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SAFE – Fire PRA

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Abstract

The new regulatory environment encourages increasing the use of PRA technology in all regulatory matters, such as Fire PRA (FPRA). This introduces additional information that will be necessary to support the development of FPRAs, such as identification of fire scenarios, the assessment of the effect of fire scenarios on the cables and equipment, and the impact of the damage on the Fire PRA models.

The System Assurance & Fire Protection Engineering (SAFE) is an engineering analysis tool that performs system failure analysis by evaluating the consequences of failed cables, equipment and systems within defined spaces; supporting various types of analysis such as 10CFR50 Appendix R, NFPA-805, Fire PRA, & Non-Power Operations. SAFE also serves as a single repository of information which simplifies the long term configuration management/control of these programs.

This paper describes how SAFE has been enhanced to integrate the various aspects of the Fire PRA analysis.

Introduction

A Fire PRA is conducted by identifying fire scenarios that may affect the safe operation of the plant (through impacts on equipment and human actions) and estimating the frequency of occurrence of those scenarios. In SAFE, the analyst composes a series of fire scenarios, each involving a specific fire source leading to a set of failed targets in the fire zone. The primary output of a FPRA is typically the estimated frequency of a fire leading to core damage and large early release, which SAFE calculates for each scenario. SAFE also maintains the following key information about a fire scenario:

- Ignition/Fire Sources information.
- Target Equipment/ Cable/ Raceway information.
- Modeling information.
- Cable routing and Equipment location information.
- Fire Ignition Frequency information.

Identify Fire Sources

In SAFE, Fire Source records identify and characterize fire ignition sources to be analyzed in terms of location within the compartment, type, size, initial intensity, growth behavior, severity/likelihood relationship, etc. The source of fire is then evaluated through the uses of Fire Scenarios and Fire Models.

Build Fire Scenarios

Fire Scenarios that may affect the safe operation of the plant (through impacts on equipment and human actions) are built in SAFE. The target set relevant to each fire ignition source considered in the fire growth and damage analysis are identified and associated with the Fire Scenarios. The location of a target set in relation to the fire ignition source, target types, failure modes, failure criteria, and other relevant information are also collected.

Model Fires

SAFE provides the analyst with a user interface to manage the Fire PRA data and fire modeling tools necessary to evaluate a specific fire situation (fire scenario) which impact Fire PRA and safe shutdown components.

Fires are modeled using tools such as FIVE worksheets, NUREG 1805 FDTs, FDS, CFAST, etc. and the results documented in SAFE. Input/ Output files generated outside of the system using tools such as FDS & Smokeview are linked in SAFE to the Fire Modeling records.

SAFE also provides the analyst with tools to calculate the fire sizes (i.e., heat release rates (HRR)) for each ignition source along with cables, fixed, and transient combustible loads within a fire zone or fire area.

Select FPRA Components

In order to identify the impact of fire on the plant systems, information such as the location of the components and their associated dependencies (e.g. cables) must be established.

SAFE's Equipment form provides the analyst with the ability to capture information a typical Fire PRA Component List should include [i.e., Equipment ID, Description, System, Component Type, Fire Zones (locations of components are identified by fire zones), Notes, etc].

Cable tracing and circuit analysis for all components in a Fire PRA is also performed using SAFE. The Cable form provides various fields to capture information a typical Fire PRA Cable List should include [i.e., Cable ID, Cable Type, To/From Equipment, Function (i.e., power, control, instrumentation), Routes (i.e., raceways through which a cable is routed), Fire Zones (locations of raceways/cables are identified by fire zones), Documents, Notes, etc]. Cable dependencies are linked in SAFE to Fire PRA and safe shutdown equipment using Equipment-to-Cable success path logics.

Map Basic Events to Equipment

Most plant equipment tag numbers will not equate to the basic events defined in the Fire PRA model. In SAFE, a new Basic Events table was created to map these relationships (i.e., Basic Event ID to Equipment ID). Fire-induced equipment failures are analyzed using SAFE's analysis engine to equate to the Basic Events failures used in the Fire PRA models.

Calculate Fire Ignition Frequencies

In SAFE fire ignition frequencies can be calculated for each ignition source located within a compartment or scenario. The equipment types (ignition sources) are generically identified as ignition frequency bins. SAFE calculates the total fire ignition frequency permitting the analyst to apply severity factors to ignition sources to adjust the fire frequency for compartments or scenarios. SAFE also provides the analyst the option to calculate severity factors for each ignition source using Excel's gamma distribution function.

Develop SAFE & Fire PRA Models

A Fire PRA model contains fire-induced sequences and failures in a scenario followed by a combination of equipment and human failures, both random and fire-induced that ultimately leads to core damage and large early release.

SAFE's analysis engine automates the cables/equipment failure analysis based against plant locations (i.e., fire zones); and evaluates the propagation of fire-induced component failures which ultimately results in system and/or performance goal failures. It is also important to note that SAFE's analysis engine uses existing database retrieval of cable routing and location information identified in SAFE.

These fire-induced equipment failures and their dependences identified in the SAFE model are then analyzed via the Fire PRA model, developed using PRA software such as CAFTA or WinNUPRA, to quantify risk (i.e. CCDP & CLERP).

SAFE identifies the equipment which is rendered inoperable due to a fire. The PRA code calculates the CCDP/CLERP for the fire, given the set of unavailable equipment. This is easily done by using the Basic Event to Equipment relationships established in SAFE, changing the PRA basic events for failed equipment to TRUE and re-quantifying the Fire PRA model.

Calculate Barrier Failure Probabilities

In Fire PRA barrier failures are modeled probabilistically. The analyst evaluates the fire barriers between compartments and determines a barrier failure probability to address multi-compartment scenarios and their effects on plant safety, should a fire propagate beyond a single location.

SAFE supports a fire compartment characterization for the entire plant. This compartmentalization includes calculating the barrier failure probabilities, evaluating barrier openings and penetrations, and identifying the presence of automatic suppression in support of multi-compartment scenario analyses.

Evaluate Uncertainties

Uncertainties associated with the data collected and model parameters in a Fire PRA analysis are quantified through propagation of estimated input distributions. Uncertainties resulting from modeling may be addressed through sensitivity studies.

The identification of potential sources of uncertainties such as those introduced by fire related faults, uncertainties in the fire modeling aspects of the Fire PRA, along with targeted uncertainties can be evaluated in SAFE for a compartment and scenario. The files used to evaluate the various uncertainties can also be linked in SAFE to a Compartment or Scenario record.

Quantify CDF and LERF

The final outcome of the Fire PRA analysis is the fire-induced cored damage and large early release frequencies for each fire scenario developed. SAFE calculates the Core Damage Frequency (CDF) by multiplying the Conditional Core Damage Probability (CCDP) with the scenario ignition frequency. The Large Early Release Frequency (LERF) is calculated by multiplying the Conditional Large Early Release Probability (CLERP) with the scenario ignition frequency. The files used to quantify the fire scenario's fire damage sequence that leads to conditional core damage probability and conditional large early release probability can also be linked in SAFE for complete tractability.

Conclusion

Using SAFE as a powerful analysis engine and a single repository of information simplifies the process of performing and later maintaining a Fire PRA analysis.

SAFE also includes the tools necessary to maintain both long term compliance following the initial Fire PRA analysis and track the changes necessary to maintain concurrence and consistency with evolving plant design.