EXPLICIT MODELING OF FIRE BARRIERS IN MULTI-COMPARTMENT ANALYSIS

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A Fire PRA plant response model is to be capable of identifying significant contributors to CDF and LERF, including plant initiating events, accident sequences, and equipment unavailabilities. Multi-compartment fire scenarios consist of a fire initiating event and fire damage occurring in one physical analysis unit (PAU), followed by propagation of the effects of the fire to one or more additional PAUs due to the failure or unavailability of credited fire barriers.

Based on Fire PRA peer review observations, multi-compartment fire scenario modeling typically quantifies the frequencies of multi-compartment scenario in side calculations, and the contribution from barrier failures is not explicitly captured. This results in both the admission of non-minimal cutsets to the final results, and difficulty in determining the risk significance of individual fire scenarios. In addition, importance measures of the barriers cannot be easily calculated.

The objective of this paper is to demonstrate an easy-to-apply methodology to explicitly model barrier failure events resulting in Fire PRA cutsets that can be used to directly identify the risk importance measures of both fire scenarios and fire barriers for use in applications, and that do not contain the non-minimal cutsets typical in existing Fire PRA multi-compartment analyses.

I. ISSUES WITH THE TREATMENT OF FIRE BARRIERS IN CURRENT FIRE ANALYSIS

A paper was previously written describing a methodology to directly incorporate fire barriers into a Fire PRA[1]. The methodology was developed in response to regulator requests to identify the importance of fire barriers in support of a new reactor's design certification. Personal experience and the experiences of colleagues gained during Peer Reviews of multiple Fire PRAs of both US and international reactors led to the realization that most, if not all, Fire PRAs do not explicitly model fire barriers. Rather, the fire barrier failure probability is generally included in the multi-compartment fire scenario frequency. In many cases, this multi-compartment fire scenario frequency also includes a combination of several factors including the fire initiating event frequency, severity factors, manual and/or automatic non-suppression probabilities, and the barrier failure probability. A unique identifier is generally applied to these multi-compartment fire scenarios which usually consists of a combination of the exposing and exposed fire compartments or the exposing fire compartment scenario identifier coupled with and an identifier for the barrier.

Incorporating the barrier failure probabilities in this manner makes determining the importance of fire barriers difficult since the barrier failure probability is buried within the multi-compartment fire scenario initiating event frequency. Additionally, lumping the fire scenario frequencies with the barrier failure probabilities can mask the importance of the fire scenarios themselves since the single compartment scenario and the multi-compartment scenario arising from the same fire scenario use different identifiers. The importances of all other equipment and human actions can be affected due to the inclusion of non-minimal cutsets which are not eliminated using normal cutset minimization (e.g., cutset compression). Finally, the total frequency (e.g., CDF, LERF, etc.), can be overstated due to the inclusion of these non-minimal cutsets.

I.A. Obscuration of Importance Measures

Since most existing multi-compartment scenario initiating event frequencies are generally identified by a lumped single event identifier consisting of some combination of the fire scenario frequency and the barrier failure probability, the attributes of both the initial fire scenario and the barrier failure probability are obscured within the multi-compartment fire scenario initiating event frequency. In addition, when barrier failure probabilities are incorporated in the multi-compartment fire scenario frequency, the cutset file developed from merging the cutsets of all fire scenarios will likely contain some non-minimal cutsets related to single and multi-compartment scenarios derived from the same fire scenario. For example, consider a cutset of a single compartment fire scenario in fire compartment 1, F[S1], which includes subsequent random failures A, P[A] and B, P[B]. In this example, P[A] and P[B] may be any type of random or common cause equipment failure probability, test/maintenance probability of human error probability. The cutset is:

$$F[S1] * P[A] * P[B] \qquad (1)$$

If a corresponding multi-compartment scenario spreading from fire compartment 1 to 2 is named using a single event based on the exposing fire compartment fire scenario and the barrier failure probability (e.g., F[S1-2]), and assuming the resultant scenario does not result in the fire-induced failure of either A or B, then the corresponding multi-compartment cutset is:

$$F[S1\text{-}2] * P[A] * P[B] \qquad (2)$$

When the single and multi-compartment cutsets are merged, the non-minimal multi-compartment cutset will not be subsumed since the PRA software sees these as two unique cutsets.

Also, consider the case of two fire scenarios in fire compartments 1 and 2 named F[S1] and F[S2], respectively. Further, consider two multi-compartment fire scenarios, one initiating in fire compartment 1 and spreading to fire compartment 2 named F[S1-2], and the other initiating in fire compartment 2 and spreading to fire compartment 1 named F[S2-1]. Note that in both multi-compartment cases, the fire barrier between the compartments is the same barrier. Therefore, in order to determine the importance of the barrier between fire compartments 1 and 2, one must consider multi-compartment scenarios in both directions. Likewise, for fire scenario importances, one must consider the importance of both the single compartment scenario as well as all multi-compartment scenarios originating in the fire compartment. In both cases, one must also account for the impact of the non-minimal cutsets. One could possibly do this, but at a great expense of time.

However, if the same corresponding multi-compartment scenario described above spreading from fire compartment 1 to 2 is developed based on the exposing fire compartment scenario (F[S1]) and a unique event for the barrier failure (e.g., P[BF-1-2]), then the multi-compartment cutset is:

$$F[S1] * P[BF\text{-}1\text{-}2] * P[A] * P[B] \qquad (3)$$

When this multi-compartment cutset is merged with the single compartment cutset (1, above), it will be marked as non-minimal, and deleted during cutset minimalization resulting in more accurate results as well as more accurate importance measures.

Note that since fire scenarios between fire compartments 1 and 2 can use the same barrier failure probability, P[BF-1-2], regardless of which compartment is the exposing compartment, the importance measures for the barrier can be explicitly calculated by the PRA software. Furthermore, since the single and multi-compartment scenarios use the same fire scenario event identifier, the true importance of the fire scenarios can be directly calculated by the PRA software. Finally, the elimination of non-minimal cutsets will result in a more accurate calculation of the importance measures of each and every event in the PRA model.

I.B. Overstatement of Measured Frequency

As shown in the previous section, when barrier failure probabilities are incorporated in the multi-compartment fire scenario frequency, the cutset file developed from merging the cutsets of all fire scenarios will likely contain some non-minimal cutsets related to single and multi-compartment scenarios derived from the same fire scenario. The addition of these cutsets ultimately results in an overstatement of the total frequency (i.e., CDF, LERF, etc.)

II. METHODOLOGY FOR DIRECT INCLUSION OF BARRIER FAILURE PROBABILITIES

Incorporation of the barrier failures into the Fire PRA model is actually a very easy task which does not involve making any changes to the existing PRA model. The methodology developed involves a simply post-processing of the CCDP and CLERP cutsets.

Most Fire PRAs quantify fire CDF and LERF by first calculating the CCDP and CLERP for the scenarios, and then applying the scenario IEF during post-processing of the cutsets to calculate the CDF and LERF. For example, if a fire scenario damages equipment and cables resulting in a loss of offsite power (LOOP), the LOOP event tree or top logic is quantified, assuming fire damaged equipment is unavailable, using a temporary initiating event (e.g., %FIRE-LOOP) set to 1.0 to calculate the CCDP and CLERP. The actual fire scenario initiating event frequency is then applied to the CCDP and CLERP cutsets resulting in CDF cutsets usually via a recovery file which replaces the temporary initiating event with the actual fire scenario initiating event frequency.

This methodology uses the same method, except that the post-processing is altered for the multi-compartment scenarios. Instead of applying a single combined multi-compartment fire scenario event with a frequency based on both the fire scenario frequency and the barrier failure probability, two events, the fire scenario initiating event frequency, and a separate event for the barrier failure probability are applied to each multi-compartment cutset. Note that the barrier failure probabilities are already calculated during the development of the multi-compartment scenarios, so there is no additional work required to obtain these probabilities.

Most, if not all, PRA software codes have the ability to post-process cutsets. An example of using post-processing tools using EPRI's FRANX[2] software was presented at the PSA 2015 conference[1]. An example using a SAREX[3] recovery file simply replaces event %FIRE-LOOP with the fire scenario initiating event F[S1], and the barrier failure probability P[BF-1-2]:

%FIRE-LOOP = F[S1] P[BF-1-2]

This recovery is applied to all CCDP cutsets for the multi-compartment scenario involving a fire initiating in fire compartment 1, and spreading to fire compartment 2. A recovery file must be created for each multi-compartment scenario evaluated. This can be a time intensive project; however, macros within the spreadsheets or databases used to calculate the barrier failure probabilities can be developed which greatly reduce the time required to create the recovery files. Regardless, the time spent in obtaining and documenting the calculations used to determine accurate importance measures can be many times greater than the time needed to develop the recovery files.

A side benefit of this methodology is that it can be use in lieu, or in tandem with the multi-compartment scenario screening task. One of the initial tasks in multi-compartment analysis is to screen scenarios where the exposed compartment fire impacts are a subset of the exposing fire impact since there would be no further damage, and all cutsets are non-minimal. In scenarios where the exposed compartment only has at most a couple components or cables, this can be done by inspection. However, when both the exposing and exposed compartments have many components and cables, the task can become time consuming. However, since any non-minimal cutsets will be eliminated using this methodology, it is usually easier to simply include these scenarios as potential multi-compartment scenarios, and allow the PRA software to eliminate the non-minimal cutsets. If all of the cutsets are non-minimal, it has the same impact as screening the scenario.

III. ADDITIONAL BENEFITS

In addition to the benefits of more accurate cutsets and importance measures, this methodology results in a model which can be used in support of numerous risk-informed activities including.

III.A Evaluation of Modifications Affecting Fire Barriers

By re-calculating the barrier failure probabilities, and re-quantifying the Fire PRA scenarios associated with the barrier, an assessment of modifications which add or eliminate fire barrier penetrations can be made. For example, regarding the addition of penetrations for routing of new cable which requires the addition of new cable penetrations, a path-of-least-risk can be determined. An initial assessment can be made by reviewing the RAW values of each penetration on each proposed path. Pathways with large RAWs can be avoided. Finally, an actual risk increase can be quantified by adjusting the barrier failure probabilities along the new path, and re-quantifying the associated scenarios.

III.B Evaluation of Modification Implementation

Determining the risk impact of implementing modifications which require temporary fire barrier degradation (e.g., to run temporary air hoses through fire doors) can be assessed. Since this methodology is applicable to both online and outage models, the risk impact of degrading a barrier during any plant operating state can be determined, and an assessment can be made to determine the best time to perform the modification with respect to fire barrier risk.

III.C Daily Risk Monitoring

Although not currently a requirement, the impact of degraded fire barriers can be assessed during daily risk monitoring activities such as Maintenance Rule (a)(4). The online risk monitor can suggest maximum "unavailability" times for the barrier.

III.D Input to the Fire Protection Program

When a fire barrier is degraded, the plant Fire Protection Program determines appropriate compensatory measures. The Fire PRA model can quantitatively access the impact of the failed penetration, and provide input to the Fire Protection Engineers. For example, fire barriers with a RAW of, or near 1 have little to no risk impact, compared to barriers with large RAWs, and compensatory measures can be incorporated commensurate with the risk associated with the barrier degradation.

IV. CONCLUSIONS

An easy to apply methodology to explicitly model fire barriers in multi-compartment analysis is described. The method results in more accurate Fire PRA cutsets, and allows for direct calculation of risk importance measures of both fire scenarios and credited fire barriers. Several potential benefits of having a Fire PRA with explicitly modeled barrier failures have been examined. Any benefits to existing risk-informed programs will be determined by the requirements and allowances of your country's specific risk-informed regulation program.

REFERENCES

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