HUMAN RELIABILITY ANALYSIS FOR IMPLEMENTATION OF INCIPIENT FIRE DETECTORS IN FIRE PRAS

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NUREG-2180, Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detector Systems in Nuclear Facilities - Final Report, provides information on the performance and use of "very early warning fire detector systems" (VEWFDS) and the associated fire human reliability analysis (HRA) and probabilistic risk assessment (PRA) quantification, for electrical cabinet installations. This report documents the results of confirmatory research for an earlier, interim NRC staff position on the use and PRA quantification of these systems.

The fire risk reduction approach used in NUREG-2180 credits any additional time provided by VEWFDS[a] *toward an earlier time for fire suppression initiation. The HRA approach for this research addressed a number of novel aspects for HRA/PRAs, including:*

- *all operator actions taken without a reactor trip*
- *actions of licensed operators in the main control room, as well as that of field operators and instrument and control technicians*
- *no standard requirements for job aids (e.g., procedures) supporting operator actions*
- *time available for operator actions represented by a probability distribution, rather than a single point estimate*

This paper summarizes key aspects of the HRA provided in NUREG-2180, especially focusing on how current HRA approaches and quantification methods can be used for this non-traditional HRA/PRA application.

I. INTRODUCTION

The purpose of this paper is to summarize key aspects of a human reliability analysis (HRA) performed to support a larger study of incipient fire detector applications in nuclear power plants (NPPs) and an associated PRA quantification. The overall study is documented in NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detector Systems in Nuclear Facilities - Final Report."[1]

II. BACKGROUND

The purpose of the overall research documented in NUREG-2180 (Ref. 1) is to evaluate the performance of smoke detection system when configured for very early warning fire detection (VEWFD) applications in NPPs.

In 2008, the U.S. Nuclear Regulatory Commission (NRC) issued a staff interim position documented in a National Protection Association (NFPA) Standard 805 Frequently Asked Question (FAQ) 08-0046 (Ref 2). This staff interim position provides guidance on the use of these systems and the associated fire probabilistic risk assessment (PRA) quantification for in-cabinet applications. At the time, there was limited test data and PRA experience for such applications. As such, a confirmatory research program was needed. In addition, research was needed to advance the state of knowledge related to the performance of these systems.

The final report, NUREG-2180, consists of three parts: 1) presentation of fundamental smoke detection terminology and theory, summary of operating experience and literature review, and experimental approach and results, 2) evaluation of the performance of smoke detection technologies in quantitative terms, including estimation of parameters needed in the HRA/PRA quantification, human performance assessment (including HRA), and updated PRA quantification via and event tree model, and 3) summary, conclusions, and recommendations for future work. The research team was composed of NRC staff with expertise in disciplines that parallel the organization of the report (i.e.., fire protection, human factors, HRA and PRA).

[a] VEWFDS is commonly referred to as *incipient detection.*

The HRA portion of NUREG-2180 reflects the understanding and insights gained from Part 1, including several new inputs that support the PRA quantification shown in Part II. In other words, the HRA is specific to the inputs, scope, and other factors discussed in NUREG-2180.

III. SUMMARY HUMAN RELIABILITY ANALYSIS APPROACH

The HRA approach supports the fire PRA for incipient detector applications by addressing these key features of the fire PRA event trees:

1. paralleling FAQ 08-0046, the PRA represents the ability to suppress a fire earlier than would be possible without the early warning provided by an incipient fire detector (but quantifies using non-suppression failure probabilities),
2. two important end states for the PRA event tree include damage to the cabinet only and damage outside the cabinet,
3. all relevant actions related to incipient detector response are addressed, and
4. both in-cabinet and area-wide installations.

In order to provide such support to the fire PRA quantification, the HRA approach included:

- An HRA process similar to that in the Joint EPRI/NRC-RES Fire HRA Guidelines, NUREG-1921 (Ref. 3)
- Additional HRA process inputs from the ATHEANA HRA method[4, 5]
- Reliance on existing HRA quantification tools
- Inputs from a human factors (HF) analysis of tasks involved in the planned response to incipient detectors

The HRA process steps used in this project are:

1. define and interpret the issue,
2. define the scope of the analysis,
3. identify and define human failure events (HFEs),
4. perform qualitative analysis (including feasibility assessment),
5. perform HRA quantification,
6. perform dependency analysis,
7. perform recovery analysis,
8. perform uncertainty analysis, and
9. complete documentation.

The first five steps in the HRA process above are briefly summarized in this paper, with the human factors analysis that supported the HRA summarized first.

IV. SUMMARY OF SUPPORTING HUMAN FACTORS ANALYSIS

It was recognized early in this research that the HRA would benefit from human factors (HF) analysis support. Consequently, an HF expert was added to the research team.

Although support was provided throughout the project, the HF analysis assisted in providing the essential understanding of the human (both operators and technicians) response at the beginning of the research effort. As documented in NUREG-2180, the HF analysis contributed to the research effort by:

- assisting in the collection and interpretation of information about VEWFDS applications and associated human response
- developing a "tabletop" analysis of VEWFD response
- evaluating factors that could affect human performance.

IV.A. Information Gathering

The HF analysis section identifies the types of information gathering activities conducted at a high level, such as:

- document reviews (e.g., trips reports for NPP site visits, aspirating smoke detector (ASD) VEWFDS *alert* and *alarm* response procedures, vendor documentation for thermal imaging cameras and portable ASDs)
- interviews and surveys of relevant personnel at NPPs having VEWFDS installations
- plant site visits, including interviews and walkdowns with relevant NPP personnel regarding VEWFDS implementation and performance and regarding specific operational experience with VEWFDS applications.

IV.B. Tabletop Analysis

A tabletop analysis [b] is a technique that involves consulting with a group of experts who have an understanding of a system to define/assess particular aspects of that system. The discussions are typically directed around some basic framework (e.g., procedures). Many HRA methods or processes refer to this activity as "task analysis" and consider it to be an important input to HRA.

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[b] A "tabletop" analysis indicates less depth than what the HF discipline typically calls a "task analysis."

The specific tabletop analysis performed for this project is consistent with the overall scope of the research (i.e., personnel response to ASD VEWFD *alert*s and *alarm*s for in-cabinet applications in a fire suppression strategy). Figure 1 shows this results of the tabletop analysis with separate columns representing the time progression of the event overall, as well as the responses of four different types of personnel:

1. main control room (MCR) operators,
2. field operators (FOs),
3. digital instrumentation and control (I&C) technicians, and
4. the fire brigade.

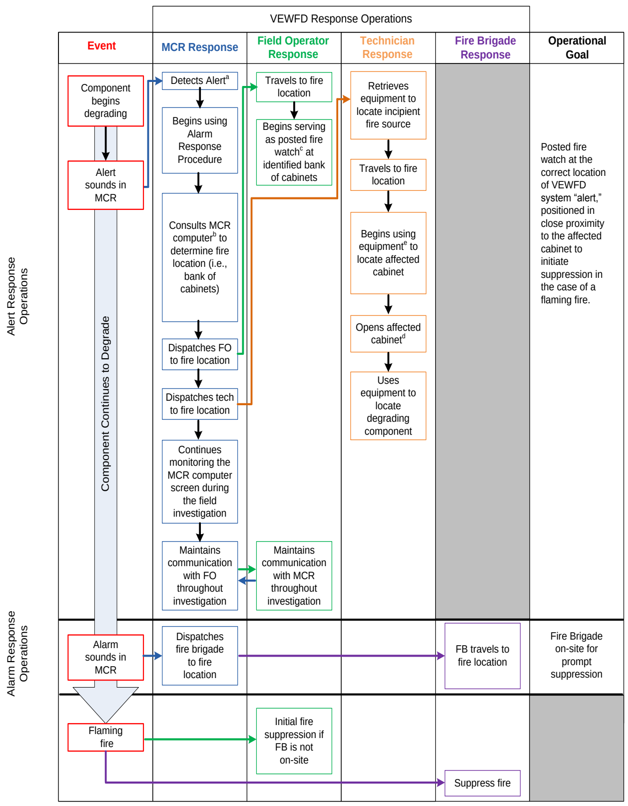

Fig. 1. Generic depiction of operations in response to an in-cabinet ASD VEWFD *alert* followed by *alarm* where a suppression strategy is being used.

Figure 1 also illustrates the following responsibilities:

- MCR operators are responsible for detecting an *alert*, using *alarm* procedures, dispatching the FO to the *alert* location, and, when the *alarm* is received, dispatching the fire brigade
- The FO is responsible for traveling to the *alert* location and providing fire suppression capability
- The technician is responsible for gathering necessary equipment, traveling to the *alert* location, opening (and unlocking, if needed) cabinets, and using a hand-held ASD to identify the source of the incipient *alert* (e.g., identifying the cabinet with the degraded component, then identifying the degraded component within the cabinet)

It was noted during the information gathering stage that NPPs vary in terms of key inputs to the HF tabletop analysis (and, therefore, the HRA). Examples of such variations include:

- where in the MCR the incipient detector *alert*/*alarm* is located
- where and how personnel retrieve information on the *alert* location (The tabletop analysis in Figure 1 assumes that there is a computer in the MCR that provides all relevant information on the VEWFD *alert*/*alarm*.)
- the level and quality of training for FOs regarding fire suppression capability
- whether keys are needed to open cabinet doors for the technician's surveys
- the type of portable detection equipment used to locate the degrading component

IV.C. Factors that Affect Human Performance

The HF analysis includes a brief discussion of factors that may adversely affect human performance. The factors addressed include:

- special equipment
- human-system interface (HSI)
- procedures
- training
- staffing
- communications
- complexity
- workload, pressure and stress

Some of these factors have been already mentioned and many of them will be discussed further as part of the HRA. In order to illustrate the type and quality of the HF discussion provided in NUREG-2180, a portion of the discussion of one factor, HSI, is summarized below.

HSI is the part of the system through which personnel interact to perform their functions and tasks. The availability, functionality, and usability of HSIs can impact personnel performance. Guidance for the evaluation of HSIs is provided in NUREG-0700, Revision 2 (Ref. 6). HSIs that are poorly designed (e.g., poor labeling, subpar computer interfaces), have been damaged, or are difficult to use, can negatively impact performance. Human performance can also be adversely impacted if the HSI does not display required information, or if the information is inaccurate. Much of the guidance in NUREG-0700 is intended for instruments, controls, and displays in the MCR, especially those needed for response to reactor trips and when using emergency operating procedures (EOPs).

The HF analysis specifically examines the requirements for alarms in the MCR. Although the NUREG-0700 guidance may be not explicitly required for *alert*s, *alarm*s, and other displays for VEWFDS, the NUREG-0700 guidance is useful because the requirements are intended to support rapid and reliable operator responses, which is also important for VEWFDS applications. Three relevant aspects of alarm design noted in NUREG-0700 are: 1) signal level of alarms (e.g., loud enough "...that users can reliably discern the signal above the ambient control room noise"), 2) alarm set points (e.g., set such that "nuisance alarms" are minimized), and 3) alarm location (e.g., alarms on MCR front panels will be responded to more quickly). As noted in the discussion of procedures, alarm response procedures (including their format, content, accessibility, and validity) can impact human performance negatively if not developed according to good human factors practices

V. HRA/PRA ISSUE AND SCOPE

These first two steps in this HRA process were borrowed from the ATHEANA[4, 5] HRA process. In the 2000s, the ATHEANA HRA team found these steps to be important when supporting a PRA on pressurized thermal shock (PTS), in which reactor vessel overcooling was the negative end state of interest (rather than the more traditional concern of reactor undercooling). Since then, these preliminary steps have been found useful in other HRA/PRA applications that address either non-NPP or other non-traditional PRA hazards or contexts.

V.A. PRA Issue to be Addressed

By defining the issue, the objective of the larger PRA study is described (as well as how the HRA must support the PRA's objective).

For the research documented in NUREG-2180, the following are the key aspects of the PRA issue(s):

- the PRA is for fire events
- the VEWFDS applications are focused on in-cabinet installations
- the overall analysis is intended to support the development of fire non-suppression probabilities appropriate for VEWFDS applications
- the objective of the VEWFDS applications (including human response) is to reduce the time needed to initiate fire suppression

Additional HRA-specific aspects of the PRA issue addressed in NUREG-2180 are:

- All human actions are taken without a reactor trip, but after a signal in the MCR from the VEWFDS.
- There are no standard requirements for traditional job aids (e.g., procedures, training, HSI) that support the human actions of interest.
- For the VEWFD applications discussed in this report, human actions and activities involve multiple types of personnel (e.g., MCR operators, field operators, I&C technician). For simplicity, all of these human activities are call "operator actions" in this research.

V.B. HRA/PRA Scope

The scope must be defined in order to understand any important assumptions or limitations for the HRA and/or PRA. These assumptions and/or limitations include:

- Because the objective of this research is to support a reduction in the overall fire non-suppression probability in the fire PRA, the human failure events (HFEs) defined must represent an end state that allows a quicker than usual suppression of a fire.
- The principal concern is fire damage outside of the cabinet where a degrading component is located (e.g., a fire that spreads to cable trays above the cabinet). Consequently, credit for “early” fire suppression is represented as an end state of “cabinet damage.” Conversely, “fire damage outside the cabinet” is a negative consequence end state.
- Adhering to HRA/PRA conventions, the HRA must appropriately represent operator actions with respect to type of operator activity, timing in the overall scenarios, location of activities, etc. Consequently, two different HFEs are modeled: 1) MCR operator actions, and 2) the combination of field operator and I&C technician actions.
- Like other fire PRA scenarios, the non-suppression probability is modeled separately from other human actions and is represented with statistical data (rather than HRA models).

- Input data for this HRA are consistent with general operational experience for NPPs and with current VEWFDS applications at NPPs, but do not represent any specific NPP.

These assumptions and limitations, along with the PRA scope, are important factors governing the development of the PRA (e.g., event trees, success criteria, input data, event tree end states) and supporting HRA. Consequently, the HRA approach and results in this research is likely to be inappropriate for other PRA efforts for VEWFDS applications.

VI. IDENTIFICATION AND DEFINITION OF HUMAN FAILURE EVENTS

In traditional PRAs, operator actions that mitigate an accident or that worsen plant conditions should be considered for representation as HFEs in PRA models. While this analysis is similar, it is not exactly the same as traditional HRA/PRA. In particular, two important things are different: 1) there is no reactor trip, so there is no traditional set of plant conditions for the operator to mitigate, and 2) instead, the objective is to model operator actions whose success would result in **early** fire suppression (i.e., earlier than traditionally modeled). Consequently, an operator "failure" in this analysis is "no early fire suppression" (i.e., normal fire suppression).

The identification of HFEs was based on: 1) earlier work (for example, Reference 7), 2) the HF tabletop analysis shown in Figure 1, 3) other HRA inputs, and 4) discussions with the project team in developing the corresponding event tree structure, heading, and success criteria.

The PRA event tree used for this HRA is given in Figure 2. As this figure shows, there are two HFEs modeled: 1) "μ" represents failure of MCR operator actions, and 2) "ξ" represents the combined failure of the field operator and technician. It is important to note that the event tree headings are for "success" (not failure) of operator actions (e.g., the event tree heading of "1-μ" represents a successful MCR response). Also shown in Figure 2, if both operator actions are successful, then "early" or "enhanced fire suppression" is possible. If both actions fail, then only conventional fire suppression is possible.

The high-level success criteria for the two modeled operator actions are:

1. after incipient detector *alert* signals, MCR operators must expeditiously dispatch both the FO and technician to the correct location for the VEWFD system in "*alert*," and
2. both the FO and technician must arrive at the correct location in a timely manner and the FO must provide fire suppression capability. (For the fire suppression strategy addressed in this research, the technician is of lesser importance than the FO.)

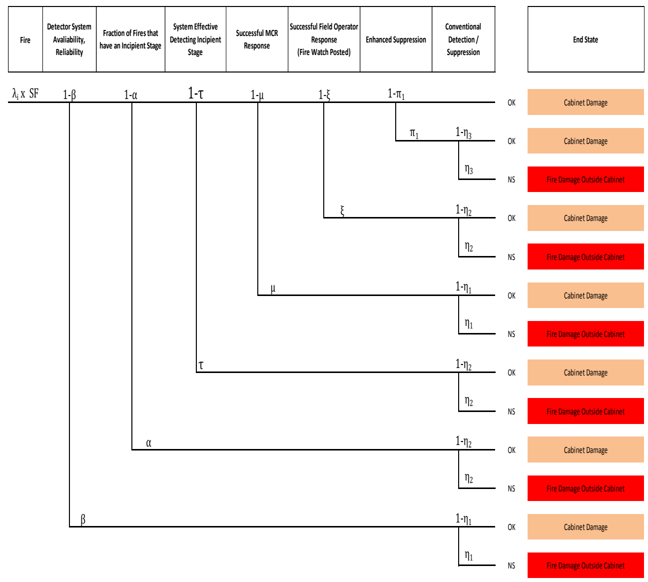

Fig. 2. Basic event tree for in-cabinet smoke detection non-suppression probability estimation.

Chapter 10 in NUREG-2180 (i.e., the HRA chapter) provides more details for the definition of the two HFEs, principally focused on "how" operator response is expected to occur for a successful and reliable outcome.

VII. QUALITATIVE HRA

As described in NUREG-1921 (Ref. 3), qualitative HRA is a vital step in HRA that provides the foundation for all other HRA products (e.g., identified and defined HFEs). Also, qualitative HRA is performed throughout the analysis, ending only when final outputs have been produced.

VII.A. General Information on Operator Response

As noted above, one of the ways that this analysis is different from other HRAs is that it has not been performed for a specific NPP installation of VEWFD. Instead, this analysis is for a "representative plant" that:

- to the extent possible, uses "real world" information (i.e., composite of information collected from three U.S. NPPs)

- is consistent with current U.S. NPP operational practices
- is based on the typical needs of existing HRA quantification tools

To illustrate the kinds of information provided in the qualitative analysis, example results for the MCR operator response are given, as follows:

- "MCR operator response" represents the collective effort of the MCR operating crew.
- VEWFD system *alert*/*alarm* annunciator panels are located in the MCR on the front panel.
- MCR operators respond to VEWFD system *alert*s and *alarm*s with urgency, as reinforced by procedures and training.
- Alarm response procedures (ARPs) guide the MCR operator response to the VEWFD signals.
- MCR operators dispatch the FO closest to the detector in "*alert*."
- Nuisance *alerts*/*alarm*s are minimal.
- VEWFD system *alert*/*alarm* signals are audible, according other MCR *alarm* standards (per HF analysis).

The qualitative analysis for the combined FO/technical response has a similar level of detail. For the FO, example results include:

- VEWFD system response is the highest priority job for the FO (upon receiving dispatch from the MCR).
- The FO is trained to travel expeditiously to the detector in "*alert.*"
- The FO is trained to suppress fires.
- The FO is trained to assume the role of fire suppression capability immediately upon arrival at the *"alert"* location.
- The FO is trained regarding incipient fire detectors and associated response (including initiation of fire suppression only AFTER there are visible effects of a fire).
- Required equipment (e.g., portable fire extinguisher) is available and accessible.
- The cabinet door does not need to be open for the FO to identify flaming conditions that require fire suppression.

VII.B. Timing Analysis: Time Available and Time Required

In addition, the qualitative analysis step includes the initial collection and assessment of timing inputs that are relevant to HRA. Timing inputs are typically produced either for the overall PRA (e.g., thermal-hydraulic calculations on when core damage occurs) or by the HRA analyst. As summarized below, there were complications in developing timing inputs for this analysis. NUREG-2180 provides more details on these difficulties and how they were resolved.

In traditional PRAs, time available inputs (e.g., time to core damage, time to steam generator dryout) are developed for the overall PRA, but are needed to HRA as well. This was true for the NUREG-2180 work as well. However, unlike traditional PRAs, the time available developed in NUREG-2180 was not a single data point; rather it was represented as a function of time and the type of incipient detector (due to performance variance). In order to address the distribution of probabilities, this research defined four sample points with which to sample the distribution. Each incipient detector type had a unique set of sample points. Table I illustrates how the sample points were used to sample the time available probability distribution for the ASD VEWFD cloud chamber.

TABLE I. Fraction of Probability Distributions for ASD VEWFD, Cloud Chamber

Sample	Cumulative probability for incipient stage ended	Time from *alert*	Fraction of probability distribution (split fraction)
1	0.10	0-12 minutes	0.10
2	0.23	>12 minutes AND < 30 minutes	0.13
3	0.40	> 30 minutes AND < ~1 hour	0.17
4	1.0	> ~ 1 hour	0.60

The time required for operator actions was determined by the HRA task. Using the available NPP inputs, a range of times were developed. Table II shows the time required for the responses of MCR operators and FO. (Note: The technician's timing is not given here since the most important timing is when the FO arrives with his/her fire suppression capability.)

TABLE II. Summary of Timing Inputs for Operator Actions after "*Alert*" Signal

Start of response	Who and Where?	Action(s) required for success	Time required (minutes)
Alert signal	MCR operator; MCR	Detect signal, use *alarm* response procedures, identify location of detector, and call to dispatch field operator	1-2
Call from MCR	Field operator in plant	Travel to location of VEWFD system in "*alert*": standby as fire watch by cabinet(s)	2-8
TOTAL TIME (MCR and field operator response)			3-10

VIII. FEASIBILITY ASSESSMENT

NUREG-1921 (Ref. 3) states that if an operator action is not feasible, then it should be assigned a failure probability of 1.0. NUREG-1921 identifies the following criteria for determining the feasibility of an operator action:

- Sufficient time
- Sufficient manpower
- Primary cues available and sufficient
- Proceduralized and trained
- Accessible location
- Equipment and tools available and accessible

Because of assumptions made in the qualitative analysis, all of the above criteria are met for the operator actions addressed in this research, **except** sufficient time. Consequently, the feasibility assessment in this work focused on assuring that the time available for performing actions exceeded that required for performing the actions.

Table III illustrates how the feasibility assessment was performed and documented for the ASD VEWFD cloud chamber detector. It should be noted that for the materials and configurations tested in the experimental program the cloud chamber typically responded sooner in the in-cabinet experiments, thus providing more time with respect to the needs of the HRA. Therefore, the results below provide an optimistic representation of VEWFD performance for in-cabinet installations.

TABLE III. Feasibility Assessment for ASD VEWFD, Cloud Chamber

Time required	Sample	Time available from *alert*	Feasible?
3-10 minutes	1	0-12 minutes	Yes
	2	>12 minutes AND < 30 minutes	Yes
	3	> 30 minutes AND < ~1 hour	Yes
	4	> ~ 1 hour	Yes

IX. SUMMARY OF HRA QUANTIFICATION

Because HRA quantification methods and associated human error probabilities (HEPs) were principally developed by and for post-initiator operator response, the overall strategy for quantification of operator actions in this research was to either describe or prescribe operational conditions for the incipient fire detector response actions that are similar or parallel to the more familiar post-initiator operator actions. The qualitative analysis is the starting point for implementing this strategy. A general basis for the HEPs is developed first, followed by a more context-specific HEP development.

IX.A. Basis for Human Error Probabilities

The development of a basis for assigned HEPs in this HRA consisted of two steps: 1) identify or define similarities in characteristics of the two contexts (i.e., post-initiator and incipient fire detection-fire suppression strategy), and 2) use identified similarities in context to justify similar HEPs. In this paper, only the basis for HEPs assigned to the MCR operator response and FO response are discussed. NUREG-2180 provides a complete discussion.

Several HRA quantification methods were considered. However, only a few HRA methods seemed suited to the context of interest. For the MCR operator response, NRC's SPAR-H method[8] and EPRI's cause-based decision tree method (CBDTM)[9] were considered appropriate matches to the operator actions taken in response to incipient fire detector signals (e.g., detecting *alarm*s, using ARPs, making phone call to FO). When both of these method when applied, the resulting HEP was in the 1E-4 range.

The FO response for the context of incipient fire detector applications involves activities that are very similar to that which might be modeled for an ex-control room action in an at-power, post-reactor trip Level 1 PRA, including some time urgency. In such cases, the Technique for Human Error Rate Prediction (THERP) HRA method[10] is often used to produce HEPs. However, typically the HFE modeled in the Level 1 PRA also involves equipment manipulation and this execution portion of the HFE would be the dominant contribution to the HEP. Since the incipient fire detector application does not involve any equipment manipulations, only a general HEP guidance from THERP and ATHEANA[4, 5] for "unlikely" or "very unlikely" failure probabilities (i.e., 1E-2 or 1E-3, respectively) is appropriate.

IX.B. HRA Quantification Results

As a reminder, the HRA quantification results summarized below apply only to those operator actions associated with the in-cabinet, VEWFD system installations, using the fire suppression strategy.

The HEP for the MCR operator response, in all cases, is assigned as 1E-4. Key reasons justifying this assignment include:

- A well-designed control room (including *alarm* panel placement and layout)
- Effective training and certifications
- Job aids (such as procedures that follow HF guidance with respect to content, presentation, and format)
- Communications protocols

The key to the success of the combined FO/technician response is for the FO to arrive quickly at the *alert* location and immediately provide fire suppression capability, per his/her training. Consequently, for this analysis (e.g., in-cabinet installation, fire suppression strategy), the only contribution to the failure probability for this HFE is from the assessment of the FO response.

In addition, the HRA quantification results will vary with between the four types of incipient fire detector technologies addressed in NUREG-2180, due to difference in timing of when the *alert* signal is produced (as it did in the feasibility assessments). Table IV shows the HRA quantification results for the ASD VEWFD cloud chamber detector (which is also the best-performing detector with respect to HRA). The table shows that an HEP of 1E-3 was used for time available less than 1 hour, and 1E-4 for more than 1 hour of available time. The total HEP (i.e., the value that is used for event tree quantification) is the sum of the probabilities calculated for each sample point in the time available probability distribution (i.e., 4.6E-4).

TABLE IV. HEP Calculations for ASD VEWFD, Cloud Chamber

Sample	Time available from *alert*	Split Fraction from Table 10-1	Base HEP	Base HEP x Split Fraction
1	0-12 minutes	0.1	1E-3	1E-4
2	>12 minutes AND < 30 minutes	0.13	1E-3	1.3E-4
3	> 30 minutes AND < ~1 hour	0.17	1E-3	1.7E-4
4	> ~ 1 hour	0.60	1E-4	6E-5
TOTAL HEP (ξ)				4.6E-4

X. CONCLUSIONS

The HRA performed in NUREG-2180 achieved its basic objective of improving upon previous efforts. Although the analysis is not plant-specific, the emphasis on using "real-world" information and existing HRA approaches and quantification tools allows this work to be used as an example for a plant-specific user.

Beneficial follow-on work could include further development of HRA/PRA guidance for de-energization strategies. NUREG-2180 provides beginning discussion on how such work would be done, but plant-specific and cabinet-specific variations make development of generic HRA/PRA guidance difficult. In addition, further development of HRA/PRA for de-energization strategies would require additional research on the reliability of the technician and of the portable detectors used to locate degraded components.

ACKNOWLEDGMENTS

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REFERENCES

1. U.S. NUCLEAR REGULATORY COMMISSION, *Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE)*, NUREG-2180 (December 2016).
2. U.S. NUCLEAR REGULATORY COMMISSION, “Closure of National Fire Protection Association 805 Frequently Asked Question 08-0046 Incipient Fire Detection System,” ADAMS Accession No. ML0932220426 (2009).
3. ELECTRIC POWER RESEARCH INSTITUTE and U.S. NUCLEAR REGULATORY COMMISSION, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines*, NUREG-1921/EPRI 1023001 (July 2012).
4. U.S. NUCLEAR REGULATORY COMMISSION, *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)*, NUREG-1624, Rev. 1 (May 2000).
5. U.S. NUCLEAR REGULATORY COMMISSION, *ATHEANA User’s Guide,* NUREG-1880 (June 2007).
6. U.S. NUCLEAR REGULATORY COMMISSION, *Human-System Interface Design Review Guidelines*, NUREG-0700, Revision 2 (2002).
7. U.S. NUCLEAR REGULATORY COMMISSION and ELECTRIC POWER RESEARCH INSTITUTE, *Fire Probabilistic Risk Assessment Methods Enhancements*, NUREG/CR-6850, Supplement 1, EPRI 1019259 (2010).
8. U.S. NUCLEAR REGULATORY COMMISSION, *The SPAR-H Reliability Analysis Method*, NUREG-6883 (August 2005).
9. ELECTRIC POWER RESEARCH INSTITUTE, *An Approach to the Analysis of Operator Actions in Probabilistic Risk Assessment*, EPRI TR-100259 (1992).
10. U.S. NUCLEAR REGULATORY COMMISSION, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, NUREG/CR-1278 (1983).