experienced, has adequate training, but has never performed actual scenario	1.20E-03

LARGE SPACE: CFM Analysis (P_c)			
HFE: Fail to flee large space in 1 minute **Critical Task:** Flee large space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.2)	The worker is performing a routine task	
Failure of Understanding	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.10E-02
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.1)	The worker is performing a routine task	

LARGE SPACE: CFM Analysis (P_c)			
HFE: Fail to flee large space in 1 minute **Critical Task:** Flee large space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
Failure of Decisionmaking	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.63E-01
	Task Complexity: C25: Competing or conflicting goals (Base HEP = 0.14)	If the worker does not complete their routine task, the facility could be left in an unsafe condition. The worker needs to decide whether to finish the task or flee the area.	
	Mental Fatigue, Stress, and Time Pressure: MF2: Time pressure due to perceived time urgency (PIF weight factor = 1.1)	The worker know they need to leave the room within 1 minute according to training	
Failure of Action Execution	**Environmental Factors**: ENV9: Slippery surface (PIF weight factor = 1.5)	Floor in Large Space scenario is known to be slippery	3.50E-04

LARGE SPACE: CFM Analysis (P_c)			
HFE: Fail to flee large space in 1 minute **Critical Task:** Flee large space within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Mental Fatigue, Stress, and Time Pressure: MF2: Time pressure due to perceived time urgency (PIF weight factor = 3)	The worker knows they need to leave the room within 1 minute according to training	
Total P_c			1.74E-01

Table 7.2-2 Large Space Timing Analysis (P_t)

LARGE SPACE: Timing Analysis (P_t)			
Macrocognitive Function	Estimated Time (s)	Range (s)	Mean Time (s)
Detection	1–10	9	5.5
Understanding	0–7	7	3.5
Decisionmaking	2–15	13	8.5
Action Execution	15–50	35	32.5
Overall	18–82	64	50
Standard Deviation Used = 16 seconds			
Total time available = 60 seconds			
Total P_t = 2.66E-01			

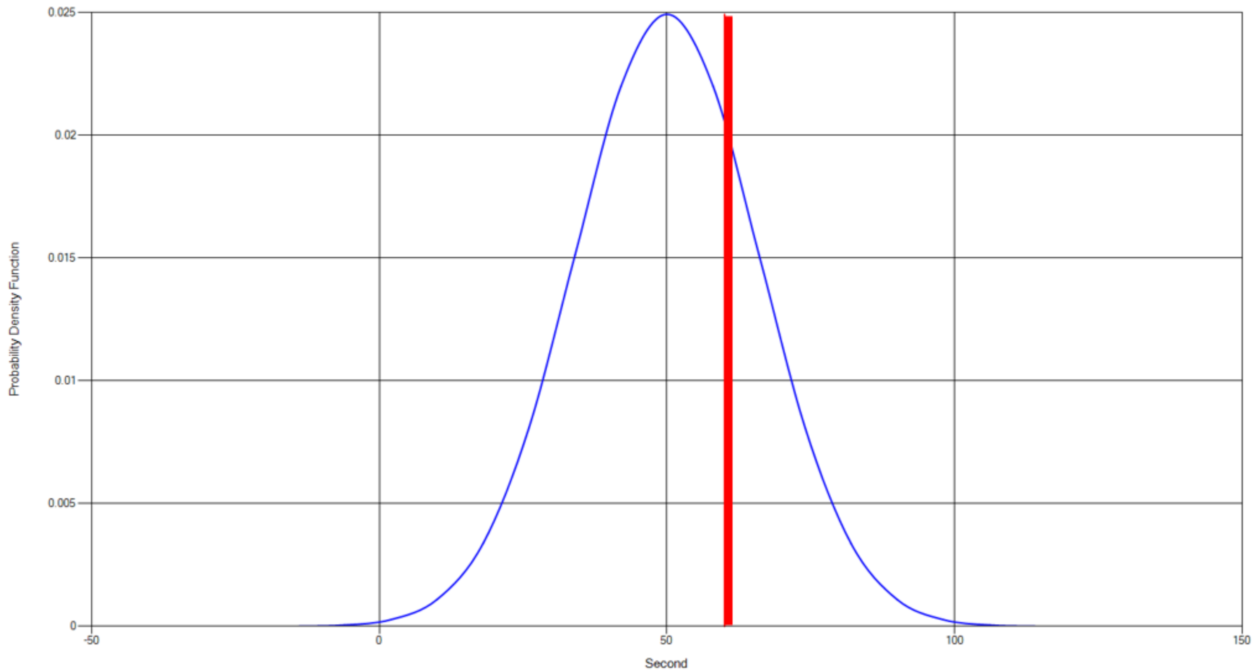

Figure 7-2 Normal distribution curve of the time-required (curve) along with the time-available (60 seconds, shown by the thick line) for see-and-flee in the Large Space scenario

Table 7.2-3 Overall HEP for see-and-flee in Large Space scenario

LARGE SPACE: Overall HEP 1 - (1 - P_c) (1 - P_t)	
P_c	1.74E-01
P_t	2.66E-01
Overall HEP	3.94E-01

Table 7.2-4 Leading Contributors to P_c Analysis

LARGE SPACE: Leading P_c Contributor			
Lead Contributor	Contribution Value	P_c without Leading Contributor	Overall HEP without Leading Contributor
Decisionmaking: Task Complexity: Competing or Conflicting Goals	1.40E-01	2.34E-02	2.83E-01

7.2.2 Leading HEP Contributors

The leading contributors to the overall HEP of 3.94E-01 were the P_t, which contributed an HEP of 2.66E-01, and the CFM Failure of Decisionmaking. The main driver to the HEP of the CFM was Task Complexity: "Competing or conflicting goals," which added a base HEP of 1.40E-01.

As for the Confined Space scenario, team members used estimates of time available as an independent variable. As described in section 6, the P_t analysis was based on time estimates for completing the see-and-flee, and not on real data. Table 7.2-2 shows the estimates used in this analysis. The leading time estimate for P_t was the time for Action Execution. The Action Execution time estimate considered the size of the room, and that the worker was 1 meter from the release and 30 meters from the nearest door. To open the door, the worker must slide their badge through a card reader and traverse the slippery floor. For Task Complexity, the same assumptions (that the worker was performing routine tasks before the release) were made. Team members considered this assumption for the Failure of Decisionmaking CFM. The Task Complexity PIF Attribute "Competing or conflicting goals" contributed a base HEP of 1.40E-01 (0.14). This translates to 86 percent of workers deciding to flee the large area once the UF_6 release is detected, and 14 percent of workers in this scenario deciding to complete the routine task rather than flee the area. Removing this PIF would significantly reduce the probability of workers staying in the large area when there is a release.

7.3 Outdoor Area

7.3.1 HEP Calculation

Table 7.3-1 defines the HFE and critical task for performing see-and-flee in the Outdoor Area scenario and gives every PIF attribute selection for each CFM and the justification for each selection. The table also shows the calculated HEP (P_c) for each CFM and the total P_c for the see-and-flee. Note that the table only lists the PIFs that impact task performance (i.e., at least one attribute of the PIF is applicable to the CFM). The table does not list the remaining PIFs because they were assessed as having no impact on the CFMs.

Table 7.3-2 gives the estimated values for the timing analysis of the Outdoor Area scenario, including the estimated lower bound and upper bound values of the time-required, the ranges, and the mean (all in seconds) for completing the macrocognitive functions and for the overall see-and-flee. The table also shows the standard deviation and total time-available used in the analysis, and the calculated P_t for the Outdoor Area scenario.

Figure 7-3 shows the normal distribution curve on the same plot as the total available time. To create this curve, the overall mean time, standard deviation, and total time available from table 7.3-2 were plugged into the IDHEAS-ECA app to calculate the P_t.

Table 7.3-3 shows the total P_c and P_t again, along with the overall HEP calculated for the Outdoor Area scenario.

Table 7.3-1 Outdoor Area CFM Analysis (P_c)

OUTDOOR AREA: CFM Analysis (P_c)			
HFE: Fail to flee outdoor area in 1 minute **Critical Task:** Flee outdoor area within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
Failure of Detection	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-3)	The worker is experienced, has adequate training, but has never performed actual scenario	1.02E-02
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 10)	The worker is working alone	
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.2)	The worker is performing a routine task	
Failure of Understanding	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.20E-02

OUTDOOR AREA: CFM Analysis (P_c)			
HFE: Fail to flee outdoor area in 1 minute **Critical Task:** Flee outdoor area within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 1.1)	The worker is working alone	
	Multitasking, Interruption and Distraction: MT1: Distraction by other ongoing activities that demand attention *Effect Level at 1* (PIF weight factor = 1.1)	The worker is performing a routine	
Failure of Decisionmaking	**Scenario Familiarity:** SF3: Scenario trained on but infrequently performed *Effect Level at 1* (Base HEP = 1E-2)	The worker is experienced, has adequate training, but has never performed actual scenario	1.78E-01
	Task Complexity: C25: Competing or conflicting goals (Base HEP = 0.14)	If the worker does not complete their routine task, the facility could be left in an unsafe condition. The worker needs to decide whether to finish the task or flee the area.	

OUTDOOR AREA: CFM Analysis (P_c)			
HFE: Fail to flee outdoor area in 1 minute **Critical Task:** Flee outdoor area within 1 minute			
CFM Selection	PIF and Attribute Selection	**Justification**	**HEP (P_{CFM})**
	Work Processes: WP2: Lack of or ineffective peer checking or supervision (PIF weight factor = 1.1)	The worker is working alone	
	Mental Fatigue, Stress, and Time Pressure: MF2: Time pressure due to perceived time urgency (PIF weight factor = 1.1)	The worker knows they need to leave the room within 1 minute according to training	
Failure of Action Execution	**Mental Fatigue, Stress, and Time Pressure: MF2:** Time pressure due to perceived time urgency (PIF weight factor = 3)	The worker knows they need to leave the room within 1 minute according to training	3.00E-04
Total P_c			1.97E-01

Table 7.3-2 Outdoor Area Timing Analysis (P_t)

OUTDOOR AREA: Timing Analysis (P_t)			
Macrocognitive Function	Estimated Time (s)	Range (s)	Mean Time (s)
Detection	1–10	9	5.5
Understanding	0–7	7	3.5

OUTDOOR AREA: Timing Analysis (P_t)			
Macrocognitive Function	Estimated Time (s)	Range (s)	Mean Time (s)
Decisionmaking	2–15	13	8.5
Action Execution	17–60	43	33.5
Overall	20–92	72	56
Standard Deviation Used = 18 seconds			
Total time available = 60 seconds			
Total P_t = 4.12E-01			

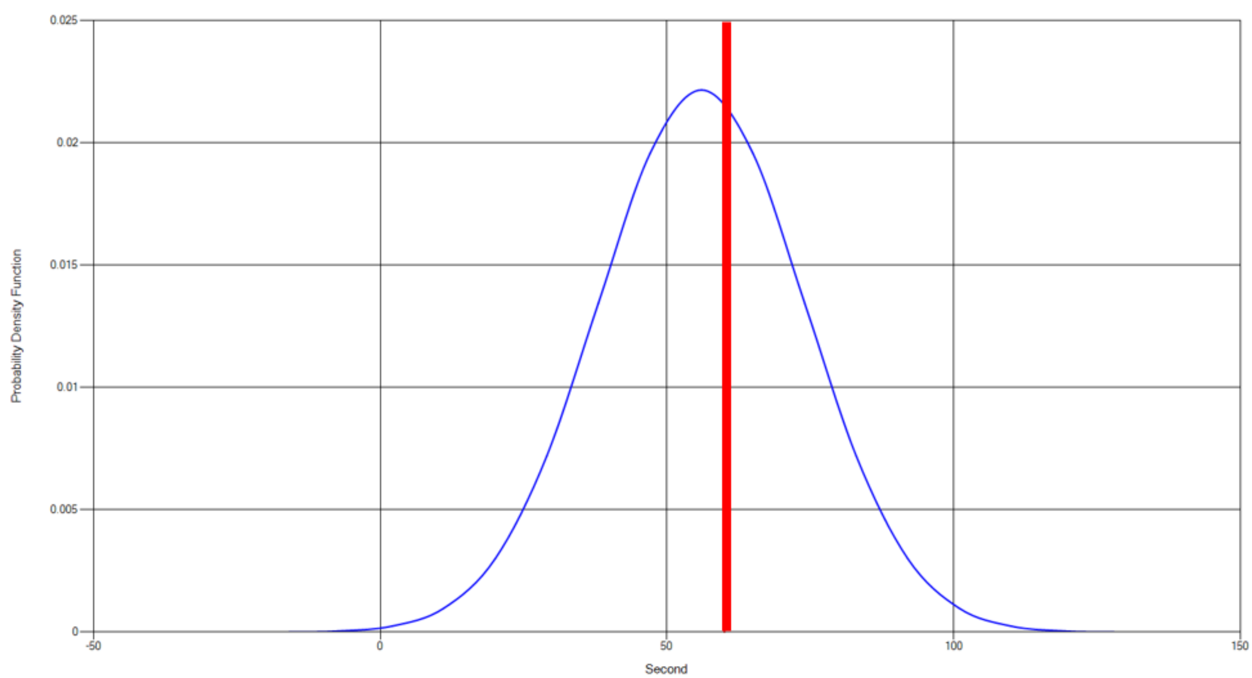

Figure 7-3 Normal distribution of the estimated time-required (curve) along with total time-available (60 seconds, shown by the thick line) for the see-and-flee in Outdoor Area scenario

Table 7.3-3 Overall HEP for see-and-flee in Outdoor Area Scenario

OUTDOOR AREA: Overall HEP 1 - (1 - P_c) (1 - P_t)	
Total P_c	1.97E-01
Total P_t	4.12E-01
Overall HEP	5.28E-01

Table 7.3-4 Leading Contributors to P_c Analysis for Outdoor Area

OUTDOOR AREA: Leading P_c Contributors			
Lead Contributors	Contribution Value	P_c without Leading Contributor	Overall HEP without Leading Contributor
Decisionmaking: Task Complexity: Competing or Conflicting Goals	1.40E-01	3.41E-02	4.32E-01

7.3.2 Leading HEP Contributors

The leading contributors to the overall HEP of 5.28E-01 were the P_t, which contributed an HEP of 4.12E-01, and the Task Complexity: “Competing or conflicting goals” PIF attribute for the Failure of Decisionmaking CFM, which added a base HEP of 1.40E-01.

As described in the Confined Space and Large Area scenarios, the P_t analysis was based on the times estimated by the analysts instead of real data. Table 7.3-2 gives the estimates used in this analysis. The leading time estimate for P_t would be the time required for Action Execution. The Action Execution time estimate considered the size of the tank yard that the worker would have to travel to successfully exit and the worker having to pick up and slide a 20-pound, large, metal vertical L-pin through a metal well.

For Task Complexity, the analysis assumed that the worker was performing a routine task when the release happened. This assumption is represented by the CFM Failure of Decisionmaking, Task Complexity PIF Attribute “Competing or conflicting goals.” The PIF Attribute contributed a base HEP of 1.40E-01. Removing the attribute of “Competing or conflicting goals” from the Decisionmaking CFM would reduce the overall HEP to 4.32E-01 from 5.28E-01.

7.4 Sensitivity Analysis

A sensitivity analysis shows how changing a variable would affect the results of interest. The first sensitivity analysis was on P_t. Sections 7.1–7.3 show the time-required estimates of the three authors. Each author estimated the boundaries of the time-required in all three scenarios and calculated the P_t. Table 7.4-1 shows the P_t each user calculated for each scenario before combining their estimates for the final analysis.

The second sensitivity analysis varied the time-available to show the impacts on P_t. This analysis used the estimated normal distribution curve from the Large Space scenario. In this analysis, the time-required distribution remains the same, while the time-available was changed in increments of 10 seconds from 30 seconds to 120 seconds. Figure 7-4 shows the plot of the P_t vs. available time. The results shows that P_t is very sensitive to time-available. With a change of 60 seconds in time-available, P_t would change about an order of magnitude.

Each sensitivity analysis is discussed further in the following section.

Table 7.4-1 Analysts' estimated time-required data for P_t sensitivity analysis

Sensitivity Analysis: P_t			
Scenario	User 1	User 2	User 3
Confined Space (P_t)	1.13E-03	2.21E-04	1.31E-04
Large Space (P_t)	2.28E-02	1.03E-02	5.00E-01
Outdoor Area (P_t)	1.29E-01	3.55E-02	8.41E-01

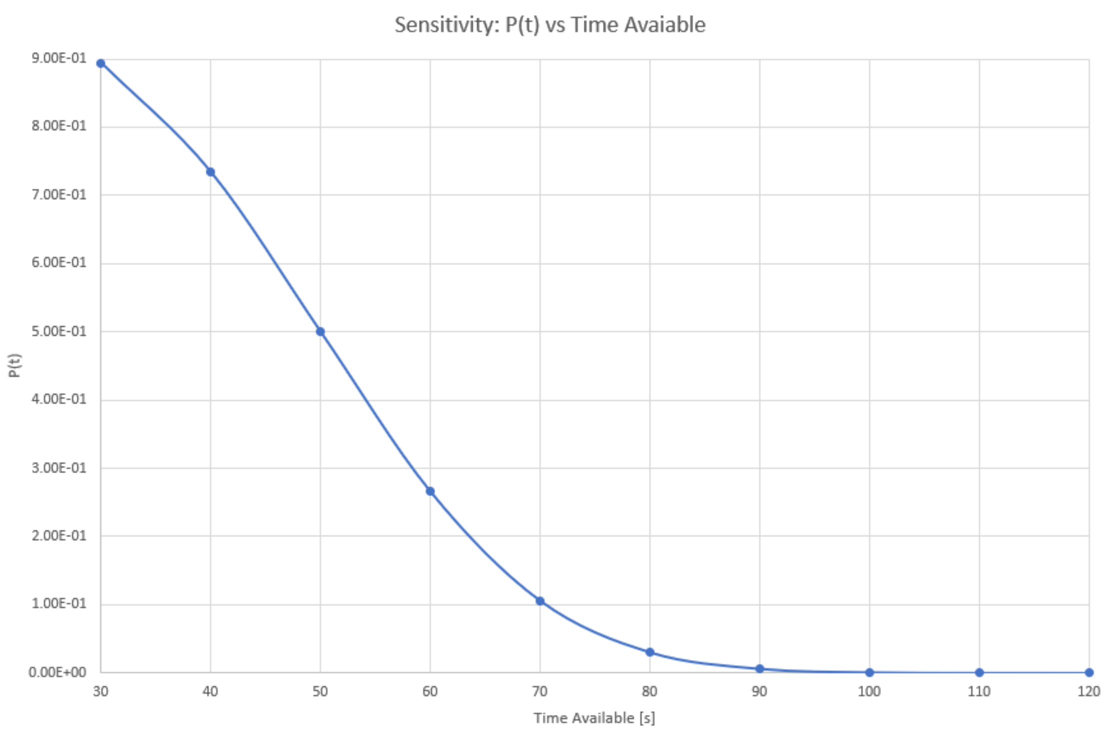

Figure 7-4 Sensitivity Analysis: P_t vs. Time-Available for the Large Space Scenario

8 Conclusion

The following PIF attributes were included in each of the three scenarios in the P_c analysis: "**Scenario Familiarity:** Scenarios trained on but infrequently performed," "**Multitasking, Interruption, and Distraction**: Distraction by other ongoing activities that demand attention (Weak)," "**Task Complexity:** Competing or conflicting goals," and "**Mental Fatigue, Stress, and Time Pressure:** Time pressure due to perceived time urgency."

"Scenario Familiarity: Scenarios trained on but infrequently performed" was chosen in each scenario for Detection, Understanding, and Decisionmaking, but not for Action Execution. From effect level 1 to 10 (with 1 having the smallest impact on HEP and 10 having the largest), effect level 1 was chosen because the worker in these scenarios has had training and has done drills on see-and-flee events but has never needed to perform the actual scenario. This PIF attribute was not selected for Action Execution because the execution of leaving the room/area in these scenarios is a relatively simple task, which the worker has assumedly done many times. This PIF attribute highlights the importance of having adequate training and drills. Without properly scheduled training and drills, the effect level of this PIF attribute could have been higher, which would increase the P_c.

"Multitasking, Interruption, and Distraction: Distraction by other ongoing activities that demand attention" was chosen in each scenario for Detecting and Understanding, but not for Decisionmaking and Action Execution. Since the worker is assumed to be performing a routine activity, this may distract them from detecting the white cloud that results from a release of UF_6. If they do detect the white cloud, their focus on the routine task may still inhibit them from understanding the significance of the white cloud. Once the workers understand that the white cloud is a possible UF_6 release, they will no longer be distracted by the ongoing activity; therefore, this PIF attribute will no longer apply to Decisionmaking or Action. The lowest effect level (i.e., weak) was chosen for this PIF attribute because the task was described as routine. Again, regularly scheduled training is recommended for workers to easily detect a release and understand what to do immediately.

"**Task Complexity:** Competing or conflicting goals" was chosen in each scenario for Decisionmaking and no other CFM. This PIF attribute alone made Decisionmaking the biggest CFM contributing to the P_c. In each scenario, the worker was assumed to be performing a routine activity. Dr. Smith noted that, if the activity were left undone, the facility could potentially be in an unsafe condition (refer to appendix B). However, workers are trained to drop everything they are doing and leave the area immediately. The IDHEAS cognitive model considers this a competing goal with the potential of the worker deciding to drop everything and leave as trained or deciding to complete the routine activity to keep the facility in a safe condition. This PIF attribute caused the P_c to be on the order of 10^{-1} instead of 10^{-2} in all scenarios. This PIF attribute is highly situational, and its influence depends on what kind of activity is being performed by the worker who witnesses the release. If abandoning the activity at hand would have adverse consequences, the worker would be more reluctant to flee immediately than if they were expecting little consequence. For further credible review, reviewing the training procedures and interviewing the workers would provide insight for assessing the reliability of see-and-flee. Again, regular training is recommended so workers understand the dangers of a UF_6 release and the importance of leaving the workplace immediately.

"Mental Fatigue, Stress, and Time Pressure: Time pressure due to perceived time urgency" was chosen in each scenario for Decisionmaking and Action Execution, and not for Detection and Understanding. Once the worker understands that the cloud of smoke detected could mean a UF_6 release, they know from their training that they have one minute to flee the area. This causes a sense of urgency due to time pressure for the Decisionmaking and Action Execution portion of the critical task. It is important for workers to leave the scene as soon as they can. However, the one-minute requirement could cause time pressure. This PIF Attribute highlights the importance of performing regular drills, so workers are more familiar with performing these tasks under time pressure.

The P_c analyses of the Confined Space and Outdoor Area scenarios were identical. The Large Space analysis and the other scenarios differed in only two ways: (1) "**Work Practices:** Lack of or ineffective peer checking or supervision" was not chosen as a PIF attribute for Detection, Understanding, and Decisionmaking in the Large Space scenario, and (2) "**Environmental Factors:** Slippery surface" was chosen as a PIF attribute for Action because it was mentioned that "the floor has been known to be slippery" in the Large Space scenario description.

In the Confined Space and Outdoor Area analyses, the workers were assumed to be alone; therefore, they had no peers or supervisors to help them with the Detection, Understanding, and Decisionmaking process. In the Large Space scenario, the worker was assumed to be with two other workers. Having peers present does not affect Action Execution because leaving the area is a simple, solitary task. These two differences caused the P_c of the Large Space scenario to be about 2 percent lower than the other scenarios. Obviously, having slippery floors in a facility could be hazardous, especially in scenarios where the worker needs to flee the scene quickly. However, and perhaps more importantly, this highlights the effectiveness of peer checking. Simply having other workers present in these scenarios lowers the P_c.

The P_t was largest in the Outdoor Area scenario and smallest in the Confined Space scenario in the final analysis (tables 7.1-2, 7.2-2, and 7.3-2) and in all three individual analyses (table 7.4-1). Estimated times for Detection, Understanding, and Decisionmaking were the same in all three scenarios, meaning only the estimated Action Execution time was different in each scenario. The estimated times for Action Execution in these scenarios were based on (1) the distance of the worker to the exit at the time of the UF_6 release and (2) the complexity of opening the exit door. Shortening the worker's distance to the exit or making the exit door easier to open should reduce the P_t in these scenarios by reducing the time it takes to accomplish the critical task.

The P_t was greater than the P_c in both the Large Space and Outdoor Area scenarios, which suggests that a worker in these scenarios is more likely to fail the critical task due to time constraints rather than due to a PIF. One way to lower the P_t would be to increase the time available for the worker to complete see-and-flee. The sensitivity analysis summarized in figure 7-4 shows how increasing the time available lowers the P_t. However, the analysis uses time estimates instead of actual data to calculate P_t. Table 7.4-1 shows that the user could have had a large influence on the resulting P_t. A more accurate analysis could be done if field data were collected on the time it takes to complete the human action in the critical task in each scenario and analyzed using the IDHEAS-ECA method aided by the IDHEAS-ECA app.

This report uses see-and-flee IROFS as an example to demonstrate the use of IDHEAS-ECA to assess the reliability of performing see-and-flee in confined space, large space, and outdoor area. The analysis demonstrates that IDHEAS-ECA can assess the reliability with explicit consideration of effects of a wide range of performance influencing factors. The analysis also demonstrated IDHEAS-ECA's ability to identify the dominant drivers of the reliability of see-and-flee IROFS. This information is invaluable for licensees to decide cost-effective actions to improve reliability and for NRC reviewers to assess impacts on safety. NUREG-1520's ISA guidance does not provide the breadth and depth to assess the reliability of see-and-flee IROFS. IDHEAS-ECA provides NMSS the capability to assess the reliability of IROFS similar to the see-and-flee example with sound technical basis.

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Appendix A: Base Human Error Probabilities and Performance-Influencing Factor Weights

This appendix was taken from Appendix B of NUREG-2256 (Ref. 13). This appendix presents the base human error probabilities (HEPs) of the three base performance-influencing factors (PIFs) in tables A-1 through A-3. It presents the PIF weights for the rest of the PIFs in tables A-5 through A-15. Each table is for one PIF, with the following exceptions: Table A-4 gives PIF weights for several PIFs in the environmental PIF category, and table A-14 gives PIF weights for two PIFs: (1) **Mental Fatigue** and (2) **Time Pressure** and **Stress**.

Each row in these tables is for one attribute, with the first row for the “No impact” state of a PIF. The first column in a table is an identifier assigned for a PIF attribute. For example, the attributes for PIF Scenario Familiarity have the identifiers SF1, SF2, and SF3, while SF0 is the identifier for “No impact,” the base state of the PIF. The second column is the description of every PIF attribute. The remaining five columns show the base HEP of a cognitive failure mode (CFM) or the PIF weight on the CFM imposed by the PIF attribute of the row. These five columns are for Failure of Detection (**D**), Understanding (**U**), Decisionmaking (**DM**), Action Execution (**E**), and Interteam Coordination (**T**). One exception is Table A-3, in which the base HEPs are separately presented for each CFM.

The base HEPs for the “No impact” states of the base PIFs in tables A-1, A-2, and A-3 (i.e., SF0, Inf0, C0, C10, C20, C30, and C40) are shown as zero. However, in the case that the three base PIFs are in their “No impact” state, $P_{CFM_{Base}}$ is not zero and should be assigned a value of the lowest HEP of a CFM, which is 1×10^{-4} for failure of Detection or Action Execution, and 1×10^{-3} for failure of Understanding, Decisionmaking, or Interteam Coordination.

Table A-1 Base HEP for Scenario Familiarity

PIF Attribute		D	U	DM	E	T
SF0	No impact • Frequently performed tasks in well-trained scenarios • Routine tasks	0	0	0	0	0
SF1	Unpredictable dynamics in known scenarios • Shifting task objectives • Dynamic decisionmaking is required	6.6E-4	6.6E-3	6.6E-3	6.6E-4	NA

PIF Attribute		D	U	DM	E	T
SF2	Unfamiliar elements in the scenario • Nonroutine, infrequently performed tasks • Unlearn a technique and apply one that requires the application of an opposing philosophy	5E-3	5E-2	5E-2	5E-3	NA
SF3	Scenarios trained on but infrequently performed	E-3	E-2	E-2	E-3	NA
	Scenario is unfamiliar, rarely performed • Notice adverse indicators that are not part of the task at hand • Notice incorrect status that is not a part of the routine tasks	1.2E-2	E-1	E-1	3.3E-2	NA
	Extremely rarely performed • Lack of plans, policies, and procedures to address the situation • No existing mental model for the situation • Rare events such as the Fukushima accident	3.3E-2	3E-1	3E-1	3.5E-1	NA
SF4	Bias or preference for wrong strategies exists, mismatched mental models	NA	2.6E-2	2.6E-2	NA	NA

NA = not applicable.

Table A-2 Base HEP for Information Availability and Reliability

PIF Attribute		D	U	DM	E	T
Inf0	No impact: Key information is reliable and complete	0	0	0	0	0
Inf1	Information is temporarily incomplete or not readily available Inadequate updates of information • Feedback information is not available in time to correct a wrong decision or adjust the strategy implementation • Different sources of information are not well organized; thus, personnel cannot readily access all the information needed • Primary source of information is not available, and secondary source of the information is in lower resolution	NA	5E-3	5E-3	NA	NA
	Information is moderately incomplete • A small portion of key information is missing	NA	5E-2	5E-2	NA	NA
	Information is largely incomplete • Key information is masked • Key indication is missing	NA	2E-1	2E-1	NA	NA

PIF Attribute		D	U	DM	E	T
Inf2	Low unreliable or uncertain • Personnel is aware that source of information could be temporally unreliable • Pieces of Information change over time; thus, they become uncertain by the time personnel use them	NA	E-2	E-2	NA	NA
	Moderately unreliable or uncertain • Source of information could be unreliable, and personnel likely recognize this • Conflicts in key information	NA	5E-2	5E-2	NA	NA
	Highly unreliable • Key information is highly uncertain	NA	E-1	E-1	NA	NA
	Extremely unreliable • Key information is misleading • Key information is inaccurate	NA	3E-1	3E-1	NA	NA

NA = not applicable.

Table A-3 Base HEPs for Task Complexity

PIF Attribute		Detection
C0	No impact on HEP	0
C1	Detection overload with multiple competing signals • Track the states of multiple systems • Monitor many parameters • Memorize many pieces of information detected • Many types or categories of information to be detected	Few (<7): 3E-3 Multiple (7–11): 1E-2 Many (11–20): 1E-1 Excessive amount (>20): 3E-1

PIF Attribute		Detection
C2	Detection is moderately complex • Criteria are not straightforward • Information of interest involves complicated mental computation • Comparing for abnormality	E-3
C3	Detection demands for high attention • Need split attention • Need sustained attention over a period of time • Need intermittent attention	E-3
C4	Detection criteria are highly complex • Multiple criteria to be met in complex logic • Information of interest must be determined based on other pieces of information • Detection criteria are ambiguous and need subjective judgment	E-2
C5	Cues for detection are not obvious • Detection is not directly cued by alarms or instructions • Personnel need to actively search for the information	5E-2
C6	No cue or mental model for detection • No rules, procedures, or alarms to cue the detection • Detection of the critical information is entirely based on personnel's experience and knowledge	E-1

Table A-3 Base HEPs for Task Complexity (continued)

PIF Attribute		Understanding
C10	No impact: straightforward diagnosis with clear procedures or rules	0
C11	Working memory overload • Need to decipher many messages (indications, alarms, spoken messages) • Multiple causes for situation assessment: Multiple independent "influences" affect the system, and system behavior cannot be explained by a single influence alone	E-2 for <11 messages 5E-2 for 11–15 E-1 for 15–20 3E-1 for >20

PIF Attribute		Understanding
C12	Relational complexity (number of unchunkable topics or relations in one understanding task) • Relations involved in a human action are very complicated for understanding • Need to integrate (use together) multiple relations	2E-2 for 2 relations 4.5E-2 for 3 relations E-1 for 4 relations 3E-1 for more than 4 relations
C13	Understanding complexity: requiring high level of comprehension	E-2
C14	Potential outcome of situation assessment consists of multiple states and contexts (not a simple yes or no)	E-2
C15	Ambiguity associated with assessing the situation • Key information for understanding is cognitively masked • Pieces of key information are intermingled or coupled	E-1
C16	Conflicting information, cues, or symptoms	E-1

Table A-3 Base HEPs for Task Complexity (continued)

PIF Attributes		Decisionmaking
C20	No impact: simple, straightforward choice	0
C21	Transfer step in procedure: integrating a few cues	4.5E-3
C22	Transfer procedure (multiple alternative strategies to choose): integrating multiple cues	1.2E-2
C23	Decision criteria are intermingled, ambiguous, or difficult to assess	1E-2
C24	Multiple goals difficult to prioritize (e.g., advantage for incorrect strategies)	3.3E-2
C25	Competing or conflicting goals (e.g., choosing one goal will block achieving another goal, low preference for correct strategy, reluctance and viable alternative)	1.4E-1
C26	Decisionmaking involves developing strategies or action plans	5E-2
C27	Decisionmaking requires diverse expertise distributed among multiple individuals or parties who may not share the same information or have the same understanding of the situation	1E-1

PIF Attributes		Decisionmaking
C28	integrating a large variety of types of cues with complex logic	1.7E-1

Table A-3 Base HEPs for Task Complexity (continued)

PIF Attributes		Action Execution
C30	No impact: simple execution with a few steps	0
C31	Straightforward procedure execution with many steps	E-3
C32	Non-straightforward procedure execution • Very long procedures, voluminous documents with checkoff provision • Multiple procedures needed	5E-3
C33	Simple, continuous control that requires monitoring parameters	3.4E-4
C34	Continuous control that requires manipulating dynamically	2.6E-3
C35	Long-lasting action, repeated discontinuous manual control (need to monitor parameters from time to time)	2E-2
C36	No immediacy to initiate execution: time span between annunciation (decision for execution made) and operation	5E-3
C37	Complicated or ambiguous execution criteria • Multiple, coupled criteria • Restrictive, irreversible order of multiple steps • Open to misinterpretation	E-2
C38	Action execution requires close coordination of multiple personnel at different locations (e.g., transport fuel assemblies with fuel machines)	5E-2
C39	Unlearn or break away from automaticity of trained action scripts	1E-1

Table A-3 Base HEPs for Task Complexity (continued)

PIF Attributes		Interteam Coordination
C40	No impact: clear, streamlined, crew-like communication and coordination	0
C41	Complexity of information communicated • Simple: 1.5E-3 • Moderate: E-2 • High: 5E-2 • Extremely high: E-1	1.5E-3 E-2 5E-2 E-1
C42	Complex or ambiguous command and control	E-2
C43	Complex or ambiguous authorization chain	E-2
C44	Coordinate activities of multiple diverse teams or organizations	E-2

Table A-4 PIF Weights for Environmental PIFs

PIF Attribute		D	U	DM	E	T
ENV0	No impact: nominal weather and environmental factors	1	1	1	1	1
ENV1	Coldness on action execution • Moderate cold (<5°C): 1.5 • Extreme coldness on manipulating instrumentation: 2 • Extreme coldness on physically demanding execution: 5 • Extreme coldness on high-precision manipulations (e.g., connecting lines to pump, remove air from lines and pumps): 20	NA	NA	NA	1.5 2 5 20	NA
ENV2	Moderate coldness (<5°C) for nonexecution	1.1	1.1	1.1	NA	1.1
ENV2	Extreme coldness for nonexecution	2	2	1.1	NA	2
ENV3	Heat (>33°C) or high humidity	1.1	1.1	1.1	1.5	1.1
ENV4	Poor lighting, low luminance (L = 0.15, compared to no impact L = 1.5) for reading information or execution	2	NA	NA	2	NA
ENV5	Strong ambient light, glare, reflection	2	NA	NA	1.5	NA

PIF Attribute		D	U	DM	E	T
ENV6	Very low visibility (e.g., heavy smoke or fog) for detecting targets or execution	5	NA	NA	5	NA
ENV7	Loud or burst noise	1.7	1.1	1.1	1.1	1.1
ENV8	Wearing heavy protective clothes and/or gloves	NA	NA	NA	1.5	NA
ENV9	Slippery surface (e.g., icing)	NA	NA	NA	1.5	NA
ENV10	Strong winds, rain, or objects close to road on physically demanding tasks	NA	NA	NA	1.5	NA
ENV11	Strong winds, rain, or objects close to road impeding vehicle movement	NA	NA	NA	2	NA
ENV12	High or chaotic traffic impeding vehicle movement	NA	NA	NA	1.5	NA
ENV13	Unstable or vibrating surface or work site	NA	NA	NA	2	NA

NA = not applicable; °C = degrees Celsius.

Table A-5 PIF Weights for System and I&C Transparency

PIF Attribute		D	U	DM	E	T
SIC0	No impact	1	1	1	1	NA
SIC1	System or I&C does not behave as intended under special conditions	1.1	1.1	1.1	1.1	NA
SIC2	System or I&C does not reset as intended	1.1	1.1	1.1	10	NA
SIC3	System or I&C is complex or nontransparent for personnel to predict its behavior	NA	2	NA	NA	NA
SIC4	System or I&C failure modes are not transparent to personnel	NA	2	NA	NA	NA

NA = not applicable; I&C = instrumentation and control

Table A-6 PIF Weights for Human-System Interface

PIF Attribute		D	U	DM	E	T
HSI0	No impact: well-designed HSI supporting the task	1	1	1	1	1
HSI1	Indicator is similar to other sources of information nearby	1.5	NA	NA	NA	NA
HSI2	No sign or indication of technical difference from adjacent sources (meters, indicators)	3	NA	NA	NA	NA
HSI3	Related information for a task is spatially distributed, not organized, or cannot be accessed at the same time	1.5	2	NA	NA	NA
HSI4	Unintuitive or unconventional indications	2	NA	NA	NA	NA

PIF Attribute		D	U	DM	E	T
HSI5	Poor salience of the target (indicators, alarms, alerts) out of the crowded background	3	NA	NA	NA	NA
HSI6	Inconsistent formats, units, symbols, or tables	5	NA	NA	NA	NA
HSI7	Inconsistent interpretation of displays	NA	5.7	NA	NA	NA
HSI8	Similarity in elements: wrong element selected in operating a control element on a panel within reach and similar in design in control room	NA	NA	NA	1.2	NA
HSI9	Poor functional localization: 2–5 displays or panels needed to execute a task	NA	NA	NA	2	NA
HSI10	Ergonomic deficits • Controls are difficult to maneuver • Labeling and signs of controls are not salient among crowd • Inadequate indications of states of controls: small unclear labels, difficult reading scales • Maneuvers of controls are unintuitive or unconventional	NA	NA	NA	3.38	NA
HSI11	Labels of the controls do not agree with document nomenclature, confusing labels	NA	NA	NA	5	NA
HSI12	Controls do not have labels or indications	NA	NA	NA	10	NA
HSI13	Controls provide inadequate or ambiguous feedback, i.e., lack of or inadequate confirmation of the action executed (incorrect, no information provided, measurement inaccuracies, delays)	NA	NA	NA	4.5	NA
HSI14	Confusion in action maneuver states (e.g., automatic resetting without clear indication)	NA	NA	NA	10	NA
HSI15	Unclear functional allocation (between human and automation)	NA	NA	NA	9	NA

HIS = human-system interface: NA = not applicable.

Table A-7 PIF Weights for Equipment and Tools

PIF Attribute		D	U	DM	E	T
TP0	No impact: Tools and parts are well maintained under proper administrative control	1	1	1	1	1
TP1	Tools/parts are complex or difficult to use	1.1	NA	NA	1.1	NA

PIF Attribute		D	U	DM	E	T
TP2	Failure modes or operational conditions of the tools are not clearly presented (e.g., ranges, limitations, requirements)	1.1	NA	NA	1.1	NA
TP3	Tool does not work properly due to aging, lack of power, incompatibility, improper calibration, etc.	1.1	NA	NA	1.1	NA
TP4	Document nomenclature does not agree with equipment labels	2	NA	NA	2	NA
TP5	Personnel are unfamiliar with or rarely use the tool/parts	2	NA	NA	2	NA
TP6	Tools or parts lack proper administrative control (so could be missing or temporally not available)	2	NA	NA	2	NA

NA = not applicable.

Table A-8 PIF Weights for Staffing

PIF Attribute		D	U	DM	E	T
STA0	No impact: adequate staffing	1	1	1	1	1
STA1	Shortage of staffing (e.g., key personnel are missing, unavailable or delayed in arrival, staff pulled away to perform other duties)	1.1	1.1	1.1	1.1	1.1
STA2	Lack of backup/lack of peer check or cross-checking (e.g., an overseer or independent reviewer is not available)	1.1	1.1	1.1	1.1	1.1
STA3	Ambiguous or incorrect specification of staff roles and responsibilities	1.1	1.1	1.1	1.1	1.1
STA4	Inappropriate staff assignment (e.g., lack of skills)	1.1	1.1	1.1	1.1	1.1
STA5	Key decision-maker's knowledge and ability are inadequate to make the decision (e.g., lack of required qualifications or experience)	1.1	1.1	1.1	1.1	1.1
STA6	Lack of administrative control on fitness for duty	1.1	1.1	1.1	1.1	1.1

Table A-9 PIF Weights for Procedures, Guidance, and Instructions

PIF Attribute		D	U	DM	E	T
PG0	No impact: well-validated procedures like most EOPs	1	1	1	1	1
PG1	Procedure design is less than adequate (difficult to use) • Requires calculation (e.g., unit conversion) • No placeholders • Graphics or symbols not intuitive • Inconsistency between procedure and displays	1.2	1.1	1.1	1.2	1.1
PG2	Procedure requires judgment	1.6	1.6	1.6	3	1.1
PG3	Procedure lacks details	2.2	2.2	2.2	2.2	1.1
PG4	Procedure is ambiguous, confusing	1.5	5	5	3	5
PG5	Mismatch: Procedure is available but does not match the situation (e.g., needs deviation or adaptation)	1.1	17	17	1.1	10
PG6	No verification in procedure for verifying key parameters for detection or execution	20	NA	NA	20	10
PG7	No guidance to seek confirmatory data when data may mislead for diagnosis or decisionmaking	NA	30	30	NA	10

EOP = emergency operating procedure; NA = not applicable.

Table A-10 PIF Weights for Training

PIF Attribute		D	U	DM	E	T
TE0	No impact: Professional staff have adequate training required	1	1	1	1	1
TE1	Inadequate training frequency/refreshment	Frequent (<6 months): 1 Infrequent (6–12 months): 1.2 Highly infrequent (>4 years): 5	Frequent (<6 months): 1 Infrequent (6–12 months): 1.2 Highly infrequent (>4 years): 10	Frequent (<6 months): 1 Infrequent (6–12 months): 1.2 Highly infrequent (>4 years): 10	Frequent (<6 months): 1 Infrequent (6-12 months): 1.2 Highly infrequent (>4 years): 10	Frequent (<6 months): 1 Infrequent (6–12 months): 1.2 Highly infrequent (>4 years): 5

PIF Attribute		D	U	DM	E	T
TE2	Inadequate training practicality: no hands-on training • Not drilled together • Training on parts, not whole scenario together	1.5	1.5	1.5	1.5	1.5
TE3	Inadequate training on procedure adaptation: Training focuses on procedure following without adequately training personnel to seek alternative interpretations, evaluate the pros and cons of alternatives, and adapt the procedure for the situation	1.1	2	2	2	NA
TE4	Inadequate amount of training: no qualification exam • Less than adequate training specification or requirement	1.8	3	3	6.1	NA
TE5	Operator inexperienced (e.g., a newly qualified tradesman, but not an "expert")	3	3	3	3	NA
TE6	Poor administrative control on training (e.g., not included in the Systematic Approach to Training Program)	2	2	10	10	NA
TE7	Inadequate training or experience with sources of information (such as applicability and limitations of data or the failure modes of the information sources)	14	NA	NA	NA	NA
TE8	Inadequate specificity on urgency and the criticality of key information, such as key alarms	20	NA	NA	NA	NA
TE9	Not trained to seek confirmatory information when dismissing critical data	NA	10	10	NA	NA

PIF Attribute		D	U	DM	E	T
TE10	Premature termination of critical data collection in diagnosis due to inadequate training on system failure modes	NA	15	NA	NA	NA
TE11	Poor training on assessing action margin in deciding implementation delay	NA	NA	5	NA	NA
TE12	Poor training on interpreting procedure in the context of the scenario for decisionmaking	NA	NA	11	NA	NA
TE13	Poor training on the importance of data in frequently checking data for execution	NA	NA	NA	10	NA

NA = not applicable.

Table A-11 PIF Weights for Teamwork and Organizational Factors

PIF Attribute		D	U	DM	E	T
TF0	No impact: adequate, crew-like teams	1	1	1	1	1
TF1	Inadequate team • Inadequate teamwork resources (short of personnel, knowledge gaps) • Distributed or dynamic teams • Poor team cohesion (e.g., newly formed teams, lack of drills, experience together)	2	2	2	2	2
TF2	Poor command and control • Unclear allocation of functions and responsibilities • Inadequate coordination between site personnel and decision-makers (e.g., adapt or modify planned actions based on site situation) • Inadequately verify the plan with decision-makers • Inadequate supervision in overseeing action execution and questioning current mission	1.5	1.5	1.5	1.5	1.5

PIF Attribute		D	U	DM	E	T
TF3	Poor information management in multiple-team tasks	NA	NA	NA	NA	2
TF4	Poor communication capabilities between teams	NA	NA	NA	NA	2
TF5	Competing resources available for multiple teams	NA	NA	NA	NA	1.5

NA = not applicable.

Table A-12 PIF Weights for Work Processes

PIF Attribute		D	U	DM	E	T
WP0	No impact: licensed personnel with good work practices	1	1	1	1	1
WP1	Lack of practice of self- or cross-verification (e.g., 3-way communication)	10	1.1	1.1	10	1.1
WP2	Lack of or ineffective peer-checking, supervision	10	1.1	1.1	10	1.1
WP3	Poor work prioritization, scheduling	1.1	1.1	1.1	1.1	1.1
WP4	Lack of or ineffective instrumentation (e.g., pre-job briefing) for personnel to be aware of potential pitfalls in performing the tasks	1.1	1.1	1.1	1.1	1.1
WP5	Lack of or ineffective instrumentation (e.g., supervision) for safety issue monitoring and identification	1.1	1.1	1.1	1.1	1.1
WP6	Lack of or ineffective instrumentation for safety reporting	1.1	1.1	1.1	1.1	1.1
WP7	Hostile work environment	1.1	1.1	1.1	1.1	1.1

Table A-13 PIF Weights for **Multitasking, Interruption, and Distraction**

PIF Attribute		D	U	DM	E	T
MT0	No impact	1	1	1	1	1
MT1	Distraction by other ongoing activities that demand attention	Weak: 1.2 Moderate: 2 High: 2.8	1.1	1.1	Weak: 1.2 Moderate: 2 High: 2.8	Weak: 1.2 Moderate: 2 High: 2.8

PIF Attribute		D	U	DM	E	T
MT2	Interruption taking away from the main task	Weak: 1.1 Moderate: 2.8 Frequent or long: 4	Weak: 1.1 Moderate: 1.5 Frequent or long: 1.7	Weak: 1.1 Moderate: 1.5 Frequent or long: 1.7	Weak: 1.1 Moderate: 2.8 Frequent or long: 4	Weak: 1.1 Moderate: 2.8 Frequent or long: 4
MT3	Concurrent visual detection and other tasks	Low demanding: 2 Moderate demanding: 5 High demanding: 10	NA	NA	NA	NA
MT4	Concurrent auditory detection and other tasks	Auditory/ visual: 10 Auditory/ auditory: 20	NA	NA	NA	NA
MT5	Concurrent diagnosis and other tasks	NA	Low demanding: 3 High demanding: 30	NA	NA	NA
MT6	Concurrent go/no-go decisionmaking	NA	NA	2	NA	NA
MT7	Concurrently making intermingled complex decisions/plans	NA	NA	5	NA	NA
MT8	Concurrently executing action sequence and performing another attention/working memory task	NA	NA	NA	2.3	NA
MT9	Concurrently executing intermingled or interdependent action plans	NA	NA	NA	5	NA

PIF Attribute		D	U	DM	E	T
MT10	Concurrently communicating or coordinating multiple distributed individuals or teams	NA	NA	NA	NA	5

NA = not applicable.

Table A-14 *PIF* **Weights for Mental Fatigue and Time Pressure and Stress**

PIF Attribute		D	U	DM	E	T
FS0	No impact	1	1	1	1	1
FS1	Sustained (>30 minutes) high-demanding cognitive activities requiring continuous attention (e.g., procedure-situation mismatches demand constant problem-solving and decisionmaking, information changes over time and requires sustained attention to monitor or frequent checking)	2.5	1.1	1.1	2.5	1.1
FS2	Time pressure due to perceived time urgency	2	2	1.1	3	1.1
FS3	Lack of self-verification due to needs to rush the task completion (speed-accuracy trade-off)	10	2	2	10	2
FS4	Reluctance to execute an action plan due to potential negative impacts (e.g., adverse economic impact, or personal injury)	NA	NA	NA	2	NA
FS5	Long working hours (greater than 4 hours) with high cognitively demanding tasks	1.5	1.5	1.1	1.5	1.1
FS6	Sudden increase in workload from a long period of low to high	1.2	1.2	NA	1.2	1.2
FS7	Sudden decrease in workload from high to normal	1.8	1.1	NA	1.8	1.2
FS8	Emotional stress (e.g., anxiety, frustration)	1.2	1.2	1.2	1.2	1.2
FS9	Physical stress or fatigue (e.g., long hours of exposure to ambient noise, disturbed dark and light rhythms, air pollution, disruption of normal work-sleep cycles, ill health)	1.1	1.1	1.1	1.1	1.1
FS10	Sleep deprivation	2	1.2	1.1	2	1.2

NA = not applicable.

Table A-15 *PIF* **Weights for Physical Demands**

PIF Attribute		D	U	DM	E	T
PD0	No impact				1	
PD1	Physically strenuous: possibly exceeding physical limits (e.g., lifting heavy objects, moving heavy things, opening/closing rusted or stuck valves)	NA	NA	NA	1.5	NA
PD2	High spatial or temporal precision	NA	NA	NA	2	NA
PD3	Precise motor coordination of multiple persons	NA	NA	NA	2	NA
PD4	Unusual, unevenly balanced loads (e.g., reaching high parts)	NA	NA	NA	5	NA
PD5	Loading or unloading objects using crane⁄hoist	NA	NA	NA	10	NA

NA = not applicable.

Appendix B: See-And-Flee Scenarios (Questions from RES and Answers from NMSS)

Overall (Priority) Questions:

1. Question: What are the hazardous properties of hydrogen fluoride (i.e., Highly toxic when inhaled, highly toxic by ingestion, corrosive)?

   Answer: HF is highly toxic via multiple pathways. Inhalation, ingestion and dermal contact are primary pathways. It takes very little to cause long term damage and not much more to cause death. https://www.epa.gov/aegl/hydrogen-fluoride-results-aegl-program

2. Question: Would UF_6 cause worker to choke, cough, etc. once in contact?

   Answer: Yes.

3. Question: What task/s is the worker performing prior to release? Can we assume he/she would be performing some type of routine activity? (potential multi-tasking, interruptions, distractions, or decision-making points)? Are there any tasks being done that need to be completed prior to exiting?

   Answer: Assume that the worker is performing some type of routine activity. As we discussed, there are some activities, though routine, that if left undone, may put the facility into an unsafe condition. However, workers are trained to drop everything they are doing and leave the area immediately. There may be one worker that is required to activate an alarm before leaving the area.

4. Question: How long has the worker been on the clock? Prior shifts? Over 8 hours? Complex tasks?

   Answer: Assume that the worker is halfway through a 10-hour shift and, as stated in Q3, is performing a routine task.

5. Question: Large or small release? Release rate?

   Answer: Please assume two release rates of UF_6: 150 g/min and 300 g/min. These rates are comparable to average release rates from real releases. UF_6 reacts with water in the air to produce uranyl fluoride and hydrogen fluoride, both of which are toxic. However, HF is the limiting toxic agent.

6. Question: Is 1 minute a reasonable amount of time to successfully flee based on leak rate and room and tank size?

   Answer: One minute is a standard time that licensees cite. Operating experience suggests that the actual time can be more or less. A result from this project may be that the probability of successfully leaving the area in one minute is relatively low. Assume two tank sizes, 200 lbs. and 2000 lbs.

7. Question: How long does the worker have to exit the room before becoming too hazardous? What are the success criteria vs. training expectation of exiting in time (Time Available)?

   Answer: Workers are trained to leave the area immediately. How long the worker has will depend on the release rate and room volume.

8. Question: What is the probability that the worker will properly assess the white cloud based on their training?

   Answer: Workers are trained to assume any white cloud is dangerous and to leave the room immediately. Licensees assume the probability is 1; however, operating experience says less than 1, but there is not much more detail than that.

9. Question: Can we get a copy of the training material (procedure/guidance)?

   Answer: This scenario is a compilation of multiple events at several facilities.

10. Question: Are there any sensors that can detect a release before the worker?

    Answer: No.

11. Question: Any other workers or teamwork involved?

    Answer:

    a. Assume for the confined area that there are no other workers in the area.

    b. For the large area, assume there are two other workers, and they are working within two (2) feet of one another. However, for a recent event, in a large area, there were three workers in the area.

12. Question: Can you explain, “HF is irritating at low concentration but not sensed at high concentration”?

Answer: At low concentration, the mucus membranes, respiratory tract, and skin will exhibit signs of exposure, e.g., sneezing, coughing and contact dermatitis. However, at higher concentrations, the skin may not show signs of damage for up to several hours after exposure. Because it can penetrate the skin and continue to cause internal damage, this potential lack of detection makes it particularly dangerous.

Questions for Large Area Scenario:

1. Question: Are there any equipment, pipes, valves, belts, or tanks low hanging or low to the ground causing worker to potentially need to step over, duck or trip if attempting to exit in a timely fashion?

Answer: Assume there are no equipment, pipes, valves, etc. near the ground. However, assume there are valves, pipes, equipment, etc. at waist level and higher that the worker can run into. Also, assume the large area is configured with equipment, pipes, etc. such that there are a few main alleys from which many smaller corridors emanate.

2. Question: Would there be any noise in the room i.e. loud machines running?

Answer: Yes, and the worker is wearing hearing protection.

Questions for Confined Space Scenario:

1. Question: What is the diameter, length, and direction of the “large pipe that runs through the middle of the room?

Answer: Assume the pipe diameter is 24 cm, length 5 m and direction is perpendicular to the wall with the alarm button.

Questions for Outdoors Scenario:

1. Question: Can we assume worker has the fitness to perform the action (opening gate)?

Answer: Yes.

2. Question: Night or day?

Answer: Results for both would be great.

3. Question: Should we account for inclement weather?

   Answer: Assume no inclement weather.

Additional Questions:

1. Question: Is the facility operating in normal mode?

   Answer: Yes.

2. Question: Could the release cause the worker/s to become distorted in any way based on size, thickness of cloud and hazardous properties?

   Answer: Yes.

3. Question: What are the boundary conditions, which describes the expected systems, site, and personnel status immediately after the initiating event? What are the assumptions prior to the rupture/release?

   Answer: Assume that immediately after the initiating event, personnel have entered emergency operations. Prior to the rupture/release personnel are performing their routine, day-to-day operations, and the facility is in normal mode.

4. Question: Workers may detect a release via sound, smell, skin irritation, hearing an alarm, or seeing fog or perhaps a spray. Which condition/s should we consider for this example?

   Answer: Assume that workers see the fog.

5. Question: How long has the worker been working at the facility (years, months)?

   Answer: Assume years.

6. Question: Do all staff at facility have the same training?

   Answer: All staff have the same training for immediately leaving the area upon seeing a white cloud.

7. Question: Are workers up to date on training?

   Answer: Yes.

8. Question: Source of UF_6 release for each scenario?

   Answer: For all scenarios, assume the release if from a ruptured valve stem on a tank.

9. Question: Does this type of event occur frequently? Has worker been in this situation before?

   Answer: Assume similar scenarios have occurred 2 times in the last five years. Assume, however, that the workers have not been in this situation before.

10. Question: Do you have any blueprints to help visualize the scenarios?

    Answer: Unfortunately, no. The scenario is based on a fictitious facility.