Attached is the Draft of the "Validation and Verification of FIVE-Rev1 & MAGIC Fire Models for Nuclear Power Plant Applications." This report is an incomplete draft provided to you for public distribution in advance of the NRC Public Meeting on NFPA 805 on October 13-15, 2004 atthe NRC Region II Offices in Atlanta, GA.

This report is an interim product of an on-going cooperative research project between Electric Power Research Institute (EPRI) and US Nuclear Regulatory Commission Office of Regulatory Research (RES). It is intended solely for review of the format and programmatic objectives and approach.

Validation and Verification of FIVE-Rev1 & MAGIC Fire Models for Nuclear Power Plant Applications

Product ID #

Draft Report for Comment, October 2004

Project Manager
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REPORT SUMMARY

TBD

ABSTRACT

TBD

ADDITIONAL FRONT MATTER SECTION(S)

TBD.

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1 INTRODUCTION

As the use of fire modeling tools increases in support of day-to-day nuclear power plant applications including fire risk studies, the importance of verification and validation (V&V) studies for these tools also increases. V&V studies provide fire modeling analysts with the needed confidence in the application of analytical tools by quantifying and discussing the performance of the model in predicting fire conditions measured in a particular experiment. The underlying assumptions, capabilities and limitations of the model are discussed and evaluated as part of the V&V study.

Engineering analyses and associated methods that are applied in demonstrating compliance with the nuclear safety and radioactive release performance criteria in NFPA 805 should have the requisite degree of technical pedigree as required by the scope and complexity of the specific application. These analyses should be performed by qualified analysts in the specific analytical methods and should include any necessary verification and validation of methods as used in the specific applications.

This document provides a V&V study for FIVE-Rev1 and MAGIC fire models according to ASTM 1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models* [1]. As such, the report is structured following the guidance provided in the ASTM standard.

1.1 Objectives

Section 2.4.1.2 of NFPA 805 requires that only fire models acceptable to the Authority Having Jurisdiction (AHJ) shall be used in fire modeling calculations. Further, NFPA 805, Sections 2.4.1.2.2 and 2.4.1.2.3 state that the fire models shall only be applied within the limitations of that fire model, and shall be verified and validated. The purpose of this report is to fulfill these requirements.

To fulfill the first requirement, EPRI is working closely with U.S. Nuclear Regulatory Commission Office of Regulatory Research (RES) in the development of this report. It is our intent that this process would lead to the first objective with regards to use of FIVE-Rev1 and MAGIC in Risk-informed / Performance-Based (RI/PB) fire protection applications including the voluntary risk-informed fire protection rule.

This report documents the Validation & Verification studies of FIVE-Rev1 and MAGIC in accordance with the requirements set in the ASTM 1355. In addition, conclusions of the V&V study should serve as guidance to fire modeling analysts in the proper application of the evaluated tools. This report is intended to meet the second requirement by establishing the bounds and confidence levels for use of these models in anticipated nuclear power plant applications.

1.2 Background

1.2.1 ASTM 1355

ASTM 1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*, provides the framework for the V&V study. The *Standard Guide* describes a methodology for evaluating the capabilities of a fire model for a specific use. The methodology consists of four areas:

1. Definition of model and scenarios for which the evaluation is to be conducted,

   The model description should include sufficient documentation of the calculation models, including computer software to allow assessment of adequacy of scientific and technical basis of the models and accuracy of computational procedures. This particular study includes two models: the zone model MAGIC, and a collection of engineering (hand) calculations available in the open fire protection engineering literature referred to as FIVE-Rev1.

   The scenario documentation should provide a complete description of the scenario or phenomena of interest in the evaluation. This description should aid in the development of realistic inputs for the model, and the criteria for judging the results of the evaluation. Typical fire scenarios in commercial U.S. nuclear power plants were selected for this study. The selected scenarios are intended to capture most of the relevant modeling attributes of fire scenarios in nuclear plants.

2. Verifying the appropriateness of the theoretical basis and assumptions used in the model,

   This step consists of an independent review of the underlying physics and chemistry inherent in the model. The review includes documentation of assumptions and approximations, an assessment of whether there is sufficient scientific evidence in the open literature to justify the approaches and assumptions used, and assessment of empirical or reference data used for constant or default values in the context of the model.

3. Verifying the mathematical and numerical robustness of the model, and

   Mathematical and numerical robustness refer to checking if the implementation of the model matches the stated documentation.

4. Quantifying the uncertainty and accuracy of the model results in predicting the course of events in similar fire scenarios.

   This last step recommends discussion in three areas: 1) model uncertainty, 2) experimental uncertainty, and 3) model evaluation. In the context of ASTM1355, model uncertainty appears to refer to both parameter and model uncertainty. That is, uncertainties in the output of the model due to both, uncertainties in the conceptualization and development of the mathematical structure of the model, and uncertainties in the input parameters. Experimental uncertainty refers to the variability in data obtained from experiments. Finally, model evaluation refers to insuring correct model inputs, correct calculations, and correct model interpretation.

1.2.2 EPRI's FIVE-Rev1

In August 2001, the Electric Power Research Institute (EPRI) published the *Fire Modeling Guide for Nuclear Power Plant Applications* (EPRI TR-1002981) [2]. This fire-modeling guide provides fire protection engineers in the commercial nuclear industry a broad overview of fire modeling theory and applications, including example calculations performed with various state of the art fire models. With the *Guide*, EPRI included a library of pre-programmed equations in Microsoft Excel that are used for estimating some aspects of fire-generated conditions. This collection of hand calculations is referred as FIVE-Rev1.

In general, the models are closed form analytical expressions that can be solved by hand. The capabilities of the various models in the library include prediction of temperature and convective heat fluxes in the fire plume or ceiling jet, irradiated heat flux, upper layer temperature, time to detection, and target heating among others.

NOTE: Not all the models included in the FIVE-Rev1 library are subjected to the V&V process. Those models subjected to the V&V will be identified throughout this report (see table 3-3 for more details)

1.2.3 EDF's MAGIC

MAGIC is a zone model developed and maintained by Electricite de France (EDF). The MAGIC software calculates as a function of time fire generated conditions single or multi-compartment geometries [3], [4], [5].

The software is a classical thermal model for fire simulations in zones able to process communicative multi-compartment problems. Each compartment is divided into two volumes assumed to be homogeneous. The solution of the mass and energy balances accumulated on each zone, together with the ideal gas law and equation of heat conduction into the walls results in the environmental conditions generated by the fire.

1.3 V&V Methodology

Consistent with the requirements of ASTM 1355, the V&V studies for FIVE-Rev1 and MAGIC are structured in the following chapters:

- Chapter 1: Introduction – This introduction provides general background on ASTM 1355, and the modeling tools FIVE-Rev1 and MAGIC.
- Chapter 2: Scenario Definition – This chapter describes the commercial nuclear power plant fire scenarios for which the fire models in the FIVE-Rev1 library and MAGIC are verified and validated.
- Chapter 3: Theoretical Bases for the Model – This chapter includes the theoretical descriptions of the models in the FIVE-Rev1 library and the zone model MAGIC. In addition, a fire protection engineering literature review has been conducted and a discussion of capabilities, limitations, and range of applications of the models is provided.
- Chapter 4: Mathematical and Numerical Robustness – A discussion on the mathematical and numerical robustness of FIVE-Rev1 and MAGIC models is provided in this chapter.

- Chapter 5: Model Sensitivity – This chapter presents the results of sensitivity analyses conducted for the models in the FIVE-Rev1 library and the zone model MAGIC. In general, the sensitivity analysis consists of evaluating model variations from a base case scenario as they are affected by changes in the input parameters.
- Chapter 6: Model Validation – This chapter documents the methodology and results of the V&V studies. The technical method to be followed for quantifying uncertainties associated with the different models when used in specific applications is currently being investigated by the EPRI and RES project teams.
- Chapter 7: Bibliography and References

1.4 Structure of this Report

The work performed for validation and verification of FIVE-Rev1 and MAGIC will be documented in a three volume set. The first volume, the Main Report:

1. Describes the technical approach,
2. Defines the fire scenarios for which the validation and verification studies have been conducted, and
3. Summarizes the results of the study and provides instructions for the use of the selected models

The second and third volume will document the V&V for FIVE-Rev1 and MAGIC respectively. That is, volume 2 includes Theoretical Bases for the Model, Mathematical and Numerical Robustness, Model Sensitivity, and Model Validation for the models in the FIVE-Rev1 library. Volume 3 includes the same information for MAGIC.

2 SELECTION AND DEFINITION OF FIRE SCENARIOS

An important aspect of evaluating the predictive capabilities of a fire model is conducting model V&V. In order to conduct model V&V, in accordance with ASTM E 1355-04, "Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models", it is necessary to define the scenarios for which evaluation is sought for each model. In accordance with Section 6.2.2 of ASTM E 1355-04 standard, for the purpose of V&V, a fire scenario definition should include a complete description of the phenomena of interest in the evaluation to facilitate appropriate application of the model. This chapter compiles a list of the scenarios to be included in the V&V of fire models used for the implementation of NFPA 805.

The list of fire scenarios expands and modifies the list originally compiled and documented by EPRI as part of the development of EPRI's Fire Modeling Guide for Nuclear Power Plant Applications (EPRI TR-1002981). The fire scenarios documented in the Fire Modeling Guide were selected based on the following evaluations (additional information is available in Chapter 3 of EPRI TR-1002981):

- A review of the range of possible configurations in the U.S. commercial nuclear industry that contribute to fire scenarios. The review focused on parameters considered important in the definition of fire scenarios.
- Identification of potentially risk significant fire scenarios through review of the Individual Plant Examination for External Events (IPEEE) submittals.
- Examination of past industry experience with fire modeling in support of regulatory applications (other than IPEEE) to help define these fire scenarios. A questionnaire was prepared and distributed to all operating NPPs in the United States concerning their experience with fire modeling. Also, with support from the NRC, industry submittals were searched to identify the use of fire modeling.

The list of fire scenarios described in this document is an expansion of the original list documented by EPRI based on comments provided by the NRC. As such, this is an agreed upon list of scenarios that will be used in the V&V process by EPRI for evaluating FIVE-Rev 1 & MAGIC and the NRC/RES for evaluating FDT_s, CFAST, & FDS.

It includes fire scenarios postulated in the following plant locations:

1. Switchgear room
2. Cable spreading room
3. Control room
4. Pump room

5. Turbine hall
6. Multi-compartment corridor
7. Multi-level building
8. Containment, PWR
9. Outdoors
10. Battery room
11. Diesel Generator room
12. Computer room

Details of each of the specific scenarios to be used in the fire model V&V exercise follow below. For each fire scenario a set of technical parameters is listed describing the various attributes of the scenario that will be used in the V&V to evaluate the fire models. The parameters listed include fire/ignition source, fire type, heat release rate (HRR) profile, enclosure geometry and boundaries, ventilation conditions, targets, target exposure. Issues to be addressed in the V&V for the scenario are also listed with each fire scenario. A matrix relating the selected fire scenarios with key attributes of fire scenarios in NPPs is provided at the end of the document.

2.1 Switchgear Room

The switchgear room (SWGR) is typically a critical area in a commercial NPP. A fire in a SWGR can have significant fire risk repercussions and is one of two plant locations most often identified as the top fire risk contributor in fire risk assessments performed under the IPEEE program. A SWGR can also be very critical to the plant operation because it contains equipment and circuits that provide the electrical power needed to operate and, in some cases, to control the plant. This area also contains potential sources of high-energy electrical fires (explosions) indoors possibly close to safety-related equipment and/or circuits. The fire scenario consists primarily of a fire in an electrical cabinet affecting a cable tray above or adjacent to a cabinet.

A pictorial representation of the SWGR fire scenario is shown in Figure 2-1.

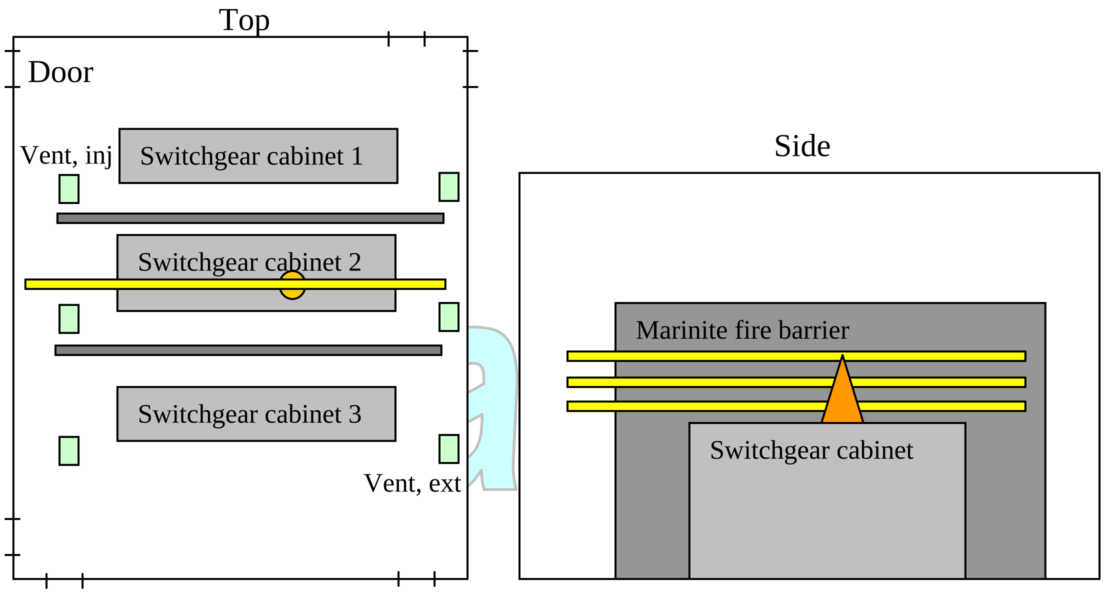

Figure 2-1: Pictorial representation of the switchgear room fire scenario

Following is a description of the attributes and ranges for this scenario.

a. Fire Ignition Source. The fire source in switchgear rooms is an electrical cabinet.

b. Fire Type. Two types of fires are evaluated in the switchgear room: 1a) an electrical cabinet fire, and 1b) an electrical cabinet high-energy arcing fault followed by an ensuing fire.

c. Heat Release Profile. Heat release rates for an electrical cabinet fire range from (1a) 65 kW to 200 kW or (1b) 65 kW to 7500 kW for an ensuing fire after high energy arching fault in the cabinet. A fire growth rate of 600 sec to peak HRR would be applied to an electrical cabinet fire. The ensuing fire after the high-energy arcing fault would have a constant HRR profile (no growth rate).

d. Enclosure Geometry and Boundaries. The applicable range of room volumes for a SWGR would be from 81 m2 (265.7 ft2) floor area x 3.65 m (11.97ft) height to 490 m2 (1607.6 ft2)floor area x 6.0 m (19.68 ft)height applied to a rectangular shaped room.

e. Ventilation Conditions. Natural ventilation is assumed in this fire scenario in the form of an open door. The door size range can be assumed to be 1 to 2 m (3.28 to 6.56 ft) wide by 2 m (6.56 ft) high. Since most SWGRs are mechanically ventilated. Fans should be assumed to exchange air at a rate of 2.5 air changes per hour (__ cfm).

f. Targets. The targets of interest would be a cable tray containing cables located above the switchgear cabinet or another adjacent electrical cabinet. The height of the tray above the cabinet could be in the range of 0.33 m to 1.8 m (1.08 to 5.9 ft). The fire is assumed to propagate outside of the cabinet.

g. Target Exposure. Target exposures evaluated in this scenario for both fire sources are exposures to the plume, ceiling jet, hot gas layer, flame radiation and flame impingement.

h. Issues Addressed. Attributes of fire scenarios to be specifically addressed in the V&V document relating to each of the attributes of this fire scenario include the following:

Targets - Evaluating the fire model capabilities for estimating surface temperature of the cable

Enclosure Geometry - Evaluating fire model capability for estimating fire conditions in relatively medium sized rooms, rectangular shaped rooms, and in rooms with flat ceilings. Most SWGRs have flat ceilings. However, flat ceilings may have different heights in different parts of the room. Rooms with flat ceilings of different heights can be considered multi-compartment scenarios with each ceiling height corresponding to a different room.

Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in naturally and mechanically ventilated rooms.

Fire Behavior - Evaluating fire model capabilities based on environmental conditions in rooms affected by an elevated fire as well as evaluation of effects of low oxygen concentration in the calculated HRR profile.

2.2 Cable Spreading Room

The cable spreading room (CSR) is typically one of the critical locations in a commercial NPP because it contains redundant instrumentation and control circuits needed for plant operation.

A CSR generally contains a high cable concentration (in cable trays and/or conduits) and fire propagation in open cable trays can be an issue in fire modeling. Some plants have areas called cable tunnels or cable lofts, which present similar challenges. These areas may contain significant amounts of cables in trays or conduits, may contain redundant circuits, and most NPPs contain little or no in-situ fire ignition sources in the CSR.

The scenario consists of a transient fire or self-ignited cable fire affecting cables in trays above.

A pictorial representation of the CSR fire scenario is shown in Figure 2-2.

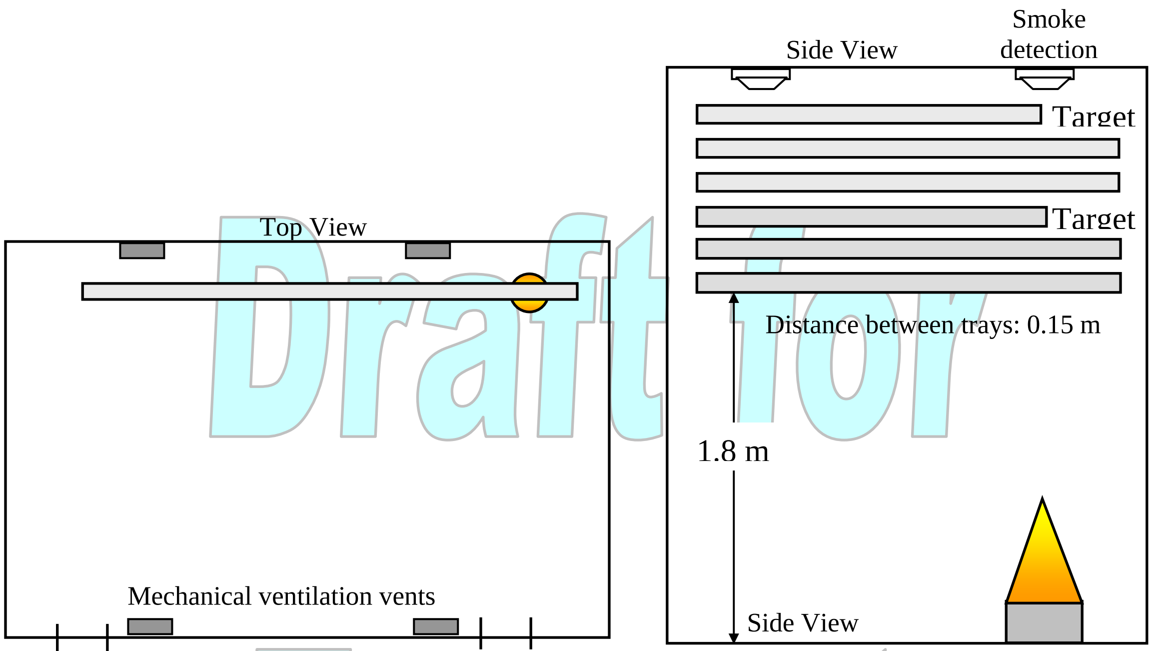

Figure 2-2: Pictorial representation of the cable spreading room fire scenario

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire sources considered for a CSR are (2a) a general transient (Trash can); or (2b) a self ignited cable. (An electrical cabinet fire is also a possible fire source in a CSR. An electric cabinet fire is considered in the switchgear room fire scenario.) A trash can was selected as the transient fire because typical equipment in CSRs is cables and electrical cabinets. These types of equipment do not require periodic lubrication.

b. Fire Behavior. The fire behaviors are evaluated in this scenario for both a general transient or a self-ignited cable include flame spread in cable trays, fire propagation between cabinets, elevated fires, and multiple fires.

c. Heat Release Profile. (2a) The HRRs could fall between 135 kW and 300 kW for a general transient with fire growth rates to peak value ranging from 300 sec to 600 sec. (2b) Fire intensities for self-ignited cable fires can be calculated as described in Chapter 7 of NUREG-1805. The initial burning area should be calculated by multiplying the width of the cable tray times an assumed length. Typical cable tray widths are 0.6 and 0.9 m (1.96 and 2.95 ft). The assumed length of the burning tray ranges from 0.3 to 0.6 mm(0.011 to 0.23 in). Fire growth rates would range from 75 sec to 300 sec.

d. Enclosure Geometry. The room volume would range from 334 m2 x 5.7 m to 1048 m2 x 6.4 m (1095 ft2 x 18.7 ft to 3438 ft2 x 20.9 ft) applied to a rectangular shaped room.

e. Ventilation Conditions. It should be assumed that mechanical ventilation in the form of an air injection and extraction system is in use in this room with a flow rate range of 1 to 5 air change per hour. Once a fire is detected the fans stop and the dampers are released. Natural ventilation paths assumed in this scenario include two normally closed doors (2x2 m, 6.56 x 6.56 ft).

f. Target. The assumed target of interest in this fire scenario is a cable tray with thermoplastic cables located 0.6 m below the ceiling, or an electrical cabinet.

g. Target Exposure. Target exposures evaluated in this scenario include exposure to the plume, hot gas layer, thermal radiation, and heat transfer.

h. Issues Addressed. The issues to be addressed in the V&V document for the various attributes of this scenario include the following:

Targets - Evaluating model capabilities for estimating surface temperature of cables.

Enclosure Geometry - Evaluating model capabilities for estimating fire conditions in relatively medium rooms, rectangular rooms, and rooms with flat ceilings.

Ventilation Conditions - Evaluating model capabilities for estimating fire conditions in naturally and mechanically ventilated rooms.

Fire Behavior - Evaluating fire model capabilities for estimating environmental conditions in rooms affected by an elevated fire, and the effects of low oxygen environments in the HRR profile.

2.3 Control Room

The main control room (MCR) in a commercial NPP is an important area for several reasons, including being one of the two locations most identified as top fire risk contributor in the fire risk assessments performed under the fire IPEEE program. An MCR contains redundant instrumentation and control circuits critical to plant control and safe shutdown. Analysis of fires in the MCR, pose unique challenges, including; timing of fire detection, smoke generation, migration and habitability, fire propagation within very large panels, and fire propagation between panels. Some plants have areas (i.e., a relay room or an auxiliary equipment room) that are similar to MCRs in that they contain redundant instrumentation and control circuits critical to plant control and safe-shutdown (same control circuits located in the MCR for plants without relay room or auxiliary electrical equipment room). However, they do not have the occupancy of the MCR but instead may be equipped with automatic suppression.

The scenario primarily consists of an electrical cabinet or transient fire affecting habitability conditions in the MCR or affecting a target inside and adjacent cabinet.

A pictorial representation of the MCR fie scenario is shown in Figure 2-3.

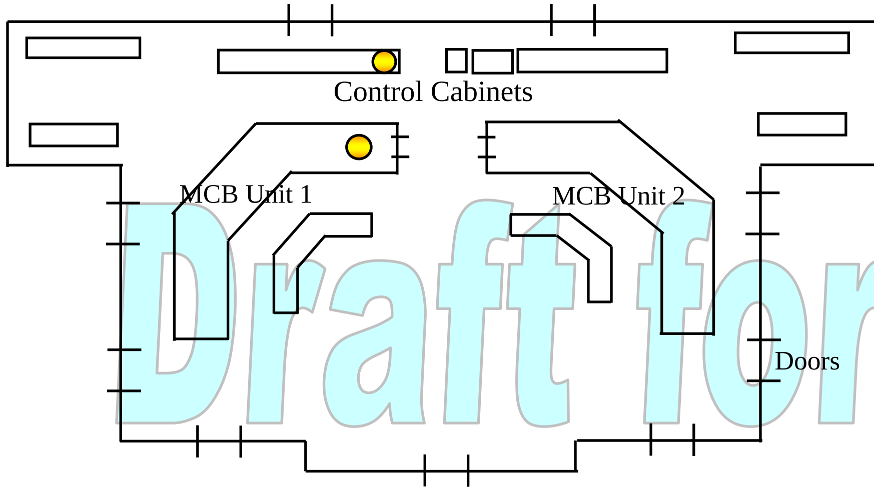

Figure 2-3: Pictorial representation of the control room fire scenario. The scenario can apply to one or two unit control rooms.

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. In the control room fire scenario the fire sources considered are (3a) a control cabinet fire (3b) a fire inside the main control board; or (3c) a transient fire with possible intermediate fire sources.

b. Fire Behavior. The fire behavior addressed for an electrical cabinet fire is fire growth inside a cabinet. Fire propagation between cabinets would be evaluated for an electrical cabinet fire inside a cabinet containing a solid-state device.

c. Heat Release Profile. (1)HRR within the range of 200 kW to 950 kW would be possible for the cabinet fire a fire growth rate of 600 sec and; (2) HRRs between 135 kW to 300 kW would be considered for a transient fire with fire growth rates of 300 sec.

d. Enclosure Geometry. The room volume considered in this scenario could fall within the range of 145 m2 x 5.8 m to 854 m2 x 2.8 m (475.7ft2 x 19.02 ft to 2801ft2 x 9.18 ft)applied to a rectangular shaped room.

e. Target. The targets of interest would be (1) a cable bundle located inside a cabinet, or a solid-state device inside a cabinet adjacent to the ignition source. (2) The occurrence of abandonment due to temperature, toxicity and visibility would also be evaluated for this scenario.

f. Ventilation Conditions. Mechanical ventilation is in place in the MCR that can be operated in four modes. For modeling purposes it should be assumed that the system is operating in normal mode in which the air is drawn in from the outside and mixed in with internally re-circulated air, then dehumidified and cooled before being supplied to the control room. In response to a smoke detector signal, the system would switch to mode 2, smoke removal mode (no air supply into the room). An extraction rate of 5 to 10 air changes per hour would be representative.

g. Issues Addressed. The issues to be specifically addressed in the V&V document for the various attributes of this scenario include the following:

   Targets - (3a) Evaluating model capabilities for estimating surface temperature of solid state devices inside cabinets; (3b) Evaluating model capabilities for estimating the surface temperature of a cable inside a cabinet; (3c) Determining whether models can provide adequate information about toxicity, visibility and temperature for determining habitability.

   Enclosure Geometry - Evaluating fire model capabilities for estimating fire conditions in relatively medium rooms and in rectangular shaped rooms.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in naturally and mechanically ventilated rooms.

   Fire Behavior - Evaluating fire model capabilities for estimating fire growth inside electrical cabinets and between electrical cabinets.

The scenario can apply to one or two unit NPP control rooms.

2.4 Pump Room

This location was selected to represent areas in a plant where a relatively large fire is possible in a rather small enclosure. Including this scenario allows fire excavation of potential flashover and its impact on enclosure boundaries.

The fire scenario consists of an oil spill pool fire affecting a cable tray near the ceiling.

A pictorial representation of the Pump Room fire scenario is shown in Figure 2-4.

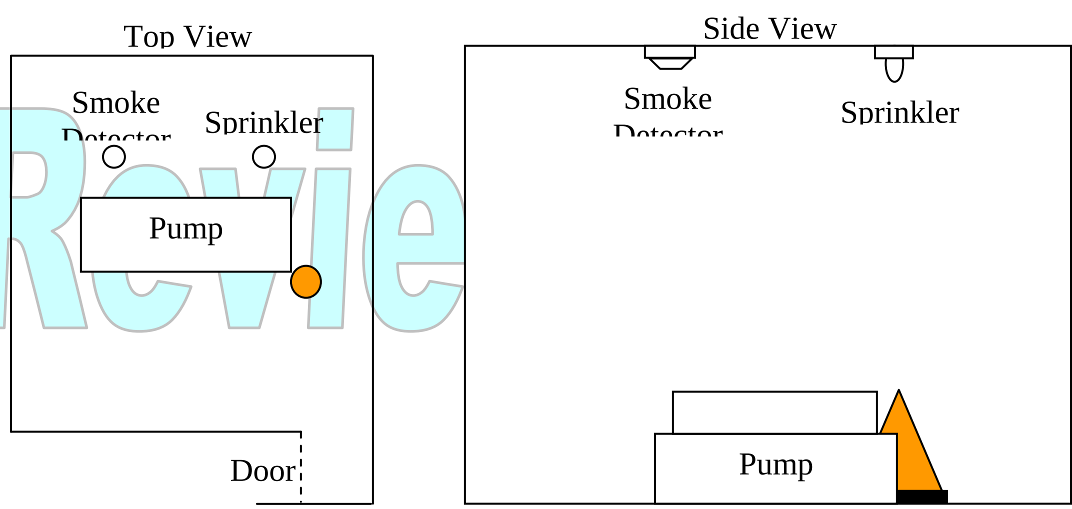

Figure 2-4: Pictorial representation of the pump room fire scenario

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. In the pump room scenario, the fire source considered is spilled oil.

b. Fire Behavior. The fire behaviors evaluated in a pump room fire scenario are elevated fires and flashover.

c. Heat Release Profile. HRRs for the oil would be calculated as described in Chapter 3 of NUREG-1805 with a fire growth rate of 75 sec. If the oil spills are constrained, the dike area should be assumed. The range of oil spill sizes is 2 to 4 m2 (6.56 to 13.12 ft2). NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg/m2-s, and 46,400 kJ/kg respectively. Using these combustion properties and the oil spill sizes, the range of heat release rates is 3,619 to 7,238 kW. The depth of the dike ranges from 2.54 to 5.0 cm (1 to 1.96 in).

d. Enclosure Geometry. Room volumes ranging from 15 m2 x 5.7 m to 86 m2 x 4.9 m (49.21ft2 x 18.7 ft to 282ft2 x 16.07 ft)are considered in this scenario applied to a rectangular shaped room.

e. Target. The target of interest is a cable tray located near the ceiling. The height of the tray above the fire source is about 4 m (13.12ft).

f. Target Exposure. The target exposures considered in a pump room fire scenario are exposure to the plume, ceiling jet, hot gas layer, and flame impingement.

g. Ventilation Conditions. The enclosure is assumed to be mechanically ventilated and with natural ventilation in the form of one normally closed 2m x 2m (6.56 x6.56 ft) door.

h. Issues Addressed. The issues to be specifically addressed in the V&V document for each of the various attributes of this fire scenario include the following:

   Targets - Evaluating fire model capabilities for estimating surface temperature of the cable, and for estimating internal and external wall temperatures. Cables are considered to be the equipment in typical pump rooms most susceptible to thermal damage. A cable connected to a pump is assumed to fail before thermal damage to the pump is observed.

   Enclosure Geometry - Evaluating fire model capabilities for estimating fire conditions in relatively small rooms, rectangular rooms, and rooms with a flat ceiling.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in naturally and mechanically ventilated rooms

   Fire Behavior - Evaluating fire model capabilities for estimating environmental conditions in rooms affected by an elevated fire and evaluation of the effects of low oxygen environments in the HRR profile.

   Another issue addressed is evaluating fire model capabilities for estimating time to flashover and flashover conditions.

2.5 Turbine Hall

The turbine hall is one of generally three portions of the multi-level turbine building. The multi-level turbine building fire is described in a subsequent scenario description. The turbine building was selected to examine fire scenarios with large (e.g., turbine lube oil) or small (e.g., transient or panel) fires in large enclosures with high ceilings. Turbine buildings are not generally a safety-critical location in Pressurized Water Reactors (PWRs) unless they contain a significant number of safety significant equipment or circuits. This is more typical in Boiling Water Reactors (BWRs) than PWRs.

The scenario consists of an oil spill fire affecting structural steel members.

A pictorial representation of the Turbine Building fire scenario is shown in Figure 2-5.

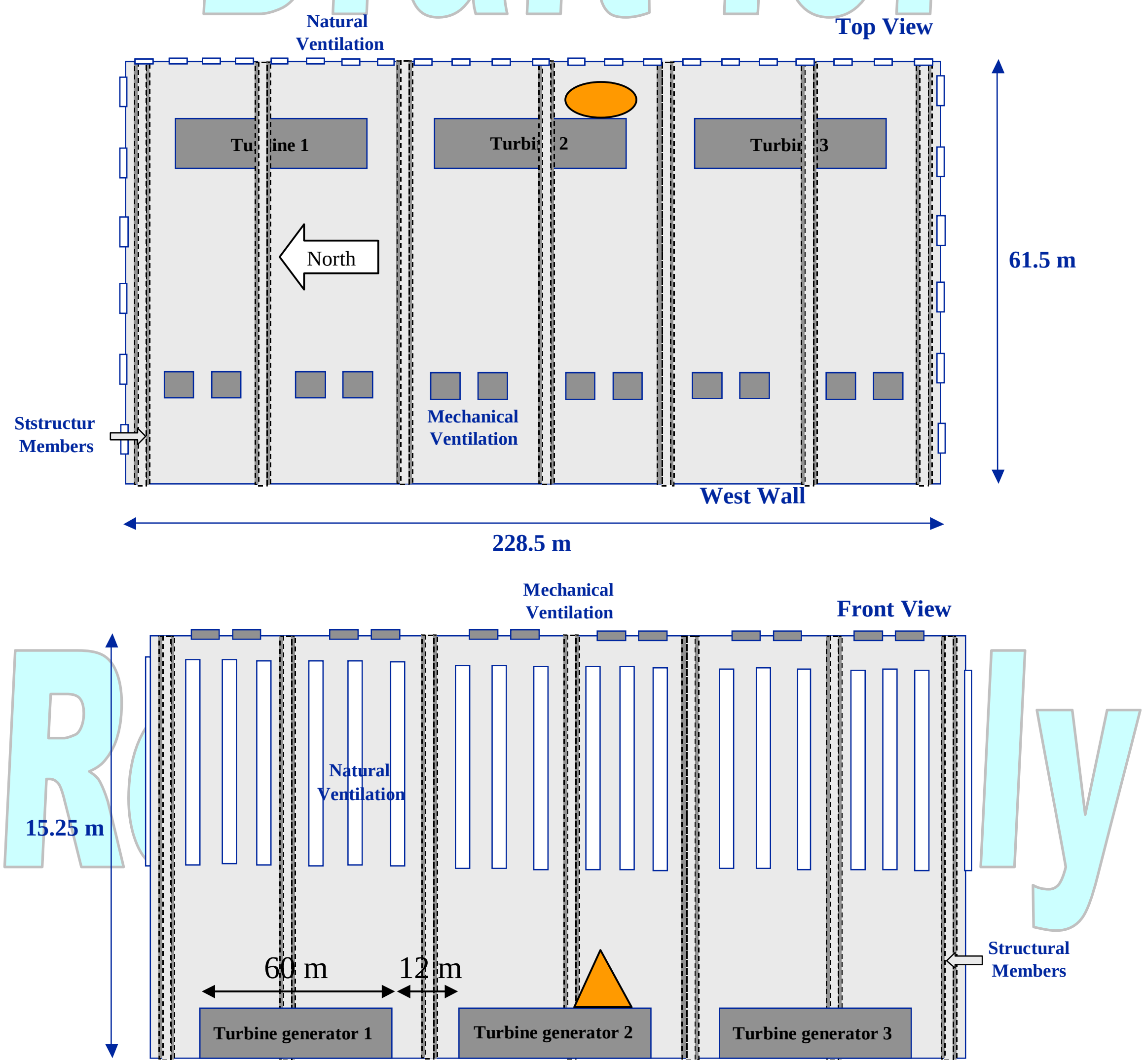

Figure 2-5: Pictorial representation of turbine hall fire scenario. The scenario can apply to buildings with one, tow or three units.

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. In the turbine hall fire scenario, the fire sources considered are (5a) an oil spill near one of the turbines; or (5b) a hydrogen leak igniting near the turbine generator.

b. Heat Release Profile. HRRs for oil fires applied in this fire scenario would be calculated as described in Chapter 3 of NUREG-1805 with fire growth rates of 75 sec. If the oil spills are constrained, the dike area should be assumed. The range of oil spill sizes is 4 to 10 m2 (13.12 to 32.18ft2). NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg/m2-s, and 46,400 kJ/kg respectively. Using these combustion properties and the oil spill sizes, the range of HRRs is 7,238 to 18,096 kW.

c. Enclosure Geometry. The turbine hall is assumed to be rectangular in shape with a hall volume ranging from 3,809 m2 x 7.5 m to 14,052 m2 x 15.3 m (ft2 x ft to ft2 x ft).

d. Ventilation Conditions. Natural ventilation in this scenario could be provided in the form of windows and (~35) doors using 100 percent outside ventilation. There is also a mechanical ventilation system in place in this scenario. The mechanical ventilation system is comprised of (~12) roof mounted fans each with a capacity of ~32.5 m3/sec (equivalent to a total of 6.6 air changes per hour), and could also include a mechanical supply system instead of the natural ventilation through the windows.

e. Target. The targets of interest in the turbine building scenario are the structural steel members and cables. Targets are located near flames where they are affected by irradiation from flames, and inside the fire plume and hot gas layer where they are affected by convective heat transfer.

f. Target Exposure. Target exposures considered for this scenario include exposure to the plume, ceiling jet, hot gas layer, flame radiation, and flame impingement.

g. Issues Addressed. The issues to be addressed in the V&V document for the various attributes of this scenario include the following:

   Targets - Evaluating fire model capabilities for estimating response of structural steel members to fire exposure.

   Enclosure Geometry - Evaluating fire model capabilities for estimating fire behaviors in relatively large rooms, rectangular rooms, and rooms with flat ceilings. Evaluating fire model capabilities for estimating response of steel walls to fire conditions is also addressed in this scenario.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in naturally ventilated rooms.

The scenario can apply to buildings with one two or three units.

2.6 Multi-Compartment Corridor

Many commercial NPPs in the United States have enclosures with multiple compartments opening into a common space or corridor. The significance of these enclosures in terms of fire safety varies from plant-to-plant because they are used to house various mechanical, electrical, waste treatment, or other equipment and/or circuits.

The fire scenario consists of a fire in one compartment affecting targets in an adjacent compartment.

A pictorial representation of the multi-compartment corridor fire scenario is shown in Figure 2-6.

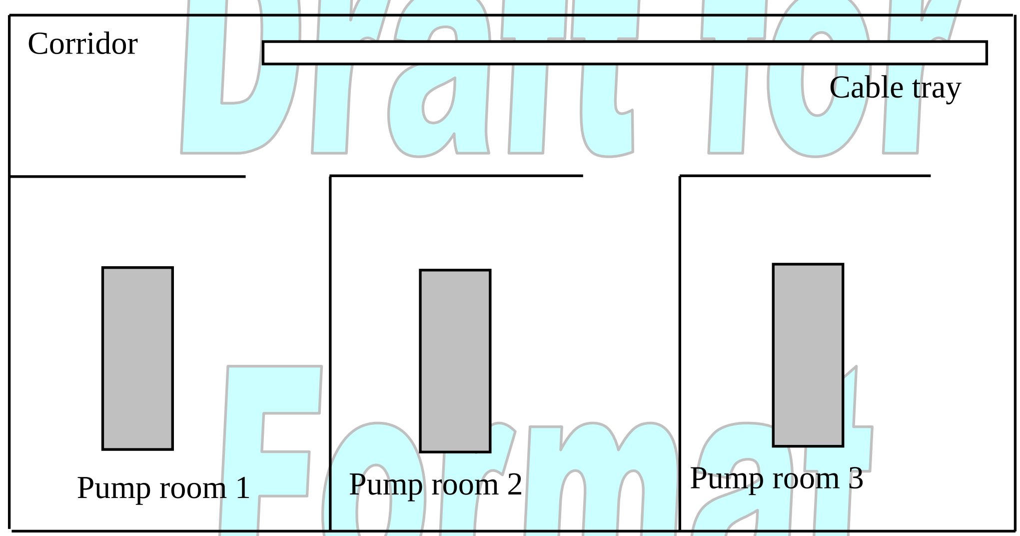

Figure 2-6: Pictorial representation of the multi-compartment fire scenario.

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire source considered in a multi-compartment corridor scenario is an oil fire starting in any one of the pump rooms. A stack of 6 cable trays is located 1.8 m (5.9 ft) above the oil spill. The cable trays ignited and contribute to the fire intensity.

b. Fire Behavior. The conditions considered in a multi-compartment corridor scenario are fire and smoke propagating to adjacent corridor or rooms.

c. Heat release Profile. The HRRs for oil fires applied in this case would be calculated as described in Chapter 3 of NUREG-1805 with fire growth rate of 75 sec. If the oil spills are constrained, the dike area should be assumed. The range of oil spill sizes is 2 to 4 m2 (6.56 to 13.12 ft2) NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg.m2-s, and 46,400 kJ/kg respectively. Using these flammability properties and the oil spill sizes, the range of heat release rates is 3,619 to 7,238 kW. The depth of the dike ranges from 2.54 to 5.0 cm.

d. Enclosure Geometry. The multi-compartment corridor consists of interconnected rooms and corridors in the same level and soffit. The volumes of the compartments are the same as the sizes of the pump rooms listed in scenario 4 connected by a 1.4 m (4.59 ft) wide corridor. To account for irregularities in the geometry of the spaces, assumptions are drawn on the effective dimensions of the area.

e. Ventilation Conditions. Natural ventilation considered for a multi-compartment corridor includes leakage paths underneath normally closed doors, and compartment to compartment openings. Mechanical ventilation in this space is in the form of an air injection and extraction system. The injection system operates at a rate of 0.25 m3/sec to 0.5 m3/s. The extraction system operates at a rate of 0.27 m3/sec to 0.52 m3/s.

f. Target. The targets considered in this scenario are cable trays located along a corridor.

g. Target Exposure. The target exposure considered in this scenario is exposure to the hot gas layer.

h. Issues Addressed. The specific issues to be addressed in the V&V document for the various attributes of this scenario include the following:

   Targets - Evaluating fire model capabilities to estimate surface temperature of the cable.

   Enclosure Geometry - Evaluating fire model capabilities to estimate fire conditions in relatively small rooms, adjacent rooms, corridors, rectangular rooms, and rooms with flat ceilings.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in mechanically ventilated rooms

   Smoke Transport - Evaluating fire model capabilities to predict multi-compartment smoke transport through natural and mechanical ventilation.

2.7 Multi-Level Building

A typical NPP in the U.S. has locations where multiple elevations of the same building are separated by partial floors/ceilings or open hatches or staircases. Turbine buildings, PWR auxiliary buildings and BWR reactor buildings are typical examples.

The multi-level turbine building is in this scenario a three level space that includes the turbine hall. The turbine hall fire is described in a previous fire scenario description. The scenario consists of an oil spill fire affecting targets located in a different level.

A pictorial representation of the multi-level fire scenario is shown in Figure 2-7.

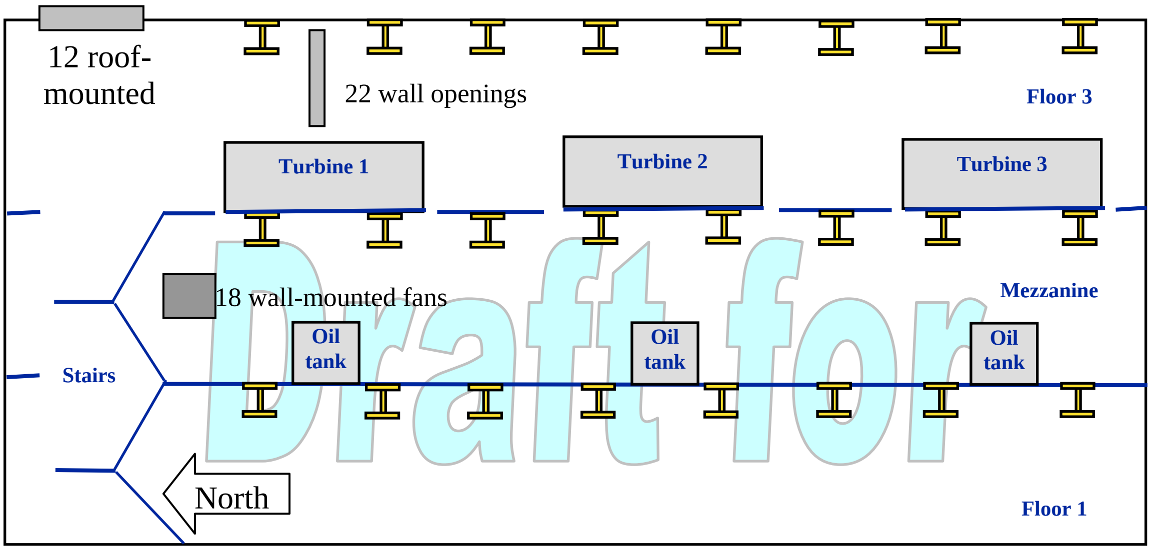

Figure 2-7: Pictorial representation of the multi-level fire scenarios. The scenario can apply to buildings with one, two or three units.

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. (1) One of the fire sources considered for a multi-level turbine building scenario is an oil spill fire occurring near the oil tank below a turbine generator generating smoke flows through mezzanine openings. Steel structural members in the mezzanine level and turbine hall are also subjected to fire conditions. (2) A second fire source considered for this type of enclosure assumes the oil spills in a pump on the second level and drips down to the first level and ignites.

b. Heat Release Profile. HRRs considered in this fire scenario would be calculated as described in Chapter 3 of NUREG-1805 with a fire growth rate of 75 sec. The range of oil spill sizes is 4 to 10 m2 (13.12 to 32.8ft2). NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as building fire scenarios. 0.039 kg/m2-s, and 46,400 kJ/kg respectively. Using these combustion properties and the oil spill sizes, the range of HRRs is 7,238 to 18,096 kW.

c. Enclosure Geometry. The compartment is assumed to be a rectangular three level area. The elevations are 0 m, 10 m, and 20 m respectively for the three levels assumed to be in this space. The volume of the turbine hall portion given in the turbine hall scenario. The floor area of the remaining levels range from 3,809 m2 to 14,052 m2 (12,496 ft2 to 46,102 ft2) respectively.

d. Ventilation Conditions. The natural ventilation in this space is in the form of 100 percent outside air drawn through outside air openings located on the upper level. In addition hatches or other openings may be present between the different levels of the space. Alternatively, a mechanical supply system may be provided instead of the natural ventilation window openings. Air is exhausted using fans located on the ceiling and along a wall. Considerable leakage paths may exist in this space.

The mechanical ventilation considered in this area consists of roof mounted exhaust fans each having a capacity of ~32.5 m3/sec. The total exhaust capacity of the multi-level area is ~881 m3/sec and the fans are normally in operation except during the winter months when the temperature falls below 2°C. During normal operations all of the doors to the outside are closed.

e. Target. The target of interest in this fire scenario is a cable tray located in the third level.

f. Target Exposure. Target exposures considered in this fire scenario are exposure to the plume and exposure to the hot gas layer.

g. Issues Addressed. The specific issues to be addressed in the V&V document for the various attributes of this fire scenario include the following:

   Targets - Evaluating fire model capabilities to estimate surface temperature of the cable.

   Enclosure Geometry - Evaluating fire model capabilities for estimating fire conditions in compartments above the location of the primary fire, rectangular compartments, and compartments with flat ceilings.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in mechanically ventilated compartments

   Smoke Transport - Estimating vertical flow through the hatches for varying ventilation conditions.

The scenario can apply to turbine buildings with one, two, or three units.

2.8 Containment Building, PWR

The containment building in PWR plants was selected because of its geometrical characteristics, namely cylindrical boundaries, domed ceiling, and a large enclosure. In many BWRs the primary containment is inerted and therefore not susceptible to large sustained fires. Issues discussed here may be applied to non-inerted BWR primary containments.

The scenario consists of an oil spill fire affecting cable in the nearby trays.

Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire source considered for a containment building fire scenario is an oil fire in the reactor coolant pump (RCP).

b. Heat Release Profile. HRRs for oil fires applied in this scenario would be calculated as described in Chapter 3 of NUREG-1805 with fire growth rates of 75 sec. If the oil spills are constrained, the dike area should be assumed. The range of oil spill sizes is 4 to 10 m2 (13.12 to 32.8 ft2). NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg.m2-s, and 46,400 kJ/kg respectively. Using these combustion properties and the oil spill sizes, the range of heat release rates is 7,238 to 18,096 kW.

c. Enclosure Geometry. The containment is assumed to be cylindrical in shape with a volume of 1555 m2 x 63 m (5,101 ft2 x 206.69 ft) and many levels and sub-compartments.

d. Ventilation Conditions. TBD

e. Target. The target of interest in this scenario is an elevated cable tray located outside the fire plume. Specifically, the tray is located, 5 m (16.4 ft) horizontally, and 5 m vertically from the fire.

f. Issues Addressed. The specific issues addressed in the V&V document for the various attributes of this scenario include the following:

   Targets - Evaluating fire model capabilities for estimating the surface temperature of the cable

   Enclosure Geometry - Evaluating fire model capabilities for estimating fire conditions in rooms above the location of the primary fire, non-rectangular compartments, and rooms with non-flat ceilings.

   Ventilation Conditions - Evaluating fire model capabilities for estimating fire conditions in mechanically ventilated compartments.

2.9 Outdoors

Outdoor fire scenarios involve for the most part large oil filled transformers or hydrogen tanks fires affecting or propagating to nearby equipment.

This scenario consists of a transformer fire affecting an adjacent transformer. Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire source considered for an outdoor fire scenario is an oil fire caused by oil dripping from a switchyard transformer.

b. Heat Release Profile. The HRRs applied for an outdoor fire would be calculated as described in Chapter 3 of NUREG-1805 with fire growth rates of 75 sec. The range of oil spill sizes is 4 to 10 m2(13.12 to 32.8 ft2). NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg/m2-s, and 46,400 kJ/kg respectively. Using these combustion properties and the oil spill sizes, the range of heat release rates is 7,238 to 18,096 kW.

c. Enclosure Geometry. N/A

d. Ventilation Conditions. Ambient outdoor conditions.

e. Target. The target of interest is an adjacent transformer located 5 to 10 m (16.4 to 32.8 ft) away. Damage to the transformer would be determined by evaluating thermal damage to the cables connected to it.

f. Target Exposure. The target exposure considered in this fire scenario is exposure to flame radiation.

g. Issues Addressed. The issues to be address in the V&V document for the various attributes of an outdoor fire include the following:

Targets - Evaluating fire model capabilities for estimating surface temperature of the cables connecting the transformer. Evaluating fire model capabilities for estimating flame radiation to adjacent equipment.

2.10 Battery Room

Battery rooms are relatively small compartment compared to other locations in nuclear power plants. Typically, these are concrete, or concrete block rooms with one or two doors. The doors are kept closed all the time. In most cases, battery rooms house one or two battery banks. No other fixed ignition source is found in such rooms. As such, combustibles of concern in battery rooms consist of hydrogen gas, electrical cables and plastic battery casings.

The postulated scenario consists of a hydrogen, cable or transient fire in a battery room. Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire sources considered in a battery room fire scenario are (9a) hydrogen, (9b) cables, and (9c) transients.

b. Heat Release Profile. The HRRs applied for a battery room fire could fall within the range of 75 kW to 150 kW with fire growth rates of 75 sec to 300 sec.

c. Enclosure Geometry. The volume of a battery room could fall with the range of 20 m2 x 2.4 m to 334 m2 x 5.7 m (65.6 ft^2 x 7.87ft to 111.5ft^2 x 18.7ft)applied to a rectangular shaped room.

d. Ventilation Conditions. Mechanical ventilation is present in this fire scenario that operates at a rate of 5 air changes per hour. The mechanical ventilation may be on or off in this fire scenario.

e. Target. Targets of interest in this fire scenario are cables.

f. Issues Addressed.

Prediction of time to smoke detection - TBD

Modeling hydrogen fires – The challenge of modeling intensity of hydrogen fires is in determining the amount of hydrogen released.

Modeling fires in small, mechanically ventilated rooms: Since battery rooms are mechanically ventilated, closed and relatively small, the evaluation of fire models in such geometry may help identify and understand capabilities related to oxygen controlled combustion and mechanical ventilation

2.11 Diesel Generator Room

Diesel generator rooms, as suggested by its name, house a diesel generator. These are relatively medium size rooms with multiple normally closed doors. The rooms are usually made of concrete. In addition to combustibles associated directly to the diesel generator, such as oil, switchgear cabinets and cable trays are also found in diesel generator rooms.

The postulated fire scenario consists of an oil spill in the diesel generator room. Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire source considered in a diesel generator room fire scenario would be a lube oil fire.

b. Heat Release Profile. The HRRs applied to oil fires in a diesel generator room fire scenario would be calculated as described in Chapter 3 of NUREG-1805 with fire growth rates of 75 sec. If the oil spills are constrained, the dike area should be assumed. The range of oil spill sizes is 2 to 6 m2 (6.56 to 19.6 ft2) The oil spill occurs adjacent to the generator, which is located in the center of the room. NUREG-1805, Table 3-2 lists the mass loss rate and heat of combustion of transformer oil/hydrocarbon as 0.039 kg/m2-s, and 46,400 kJ/kg respectively. Using these flammability properties and the oil spill sizes, the range of heat release rates is 3,619 to 10,858 kW.

c. Enclosure Geometry. The diesel generator room volume could fall within the range of 155 m2 x 8.8 m to 372 m2 x 11 m (508.5 ft2 x 28.8 ft to 1220.4 ft2 x 36.08 ft) applied to a rectangular shaped room.

d. Ventilation Conditions. Mechanical ventilation is present in this fire scenario that operates at an assumed rate of 5 air changes per hour. The mechanical ventilation may be on or off in this scenario.

e. Target. The targets of interest in this scenario are cables.

f. Target Exposure. Target is located in a cable tray along a room wall 3.65 m 11.97ft) from the floor.

g. Issues Addressed.

    a. Target heating in the hot gas layer

    b. Prediction of time to smoke detection

    c. Modeling oil spill fires

2.12 Computer Room

Computer rooms are typically found within the main control room complex. Other names that could be associated to computer rooms in the commercial nuclear industry may be relay room, or control room annex. Typical combustibles in these rooms include personal computers, control and relay cabinets, cable trays and other transient combustibles such as paper, and furniture.

The postulated fire scenario includes a transient or computer fire in the computer room. Following is a description of the attributes and ranges for this scenario.

a. Fire Source. The fire sources considered in a computer room fire scenario include (11a) furniture; or (11b) a workstation.

b. Heat Release Profile. The HRRs applied in a computer room fire scenario could fall within the range of (11a) 135 kW to 300 kW for furniture; and (11b) 135 kW and 300 kW for a workstation fire. Fire growth rates should fall in the range of 300 sec to 600 sec.

c. Enclosure Geometry. A computer room is assumed to be rectangular in shape with a volume ranging from 54 m2 x 4.8 m to 334 m2 x 5.7 m (177 ft2 x 15.74 ft to 1095 ft2 x 18.7 ft).

d. Ventilation Conditions. Mechanical ventilation is present in this scenario that operates at a rate of 5 air changes per hour. The mechanical ventilation may be on or off in this scenario.

e. Target. The target of interest in a computer room is a control cabinet 1.5 m (4.92 ft) from the workstation.

f. Target Exposure. The control cabinet would be affected by flame radiation and heat transferred from the hot gas layer.

g. Issues addressed.

Modeling water based suppression

Modeling target heating due to flame radiation and heat transfer from the hot gas layer

2.13 Summary of Fire Scenario Attributes

The following table provides a list of general fire scenario attributes relevant to nuclear power plant applications. These attributes are mapped in the table to the selected fire scenarios.

Table 2-1: Summary of modeling attributes addressed in each fire scenario. The symbol "x" indicates that an attribute is addressed in the corresponding fire scenario.

Scenario	Fire Source	Range of HRR	Geometry Area, Height Volume	Ventilation Openings Forced	Target - *[Damage Criteria]*
1.Switchgear Room	Cabinet Cable tray ignition	65 KW - ___MW	81-490 m2 3.7-6.0 m 300-2940m3	Door 2-4 m2 MV 2 acph	Cables *[Surf. Temp.]*
2. Cable Spreading Room	Trash can Cable tray (elevated) Multiple fires	65 KW - ___MW	334-1048m2 5.7-6.4 m 1904-6707m3	2 doors - 4 m2 each MV 1-5 acph	Cables *[Surf. Temp.]* Electrical cabinets ?
3. Control Room	Control cabinet Main Control Board Transient	65 KW - ___MW	145-854 m2 2.8-5.8 m 841-2391 m3	MV 5-10 acph	-cable or SSD inside cabinet -human . temp. . toxicity . visibility
4. Pump Room	Oil spill	65 KW - ___MW	15-86 m2 4.9-5.7 m 86-421m3	Door 4 m2 MV ????	Cables *[Surf. Temp.]* Walls
5. Turbine Hall	Oil spill Hydrogen	65 KW - ____MW	3809-14,052m2 7.5-15.3 m 28,568-214,996 m3	NV, MV, & NV/MV NV-windows MV 6.6 acph	- Cables - Beams *[Surf. Temp.]*
6. Multi-Compartment	Oil spill cable tray	65 KW - ___MW	- 3 rooms like Pump Room - Corridor 1.4 m wide	Doors MV ???	Cables *[Surf. Temp.]*

Scenario	Fire Source	Range of HRR	Geometry Area, Height Volume	Ventilation Openings Forced	Target - *[Damage Criteria]*
7. Multi-Level Building	Oil spills	65 KW - ____ MW	3809-14,052m2 10 m each level 38,090-140,052 m3	NV, MV, & NV/MV NV-windows MV 6.6 acph (per level)	Cables *[Surf. Temp.]*
8. Containment PWR	Oil spills	65 KW - ____MW	1555 m2 63 m 97,965 m3 multi- level & compartment	?????	Cables *[Surf. Temp.]*
9. Outdoors	Oil spill	65 KW - ____MW	N/A	Ambient	Cables *[Surf. Temp.]*
10. Battery Room	hydrogen cable tray wood pallets	65 KW - ____MW	20-334 m2 2.4-5.7 m 48-1904 m3	Door MV 5 acph	Cables *[Surf. Temp.]*
11. Diesel Generator Room	Oil spill	65 KW - ____MW	155-372 m2 8.8-11 m 1364-4092 m3	Door MV 5 acph	Cables *[Surf. Temp.]*
12. Computer Room	furniture workstation	65 KW - ____MW	54-334 m2 4.8-5.7 m 260-1904 m3	Door MV 5 acph	Control cabinet

3
UNCERTAITY IN PREDICTION OF SELECTED FIRE MODELS

TBD

4 CONCLUSIONS

TBD

5 REFERENCES

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