Modeling fire initiation in nuclear power plants

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1 INTRODUCTION

The risk due to fires in nuclear power plants, similar to the overall plant risk, is the sum total of the risk from numerous individual scenarios. Each fire scenario is defined by the physical characteristics of the initiating fire, i.e., its initial location, size, fuel, and ignition source strength. Following ignition, most scenarios of interest involve the growth of the fire to damaging proportions, efforts to control and extinguish the fire, and the plant and operator response to the loss of equipment (Kazarians 1985).

Clearly, the frequencies of the initiating fires play important roles in establishing the risk of the associated scenarios. It is less obvious, but also true, that the uncertainties in these frequencies are often very large contributors to the uncertainties in the overall analysis results. The results of plant-specific studies show that the fire risk contributions of extremely severe, highly unlikely transient-fueled fires in key areas of the plant are important and sometimes dominant (PLG 1982, PLG 1983, and NUS 1983). Such fires have not yet been observed and are not expected, given the lack of very flammable materials in these key areas, the lack of activities in these areas requiring such materials, and current administrative controls on the materials. The large uncertainties in the frequencies of these fires lead directly to large uncertainties in the plant damage frequencies for these scenarios.

As an example, we refer to a recent switchgear room fire analysis (Kazarians 1985). A fire can initiate a serious accident scenario if it damages a set of elevated cable trays. Physical modeling indicates that the fires of greatest risk significance are located underneath the tray and are greater or equal in severity to a one-foot diameter oil pool fire. The frequency of such fires, λ, is given by

$$\lambda = \lambda_{AUX}\, f_{SWG}\, f_L\, f_S \qquad (1)$$

where λ_{AUX} is the annual frequency of auxiliary building fires, f_{SWG} is the fraction of auxiliary building fires occurring in the switchgear room, f_L is the fraction of switchgear room fires occuring underneath the trays (i.e., in the critical location of the room), and f_S is the fraction of critical location fires which are large enough to potentially cause damage to the trays.

Of the four parameters in Eq. (1), only λ_{AUX} is estimated directly from the data; the remaining three are assessed judgmentally based on the qualitative characteristics of the room. For instance, the distribution for the fraction f_S incorporates the reasons a fire of the specified type is very unlikely (e.g., no maintenance is performed in the room during power operation, the room is not used as a passageway, etc.) and the fact that any such fire has not been observed in a switchgear room.

The large uncertainty in f_S resulting (often spanning orders of magnitude) provides strong motivation for more explicit modeling of significant scenarios. A more detailed model may reduce the number of parameters to be judged, will improve the consistency in judgments, and will thereby increase our ability to automate the analysis. It will also indicate more clearly the important sources of risk and may reduce some of the uncertainty in the calculations.

2 APPROACH

The approach adopted deals directly with a number of the factors affecting fire occurrence, in order to improve the treatment of the very severe transient fueled fires that often dominate the fire risk, and to improve the use of judgment in location-specific analyses. The approach relies partially upon the fire data base and therefore builds upon earlier, statistically oriented analyses of fire frequency; these latter involve the classification of fires actually observed and the estimation of the frequency of fires for each category (Kazarians and Apostolakis 1982).

The classification used in Kazarians and Apostolakis (1982) is based largely on the type of room containing the postulated fire (e.g., cable spreading room versus control room). The room type acts as a single measure for all of the characteristics that may influence fire occurrence, such as room contents, traffic, use as a storage area, and so forth. The classification used in Gallucci (1980) is based solely on fuel types. In this model, the total plant fire frequency is multiplied by the fraction of these fires involving a given fuel type (e.g., wood, oil, electrical cables). These fractions are developed generically on a plant-wide basis, i.e., regardless of location in the plant.

Both of these basic approaches exhibit weaknesses when applied to specific fire scenarios. The room-based approach does not provide explicit guidance when determining the frequencies of variously sized fires at different locations within a room, i.e., in assessing f_L and f_S. The fuel-based approach does not account for any important factors other than fuel type.

The approach adopted involves using a more mechanistic, room-specific model for fire initiation. It recognizes that the frequency of fires in a room is the sum of the frequencies of many different fire scenarios. These scenarios are identified explicitly, although only the risk significant ones are actually treated.

The approach requires that the analyst develop a table (or checklist) for all potential scenarios in the room of interest based mainly on the room contents (e.g., number and locations of specific components). He then uses information on factors influencing the likelihood of the scenarios, including the frequency of various types of construction or maintenance, the likelihood of storing materials in the room, etc., in order to quantify the model parameters. The fire event data base is used when possible; it is best suited for treating component-initiated

fires. When the direct statistical evidence is weak or non-existent, simple models, whose parameters can be estimated from other sources, are developed, as is done in the overall PRA.

3 DATA BASE

The fire event data base used is developed from two sources. Nuclear Power Experience (Nuclear Power Experience 1983) contains narratives of reportable events (not just fires) based primarily on Licensee Event Reports, submitted by utilities to the USNRC. Dungan and Lorenz (1983) provide a number of event descriptions and summary data for fires reported to nuclear plant insurers and to various utility organizations (e.g., the Institute for Nuclear Power Operations), as well as for some of the fires discussed in Nuclear Power Experience (1983).

A summary of the data for operating plants based on these sources is given in Table 1. It can be seen that while there is a reasonable amount of data for component fires, the evidence is very weak for transient fueled fires. Incorporating evidence from plants in shutdown, testing, or construction increases the transient fire data base somewhat, as expected.

Table 1. Breakdown of fires in nuclear plants: 2/65-2/82 (operating plants/all plants*)

	Component fire		Transient fuel fire		
Component Involved	Self Ignition	External Ignition	Class A	Class B	Total
Reactor coolant pumps	5/9	0/2		1/1	6/12
Other pumps	6/11	1/1			7/12
Motors/valves	3/3				3/3
Diesel generators	19/23				19/23
Cables/buses	7/9	2/6		1/1	10/16
Switchgear, MCCs, panels	14/27		0/1		14/28
Outdoor transformers	7/7				7/7
Indoor transformers	2/2				2/2
Main turbine/ generator	6/9	1/1			7/10
Batteries	2/2	1/1			3/3
No components			2/9	0/1	2/10
Other	2/4	2/3	1/5	0/1	5/13
Total	73/106	5/14	3/15	4/4	85/139

*"All plants" include plants in operation, in shutdown, undergoing testing, and under construction.

It should be cautioned that the data base very likely does not contain all fires that have occurred in nuclear power plants (Dungan and Lorenz 1983). Very small fires or fires with no impact on safety equipment may not be consistently reported, especially when the plant is not in operation.

4 MODEL

As discussed earlier, any one of a number of fire scenarios can occur in a room. In the switchgear room example, the fire may involve a set of breakers, an indoor transformer (4160/480V), cables, transient fuel, and so forth. The purpose of the fire initiation model is to provide a framework for identifying and quantifying the frequency of each of these scenarios.

In each scenario, both an ignition source and a body of fuel must be present (for most cases, it is safe to assume that oxygen is present). Of course, the ignition source must be sufficiently strong to actually ignite the fuel. Either or both of the ignition source and the fuel may be in situ or transient. Thus, the scenario may involve an in situ source and in situ fuel (e.g., the self-ignition of a cable), a transient source and in situ fuel (e.g., welding slag igniting a cable), an in situ source and transient fuel (e.g., cleaning fluid igniting on a hot pipe), and a transient source and transient fuel (e.g., griding sparks igniting a bucket of glue). Each of these four general classes can be further subdivided, as shown in Figure 1.

Figure 1 is a tabular representation of a fault tree for the occurence of a "hazard event", the simultaneous presence of an ignition source and fuel in the room. Using the deductive logic of the tree, we have assurance of some reasonable degree of completeness. For example, the tree incorporates "odd" (but observed) scenarios where non-flammable materials are improperly replaced by flammable ones, and where flammable material to be covered by protective coatings are not yet covered at time of ignition.

The fault tree can be expanded to analyze the ignition event which follows the hazard event. A somewhat more convenient representation is provided by an event tree, as shown in Figure 2. This event tree recognizes different fuel types and sizes for each hazard event, and also treats the possibility of delayed ignition. These are both useful in the enusing fire growth and suppression analyses; the issue of delay is potentially significant for fires started by transient ignition sources because the personnel starting the fire do not detect it immediately and may actually leave the area before ignition.

Figures 1 and 2 contain the formal fire initiation model. The frequency of any one ignition scenario is the product of the hazard event frequency (developed using the fault tree), the conditional frequency of a particular amount and type of fuel, and the conditional frequency of ignition (immediate or delayed). The model is formal in the sense that some of the scenarios do not require the entire model. For example, the frequency of most component fires can be estimated directly from the data; the frequency of the hazard event is unity, and the issue of ignition delay is not important.

In general, it is expected that a number of model parameters, especially those involving transient fires, can be quantified only on a highly room-specific basis. For this reason, generic factors for estimating the frequency of the different scenarios are not presented. Rather, Figure 1 provides the hazard event fault tree in the form of a simple table to be used by the analyst in identifying scenarios. The rows of the table are the different fuel packets in the room and the columns are the various potential ignition sources. The entries in the table are the different hazard events (or fire scenarios) that may occur.

		Ignition Source	
		In situ A) Normally present (hot surfaces, electrical, ...) B) Component failure (electrical, mechanical, ...)	Transient C) Used in room (maintenance, construction, ...) D) Administrative violation (cigarette, open flame)
Fuel	In situ A) Anticipated (insulation, lube oil, fuel oil, ...) B) Unanticipated (wrong material, unprotected material, ...)	1, 2, 3	
	Transient C) Used in room (maintenance, construction, ...) D) Stored in room (planned storage, administrative violation, ...)	4	5

Hazard Events/Fire Scenarios

1) Switchgear breaker fire
2) 4160/480V transformer fire
3) Electrical cable fire, self-ignition
4) Cleaning fluid spill into switchgear cabinet
5) Grinding sparks ignite scrap material

Figure 1. Example checklist for identifying fire scenarios.

5 SUMMARY AND CONCLUSIONS

A formal model for fire initiation is presented in this paper. The model accounts for extremely room-specific factors, such as the frequency of maintenance within the room. It also accounts for parameters that can be quantified more generically, such as the frequencies of breaker fires and pump fires. It is intended to treat the severe, transient-fueled fires that often dominate the fire risk.

Because of the specificity of the model, an application to a generic room will not be very useful. Applications in the context of actual risk analyses will be reported in forthcoming papers.

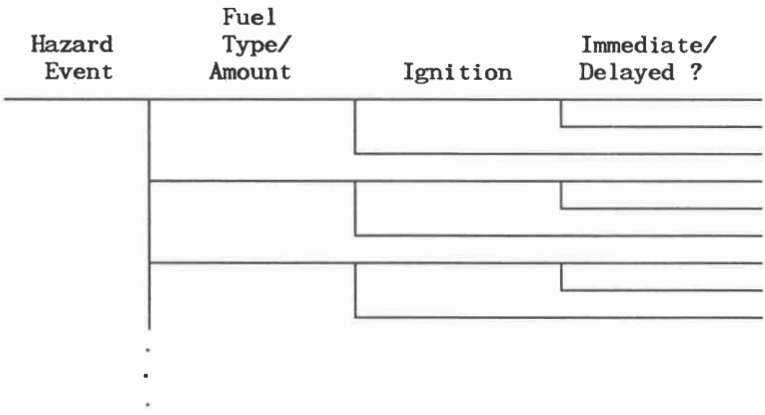

Figure 2. Event tree model for fire ignition.

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