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PROBABILISTIC FIRE RISK ANALYSIS - A TOOL FOR DECISION MAKING ON PLANT IMPROVEMENTS

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ABSTRACT

Probabilistic fire risk analysis can act as a tool for decision making on plant improvements. Such analysis allows the identification of weak points based on quantitative results and thus will provide a strictly safety-related basis for setting priorities for improvement measures.

Therefore an investigation on current probabilistic fire risk analysis methods has been performed. The analysis objective is twofold: the critical plant zones that present the largest contribution to the total core damage frequency will be identified by an appropriate screening process and fire event sequences will be established which reflect the effects of fire occurrence, fire detection, room closure (openings, ventilation), fire suppression and equipment damage due to the suppression agent. Selection criteria, based on fire loads, safety related equipment, equipment for power operation and measuring devices of power limiting and safety systems, define rooms or pairs of rooms as critical fire zones. In a quantitative event tree analysis the fire caused frequency of initiating events and different core damage states will be determined. The fire frequency - based on 800 fires in 480 BWR years and 790 PWR years over a time span of 1965 - 1988 in USA - will be used and adapted to German requirements.

Results for the fire related core melt frequency show that the potential for improving plant fire protection varies to a large extent. A low fire-related contribution can be achieved.

1 INTRODUCTION

The safety criteria for nuclear power plants (NPP's) [1] include safety-related design principles. Criteria 1.1 "Principles of Safety Precautions" requires reliable safety systems. In a footnote to this principle it is stated that the reliability of these systems and components can be determined with appropriate probabilistic methods. The committee "Probabilistic Safety Analysis (PSA) for NPP's" prepared a guideline for performing such a PSA [2]. In that guideline an analysis of plant internal fires and external events is explicitly not required. On the other hand in USA and partly in Europe, i.e. Finland, Spain, Sweden and Switzerland, a full scale PSA including external events is common practice. Within the scope of the German Risk Study, Phase B [3] a probabilistic fire risk analysis (PFA) has been performed for a typical 1300 MWe PWR plant. The Gesellschaft für Reaktorsicherheit published comprehensive work on fire risk quantification that serve as basis for the fire analyses done for the German Fire

Risk Study [4]. Within the ABB group fire risk analysis work was done for BWR, PWR and radio-chemical facilities. Early work was sponsered by the Swedish Nuclear Power Inspectorate [5, 6]. Today's activities concentrate on backfitting programs of older plants and analyses of advanced reactor designs (System 80^{+}, BWR90).

In order to provide a basis for further discussions on benefits and limits of PFA in Germany ABB Reaktor under sponsorship of the Bundesamt für Strahlenschutz worked out a method for the probabilistic analysis of fire risks. The proposed method is simple in application and despite the uncertainty in the models will give clear answers with respect to plant vulnerability and fire-induced core melt frequencies.

2 PROBABILISTIC FIRE RISK ANALYSIS

2.1 Screening analysis

The complete PFA will be done in different procedural steps (see Table 1). Major tasks are the qualitative screening process to identify critical fire zones and the quantitative analysis. The screening analysis should not be so conservative that an unmanageable number of fire scenarios remain for the detailed quantitative analysis. The proposed method using a PC based software package will be described. In the first step a detailed data collection will be done in all rooms of the plant to identify the essential and the critical fire zones.

A fire area is defined as a building or part of a building, sufficiently bounded by fire barriers which prevent fire propagation to adjacent buildings or parts of buildings [7]. A fire zone is a subdivision of a fire area preventing propagation or unallowed consequences to other subdivisions.

An essential fire zone contains:
- equipment related to power operation,
- safety related equipment,
- fixed or transient combustibles.

A critical fire zone is an essential one, in which a fire
- damages at least one safety-related component or system and
- causes a safety related initiating event.

A plant transient will be initiated, when operational or sensing equipment of the reactor protection system fails. A transient changes into a safety related event, when the operational equipment to handle the transient is not available.

The data collection will be done with a reasonable effort. One starts with the collection of data for about 1000 rooms and during the screening process reduces the number of rooms to around 10 - 30 for which a remarkable contribution to the fire initiated core melt frequency is to be expected.

The data collection comprises:

1. Fire protection maps in which all buildings are subdivided in numbered fire zones and rooms. The definition of a "room" is not necessarily related to fire rated enclosures but takes into consideration distance, system installation areas and range of suppression systems.
2. Inventory lists of fixed and transient combustible loadings. The fire load per floor area [kWh/m^2] will be calculated for each combustible material such as oil, cable insulation, tissues, clothes, paper, filters, plastic etc. The insulation of cables within metal conduits or cabinets or electrical motors are to be considered, too. If the fire load is less than 7 kWh/m^2 [8] the room will be neglected.
3. Lists of electrical and sensing equipment per room. These lists contain all electrical consumers, such as valves, pumps, drives, motors, cranes, electrically ac-

tuated dampers, heaters, ventilators, temperature, pressure and level measurement equipment etc. In most plants these data are available on computer files.

4. Tables of cable routings for safety and operational systems. This table contains the location of the components (room number), the electrical bus providing power to the components, rooms crossed by cables (room numbers), redundancy assignment etc. The assumption is, that the failure of the cable in any room can lead to the same consequence as the failure of the component itself. Both, power and signal cables are to be taken into account.
5. A list of initiating events, mitigating systems and functions of the existing level 1 PSA (expected soon to be available for every NPP in Germany).

In case the above information does not exist, numerous plant walk downs are necessary for this data collection. The screening process starts with the identification of all rooms for which at least one of the following 3 criteria is fulfilled:

- Fire load > 7 kWh/m^2
- Room contains safety related equipment or cables of such equipment
- Room contains operational or sensing equipment of the reactor protection system

Rooms, for which all 3 criteria are fulfilled simultaneously, will be identified as essential fire zones / rooms. For rooms in which 2 out of 3 criteria are fulfilled, adjacent rooms are checked to identify pairs of rooms that fulfil all 3 criteria. The critical fire zones / rooms and pairs of rooms are selected based on the above described criteria.

Having screened out all unimportant rooms, a detailed data collection concerning fire protection will be done for the remaining critical ones: Data with respect to the building structures (fire resistant enclosure, rated barriers such as doors, sealed openings, heat and smoke removing systems), data with respect to installations (equipment for fire detection, alarm and suppression), data with respect to management and administration (trained personnel, fire brigade, fire protection inspection and maintenance procedures). For the fire propagation the ventilation of the fire zone plays an important role, so that data concerning room geometry (floor area, surface, volume), ventilation (natural or forced convection, openings, fire dampers etc.) and combustible loading (physical properties, quantity, location, burning rate, etc.) are necessary.

2.2 Quantitative analysis

For each critical fire zone or room an event tree will be developed with nodes for fire initiation, ventilation of the room, fire detection, fire suppression and propagation. The development of a fire, once initiated, depends on the availability of the fire detection and suppression systems. The availability of the fire barriers influences the fire propagation to adjacent rooms. Fig. 1 shows a typical event tree for an oil fire in a diesel generator room. For the fire ignition frequency the latest published data base [9] for US plants will be used, since it includes 800 fire incidents caused by fixed and transient ignition sources due to normal plant operation and maintenance activities from 114 BWR and PWR units representing a total sample size of 1270 reactor years. The older data base, covering a period from 1968 to 1978, gives an average fire frequency per year and plant of 0,17 [10] (only such fires are counted, which are relevant to the plant safety). The new data base, covering a period up to 1988, gives a number of 0,38, counting fires in all plant locations during power operation and maintenance activities. The German data base covers only 55 fire events in 18 plants (including test and demonstration plants) from their first criticality until November 1983. The average fire frequency per plant and year of 0,40 [11] compares very well with the US figure. In principle the US data base can be applied to German plants, however certain adjustments are recommended to allow for design differences. One such difference is that in German plants all switchgear is concentrated in one switchgear building, and no motor control centers are placed with mechanical equipment like pumps etc. To calculate the fire frequency for a single room in a building additional weighting factors based on the fractional amount of ignition sources, the weight of cable insulation, the number of relevant fire zones and special factors for the ignition sources [9] are necessary.

The nodes "early and late fire detection", "early and late fire suppression", "room closure" are quantified according to [4, 12]. The node "equipment damage caused by fire suppression agent" is introduced due to a NRC request [13] and a 0.3 probability for suppression damage is assumed in case agent-susceptible equipment is in the room.

As a result of the PFA 5 different damage states are distinguished:

- Minimal damage (a) occurs when early detection and early suppression are successful. Only the specific component, cable or combustible, where the fire started, is damaged.
- Partial damage (b) exists when early detection is successful, the use of portable extinguishers fails and the use of a hose or deluge system is successful to suppress the fire. Safety related components close to the point of fire ignition are assumed to be damaged.
- Partial damage (c) corresponds to partial damage (b) but the suppression agent, mostly water, has damaged the agent susceptible equipment in the room.
- Total damage (d) exists, when early detection and suppression fail, but late suppression with fixed installed equipment prevents propagation to a neighbouring room or fire zone. All safety related equipment and cables of critical components in the room are damaged.
- Total damage and propagation (e) happens when all fire protection measures fail to prevent the propagation to adjacent rooms. All safety related equipment is damaged in the neighbouring rooms.

For each critical fire zone / room the following results are obtained:

- Freqency and nature of fire initiated transients.
- A list of damaged equipment, categorized corresponding to the damage states (a), (b), (c), (d), and (e).
- Frequency of the damage states.

This will give an insight in the fire vulnerability of the plant. But finally the combination of the PFA with the PSA, level 1 will allow to calculate the fire induced contribution to the core melt frequency. For each initiating event the fire caused frequency will be summed up and specified as input to the corresponding event tree of the PSA, level 1. Additionally the damage state of the safety related equipment has to be introduced into the fault trees. For all components that are not affected the statistical failure behaviour is used. The core melt frequency is calculated for each transient as the sum of the single event core melt frequencies. The total core melt frequency is obtained by summing the contribution of all transients.

2.3 Results and discussions

Fires have occurred in almost all NPP's. Based on the experience gained in the USA since 1968 the frequency of reportable fires during plant operation is approximately 0.38 per reactor-year, leading to the observation that, on average, a plant can expect

15 fires during its 40 year design life. Up to now no fire has led to core damage, but several incidents represent significant precursors. Some of the published PSA's have included an analysis of fires and shown that fires contribute up to 55 % to the overall core damage frequency [14]. Plant modifications in Indian Point 2, Limerick and Haddam Neck reduced the fire induced core damage frequency up to a factor of 10. But the risk from fire is still considered as a contributor to the overall risk. The weak point in these plants was the switchgear room with the cable routings without fire barriers between the redundancies. For older German plants the licensing authority asks for an updating of the fire protection status according to the current state of science and technology. The actual status will be compared to the required status outlined in the applicable rules and regulations. Such analyses are under development. Resulting deficiencies are catalogued, evaluated and discussed with the utility and with the competent authority. In this context a PFA can help to evaluate the deficiencies and to set priorities for fire protection improvement measures. The analysis for Haddam Neck for instance shows that the core melt frequencies are highest for the auxiliary building and the switchgear room [15] and lowest for the control room and the diesel generator building. Cost / benefit reflections lead to fire protection backfittings in those fire areas with relatively high core melt frequency.

The models used in the analysis are, in despite of the simplifications, accurate enough to identify plant vulnerabilities due to fire incidents and to assess plant improvements with respect to fire protection.

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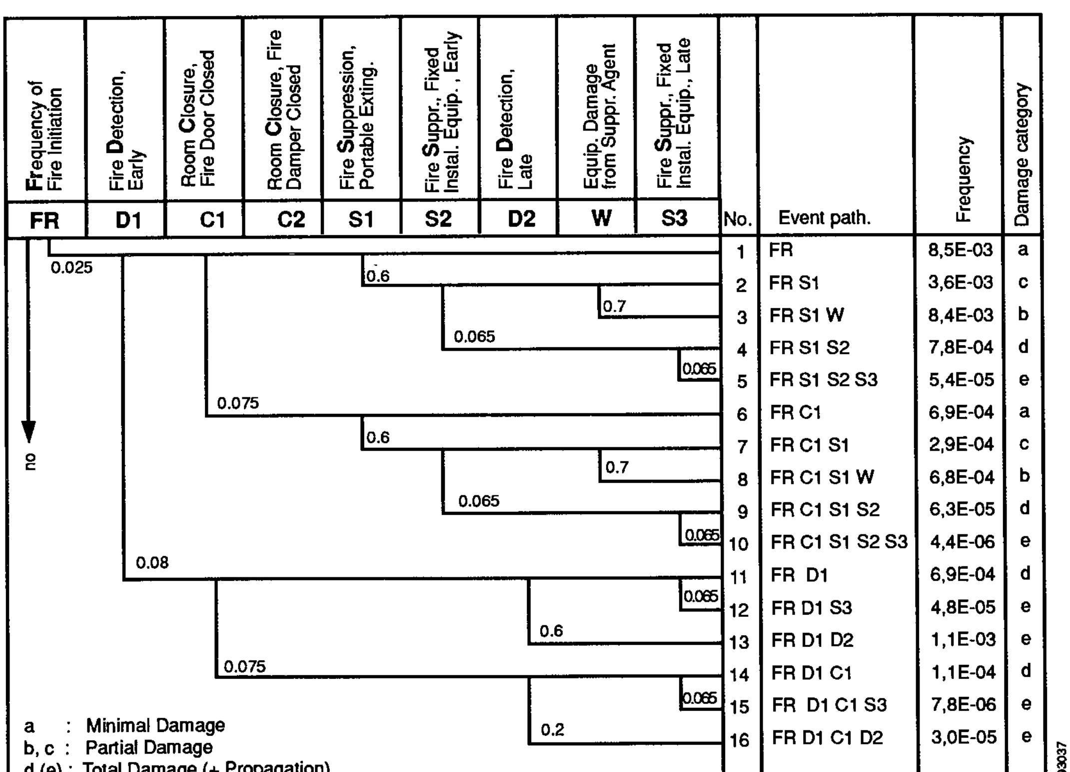
Table 1: Probabilistic Fire Risk Analysis, Procedural Steps.

SCREENING PROCESS:

- Data collection
- Allocation of combustible loading, allocation of safety and operational components and systems to rooms and fire zones
- Identification of essential and critical fire zones (rooms and pairs of rooms)

QUANTITATIVE ANALYSIS:

- Data collection
- Development and quantification of event trees for the critical fire zones / rooms
- Evaluation of frequencies of occurrence for the different plant damage states and transients
- Quantification of fire induced core melt frequencies



No.	Event path.	Frequency	Damage category
1	FR	8,5E-03	a
2	FR S1	3,6E-03	c
3	FR S1 W	8,4E-03	b
4	FR S1 S2	7,8E-04	d
5	FR S1 S2 S3	5,4E-05	e
6	FR C1	6,9E-04	a
7	FR C1 S1	2,9E-04	c
8	FR C1 S1 W	6,8E-04	b
9	FR C1 S1 S2	6,3E-05	d
10	FR C1 S1 S2 S3	4,4E-06	e
11	FR D1	6,9E-04	d
12	FR D1 S3	4,8E-05	e
13	FR D1 D2	1,1E-03	e
14	FR D1 C1	1,1E-04	d
15	FR D1 C1 S3	7,8E-06	e
16	FR D1 C1 D2	3,0E-05	e

Fig. 1: Event tree for a typical fire incident (here diesel generator building)