Proceedings of the High Energy Arcing Fault (HEAF) Workshop

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

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Disclaimer

Proceedings of the High Energy Arcing Fault (HEAF) Workshop

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Technical Report, November 2023
NRC Research Information Letter

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
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NOTE

ABSTRACT

This report documents the proceedings from a two-day workshop focusing on improving realism in the modeling of high energy arcing faults (HEAFs). The workshop was jointly sponsored under a collaborative research agreement between the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI). The workshop took place May 17-18, 2023, at the NRC Headquarters' Auditorium, One White Flint North, P2 Auditorium, 11555 Rockville Pike, Rockville, MD.

Presentations made by members of both research organizations, consultants, utilities, and NRC staff from the Office of Nuclear Reactor Regulation were made. The day one presentations provided the background, early work to understand the impact, experimental work, and model development. The second day was dedicated to presenting the probabilistic risk assessment (PRA) methodology and application. This included development of HEAF zone of influences, breakdown of an electrical distribution system, and a detailed presentation of the updated HEAF PRA methodology.

The workshop objective was to communicate the findings of the completed research to stakeholders and embrace the "teach" concept of the NRC's Be riskSMART framework. The workshop was hybrid (in-person and virtual participation).

Keywords
Arcing fault
Electrical explosion hazard
Fire probabilistic risk assessment
High energy arcing fault

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EXECUTIVE SUMMARY

PRIMARY AUDIENCE: Power generation facility staff, fire protection, electrical, and probabilistic risk assessment (PRA) engineers conducting or reviewing fire risk assessments related to high energy arcing faults (HEAFs).

SECONDARY AUDIENCE: Engineers, reviewers, utility managers, and other stakeholders who conduct, review, or manage fire protection programs and need to understand the underlying technical basis for the hazards associated with HEAFs.

KEY RESEARCH QUESTION

How do we communicate and teach the HEAF PRA methodology and lessons learned from the HEAF research program?

RESEARCH OVERVIEW

The Nuclear Regulatory Commission Office of Nuclear Regulatory Research (NRC-RES) and the Electric Power Research Institute (EPRI) HEAF working group was tasked with improving the methodology for assessing HEAF hazards at nuclear power plants. Through collaboration, an updated HEAF PRA methodology was published as NUREG-2262 / EPRI 3002025942, *High Energy Arcing Fault Frequency and Consequence Modeling*.

The development of NUREG-2262 evolved over several years. During that time, a thorough review of operational experience, performance of testing, development of target fragility estimates, application of fire modeling tools and development of risk modeling data and methodologies were conducted. An initial draft of the methodology was applied at two reference plants. The impact of the new methodology provided better insights and understanding of HEAF risk as compared to the simplistic treatment in NUREG/CR-6850 and Supplement 1. Through these efforts, significant progress was made in understanding the HEAF phenomena and improving realism in the methods used to assess facility risk from HEAF.

This report documents the presentations and discussions that took place during the two-day hybrid workshop held in May 2023 at the NRC Headquarters.

KEY FINDINGS

The workshop provided a forum to communicate the research findings and teach the new methods to the participants. Key insights from this workshop include:

- Operational experience played a key role to outline the scope of the hazard and focus research efforts.
- Review and understanding of the electrical distribution system focused the scope of the HEAF scenarios and defined the hazard by determining the typical fault currents and how to determine the fault clearing time input parameter.
- Testing provided needed data to evaluate target damage, provide model input values and

to support model validation.

- Use of expert judgment allowed for the development of target fragility thresholds along with technical guidance for applying the methodology.
- Computational fluid dynamic models allowed the research team to obtain data related to the surrounding environment in HEAF-susceptible equipment that could not be practically captured via experimentation due to the large number of configurations considered.
- The structured and detailed HEAF PRA methodology provides the needed updates to improve realism in risk assessment and allow the end user to focus resources on risk significant scenarios.

WHY THIS MATTERS

This report communicates the findings and products of the HEAF research to assist researchers, analysts, and stakeholders in evaluating the HEAF hazard.

HOW TO APPLY RESULTS

Engineers performing fire PRAs should focus on Section 11 of this report.

LEARNING AND ENGAGEMENT OPPORTUNITIES

The methodology and data described in the workshop proceedings is based off the technical report *High Energy Arcing Fault Frequency and Consequence Modeling* (NUREG-2262 and EPRI 3002025942).

Users of this report may be interested in periodic stakeholder engagement opportunities with EPRI and/or NRC on this topic.

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NRC CONTACT: Gabriel Taylor, Senior Fire Protection Engineer, gabriel.taylor@nrc.gov

PROGRAM: Nuclear Power, P41; and Risk and Safety Management, P41.07.01

IMPLEMENTATION CATEGORY: Reference – Technical Basis

CITATIONS

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This publication is a corporate document that should be cited in the literature in the following manner:

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ACRONYMS

ACRS	Advisory Committee on Reactor Safety
ADAMS	NRC’s Agencywide Document Access and Management System
CIGRE	Conseil International des Grands Réseaux Electriques, or International Council on Large Electric Systems
CRIEPI	Central Research Institute of Electric Power Industry
DG	diesel generator
EDS	electrical distribution system
EPRI	Electric Power Research Institute
ERFBS	electrical raceway fire barrier systems
FAQ	frequently asked question
FDS	Fire Dynamics Simulator
GCB	generator circuit breaker
HEAF	high energy arcing fault
HRR	heat release rate
IN	Information Notice
INPO	Institute of Nuclear Power Operations
IOC	instantaneous overcurrent
IPBD	isolated phase bus duct
LV	low-voltage
MV	medium-voltage
NEA	Nuclear Energy Agency
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation
NSBD	non-segregated bus duct
OECD	Organisation for Economic Co-operation and Development
PIRT	phenomena identification and ranking table
PRA	probabilistic risk assessment

RES	NRC's Office of Nuclear Regulatory Research
SAT	station auxiliary transformer
SF	severity factor
SNL	Sandia National Laboratories
UAT	unit auxiliary transformer
ZOI	zone of influence

1 INTRODUCTION

1.1 Background

Fire probabilistic risk assessments (PRAs) for nuclear facilities include consideration of high energy arcing faults (HEAFs), as documented in Electric Power Research Institute (EPRI) 1011989 / NUREG/CR-6850, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, issued September 2005 [1]. Volume 2 of NUREG/CR-6850 contains guidance for switchgear and load centers (Appendix M), and Supplement 1 [2] contains guidance for bus ducts. Both methods provide a simplified approach to quantifying the HEAF hazard; that is, they assume physical damage zones based on available operating experience that demonstrated extensive damage to surrounding equipment. Although the details of each method are documented in the references identified above, the methods generally assume all components and systems within the physical damage zone are ignited and unable to perform their intended function. Accordingly, these methods were considered conservative and simple approaches to quantify facility risk from HEAF events.

Starting in the 2010s, the NRC began an international collaboration to better understand the HEAF phenomena and advance the existing state of knowledge. This collaboration was facilitated through the Nuclear Energy Agency (NEA)/ Organisation for Economic Co-operation and Development (OECD), of which the NRC is a member. Under an OECD FIRE data exchange project, member countries share operating experience related to fires occurring at nuclear facilities in 12 countries. As part of the analysis of this data, “a nonnegligible number of reportable events with non-chemical explosions and rapid fires resulting from high energy arcing faults” was observed [3]. As a result of this observation and in alignment with the major goals of the NEA/OECD task to develop a correlation for predicting damage, establishing input data, and establishing boundary conditions for more detailed modeling, the member countries recommended the performance of a series of experiments.

From 2014 to 2016, the NRC led an international experimental program, as documented in NEA/CSNI/R(2017)7, *Report on the Testing Phase (2014-2016) of the High Energy Arcing Fault Events (HEAF) Project,* issued May 2017 [4]. This report documents 26 HEAF tests performed on a variety of donated electrical equipment. One significant finding from this work was that HEAFs involving aluminum components may result in greater damage and different failure modes than HEAFs that do not contain aluminum. Based on these findings, the international group recommended additional testing.

These findings prompted the NRC staff to re-evaluate the operating experience and identify HEAF events that involved aluminum components. The staff documented the results of this effort in Information Notice (IN) 2017-04, *High Energy Arcing Faults in Electrical Equipment Containing Aluminum,* issued August 2017 [5]. This IN summarizes the test results and identified six HEAF events that involved aluminum components and provides a qualitative description of those events.

In parallel, the NRC, EPRI, and the industry have also worked to better understand the HEAF phenomena. One of these initiatives include Frequently Asked Question (FAQ) 17-0013, *High Energy Arcing Fault (HEAF) Non-Suppression Probability (NSP),* dated March 21, 2017 [6]. This FAQ refined the manual NSPs for HEAF events. In addition, EPRI developed three whitepapers [7, 8, 9] that address the importance of maintenance, an overview of nuclear power plant electrical distribution systems, and characterize operating experience and testing.

In 2017, the NRC staff began formalizing an international agreement to perform a Phase II testing campaign to address knowledge gaps and further explore the impact aluminum plays in HEAF events. The NRC issued a draft test plan for public comment in the Federal Register on August 2, 2017, and held a public workshop on April 18–19, 2018, at the NRC Headquarters in Rockville, MD. The information from that workshop is presented in NUREG/CP-0311 [10].

Following the 2018 workshop, the NRC formalized the international agreement and test plan and presented its plan to the Advisory Committee on Reactor Safety (ACRS). The first series of medium-voltage switchgear was performed in 2018 [11], with a second series of low-voltage switchgear and open box testing performed in 2019 [12, 13]. Subsequent testing was planned for 2020, but due to the COVID-19 global pandemic, the testing was put on hold until 2022.

EPRI performed a thorough and comprehensive survey and analysis relative to HEAFs in the presence of aluminum for US nuclear facilities [14]. This effort revealed that substantially more medium-voltage switchgear, low-voltage switchgear, and non-segregated bus ducts contain aluminum than may have originally been assumed. This work also provided valuable information on the types and population of equipment, along with fault clearing times that was essential for defining HEAF scenarios.

To continue advancements to the state of knowledge, the NRC and EPRI formed a working group under a Memorandum of Understanding. The mission of the group was to leverage technical expertise and resources from both organizations to efficiently advance the state of knowledge and improve understanding of risk from electrical arcing fault hazards in nuclear power plants. The charter of this working group identified its goals as 1) characterize the primary factors that influence the occurrence and severity of arcing fault events and 2) develop tools and methods to assess the risk posed by arcing fault events based on experimental data, operating experience, and engineering judgment. This collaboration resulted in several technical reports and ultimately the publication of an updated and more realistic fire PRA method to assess HEAF risk [15].

1.2 About This Report

This report summarizes the presentations and discussions held during a two-day workshop from May 17-18, 2023, held at the NRC Headquarters in Rockville, MD. The workshop was jointly sponsored by NRC and EPRI. The workshop communicated findings of data and methods related to risk assessment for HEAFs. The workshop supported the “Teach” element of the NRC’s Be riskSMART framework.

The workshop was held over two days with 22 presenters and over 30 presentations. Presentations from both research organizations, consultants, utilities, and NRC staff from the Office of Nuclear Reactor Regulation were made. The first day presentations included providing a background, early work to understand the impact, testing, and model development. The second day was dedicated to the application of the updated PRA methodology. This included development of HEAF zone of influences, breakdown of an electrical distribution system, and a detailed presentation of the updated HEAF PRA methodology. Questions and responses received during the workshop are summarized in this report.

1.2.1 Day 1 – May 17, 2023

The first day agenda is presented in Table 1-1 with reference to the presentation which can be accessed via the NRC Agencywide Document Access and Management System (ADAMS) Accession number. The ADAMS package containing all slides has the accession number ML23150A023.

Table 1-1
Agenda, Day 1 - May 17, 2023

<table>
<tr><th>Time</th><th>Topic</th><th>Presenter</th><th>ADAMS Accession #</th></tr>
<tr><td rowspan="3">8:30 am</td><td rowspan="3">Welcome and Introduction</td><td>John Tappert
Acting Deputy Director
Office of Nuclear Regulatory Research
U.S. NRC</td><td>ML23150A024</td></tr>
<tr><td>Fernando Ferrante
Risk and Safety Management Program Manager
Electric Power Research Institute</td><td>ML23150A025</td></tr>
<tr><td>Mark Henry Salley
Branch Chief
Office of Nuclear Regulatory Research
U.S. NRC</td><td>ML23150A026</td></tr>
<tr><td>9:00 am</td><td>Be riskSMART</td><td>Mark Henry Salley</td><td>ML23150A027</td></tr>
<tr><td rowspan="5">9:15 am</td><td colspan="2">The Concern</td><td></td></tr>
<tr><td>Background</td><td>Nicholas Melly
Fire Protection Engineer
Office of Nuclear Regulatory Research
U.S. NRC</td><td rowspan="3">ML23150A028</td></tr>
<tr><td>Operating Experience</td><td>Ken Fleischer
Principal
Fleischer Consultants, LLC</td></tr>
<tr><td>International Experience</td><td>Nicholas Melly</td></tr>
<tr><td>Japanese Regulations</td><td>Koji Shirai
Program Director
Central Research Institute of Electric Power Industry (CRIEPI)
Koji Tasaka, CRIEPI</td><td>ML23150A029</td></tr>
</table>

Table 1-1 (cont.)
Agenda, Day 1 - May 17, 2023

Time	Topic	Presenter	ADAMS Accession #
10:00 am	Early Risk Insights		
	LIC-504	Reinaldo Rodriguez Reliability and Risk Analyst Office of Nuclear Reactor Regulation U.S. NRC	ML23150A030
	IN 2023-01	Charles Moulton Fire Protection Engineer Office of Nuclear Reactor Regulation U.S. NRC	ML23150A031
10:30 am	Break		
10:45 am	Prevention and Maintenance	Ken Fleischer	ML23150A032
10:55 am	The Working Groups		ML23150A033
	PIRT	Ken Hamburger Fire Protection Engineer Office of Nuclear Regulatory Research U.S. NRC	
	EPRI/NRC Working Group	Ken Hamburger Marko Randelovic Principal Technical Leader Electric Power Research Institute	
11:10 am	Testing		ML23150A034
	Cable Fragility Testing	Gabriel Taylor Senior Fire Protection Engineer Office of Nuclear Regulatory Research U.S. NRC	
	Small-scale Testing	Austin Glover Science and Engineering Project Manager Sandia National Laboratories	
12:00 am	Lunch Break		
1:00 pm	Testing (continued)		ML23150A034
	Open Box Testing	Gabriel Taylor	
	Large-scale Testing	Gabriel Taylor	
1:45 pm	Questions and Discussions		
2:00 pm	Break		

Table 1-1 (cont.)
Agenda, Day 1 - May 17, 2023

Time	Topic	Presenter	ADAMS Accession #
2:15 pm	The Modeling		
	Modeling Approach	Marko Randelovic	ML23150A035
	FDS physics and proof of concept	Kevin McGrattan Fellow National Institute of Standards and Technology (NIST)	
	Input development	Ken Hamburger	
	Model Validation	Sean Hunt Senior Engineer Jensen Hughes	
4:00 pm	Questions and Discussion		
4:15 pm	Fragility	Gabriel Taylor	ML23150A036
4:45 pm	Adjourn for Day 1		

1.2.2 Day 2 – May 18, 2023

The second day agenda is presented in Table 1-2. The ADAMS package containing all slides has the accession number ML23150A023.

Table 1-2
Agenda, Day 2 - May 18, 2023

Time	Topic	Presenter	ADAMS Accession #
8:30 am	FDS ZOI Report		ML23150A037
	ZOI Simulation Matrix	Dane Lovelace Circuit Analysis Supervisor Jensen Hughes	
	Low-Voltage Simulations	Dane Lovelace Sean Hunt	
	Medium-Voltage Simulations	Dane Lovelace Sean Hunt	
	Non-segregated Bus Duct Simulations	Ken Hamburger	
9:30 am	Electrical Distribution Systems (EDS)		ML23150A038
	HEAF EDS Zones	Ken Fleischer	
	Generator Circuit Breaker	Ken Miller Team Lead Office of Nuclear Regulatory Research U.S. NRC	

Table 1-2
Agenda, Day 2 - May 18, 2023

Time	Topic	Presenter	ADAMS Accession #
	Fault Progression	Gabriel Taylor	
11:15 am	Fire PRA Methodology		ML23150A039
11:30 am	Overview of PRA report	Ashley Lindeman Principal Project Manager Electric Power Research Institute	
11:45 am	Questions and Discussion		
12:00 pm	Break		
1:00 pm	Fire PRA Methodology (continued)		ML23150A039
	Low-Voltage Switchgear (Load Centers)	Ashley Lindeman	
	Medium-Voltage Switchgear	Ashley Lindeman	
2:30 pm	Break		
2:45 pm	Fire PRA Methodology (continued)		ML23150A039
	Non-segregated Bus Duct – Counting, Frequency, ZOI, Modeling	Nick Melly	
	Iso-phase Bus Duct		
3:15 pm	Questions and Discussion		
3:30 pm	User Perspectives	Suzanne Loyd Senior Manager Constellation	ML23150A040
		Charlie Young Risk Analyst Jensen Hughes	
		Gregory Zucal Risk Management Engineer Jensen Hughes	
	Program Wrap-up		
4:15 pm	Non-PRA Applications for Fire Analysis	Mark Henry Salley	ML23150A041
4:30 pm	Remaining Work: OECD/NEA Program	Nick Melly	ML23150A042
4:45 pm	Closing Remarks	Michael Franovich Director Division of Risk Assessment Office of Nuclear Reactor Regulation	ML23150A043
		Fernando Ferrante	
5:00 pm	Adjourn Workshop		

2
WELCOME AND OPENING

2.1 Workshop Opening

John Tappert, Acting Deputy Director in the NRC Office of Nuclear Regulatory Research, opened and welcomed everyone to the workshop. After welcoming the workshop participants, Mr. Tappert provided an overview of the work completed by the research organizations. Mr. Tappert's key message was the updated methodology represents a significant enhancement to the realistic treatment of high energy arcing faults (HEAFs). Application of the methodology allows the probabilistic risk assessment (PRA) to factor in the latest operating experience, experimental data, and state-of-the-art modeling which will yield a better understanding of the risk posed by HEAFs. Mr. Tappert acknowledged the many organizations that made this research possible along with wishing all participants a productive workshop.

Fernando Ferrante, Risk and Safety Management Program Manager at the Electric Power Research Institute (EPRI) welcomed the participants and provided an overview of the technical issue. Mr. Ferrante identified that a number of deliverables provided significant value to the stakeholders. He highlighted the tremendous value of the collaboration between the two organizations to leverage technical expertise and provide key insights and takeaways from this project. All these efforts demonstrate that risk assessment is an extremely valuable tool.

Marko Randelovic, HEAF Project Manager at EPRI, provided his background and introduced the EPRI working group members. Following these introductions, Mark Henry Salley, Branch Chief of the Fire and External Hazards Analysis Branch (FXHAB) in the Office of Nuclear Regulatory Research (RES) at the NRC introduced the NRC working group members.

Lastly, Mr. Salley, provided a presentation on the application of the NRC's Be riskSMART framework used for evaluating the HEAF concern. Be riskSMART is a program endorsed by the NRC in its efforts to becoming a modern risk-informed regulator. The program involves five key elements; Spot, Manage, Act, Realize, and Teach. This workshop embraced the TEACH element of Be riskSMART.

2.1.1 Presentation Slides

The slides presented in the workshop opening are available at the NRC's Agencywide Document Access and Management System (ADAMS) as follows:

- ML23150A024 – NRC Opening Remarks
- ML23150A025 – EPRI Opening Remarks
- ML23150A026 – HEAF Working Group Introduction
- ML23150A027 – Be riskSMART

3
THE CONCERN

3.1 Background

Nicholas Melly, Fire Protection Engineer in the NRC Office of Nuclear Regulatory Research (RES) provided a background of the high energy arcing fault (HEAF) concern. A list of definitions for arc flash, arc blast, and a HEAF was presented to distinguish between these three electrical arc fault types and to differentiate between a HEAF (which is evaluated in risk analysis) versus the other types of electrical arcs which are not included in the HEAF evaluation. Next a brief history of the HEAF probabilistic risk assessment (PRA) methods were presented, along with research and efforts undertaken between the development of the initial methods and the potential HEAF concern identified in 2017 [5].

3.1.1 Presentation Slides

The slides presented on the background of the HEAF project are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A028.

3.2 Operating Experience

Ken Fleischer provided a detailed overview of recent operational experience, including a description of a generator fed fault and the impact of a fault fed by a generator's rotating decay energy.

3.2.1 Presentation Slides

The slides presented on HEAF operating experience are available at NRC's ADAMS under accession number ML23150A028.

3.3 International Experience

Nick Melly presented a historical international event that occurred at Maanshan (Taiwan) in 2001 and resulted in several complicating factors that impaired a timely plant response. The HEAF operational experience at Onagawa in 2011 was also discussed. This was a seismically-induced HEAF that caused arcing and subsequent fire damage in the medium-voltage switchgear. This HEAF event took an extended period of time to extinguish due to earthquake damage in the area impeding the offsite fire department access to the site.

3.3.1 Presentation Slides

The slides presented on international HEAF experience are available at NRC's ADAMS under accession number ML23150A028.

3.4 Japanese Regulations

Koji Shairai and Koji Taska from the Nuclear Risk Research Center (CRIEPI) in Japan presented their experimental research activities. Dr. Shairai identified the HEAF/OECD projects and deliverables since 2012. Changes in Japanese regulations were identified along with an overview of the test facilities used for Japanese research. Mr. Taska presented the CRIEPI research program including the six phases of the program. Open tests were used to develop a proposed ZOI model, along with evaluation of ignition and target damage. Research did identify that the thermal impact differed dependent on the presence of aluminum or copper conductors.

3.4.1 Presentation Slides

The slides presented on the Japanese HEAF research efforts are available at NRC's ADAMS under accession number ML23150A029.

4
EARLY RISK INSIGHTS

4.1 LIC-504

Reinaldo Rodriguez, Reliability and Risk Analyst from the NRC's Office of Nuclear Reactor Regulation (NRR) presented on the LIC-504 assessment. LIC-504 is an NRC process used to disposition emergent safety issues and document the basis for those decisions. A brief background of LIC-504 was presented along with an example of its graded approach. Mr. Rodriguez then provided a summary of the LIC-504 application to the high energy arcing fault (HEAF) assessment, which included its scope, effort, insights, and recommendations.

4.1.1 Presentation Slides

The slides presented covering LIC-504 are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A030.

4.2 Information Notice 2023-01

Charles Moulton, Fire Protection Engineer in NRR, provided an overview of Information Notice 2023-01, *Risk Insights from High Energy Arcing Fault Operating Experience and Analyses* [16]. Insights included an emphasis on prevention, maintenance, and probabilistic risk assessment (PRA) models to identify risk significant equipment and help focus resources.

4.2.1 Presentation Slides

The slides presented on Information Notice 2023-01 are available at NRC's ADAMS under accession number ML23150A031.

4.3 Prevention and Mitigation

Ken Fleischer provided a presentation on HEAF prevention and mitigation, summarizing the work documented in EPRI 3002015459, *Critical Maintenance Insights on Preventing High-Energy Arcing Faults* [7]. This effort was performed by EPRI and focused on maintenance insights and its importance for minimizing the likelihood and/or severity of a HEAF. This presentation identified other documents related to the reliability and maintenance of electrical equipment to reinforce the concept and importance of maintenance to help either prevent or improve the mitigation of HEAF events.

4.3.1 Presentation Slides

The slides presented on HEAF prevention and mitigation are available at NRC's ADAMS under accession number ML23150A032.

5
THE WORKING GROUP

5.1 International Phenomena Identification and Ranking Table

Ken Hamburger, Fire Protection Engineer, in the Office of Nuclear Regulatory Research (RES) presented a summary of the international phenomena identification and ranking table (PIRT) exercise conducted for HEAF. Mr. Hamburger started by presenting an overview of the OECD Phase 1 testing program, which identified that a PIRT would be beneficial to help focus research efforts to better understand parameters that impact the HEAF hazard as well as the state-of-knowledge for HEAFs. Mr. Hamburger summarized the conclusions and recommendations from the International PIRT.

5.1.1 Presentation Slides

The slides presented on the international PIRT exercise are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A033.

5.2 EPRI/NRC HEAF Working Group

Ken Hamburger next presented the EPRI/NRC HEAF Working Group. This presentation included identifying the need, objectives, members, and deliverables from the working group.

5.2.1 Presentation Slides

The slides presented on the EPRI/NRC HEAF Working Group are available at NRC's ADAMS under accession number ML23150A033.

6
TESTING

6.1 Cable Fragility Testing

Gabriel Taylor, Senior Fire Protection Engineer, in the NRC Office of Nuclear Regulatory Research provided a presentation on the testing performed to support data development, analysis, and decision making for the project. Fragility testing summarized the need for data to support a determination of when probabilistic risk assessment (PRA) targets are damaged or ignited from a high energy arcing fault (HEAF). Mr. Taylor presented the approach, test facility, phases of testing, instrumentation, and results from the fragility testing.

6.1.1 Presentation Slides

The slides presented on cable fragility testing are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A034.

6.2 Small-Scale Testing

Austin Glover, Project Manager, Risk and Reliability Analysis Department, Sandia National Laboratories provided an overview of the small-scale testing performed to evaluate the differences between electrode materials. Mr. Glover presented the need for data, the types of information that was collected, the approach taken to obtain the information, and the results. The results from this work were used to inform model development and input parameter formalization.

6.2.1. Presentation Slides

The slides presented on small-scale testing are available at NRC's ADAMS under accession number ML23150A034.

6.3 Open Box Testing

Gabriel Taylor presented the results of the open box test experiments. The need, approach, test facility, instrumentation, test matrix, and results were presented. In addition, Mr. Taylor presented videos taken during the experiments that demonstrated key insights with respect to arc characteristics. Key insights included valuable data for mass loss (enclosure and electrode), energy characterization by material type, useful data to disposition air conductivity, air breakdown, and surface conductivity concerns.

6.3.1 Presentation Slides

The slides presented on open box testing are available at NRC's ADAMS under accession number ML23150A034.

6.4 Large-Scale Testing

Gabriel Taylor closed out the testing presentation by providing an overview of the full-scale HEAF testing. The presentation included identifying the need, objectives, approach, facility, equipment, instruments and arrangement, imaging techniques, and experimental parameters. Mr. Taylor presented several videos taken during the testing, and then summarized the key insights from the full-scale testing, including, enclosure breach characteristics, mass loss, energy measurement insights, pressure measurements, and particle analysis results that were consistent with the small-scale experimental results.

6.4.1 Presentation Slides

The slides presented on large scale testing are available at NRC's ADAMS under accession number ML23150A034.

7
THE MODELING

7.1 Modeling Approach

Marko Randelovic, EPRI Principal Technical Leader, provided a background on the decision to use the National Institute of Standards and Technology's (NIST's) Fire Dynamics Simulator (FDS) to simulate the HEAF hazard. Mr. Randelovic noted the work performed by Sandia National Laboratories (SNL) to explore the multi-physics model and development of input parameters and model characterization. As part of the FDS effort, a proof of concept and benchmarking were performed to evaluate the applicability of using FDS to estimate the HEAF hazard.

7.1.1 Presentation Slides

The slides presented on the HEAF modeling approach are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A035.

7.2 FDS Physics and Proof of Concept

Dr. Kevin McGrattan, Fellow at NIST, presented the early work performed by SNL and the differences in assumptions between FDS and SNL's Aria/Fuego simulation model. Next the features and limitations of FDS were presented, along with the key assumptions relevant to the modeling in FDS. Next Dr. McGrattan discussed the application of the model and the comparisons to the experimental results, noting the importance of enclosure breach. Finally, a discussion on the oxidation and modeling of this phenomena was presented.

7.2.1 Presentation Slides

The slides presented on the use of FDS are available at NRC's ADAMS under accession number ML23150A035.

7.3 Input Development

Ken Hamburger, Fire Protection Engineer, NRC/RES, presented the theory and development of the input parameters for the HEAF FDS model. The HEAF volumetric heat source profiles were presented along with the basis for these profiles. The basis for the radiative fraction was next discussed focusing on the research performed by Cressault, et. al, on radiation of long and high-power arcs [17]. Next the electrode mass loss estimation and the method of Stanback Jr. was discussed. Finally, the particulate characterization from experimentation to model were presented and the focus on 5-10 micron size distribution, along with how these particles are released into the FDS computational domain. Finally, Mr. Hamburger summarized the input parameters and model adjustments required to allow FDS to simulate HEAF conditions and the associated hazard estimation.

7.3.1 Presentation Slides

The slides presented on the FDS input development are available at NRC's ADAMS under accession number ML23150A035.

7.4 Model Validation

Sean Hunt, Senior Engineer at Jensen Hughes, presented the FDS results. First the FDS grid resolution and domain configurations (resolutions) were presented. Next the model output quantities were identified to be consistent with the fragility to allow for determination of the zone of influence (ZOI). The model evaluation of uncertainty and bias were then presented. Finally, Mr. Hunt presented the approach taken to correlate model output to ZOI.

7.4.1 Presentation Slides

The slides presented on the FDS model validation are available at NRC's ADAMS under accession number ML23150A035.

8
TARGET FRAGILITY

8.1 Target Fragility

Gabriel Taylor presented the approach taken to develop target fragility estimates. Fragility refers to the criteria where a component is assumed to fail. For HEAF fragility, both loss of function (damage) and ignition were evaluated. Mr. Taylor identified the need for determining target fragility for HEAFs and how the fragility and modeling results are used to determine the zone of influence (ZOI). The fragility determination used a simplified expert elicitation process, and Mr. Taylor presented an overview of the approach, objectives, and scope of the process. Next the results from the effort were presented along with the special cases such as electrical raceway (conduits, cable trays with bottoms and covers) and electrical raceway fire barrier systems (ERFBS). Lastly, Mr. Taylor presented the fragility for non-cable targets addressed in NUREG-2262 Appendix F [15]. The approach, results, and guidance were presented.

8.1.1 Discussion

Question 8.1: Doesn't defining a fragility for steel air piping create an opportunity to challenge plant process piping? I think it would be limited to thin wall instrument tubing.

Response 8.1: The guidance is only appliable to air instrumentation lines which are fairly thin and filled with air. Liquid piping is generally thicker walled, and the liquid has a high heat capacity.

8.1.2 Presentation Slides

The slides presented on target fragility are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A036.

9
FIRE DYNAMICS SIMULATOR HIGH ENERGY ARCING FAULT ZONE OF INFLUENCE REPORT

9.1 ZOI Simulation Matrix

Dane Lovelace, Circuit Analysis Supervisor at Jensen Hughes, presented the overview and process used to develop the simulation matrix.

9.1.1 Presentation Slides

The slides presented on the FDS ZOI simulation matrix are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A037.

9.2 Medium-Voltage Switchgear Simulations

For medium-voltage (MV) switchgear, Mr. Lovelace identified that the industry survey performed by EPRI [14] provided valuable information that helped focus on the important parameters to consider in the model simulations (e.g., the types and population of switchgear and the fault clearing times). Next Mr. Lovelace discussed the equipment configurations and the likely locations for the arc to occur based on operational experience. A brief discussion on power flow was given to communicate the influence of power flow on the ultimate arc fault location. Power profiles were discussed and how the profiles were developed and used for the simulation process. Finally, Mr. Lovelace summarized the minimal set of simulation scenarios for modeling.

Sean Hunt next presented the MV switchgear simulations, results, and insights from the FDS modeling of MV switchgear HEAFs. Vertical lift and horizontal draw out type medium-voltage switchgear simulations were presented. FDS predicted trends and comparisons between aluminum and copper were provided. Mr. Hunt concluded with a summary of the ZOI range for the MV switchgear simulations.

9.2.1 Presentation Slides

The slides presented on the MV switchgear HEAF simulations are available at NRC's ADAMS under accession number ML23150A037.

9.3 Low-Voltage Switchgear (Load Centers) Simulations

Dane Lovelace discussed the type of low-voltage switchgear found in the United States based on the EPRI survey [14]. Next, he provided a brief presentation on load center design and the insights from testing. A low-voltage switchgear HEAF event from EPRI's fire events database was discussed in detail as this event formed the basis for the power profile for the low-voltage FDS simulations. Finally, low-voltage switchgear parameters, power profile / flow, sensitivities, and the simulation matrix were presented.

Sean Hunt presented the low-voltage switchgear simulations, results and insights from the FDS modeling of low-voltage switchgear. FDS predicted trends and comparisons between aluminum and copper were provided. Mr. Hunt concluded with a summary of the ZOI range for the low-voltage simulations.

9.3.1 Presentation Slides

The slides presented on the low-voltage switchgear HEAF simulations are available at NRC's ADAMS under accession number ML23150A037.

9.4 Non-segregated Bus Duct Simulations

Ken Hamburger presented the non-segregated bus duct scenario development. First the parameters and general configurations found in the field were presented. Then the power profiles and simulation matrix were shown. Then Mr. Hamburger went over the results from the bus duct tee simulations. Mr. Hamburger noted the difference between the aluminum bus duct housing versus the steel duct housing and described why this was expected but has an impact on the determination of the ZOI.

9.4.1 Presentation Slides

The slides presented on the non-segregated bus duct HEAF simulations are available at NRC's ADAMS under accession number ML23150A037.

10
ELECTRICAL DISTRIBUTION SYSTEMS

10.1 HEAF Electrical Distribution System Zones

Ken Fleischer, presented on the electrical distribution system (EDS) and the high energy arcing fault (HEAF) zones. Mr. Fleischer went over key events and the lessons learned from a detailed understanding of these events. Next a simplified EDS was introduced, including the concept of a unit connected design and its impact for generator fed faults. Various types of faults were described as they relate to the EDS. Mr. Fleischer presented the EDS zones as defined for use in the HEAF methodology and followed with a brief discussion on fault clearing times and coordination. The fault clearing times for auxiliary power transformers were presented based on information collected from the EPRI survey [14]. Finally, Mr. Fleischer presented examples of fault scenarios, including the concept of a supply breaker limited fault.

10.1.1 Discussion

Question 10.1.1: Mr. Fleischer showed a slide illustrating EDS selective coordination. It showed that when a fault occurs, and the first circuit breaker does not open, that the delay necessary for the next upstream breaker to open could increase arc duration. The upstream breaker will likely have a higher working current. In general, what is the relative importance of these two factors on potential arc energy in a typical nuclear power plant?

Response 10.1.1: On slide 16 if the breaker closest to the fault opens first, the arc energy will be less than the next upstream breaker opening to clear the fault. The available fault current is calculated at both buses; however, the typical running current does not have a significant impact on the opening time of the next upstream breaker and as such the running current would be minimal in comparison to the magnitude of the fault current. If the first breaker upstream of the fault does not clear the fault, the next upstream breaker will, and the amount of energy released to the fault is dependent on the time current characteristic curve for that breaker. Generally, this is expected to be longer, but the actual amount of additional time will be dependent on the fault current and the characteristic curve. In relation to the total energy, the extended duration is expected to have a higher impact than current for a HEAF event (scenario) where the first breakers open.

10.1.2 Presentation Slides

The slides presented on the EDS and HEAF zones are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A038.

10.2 Generator Circuit Breaker

Kenn Miller, Team Lead, NRC/RES provided a presentation on the generator circuit breaker (GCB) and its impact on the ability to experience a HEAF in certain locations within the EDS along with crediting the GCB in the PRA methodology.

10.2.1 Presentation Slides

The slides presented on GCBs are available at NRC's ADAMS under accession number ML23150A038.

10.3 Fault Progression

Gabriel Taylor concluded the EDS presentation by walking through the fault progression process that the working group performed to determine the duration of HEAFs for various EDS zones with different equipment failure assumptions. Mr. Taylor provided a detailed description of the fault progression for a bus duct fault fed by the unit auxiliary transformer (UAT). Finally, an overview of the site auxiliary power transformer zone and Zone 1 scenarios were presented.

Ken Fleischer finished the EDS presentation with a summary of the EDS zone breakdown and the key concepts developed by the working group and used in the PRA methodology.

10.3.1 Presentation Slides

The slides presented on fault progression are available at NRC's ADAMS under accession number ML23150A038.

11
FIRE PROBABILISITIC RISK ASSESSMENT METHODOLOGY

11.1 PRA Methodology Overview

Ashley Lindeman, Principal Project Manager (EPRI's fire probabilistic risk assessment (PRA) project manager), provided an overview of the HEAF PRA methodology. Mrs. Lindeman started by outlining the various sections of the report. The work performed on the EDS setup the process and basis for the PRA methodology. Fragility results (presented in Section 8) were reviewed and summarized. Mrs. Lindeman discussed basic PRA assumptions related to physical barriers, suppression and detection, and bus duct initiation locations. Next a graphical representation of the HEAF ZOIs (both energetic and ensuing fire) were presented.
A comparison between switchgear and load center ZOIs from NUREG/CR-6850 and NUREG-2262 was presented. Mr. Melly provided additional insights on the shape and application of the ZOIs. Next, Mrs. Lindeman presented a comparison between the bus duct ZOIs from NUREG/CR-6850 Supplement 1 and NUREG-2262.

11.1.1 Discussion

Question: 11.1.1: ZOI diagrams in NUREG-2262 (Figure 6-3) [15] indicate HEAF influence areas to the front/back/sides/top of the enclosure, appearing to exclude areas extending from the corners of the cabinets. However, the testing clearly indicates heat and particulate ejecta emanating from the corners where the panels are initially bowed out. Are the ZOI block diagrams supposed to be interpreted more as a cylinder like the ensuing fire ZOI, similar to the diagram for a bus duct (Figure 6-4)? The discussion on page 6-3 [15] states that arc-plasma jet should considered "squared off" from the faces.

Response 11.1.1: From the analysis of the data and evidence available to the working group, the predominate areas where damage was either predicted or observed was perpendicular to the surface of the enclosure. The corners of the enclosure typically have reinforced structures that provide an additional layer of protection in those areas. The ensuing fire does cover the area near the corners of the enclosure.

Question 11.1.2: Regarding the generator circuit breaker failure probability shown in slide 15, is this a stable estimate to use or is there an expectation we will be required to update this in the future?

Response 11.1.2: Institute of Nuclear Power Operations (INPO) has a limited dataset for this type of data, so the working group had to look at the Conseil International des Grands Réseaux Electriques (CIGRE) literature survey for a variety of facilities around the world, which we ultimately used in our estimates. We believe this estimate is fairly stable but do understand that operational experience will have to be considered if it becomes available in the future.

11.1.2 Presentation Slides

The slides presented on the PRA methodology overview are available at NRC's ADAMS under accession number ML23150A039.

11.2 Load Centers

Ashley Lindeman continued the methodology discussion for load centers starting with an overview of the sections in the report related to analyzing load center HEAF risk. The basis for excluding motor control centers was discussed. Mrs. Lindeman presented the counting guidance for apportioning the low-voltage HEAF frequency to load center supply breakers, including an example of the guidance. Next the updated generic low-voltage HEAF ignition frequency and HEAF manual suppression likelihood estimates were presented. The HEAF ZOIs were discussed with four location dependencies emphasized. Lastly, guidance on how to model the ensuing fire including details on fire growth, steady state, and decay periods of the profile were presented.

11.2.1 Discussion

Question 11.2.1: HEAF Phase 1 Test 23, showed destruction of the switchgear upper interface on the top and side. Was this viewed as an atypical case for United States switchgear?

Response 11.2.1: Yes, this was seen as an outlier to the United States operating experience and a non-typical design of a load center in the US. A post-test photo of the experiment in question is shown in Figure 11-1.

Figure 11-1
Test 23 of OECD/NEA Phase 1 Program – Post Test

Question 11.2.2: Just to clarify – on a ‘double-ended’ load center, is the tie breaker ‘counted’ as a supply breaker?

Response 11.2.2: For load center counting, the tie breaker counting is dependent on the normal operation of that breaker. If the tie breaker is normally open, which is a common configuration, then it is not counted as a supply breaker. Appendix G.3.2 of NUREG-2262 [15] provides an example of this configuration. Alternatively, if the tie breaker is normally closed and energizing another section of load center, then it is counted as a supply breaker.

Question 11.2.3: If one supply breaker used to energize the bus 95% of the time and three other supply breakers e.g., diesel generator (DG) #1, DG #2, and alternate off-site supplies are used the remaining 5% of the time. The count is still 4?

Response 11.2.3: Under normal operation the diesel is not connected to the bus, and as such the two diesels are not considered a source, so the count is 2. Typically, on the alternate supplies the breaker is open, but the high side of the switchgear is still energized from the supply (primary or alternative) and a HEAF could still occur in the sections with the open circuit breakers due to the main bus being energized.

Question 11.2.4: Can we assume the positional ZOIs for 'B' still applies even if 'A' is a 'blank' cubicle? For this question, the 'compartment' A barriers are still present. This question is in reference to Slide 27.

Response 11.2.4: If A is a physical cubicle but empty, you can still use the B location for the ZOI and while the A cubicle is considered in the ZOI, the top of the A cubicle enclosure will not breach and you do not have to assume that the HEAF ZOI extends vertically above cubicle A.

Question 11.2.5: Please clarify if a weighting factor for load centers should be developed for each load center or just for the total number of supply circuit breakers for the plant. In the supply breaker counting example, there was a weighting factor calculated as 3/16. The 16 stated in the image says, "16 breakers in 4 sections" (of the load center), but my interpretation of the discussion was that the 16 represented the total numbers of supply circuit breakers in the plant.

Response 11.2.5: The count of load center supply breakers is on a plant wide count. Therefore, on Slide 23, the ignition source weighting factor is 3 supply breakers in the load center divided by 16 supply breakers in the plant. This figure is a little confusing because it also includes 16 total breakers in a 4 section lineup, but this total number of breakers for this scenario doesn’t influence the ignition source weighting factor.

Question 11.2.6: Would you consider a HEAF in a 600 V transformer and lighting panel?

Response 11.2.6: Transformers are not covered under NUREG-2262. Lighting panels, even at 600 V are not considered low-voltage switchgear (i.e., load centers) per NUREG-2262 and would not require the postulation of HEAFs.

Question 11.2.7: Where can I find this exclusion in NUREG-2262 of greater than or equal to 480V lighting panels as not to be considered as LV load centers?

Response 11.2.7: Low-voltage switchgear (load centers) are defined in the guidance specifically as devices that have powered circuit breakers. Panels such as lighting panels or motor control centers that use molded case circuit breakers are not part of the HEAF methodology in NUREG-2262.

Question 11.2.8: Obstructed plume and obstructed radiation should not be credited, is that for any location?

Response 11.2.8: The obstructed methods should not be credited due to the potential for an enclosure breach. In many HEAF events and tests, the enclosure door typically opens, so crediting the obstructed methodologies would not be consistent with that experience. If the analyst credits the obstructed methodology, that would be inconsistent with NUREG-2262 and is up to the analyst to provide the justification.

11.2.2 Presentation Slides

The slides presented on load center HEAF modeling are available at NRC's ADAMS under accession number ML23150A039.

11.3 Medium-Voltage Switchgear

Ashley Lindeman continued the discussion on the PRA methodology for medium-voltage (MV) switchgear. A summary slide showing the relevant sections of NUREG-2262 for MV switchgear was presented along with a refresher on the EDS. A roadmap for applying the ZOI for a scenario was shown. MV switchgear counting, frequency, weighting factors, and manual non-suppression rate was covered. A refresher on fault clearing times was provided followed by the graded approach for determining MV switchgear ZOIs. Mrs. Lindeman went over the various refinement levels that could be used if more refinement over the screening approach was needed. Finally, the ensuing fire modeling guidance for MV switchgear was presented.

11.3.1 Discussion

Question 11.3.1: If I have two off-site source breakers (one from the UAT and one from the station auxiliary transformer (SAT)) to one medium-voltage switchgear, and two source breakers are at opposite ends of the bus (with different targets), can I postulate two HEAF scenarios, one for each location. Can I apportion the frequency 50/50 to the two scenarios, or is there a better ratio to use?

Response 11.3.1: Both are considered due to operating experience and the potential for fast transfer complications. Split fractions have been developed that encompass the operating experience, the normal configuration, alternative configurations as well as what can potentially occur during an event progression, as well as power ascension and descension.

Question 11.3.2: If I have a single 'stack' switchgear that supplies a large motor - and that 'switchgear' is supplied by a load breaker from a Zone 1 switchgear to 50/51 devices - and possibly an 87 device (yes - 2 load breakers in series, but separated by over 100 feet) - is that 'second' switchgear still subject to HEAF treatment - counting and ZOI? An example of this configuration could be a motor located inside containment - redundant protection required per RG 1.63.

Response 11.3.2: Consistent with Section 3.8 of NUREG-2262, this 'single stall" switchgear is in Zone 2. Zone 2 is described on page 3-35 of NUREG-2262 as "Zone 2 is fed from the Zone 1 load branch circuit breakers without an instantaneous overcurrent (IOC) (50) relay." Therefore, the described scenario is in Zone 2 and a HEAF should be postulated.

Question 11.3.3: Are all the loads downstream of a Zone 2 switchgear considered a "load"? Or would you postulate another MV switchgear bank downstream of a Zone 2 Switchgear. (I would call it Zone 3 but that's already taken for LV).

Response 11.3.3: It is considered a HEAF ignition source and should be included in the frequency count. This particular case would fall into Zone 2.

Question 11.3.4: If there is only one supply to a lineup, what split fraction should you use?

Response 11.3.4: The split fractions for the normal and secondary supply should be added together.

Question 11.3.5: The only thing credited in propagation is the severity factor (SF). The growth is assumed instant?

Response 11.3.5: Section 6.5.1, "Fire Spread Between Adjacent Cabinets" of NUREG-2262 provides guidance on fire spread in adjacent cabinets. Due to the potential for the arc to breach the shared boundary, fire spread to the adjacent cabinet is postulated under certain arc energies. The fire growth is presented on Page 6-39 of NUREG-2262 and follows past practice for fire growth, steady-state, and decay profiles. For the vertical section with the HEAF, there is no growth time (the fire immediately reaches its peak heat release rate (HRR)). For propagation to the adjacent vertical section, the fire is assumed to begin at the initiation of the HEAF but grows to its peak in 12 minutes (growing fire from NUREG-2230). The times for an interruptible fire in NUREG-2230 do not apply.

Question 11.3.6: The hot gas layer needs to also assume secondary combustibles in the cable trays above and away from the switchgear. For suppression of these secondary combustibles, do I still need to use the HEAF suppression curve?

Response 11.3.6: Yes, you still need to assume secondary combustibles in the cable tray above and away from the switchgear HEAF. Yes, you still need to use the HEAF suppression curve.

11.3.2 Presentation Slides

The slides presented on MV switchgear HEAF modeling are available at NRC's ADAMS under accession number ML23150A039.

11.4 Non-Segregated Bus Ducts

Nicholas Melly presented the PRA methodology for non-segregated bus ducts (NSBD). A summary slide highlighting the numerous sections of the report applicable to NSBDs was shown. Then a summary of the EDS with applicable zones (i.e., BDUAT, BDSAT) was presented. Frequency partitioning (based on operating experience) was described. Counting and frequency apportioning methods were discussed. Next the event trees and ZOIs were presented, including the ZOI for the waterfall. Mr. Melly made the point of clarifying the differences between NUREG/CR-6850 Supplement 1 and NUREG-2262 in that the most recent method measures the ZOI from the exterior of the bus duct enclosure. Examples for applying the NSBD PRA guidance were covered. The session wrapped up with a presentation of the iso-phase bus duct HEAF modeling summary. Mr. Melly noted that the iso-phase bus duct guidance is consistent with the previous ZOI guidance (e.g., was not changed). However, the frequency and manual non-suppression rate were updated.

11.4.1 Discussion

Question 11.4.1: Unlike other post-HEAF ensuing fires which use the HEAF suppression rate, if a bus duct HEAF is assumed to ignite a switchgear (waterfall target) without a solid steel top, would this be a case for use of a Bin 15 suppression rate given an expected incipient phase?

Response 11.4.1: No, you still use the HEAF suppression rate.

Question 11.4.2: Did you consider a difference for ventilated (louvered) bus duct enclosures? The waterfall extends 1.5 ft from the edge of the duct. Does this mean any target below will be damaged and ignited?

Response 11.4.2: Ventilated bus ducts were considered. The damage and ignition assumptions are based on the fragility criteria for the target. Section 6.1.2 of NUREG-2262 [15] has guidance on damage and ignition assumptions depending on the scenario.

Question 11.4.3: Why is the iso-phase bus duct (IPBD) fault duration 4 to 18 seconds?

Response 11.4.3: Primary protection is differential protection, on failure of primary protection, backup protection is credited, and this serves the basis for the fault duration.

Question 11.4.3: Figure 11-2 shows a bus duct with "filtered breathers" located every 5 feet on the bottom of the ducts. Are these breathers considered "vents" per NUREG-2262? We consider them, since that was the ingress point for rain that led to a HEAF.

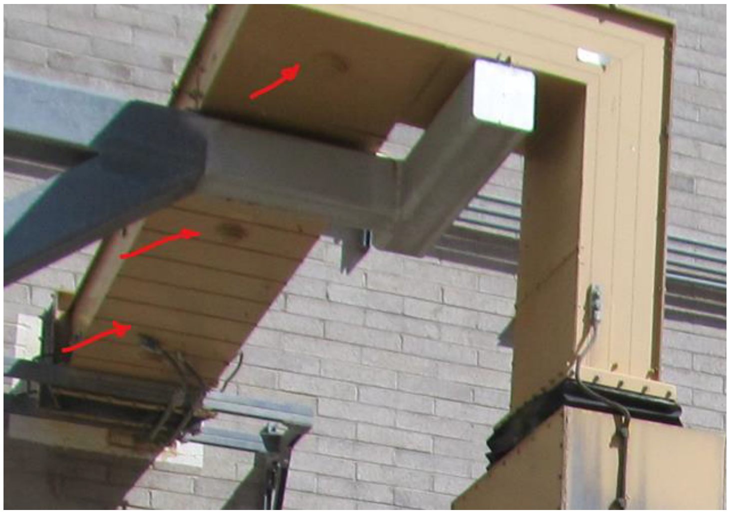

Figure 11-2
Attendee provided photo of bus duct with breathers

Response 11.4.3: Yes, that is the type of configuration that NUREG-2262 considers when it discusses vents on outdoor bus ducts.

Question 11.4.4: If HEAF occurs in a bus duct offset from the tray stack (say 1 foot to the side), do you need to consider all trays are exposed?

Response 11.4.4: Section 6.1.2 has guidance on the truncation of the waterfall based on the targets encountered. Using that guidance there may be cases where you can limit the number of cable trays provided the criteria are met (e.g., cable tray with solid metal cover, or for stacked cable trays in which the first open-top cable tray is sufficiently filled, etc.).

Question 11.4.5: Are covered panels within the waterfall not damaged and not ignited or just not ignited.

Response 11.4.5: A covered panel within the waterfall will not be ignited and will not be damaged. Section 6.1.2 provides guidance; damage within the energetic ZOI occurs at time zero, but secondary combustibles within the waterfall ZOI should be assumed to develop over time from a single point of ignition. Damage and ignition are dependent on the target and Section 6.2 provides a summary of that guidance.

Question 11.4.6: If the target is an adjacent bus duct, am I allowed to take credit of the interior spacing between the 'cover' and the nearest interior bus bar?

Response 11.4.6: The ZOIs are based on the distance from the exterior of the bus duct to the target. You cannot take credit for the internal space between the bus bar and duct enclosure.

11.4.2 Presentation Slides

The slides presented on NSBD HEAF modeling are available at NRC's ADAMS under accession number ML23150A039.

11.5 User Perspectives

Suzanne Loyd, Senior Manager of Risk Management at Constellation along with Charlie Young, Lead Engineer and Gregory Zucal, Senior Engineer of Jensen Hughes provided a presentation on the industry perspective, having applied the new methodology [15] at a nuclear power plant. Mrs. Loyd provided a high-level impression of the methods in NUREG-2262. Mrs. Loyd mentioned that maintenance and other preventative measures are being performed at the facilities to help reduce the likelihood of a HEAF occurring. The application of the method allowed for identification of improvements to the method, which were incorporated into the final publication of NUREG-2262.

Mr. Young discussed qualitative insights from applying the method. The ignition frequency and counting method were consistent with previous methods, but enhancements made it easier to apply. Mr. Young mentioned that crediting electrical raceway fire barrier systems was very beneficial, the ZOI determination was relatively easy, and the fire growth profile was also easy to implement. The benefit of not having to assume ignition of cable trays during the arcing phase was beneficial.

Mr. Zucal discussed the detailed results from implementing the guidance, which was generally positive. Application of the HEAF methodology at the reference plant shows a reduction in risk contributions as various levels of refinement and application of the methodology were performed.

11.5.1 Discussion

Question 11.6.1: Did you or are you planning to have a focused scope peer review for implementing NUREG-2262? If so, what was the reason for needing one?

Response 11.6.1: Yes, we are planning on having a focused scope peer review. The rationale was that we felt it prudent, and the level of refinement suggested to perform the focused scope peer review.

Question 11.6.2: What was the level of effort to implement the new methodology?

Response 11.6.2: It's important to note that refinement level 1 or screening is easy to do. The largest resource burden was determining the fault clearing times. The level of resolution of your walk downs will be a limiting factor. Sensitivity studies showed the importance of the fault clearing times and could have a significant impact on the scenario risk.

Question 11.6.3: Did you encounter any issues with the methodology that was either silent on or made you scratch you heads?

Response 11.6.3. We had an increase in our BDSAT scenario of 1,000%. All frequency went into one location. It made sense but was a large outlier among the scenarios.

11.5.2 Presentation Slides

The slides presented on the user implementation of the PRA methodology are available at NRC's ADAMS under accession number ML23150A040.

12
PROGRAM WRAP-UP

12.1 Non-Probabilistic Risk Assessment Applications for Fire Analysis

Mark Henry Salley, Branch Chief, FXHAB, provided a brief presentation on the use of high energy arcing fault (HEAF) research to support non-probabilistic risk assessment (PRA) applications. Mr. Salley noted that HEAFs can occur at all nuclear facilities. These insights are also not nuclear specific as these types of events can and do occur at non-nuclear facilities and those facilities can benefit from lessons learned from this project.

12.1.1 Presentation Slides

The slides presented on the non-PRA use of the HEAF methodology are available at the NRC's Agencywide Document Access and Management System (ADAMS) under accession number ML23150A041.

12.2 Remaining Work: OECD/NEA Program

Nick Melly presented the remaining work planned under the international agreement with the Organisation for Economic Co-operation and Development (OECD) / Nuclear Energy Agency (NEA). Mr. Melly identified the agreement member countries, the test parameters, test matrix, types of equipment and how that equipment corresponds to the updated HEAF PRA methodology. Instrumentation and tentative schedule were also discussed.

12.2.1 Presentation Slides

The slides presented on the remaining HEAF efforts under the OECD/NEA are available at NRC's ADAMS under accession number ML23150A042.

12.3 Closing Remarks

Fernando Ferrante, RSM Program Manager at EPRI provided closing remark from an EPRI perspective. Mr. Ferrante recognized the success of this project was due largely to the high skilled professionals on both the NRC and EPRI. He also recognized the industry who supported the project on numerous occasions. For this complex issue, the structured and collaborative nature of this effort greatly supported its successful completion.

Michael Franovich, Director, Division of Risk Assessment, Office of Nuclear Reactor Regulation, NRC, provided the workshop closing remarks. Mr. Franovich acknowledged all the participants of the workshop and the level of engagement. Mr. Franovich noted the design guidance from 40 years ago did not necessarily consider the hazards and the more complete toolbox that is available today. Mr. Franovich identified that realism in PRA has been a large focus of effort in recent history, and HEAF is now in that group of improved methods. Mr. Franovich closed out by thanking everyone for attending the workshop.

12.3.1 Discussion

Question 12.3.1: How can we be kept informed on follow-up workshops?

Response 12.3.1: We will maintain the NRC HEAF website (https://www.nrc.gov/about-nrc/regulatory/research/fire-research/heaf-research.html) and advertise any future HEAF related meetings and products there. In addition, the NRC issues public meeting notices on its website. Lastly, we have e-mail addresses for everyone who registered for this workshop, and we will notify the participants of this workshop of any subsequent HEAF workshops.

13
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