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Current status of fire risk assessment for nuclear power plants

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1. Introduction

Depending on design and operational characteristics of a nuclear power plant (NPP), operating experience worldwide has shown that fire can be a safety significant hazard. Thus, the regulators expect the licensees to justify their arrangements for identifying how fires can occur and spread, assessing the vulnerability of plant equipment and structures, determining how the safe operation of a plant is affected, and introducing measures to prevent a fire hazard from developing and propagating as well as to mitigate its effects.

Methods to analyze existing plants systematically regarding the adequacy of the implemented fire protection features can be deterministic as well as probabilistic ones. Fire risk assessment has become an integral part of probabilistic safety assessment (PSA) and, on an international level, fires have been recognized as one major contributor to the risk of NPP depending on the plant specific fire protection concept.

Operating NPP in Germany have been designed and constructed in different plant generations resulting in differences in the design and layout of fire protection features.

However, as a result of permanent supervision and specific fire safety reviews, comprehensive backfitting and upgrading measures have been realized including passive, mainly structural means (e.g. fire barriers) as well as active fire detection and extinguishing features and operational fire protection means (for manual fire fighting) resulting in significant improvements in fire safety, in particular of nuclear power plants built to earlier standards.

In the past, most of the engineering work in designing NPP fire protection features has been performed on a deterministic basis. Moreover, the use of deterministic fire analysis is current practice in Germany to review the fire protection status of operating NPP.

As an observation from other areas, the probabilistic approach provides different insights into design and availability of systems and components supplementing the results from deterministic analyses and enhances the understanding of fire risk compared to the consideration of deterministic analysis. Thus, probabilistic aspects have been taken into account for decision making on a case-by-case basis for fire protection aspects, too. A more comprehensive fire risk assessment is recommended in the frame of periodic safety reviews (PSR) which are now a common tool in nearly all countries.

2. Deterministic Safety Status Analysis

Fire safety is already addressed in the safety criterion 2.7 "Fire and Explosion Protection" of the Safety Criteria for Nuclear Power Plants (BMI, 1977) and in the Incident Guidelines (BMI, 1994) requiring that protective measures against fires shall be taken by means of plant engineering. The specifications of these precautions are outlined in three nuclear safety standards defining and prescribing the basic requirements, fire safety measures regarding structural plant components, fire safety measures for mechanical and electrical plant components (KTA, 2000). The basic requirements describe the design principles, structural and equipment-related fire protection measures against building internal and external fires, operational fire protection measures as well as tests and inspections.

Part 2 covers location and accessibility of buildings, fire compartments, structural elements enclosing fire compartments, structural elements for rescue routes, ventilation systems as well as heat and smoke removal systems, cable ducts, cable support structures including mounting elements in the vicinity of cable fire shields. Moreover, a simplified validation procedure for determining the required fire resistance rating of structure-related fire protection measures. The German nuclear safety standards on fire protection are currently under revision.

The plant internal hazard fire has to be considered in the deterministic safety status analysis as part of the PSR in order to review if the protection goal oriented requirements outlined in the regulatory framework are met, but also more recent, corroborated findings are resolved, i.e. if the nuclear protection goals such as reactivity control and fuel element cooling are achieved by the fire protection features implemented.

3. Probabilistic Safety Assessment

For performing the PSR, a PSA Guide which has been issued in Germany by the regulatory body containing reference listings of initiating events for NPP with PWR and BWR respectively, which must be checked plant specifically with respect to applicability and completeness. Plant internal fires are included in these listings. Detailed instructions for the analysis of plant internal fires, fire frequencies and unavailability of fire detection and alarm features as well as data, e.g. on the reliability of active and passive fire protection means, are provided in the technical documents on PSA methods (FAK PSA, 2005a) and PSA data (FAK PSA, 2005b). These technical documents have been developed by a working group of technical experts from nuclear industry, research centres, universities, authorities and technical support organizations chaired by the BfS (Bundesamt für Strahlenschutz, Federal Office for Radiation Protection).

At present, it is international practice to perform a Fire PSA as part and supplement of the internal events PSA (EPRI, 2005; ANS, 2007). However, up to the time being probabilistic fire risk analysis (Fire PSA) is a methodology needing further development.

A Fire PSA is required in the German PSA Guide as explained earlier. In this context, a state-of-the-art approach for performing Fire PSA has been developed in Germany, which has been exemplarily and completely applied to a German NPP with boiling water reactor (BWR) of the type BWR-69 for full power (FP) operation (von Linden et al., 2005).

It is the task of a Fire PSA to determine the annual frequency of fire induced core damage states (FCDF) of a NPP within the in advance defined global analysis boundary. The set of all compartments is the starting point of the fire analysis. The spatial plant partitioning should be performed in a way that all compartments characterize the global analysis boundary and that the compartments do not overlap. In this case, the annual frequency of fire induced core damage states of the plant results from the sum of all compartment related annual frequencies of fire induced core damage states.

It is assumed that compartments with a low fire load density do not impact the Fire PSA result. Such compartments are screened out before starting the detailed compartment and scenario specific analysis. The fire induced core damage frequencies of all the remaining compartments are determined in a first step using simplified and conservative assumptions. In the following, only such compartments must be analyzed in detail, for which in case of fire a relevant contribution to the FCDF of the whole plant is to be expected.

3.1. General approach for fire PSA

A comprehensive Level 1 Fire PSA has to be performed for power operation as well as shutdown plant modes. For the analysis, it is assumed that the plant contains *n* disjoint spatial units (so-called compartments) for the plant operational states mentioned in Table 1. The Level 1 Fire PSA aims on estimating the frequencies of fire induced damage states (in the most cases hazard states or core damage states) per reactor year (ry). The total FCDF is the result of adding up the FCDF for the entire compartments and plant modes including full power (FP) as well as low power (LP) and shutdown (SD) states.

$$FCDF = \sum_{i=1}^{n} \sum_{j=1}^{m} f_{ij} \ .$$

Compartment i	Plant operational state j					
	1	…	j	…	m	$\sum j$
1	f_{11}	…	f_{1j}	…	f_{1m}	$f_{1\bar{j}}$
…	…	…	…	…	…	…
i	f_{i1}	…	f_{ij}	…	f_{im}	$f_{i\bar{j}}$
…	…	…	…	…	…	
n	f_{n1}	…	f_{nj}	…	f_{nm}	$f_{n\bar{j}}$
$\sum i$	$f_{\bar{i}1}$		$f_{\bar{i}j}$		$f_{\bar{i}m}$	FCDF
	f_{FP}	$f_{LP/SD} = \sum_{j=2}^{m} f_{\bar{i}j}$				

Table 1. Denominations of the fire induced core damage state frequencies per compartment and plant operational state (Röwekamp et al., 2010)

For estimating the overall plant FCDF (for the entire plant) the individual frequencies for each compartment *i* (*i* = 1, …, n) and each plant mode *j* (*j* = 1, …, m) have to be calculated. For minimizing this effort, a stepwise approach is chosen. If a screening approach provides the result of f_{ij} exceeding a specific threshold a detailed analysis is carried out for estimating f_{ij} considering all the available information and data. A threshold value of 1.0 0E-07/ry has been used for the Fire PSA for full power modes.

First, each compartment is analyzed with respect to fire specific aspects. If this analysis gives the result that no fire impairing nuclear safety can occur under the boundary conditions of plant mode being analyzed the compartment can be excluded from further analysis for this mode. This corresponds i.e. to the German fire load criterion of screening out compartments with a fire load density of less than 90 MJ/m² provided in (FAK PSA, 2005a).

For estimating the fire-induced core damage frequency f_{ij} for a specific compartment *i* and a plant mode *j* the compartment inventory as well as that of adjacent ones must be analyzed with respect to fire specific aspects and to the safety significance of the inventory. The potential fire event sequence can be analyzed by several fire scenarios with {source *a*, target *z*}, where the fire source *a* is located inside the fire compartment *i* to be analyzed, while the critical target *z* can be located in the same compartment *i* or in the adjacent ones. The fire-induced CDF f_{ij} is calculated corresponding to Figure 1 (Röwekamp et al, 2010). f_{ij} is the sum of all the critical fire scenarios with {source *a*, target *z*} identified for the compartment *i* and plant state *j*. In this context, a scenario is called a critical one if the target is an item, for which its failure causes an initiating event or which itself is a safety related component.

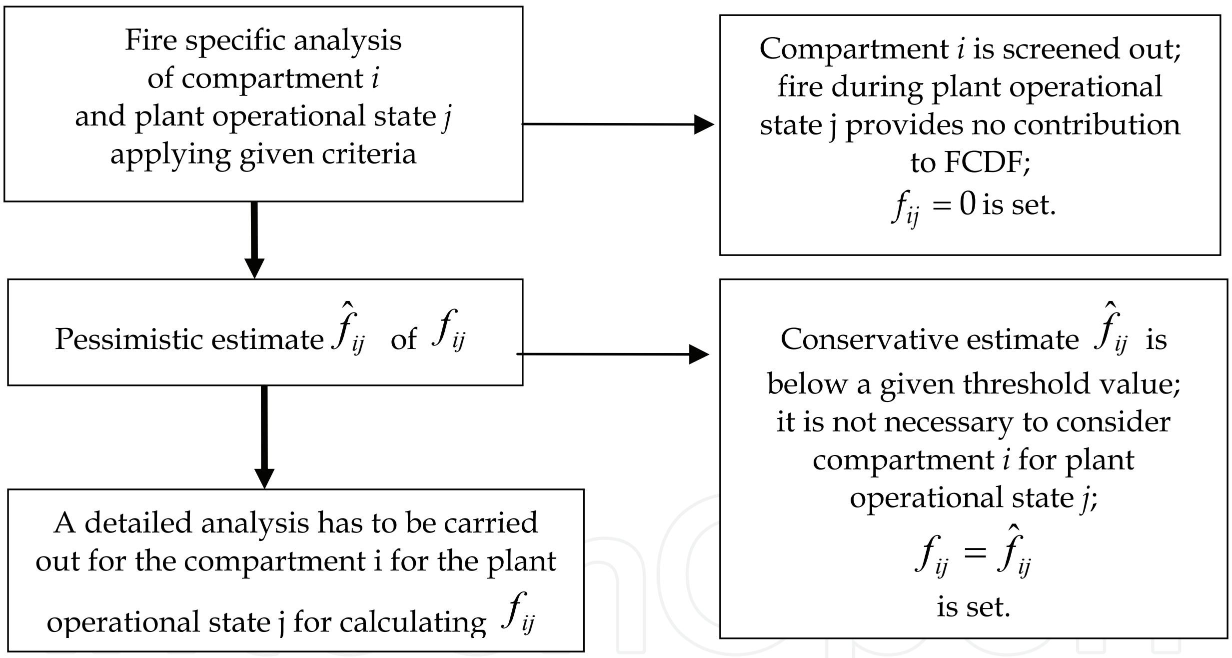


Fig. 1. Scheme for estimation of f_{ij} for compartment *i* and plant mode *j*

Some simplifications are particularly applied for a conservative estimate $\hat{f}_{ij}$ of f_{ij} (cf. Figure 1). One assumptions is that a fire inside a compartment *i* impairs the entire equipment in this compartment. Another one is that no fire source *a* is specified in the compartment *i*.

As a result, the fire occurrence frequency of the compartment *i* is used for calculating $\hat{f}_{ij}$.

Table 2 provides the characteristic parameters needed for determining for a given fire sequence {a,z} the fire induced CDF as well as the steps of the analysis for which they are needed. This information is typically used in the frame determining f_{ij} for those scenarios not screened out before (cf. Figure 1, detailed analysis).

Characteristic Parameters		Analysis
a	fire source	Selection of a fire scenario with {source a, target z} in a compartment to be analyzed
z	fire target: A fire at the source a endangers equipment z.	
f_a	Fire occurrence frequency of fire source a	Calculation of f_a
$p_{z/a}$	Conditional failure probability for target z due to fire at source a	Estimation of $p_{z/a}$ by deriving and quantifying a fire specific event tree considering all aspects of fire suppression
$f_{z/a}$	Failure frequency of target z due to fire at source a	$f_{z/a} = f_a \cdot p_{z/a}$
IE	Initiating event (IE) due to failure or damage of target z	Estimation of IE depends on plant operational state to be analyzed; if the failure of target z does not result in an IE (z is safety related component), experts make a conservative assumption corresponding to approach given in the plant operating manual.
$p_{IE/z}$	Conditional occurrence probability of initiating event (IE) due to failure of target z	In many cases, estimation of $p_{IE\ /\ z}$ by expert judgment (simplified assumption: only one initiating event (IE) possible in case of target z failure)
$f_{IE/z}$	Occurrence frequency of an initiating event IE due to a fire at fire source a	$f_{IE/z} = f_{z/a} \cdot p_{IE/z} = f_a \cdot p_{z/a} \cdot p_{IE/z}$
$p_{SYS/IE}$	Conditional failure probability of safety functions required for control of the initiating event IE	Estimation of $p_{SYS\ /\ IE}$ by deriving and quantifying the systems specific event tree for control of the initiating event (IE); depending on the plant operational state to be analyzed the analyst can fall back to event sequences of the Level 1 PSA for full power as well as for low power and shutdown states; if target z is a safety related component, its failure has to be considered in the PSA plant model.
$f_{\{a,z\}}$	CDF for a fire at source a with target z	$f_{\{a,z\}} = f_a \cdot p_{z/a} \cdot p_{IE/z} \cdot p_{SYS/IE}$

Table 2. Scheme and parameters for estimating fire induced damage frequency $f_{\{a,z\}}$ for a given plant state

3.2. Screening analysis as described in the full power operation PSA documents for PSR

The screening process to identify critical fire compartments is an important first step within fire risk assessment. Such a screening analysis should not be too conservative so that an unmanageable number of fire scenarios remains for the detailed quantitative analysis. However, it must be ensured that all areas relevant for nuclear safety are investigated within the quantitative analysis.

The recent German documents on PSA methods (FAK PSA, 2005a) and PSA data (FAK PSA, 2005b) do only cover approaches for a Level 1 Fire PSA for full power operation. According to (FAK PSA, 2005a and 2005b), the systematic check of the entire plant compartments and/or compartment pairs can be performed in two different ways: Critical fire compartments can be identified within the frame of a qualitative (qualitative screening) or a quantitative process (screening by frequency). The qualitative screening allows - due to the introduction of appropriate selection criteria - the determination of critical fire compartments with a limited effort. Applying the screening by frequency, critical fire compartments are identified by means of a simplified event tree analysis.

The systematic analysis of all plant compartments and/or compartment pairs requires detailed knowledge of the plant specific situation.

3.3 Plant partitioning analysis

3.3.1 General approach

It is the task of a Fire PSA to determine and to assess fire induced plant hazard states or plant core damage states for the NPP. A plant hazard state (HS) occurs if the required safety functions fail. A core damage state (CDS) occurs, if also intended accident management measures fail.

In the following, the recent German Fire PSA methodology (Türschmann et al., 2005) is explained for deriving fire induced core damage frequencies. An analogous approach is applied for obtaining fire induced plant hazard state frequencies.

For determining fire induced CDF it is in principle necessary to identify all those permanently as well as temporarily present combustibles (fire loads) in the plant, for which by any potential ignition a fire impairing nuclear safety is possible. For quantification of the consequences the annual combustible specific f_a has to be determined for each fire load a being present. The fire induced CDF of the entire NPP is derived from the sum of f_a related to the entity of combustibles present. In practice, it is impossible to determine the f_a for each combustible being present in a plant. Therefore, several combustibles are grouped in an appropriate manner, i.e. locally interconnected plant areas, so-called compartments, are generated inside the buildings. In case of a partitioning of the entire plant into disjoint compartments not overlapping each other the annual FCDF is derived from the sum of all compartment related f_{i1}.

Practical considerations suggest analyzing compartments according to the plant specific identification system. Depending on the compartment specific characteristics a different partitioning of compartments may be necessary in exceptional cases, e.g.:

- Compartments with internally implemented fire barriers (e.g. long cable channels, cable ducts, etc.);
- Compartments with cable routes/raceways protected by wraps, coatings, etc. (such a cable duct or channel should be understand as compartment itself);

- Extremely large fire compartments (reactor annulus, big halls (e.g. turbine hall), staircases, etc.).

Performing Fire PSA starts by determining the building structures to be analyzed (Türschmann et al., 2006). This task requires some sensitivity, insofar as the effort of the analytical work can be drastically reduced selecting compartments by engineering judgement for the detailed analyses based on the knowledge of the plant in general, of the plant's fire protection in particular and, in addition, of the calculation methods used in the Fire PSA.

A compromise has to be made for the optimum partitioning between the greatest level of detail (analysis of each individual fire load) and too little details in the plant partitioning. The only requirement to be met is that each fire load considered has to be correlated only to one compartment.

3.3.2 Exemplary analysis for a BWR-69 type nuclear power plant in Germany

Five buildings of the entire NPP have been found to be representative for being analyzed within the Level 1 Fire PSA for full power plant states (Röwekamp et al., 2006) exemplarily performed for a German BWR-69 type NPP (see Table 3).

Building	**Number of Compartments**	
	Using identification system	**To be analyzed**
Reactor Building	306	351
Switchgear Building	165	203
Turbine Building	82	106
Diesel Building	25	26
IES Building*	36	42
total	**614**	**728**
* bunkered independent emergency systems building (IES building)		

Table 3. Spatial partitioning of the buildings relevant for Fire PSA in a BWR type reference plant analyzed

The spatial plant partitioning for the plant analyzed is principally based on the given plant specific identification system. In a few exceptional cases deviations from this procedure have to mentioned, e.g. the subdivision of the very large reactor annulus into quadrants, or that of extremely long cable rooms and stairways. Some fire protected (sealed) cable ducts (raceways) without compartment numbers have been reassigned.

The analytical step of the spatial partitioning into compartments and the complexity of the following analyses can be simplified if the tasks are carried out building by building. It is possible to exclude those buildings from the Fire PSA, for which it can be demonstrated that there are no components present, whose fire induced functional failure might impair nuclear safety (so-called safety related components). It should be simultaneously checked, if a fire in a compartment of such a building has the potential of spreading to any other building with safety related components.

The partitioning of the NPP into compartments is an important step in performing a Fire PSA. In the frame of this step of the analysis it is the major task to make available all the data and information necessary to calculate the compartment related f_{ij}.

3.4 Fire PSA database

For performing a quantitative fire risk assessment, a comprehensive database must be established which should, e.g., include initiating frequencies, reliability data for all active fire protection means, details on fire barriers and their elements, etc. Detailed information is needed on potential ignition sources, fire detection and extinguishing systems, and manual fire fighting capabilities including the operational fire protection (fire brigade, etc,). Further information on secondary fire effects, safety consequences, analysis of the root cause of the event and corrective measures, etc. would be helpful. It should be pointed out that plant specific data are to be applied as far as feasible. However, generic reliability data have been provided as an additional input (Berg & Röwekamp, 2000).

The database for performing a Fire PSA is developed based on a partitioning of all the buildings to be analyzed. Basis for the building selection is the entire nuclear power plant.

In particular, the following four questions have to be answered by means of the collected data:

(1) Can an initial incipient fire (“pilot fire”) develop to a fully developed fire spreading all over the compartment?
(2) Which damage can be caused by a fire inside the compartment?
(3) Is fire spreading/propagation to adjacent compartments possible?
(4) How can damage of components by the fire and its effects be prevented?

Question (1) mainly concerns the type and amount of combustibles present inside the compartment and their protection (e.g. protective coatings and wraps for cables, enclosures of combustible lubricants, fuels, charcoal, etc.). Based on these data, the compartment specific fire load density (fire load per compartment floor size) can be estimated. Only in case of ignition a fire occurs. Therefore, the entity of the potentially permanently or temporarily available ignition sources (e.g. staff attendance frequency, availability of hot surfaces, amount of mechanical and electrical equipment present) in the compartment have to be compiled for answering question (1).

The answer to question (2) mainly depends on the inventory of the compartment. That means there must be an allocation of the entire compartment inventory (components and equipment including cables) to the corresponding compartments. The required equipment functions as well as the potential consequences of their failure or malfunction have to be known. The inventory has to be classified. Distinguishing between important safety related equipment (so-called PSA components) and equipment, for which their failure results in a transient or an initiating event (so-called IE components) is necessary.

For answering question (3) the entire building structures of the NPP must be included in the database. For each compartment, the fire compartment boundaries (fire barriers such as walls, ceilings, floors including all the fire barrier elements, e.g. doors and dampers) as well as the connections between compartments (e.g. doors, hatches, ventilation ducts, cable raceways and their attributes) have to be known and documented. In this context, it has to be ensured that the questions (1) and (2) cannot only be answered for the compartment being analyzed but also for the entity of compartments adjacent to it.

Question (4) – to what extent damage by fire can be prevented – can only be answered based on information about the fire protection features being implemented in the initial fire compartment itself and its adjacent compartments. This concerns all the potential means for fire detection and alarm a well as for fire suppression.

The Fire PSA database must meet the following requirements:

- Provision and compilation of compartment related primary data for all compartments in the entire NPP necessary to answer the questions (1) to (4);
- Compilation of data and information such as list of inventory or generation of sets of compartments applying different criteria (e.g. accumulation of compartments being openly connected to each other);
- Derivation of compartment specific characteristics such as fire load density, fire occurrence frequency or fire spreading probability from one compartment to another based on the primary data for calculating f_{ij} (see 3.6 below).

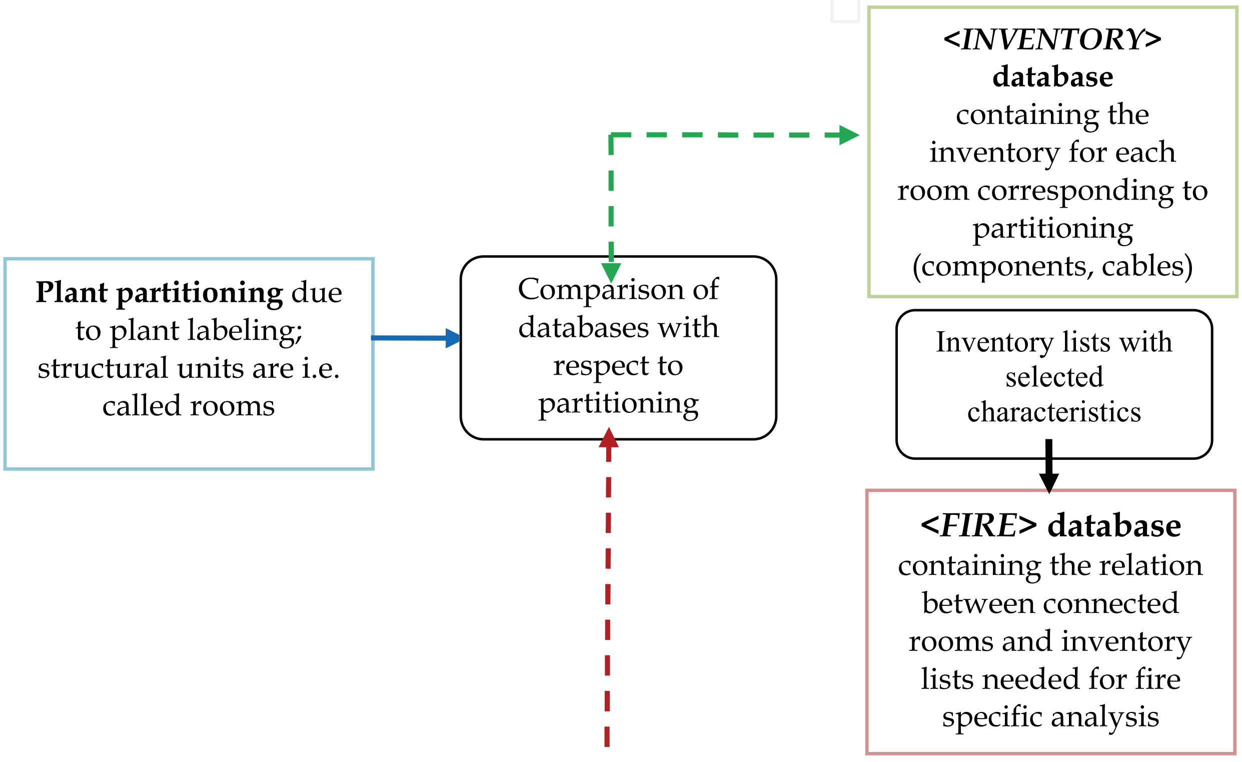


Fig. 2. Fire PSA Database from (Röwekamp et al., 2010)

Such a database enables a flexible overview and examination of the primary data available and guarantees the traceability of the Fire PSA analyses.

The basic structure of the Fire PSA database as well as some important input and output parameters are depicted in Figure 2.

The database is composed of two databases, the database <INVENTORY> containing the data on the compartment specific inventory, and a database <FIRE> containing for each compartment all the needed compartment related fire specific information.

3.5 Simplified fire effects analysis within the screening by standardized fire simulations

The actual Fire PSA enhancements also aim on developing an approach for applying standardized fire simulations by means of relatively simple, publicly available zone models such as CFAST.

In this approach, which still has to be validated for a complete application, generalized basic scenarios, so-called cases and sub-cases, have been defined in a first step for representative compartments and their characteristics with the corresponding dependencies of those parameters affecting the fire event sequence and the fire consequences significantly. As a second analytical step, each fire event sequence has been characterized by means of so-called design fires carrying different input parameter including standardized time sequences and heat release rates taking into account the combustibles typically available.

In this context, the significant parameters for binning of standard compartments to groups are floor size, room height, fire load and/or fire load density, natural and forced ventilation conditions, as well as the type of fire. An example of different standard cases is given in (Frey et al., 2008; Röwekamp et al., 2008).

For a set of characteristic fire compartments standardized fire simulations with CFAST have been successfully carried out. For automating these simulations, specific program modules and interfaces for handling the input and output data as well as information retrievals are needed. The main components for the automation are presented in Table 4 and Figure 3.

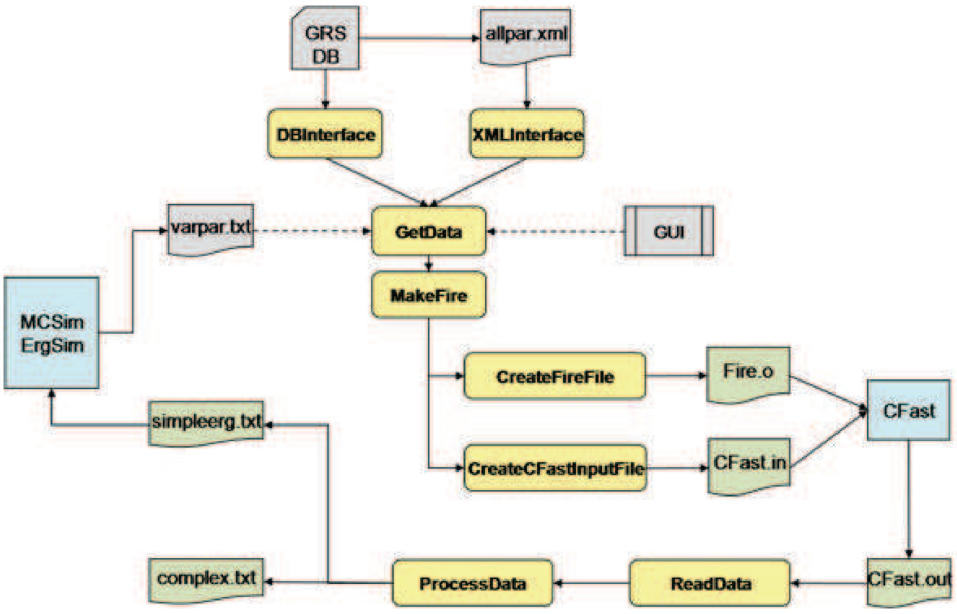


Fig. 3. Approach for automated standard fire simulations with CFAST from (Frey et al., 2008)

Module	Meaning / Task
GRS DB	Containing the geometric and fire related information on compartments in a MS ACCESS® database
allpar.xml	Alternative to the database containing all input data (XML format) needed für CFAST simulations
DBInterface	Interface for using data from alternative data sources
XMLInterface	Converting XML structure and the data included in the *allpar.xml* file to a C++-class; alternative to the direct data transfer by the *DBInterface*
GetData	Method oriented interface for sampling data stored in *ReadXML* and mapping them in a class structure

Module	Meaning / Task
MakeFire	Estimating the parameters of a standardized HRR course using information from *allpar.xml* and storing them in a class / object
CreateFireFile	Creating the CFAST for the fire target *Fire.o*
CreateCFastInputFile	Writing the CFAST input file *CFast.in* by means of the *GetData* data structure
Fire.o	Fire object imported by the CFAST application
CFast.in	Containing all data on fire compartment, fire barriers, ventilations and systems engineering
CFast	Program logic starting the CFAST simulation
ReadData	Reading out time dependent output (e.g. hot gas temperatures)from the CFAST-output file *cfast.n.csv* storing them in an adequate class
ProcessData	Assessing the output data imported by *ReadData* depending on the program logic by means of criteria (e.g. effects on safety significant targets)
Simple.erg	Output text file E for process control in case of performing a Monte Carlo simulation; solving problem oriented equations for limiting states for being able to assess the effects of different parameters on safety significant targets
Complex.txt	Output text file for all simulation results for further processing and use of time dependent sequences of the individual simulations
MCSim (iBMB)	Generating user defined discrete random variables for Monte Carlo simulations and evaluating the distribution function of the output values providing mean values and standard deviations and the resulting safety margin β
Varpar.txt	Data file created by *MCSim* containing random values for those parameters, defined as ′stochastic′ ones in the input file *allpar.xml*
GUI	Grafic User Interface for calculations´ control

Table 4. Modules for automated standardized CFAST fire simulations from (Frey et al., 2008)

In this context, it has to be mentioned that a probabilistic calculation for individual compartments is possible, if distributions for single parameters can be provided.

3.6 Stepwise compartment fire analysis

Based on the data and information contained in the database (see 3.4), the fire induced core damage frequency f_{ij} has to be determined for each compartment *i* and each plant mode *j* (see Figure 1).

In the frame of an exemplary Fire PSA performed for a BWR-69 type NPP, in total 351 compartments are analyzed within the reactor building. For 287 compartments the fire load density is less than 90 MJ/m^2. For all of the remaining compartments the frequencies of fire induced plant hazard states are pessimistically estimated. The sum of the estimated frequencies for 64 compartments equals 2.3 E-03/a. For 28 compartments, this frequency exceeds 1.0 E-07/a. The sum of the frequencies for the entire compartments with a very small frequency value is equal 2.5 E-07/a so that the frequency value for the 28 compartments covers more than 99 % of the sum of all pessimistically estimated frequency values. Finally, the frequency of fire induced plant hazard states of the reactor building is estimated to be 3.8 E-06/a. This is the result of summarizing the plant hazard state by fire for all the 28 compartments. Considering accident management measures the reactor building fire induced core damage frequency is estimated to 7.8 E-07/a for the reference plant.

3.7 Frequency calculation for fire induced core damage states

The in 3.4 mentioned necessary classification of the entity components of the NPP is extremely time-consuming in the run-up of estimating the fire induced CDF. As mentioned before, in particular, two classes of components have to be distinguished being significant:

- A component is called IE-component, if its failure alone or together with additional failures of other components has got the potential to be an initiating event (IE).
- A component is called a PSA-component, if its failure is regarded as a basic event in the fault trees of the corresponding Level 1 internal events PSA.

Depending on the fire growth a fire event may cause damage. The extent of the damage is characterised by the set of components affected/impaired. By means of assessing the extent of damage, in particular affecting IE components, it can be found, in how far the fire induced core damage may induce an initiating event (IE) modelled in the Level 1 internal events PSA.

The compartment related fire induced frequency of core damage states f_{ij} results from the product of

- the fire induced IE frequency and
- the unavailability of system functions required to control the adverse effects of the corresponding IE.

The unavailability of the required system functions is calculated by means of the Level 1 internal events PSA plant model taking into consideration the failures of the components from the set of components affected by fire.

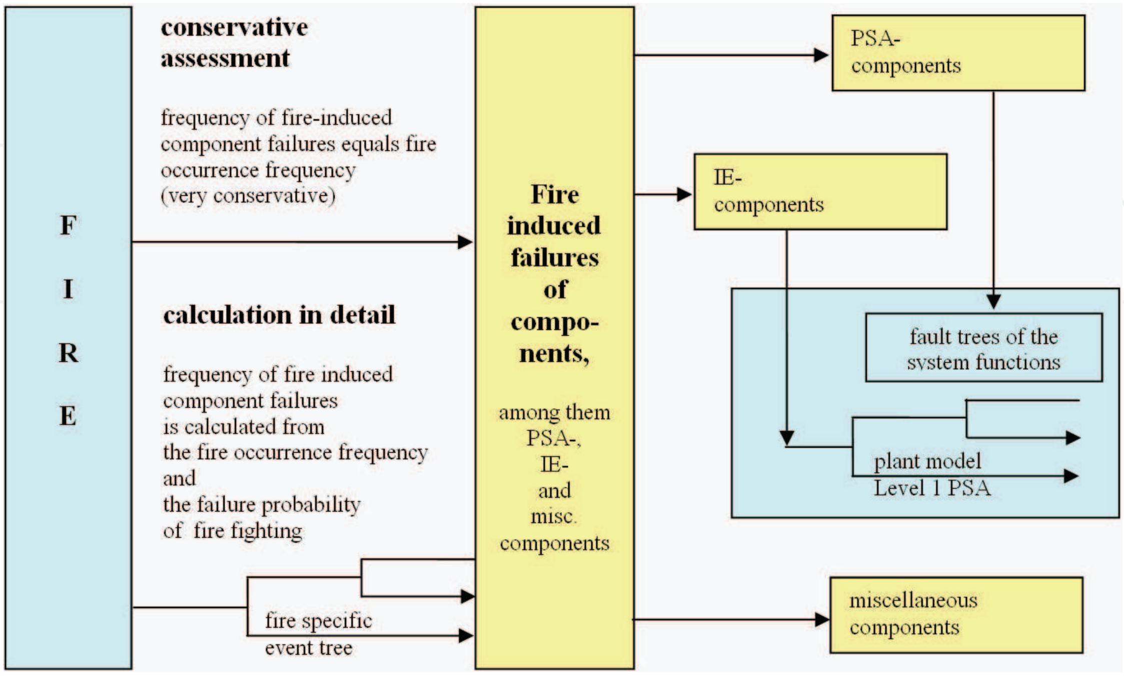


Fig. 4. Estimation und calculation of f_{ij}

The GRS code CRAVEX is applied for determining those components failed by the fire and its effects and their failure probabilities, in order to perform these analyses in an as far as practicable automatic manner. CRAVEX combines the fire specific and compartment specific data for determining the fire induced component failures and the PSA models for estimating core damage frequencies. It supplements the screening process as well as the detailed analyses, because the event and fault trees contained in these models describe in detail the interconnection between component failures and the occurrence of damage states. The following input data are generated by means of the database (see Figure 1): compartment specific fire occurrence frequencies, all probabilities of fire propagation to adjacent compartments, and the inventory list of all compartments affected by fire.

Furthermore, compartment related f_{ij} can be estimated by CRAVEX (see Figure 4). The Level 1 internal events PSA plant model and the fire induced component failure probabilities are used as input data for the calculations. The approach of these calculations by CRAVEX is in principle depicted in Figure 5 for an individual fire scenario. The fire occurrence is assumed inside a compartment C_i with i = 1, … , N.

The Level 1 internal events PSA plant model and the fire induced component failure probabilities are used as input data for the calculations.

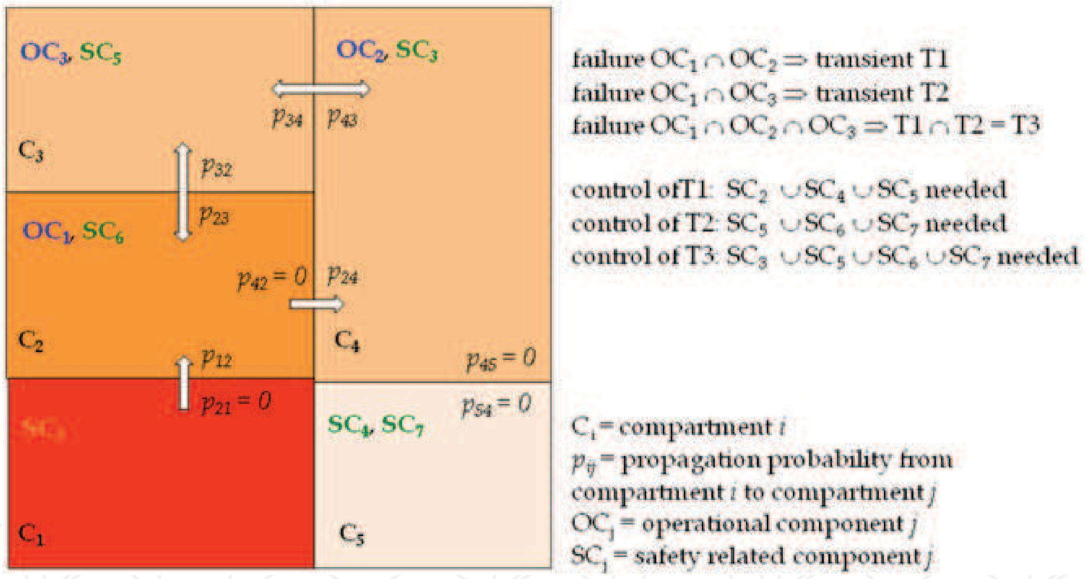


Fig. 5. Compartment configuration with fire source, components, and propagation paths

3.7.1 Frequency estimation (pessimistic estimate)

The following assumptions are made for pessimistic estimations:

- All active functions of the components in the compartments affected by fire are failed. This is considered for the initial fire compartment as well as for all the compartments, to where the fire may propagate.
- The fire occurrence frequencies are known for each compartment. The compartment specific fire occurrence frequencies are determined by means of the Berry method (Berry, 1979). The building fire frequencies needed as input for calculating compartments specific frequencies are estimated plant specifically.
- The so-called fire propagation probability is a pessimistic estimate of the probability of a fire propagating from a given compartment to an adjacent one. The fire propagation

probabilities are automatically calculated for each pair of adjacent compartments applying pessimistic assumptions for the unavailability of fire detection and suppression as well as for the fire barriers separating compartments.

For estimating the compartment specific fire induced CDF it is additionally assumed that the active component functions fail corresponding to the fire occurrence frequency of the initial fire compartment, where the fire started, that means that the possibilities of fire detection and suppression are neglected.

3.7.2 Frequency calculation in detail

For a detailed quantification, the pessimistic assumptions used by the estimation have to be verified and possibly corrected taking into consideration detailed plant specific information as explained earlier.

The realistic assessment of the fire induced damage frequencies is very important. For this assessment, fire specific event trees are developed and quantified. The development of fire specific event trees for compartments requires knowledge on the plant specific fire protection such as:

- Equipment including fire protection features (e.g. fire detection and alarm features, fire extinguishing means, fire barriers and their elements), arrangement of combustibles, presence and type of potential ignition sources inside the initial fire compartment and adjacent compartments;
- Verification of possible fire sources in the compartments;
- Examination of the fire occurrence frequency roughly estimated by means of the method of Berry based on the information concerning compartment inventory and the compartment characteristics (replacing the application of the more generic top-down-method within the screening by a bottom-up approach for estimating as far as possible realistic compartment specific frequencies);
- Plant specific unavailability of fire protection equipment in the compartments;
- Analysis of human behaviour and performance in case of fire;
- Using results of existing fire simulations or – in difficult cases - performing additional calculations for the compartment under consideration.

The reactor building of the reference plant having been analyzed consists of 351 compartments, among them 47 compartments on the building level 01. In 15 of the above mentioned 47 compartments the fire load density exceeds the threshold value of 90 MJ/m^2 during full power operational plant states. The analysis of possible compartment related fire damages gives the result that important PSA related components are present in 12 of the 15 compartments so that a fire in these compartments will cause an IE. The identified transients are exclusively transients induced by cable failures (e.g. by erroneous signals or failures of the power supply of solenoid valves of the main steam isolation valves). The fire related PSA component failures are taken into account when calculating compartment specific fire induced CDF. The fire induced core damage frequency is revealed from a possibly modified fire occurrence frequency taking into consideration fire extinguishing means.

4. Potential Improvements

The fire occurrence frequencies directly affecting the finally resulting core damage frequencies have been determined based on realistic and as far as practicable plant specific data. In principle, the results of the approach of Berry (Berry, 1979) have been used for estimating the fire occurrence frequencies. This methodology compares compartments within a building to each other with respect to the potential for ignition. Based on the fire frequency for the total building compartment specific frequencies are estimated. Depending on the amount if data used for calculating the building specific fire frequency the approach is more or less conservative.

Taking also the plant specific operating experience on all incipient fires into account as far as possible realistic fire frequencies can be estimated. For the reactor building of the reference plant this resulted in a relatively high fire occurrence frequency of 1.6 E-01/a in comparison to that of a Fire PSA for another NPP applying only generic data (6.9 E-03/a). Furthermore, all possibilities of fire propagation from the initial compartment to adjacent ones and to further compartments have been considered. By this systematic approach it could be demonstrated that fire propagation is less important for the probability of fire induced initiating events and the unavailability of system functions.

The Level 1 FP Fire PSA having been performed for the reference plant resulted in a fire induced CDF of 1.9 E-06/a. This value is higher than the CDF value of 1.4 E-06/a for internal events in case of full power operational states. Approx. 69 % of the CDF result from fires inside the reactor building, while fires in the auxiliary building provide a contribution of approx. 17 %.

The compartment based Fire PSA uses the assumption that in case of fire non-suppression all equipment including cables inside the fire compartment will fail. In case of applying this methodology to cable channels the approach may be too conservative. Depending on the protection of the channels these have to be treated as separate sub-compartments. The results of the Fire PSA may be optimized by systematically checking if protected cable channels have been treated correctly.

For the plant under consideration, the Fire PSA provided some recommendations for improving the fire protection: In a few cable channels in the auxiliary building and the independent emergency systems building no fire detectors are installed. An early fire detection and suppression cannot be ensured. The frequency of an incipient fire for these channels is the same as the fire induced damage frequency. On the other hand, the fire occurrence frequencies estimated are too pessimistic. In conclusion, the installation of automatic fire detectors in these compartments will reduce the compartment specific fire induced damage frequency.

Similar improvements can be performed in specific compartments inside the reactor building. The installation of fire detector chains with 2 - 4 fire detectors in compartments for the pre-heaters, an installation stairwell, a room with a control board for the safety valves, and other process rooms will significantly reduce the compartment specific CDF.

The fire load density of the compartment for the additional water supply vessel inside the reactor building has been treated quite pessimistically. The plant documentation provided a fire load of 560 MJ resulting in a fire load density significantly lower than the threshold value of 90 MJ/m^2 for the compartment floor size of approx. 50 m^2. However, the compartment has been included in the analysis due to the permanently as well as temporarily available fire loads. Here again, the core damage frequency may be reduced by installation of more suitable fire detection features or by reducing the fire loads.

5. Specific Consideration for Low Power and Shutdown States

5.1 Differences in the approach for power operation and shutdown states

As explained earlier, the recent German approach for Fire PSA contains the following steps of the analysis:

- A systematic plant partitioning of the entire plant, and
- An as far as necessary detailed estimation of FCDF for each of the compartments.

Working step	Differences between power operation and shutdown states
1. Plant partitioning	
1.1.Selection of buildings	Building selection by classified inventory lists (PSA and IE components); different amount of PSA and IE components can lead to different buildings to be analyzed
1.2. Building partitioning	Partitioning mainly due to given building structures with fire specific aspects being considered; plant state does not make significant difference
2, Estimation of fire induced damage state frequencies per compartment and plant operational state	
2.1. Fire occurrence frequency	Estimation of the fire occurrence frequency by Berry methodology is the same for differing plant operational states, but the input data are different
2.2. Fire damage frequency	Same methodology for fire damage frequency calculation, but differing database for different plant operational states
2.3. Core damage frequency	The corresponding PSA plant models for Level 1 PSA for power operation and shutdown states are applied; for low power and shutdown states it is important if and in which detail human actions can be performed.

Table 5. Analytical steps of a Fire PSA for power operation and shutdown states (Röwekamp et al., 2010)

When further sub-dividing these analytical steps some differences in the approach for power operation and shutdown states become visible (see Table 5).

The analyses for German NPP have demonstrated that it has to be considered in the estimation of compartment specific fire occurrence frequencies for LP/SD that there temporarily fire loads being present and that maintenance and repair work is particularly performed in those plant areas and compartments being isolated. This may result in a change of the compartment specific fire occurrence frequencies. However, the probability of relevant fire induced damage in an isolated compartment is low, as - with only very few exceptions - initiating events do not occur in such compartments and safety functions remain available.

5.2 Specific considerations for screening

The first working step is a fire specific compartment analysis corresponding to given criteria for the given plant operational mode (FP or LP/SD). Up to the time being, a fire load density criterion of screening out compartment with fire load densities lower than 90 MJ/m^2 is applied due to (FAK PSA, 2005a). This criterion resulted from safety demonstrations for non-nuclear industrial buildings. For mechanically ventilated compartments in nuclear installations it has been demonstrated that a fire in a compartment with a fire load density of only 10 MJ/m^2 may result in temperatures exceeding 200 C and thus may impair the function of sensitive electrical equipment and cables. Ongoing research activities suggest replacing this screening criterion in the future by a fire specific qualitative screening criterion considering the really in the compartment present ventilation conditions and fire propagation velocities applying the fire load density values only for a fire specific ranking of compartments.

During LP/SD so-called transient fire loads and/or additional ignition sources are temporarily present in those rooms where these are needed for maintenance and repair activities including hot work. This could be demonstrated for the reference NPP by the logs from the Fire PSA plant walk-through. For this type of activities specific work permits for isolation of systems/components and clearance procedures for the work including hot work permits for fire relevant activities corresponding to the plant operating manual including specific requirements for the unit control room and shift personnel are needed. All the provisions for preparing and performing maintenance and backfitting activities including procedures for electrical as well as process engineering isolations of components and systems correspond to these work permits. In case of temporary presence of additional potential ignition sources and fire loads specific preventive measures are foreseen corresponding to the plant fire protection manual, e.g.:

- Protecting the affected area against sparks from welding,
- Covering and isolating openings, gaps, slots, grates, etc.,
- Providing additional portable fire extinguishers,
- Installation of fire watches in case of fire detectors not being active,
- Ensuring highly effective mechanical ventilation,
- Limiting gas reservoirs for activities with gas to a daily amount;
- Eliminating combustibles in the hot work area,
- Protective covering of combustibles which cannot be eliminated,

There is no difference between FP and LP/SD plant modes within the compartment screening due to the 90 MJ/m^2 fire load density criterion. This criterion is only applied for deciding if there can be a fire with potentially significant damage in the compartment. By inserting transient fire loads during LP/SD states the fire load density may be increased exceeding the threshold value of 90 MJ/m^2 so that the compartment can no longer be screened out. The practical application has demonstrated that this happens only under the above mentioned boundary conditions with the corresponding protection measures and mainly in those compartments where the most components are isolated during LP/SD. However, it is necessary to roughly estimate the change in the compartment fire load density. This has to be considered, e.g. in the simulations of the fire sequence.

Changes in the ignition conditions due to hot work and isolation of electrical systems and components play an important role for estimating fire occurrence frequencies. However, it has to be discussed (particularly for fire occurrence frequency estimation in the frame of screening) if the Berry parameters (Berry, 1979) applied for FP states can also be applied for LP/SD states. It has to considered that the prerequisites for the occurrence of an initial incipient fire do not change in those compartments not being isolated during LP/SD, while for the isolated compartments the consequences have to be balanced. Isolation of electrical components reduces the fire risk, hot work increases it.

In addition, hot work activities correspond to the presence of personnel in the affected compartment resulting in an early manual fire detection and suppression. Recent German research activities have demonstrated that an evaluation of the hot work permits is particularly needed for observing and considering potential peculiarities during these activities typically performed during LP/SD from the beginning of the analysis and being able to consider those time periods explicitly for the fire occurrence frequency estimation.

5.3 Particular requirements for low power and shutdown states

The fire protection regulations and standards do not only have to be applied for FP modes but also for LP/SD modes, in particular:

- Control room and shift regulations (part of the plant operating manual),
- Maintenance rules (part of the plant operating manual),
- Alarm regulation (part of the plant operating manual),
- Fire protection regulation (part of the plant operating manual),
- Fire protection concept,
- Service instruction concerning tasks, organization, skills, and training, and of the on-site fire brigade.

In the following, some aspects significant in particular for LP/SD modes are pointed out. During the operation and tripping time period compliance with the following rules for minimizing transient fire loads and potential ignition sources is required:

- Transient fire loads have to be avoided as far as practically possible.
- All people working on-site are obliged to keep their work places as far as practically possible free from combustible materials and/or to eliminate them from these materials in the shortest possible time period.
- Combustible solids, liquids, and gases are only permitted to be present at the work place in an amount needed per one shift.
- Drained vessels no longer in use, formerly filled with combustible liquids have to be stored in a special storage room for scrap and lubricants.
- Handling and treatment of liquid or gaseous combustibles is only permitted under given prerequisites and standards specified in the corresponding work order.
- Hot work (work with open flames, welding, cutting, etc.) requires specific written hot work permits before starting the activities. The required necessary protective provisions including fire watches and control walk-troughs are explicitly specified in the hot work permit.

5.4 Exemplary results for a BWR-69 type nuclear power plant in Germany

For the BWR-69 type reference plant being analyzed it could be demonstrated that for LP/SD plant modes the same six buildings as for FP modes have to be analyzed. The spatial partitioning is principally based on the plant specific identification system of the entire NPP. In a few exceptional cases there were deviations from this procedure, e.g. the sub-division of the large reactor annulus into quadrants, or very long cable rooms and stairways. Some fire protected (sealed) cable raceways without compartment numbers were reassigned.

The screening has been performed in the same manner for FP and LP/SD plant modes. In this context, it has to be stated that particular differences in the screening of compartments result from maintenance and repair activities including hot work. Significant findings have not been observed for the plant being analyzed. As an important finding it has to be mentioned that many connections between compartments have pessimistically to be assumed open during LP/SD, as the activities being performed during these periods often create conditions where barriers elements (e.g. doors, cable penetration seals, etc.) are being left open or blocked due to practical reasons for the ongoing activities.

Building	**Plant Operational State**			
	FP		***LP/SD***	
	No. of fires	Fire occurrence frequency	No. of fires	Fire occurrence frequency
Reactor Building (without Containment)	4	1.6 E-01	6	2.4 E-01
Switchgear Building	8	2.9 E-01	3	1.2 E-01
Turbine Building	4	1.6 E-01	11	4.0 E-01
Diesel Building	0	1.7 E-02	0	1.7 E-02
Independent Emergency Systems (IES) Building	0	1.7 E-02	0	1.7 E-02
Other buildings and plant areas	16		15	
Total	***32***		***35***	

Table 6. Fire events and occurrence frequencies (expected values) in the reference plant for full power and low power / shutdown states

On the other hand, the higher presence of humans during these operational modes in the buildings results in early detection of situations which could create a fire and/or a manual fire detection and suppression during the incipient fire phase. This may explain the first rough results when comparing fire occurrences during FP and LP/SD. In total 67 fire events occurred in the reference plant from 1980 (start of commercial operation) to the end of 2008, 32 of these during FP modes, and 35 during LP/SD modes. Only one of these was reportable due to the German reporting criteria, 66 were incipient fire events below the reporting thresholds. Table 6 provides the corresponding building specific event distribution and fire frequencies (Röwekamp et al., 2010).

Determining fire occurrence frequencies for LP/SD plant modes the durations of the different phases of the operational modes and the frequencies estimated for each phase have to be considered. For selected buildings, e.g. the diesel building, there are nearly no differences between FP and LP/SD states. In this case, the approach is the same for both operational modes. For all the other buildings the approach has to be adjusted to the boundary conditions and data stored in the Fire PSA database for this mode.

6. Conclusions and Outlook

A state-of-the-art methodology for Fire PSA has been developed and successfully applied for a German NPP. This methodology is based on a combined multi-step qualitative and quantitative screening approach applying a comprehensive database specifically developed for the application within the frame of Fire PSA. The approach being applied enables to automatically perform several analytical steps of the Fire PSA. Some of the automatisms, e.g. the calculation of compartment specific fire occurrence frequencies or the probabilities of fire propagation to adjacent and further compartments, have been successfully implemented in the database. Standardized input data files have been provided for other applications of the Fire PSA database, e.g. for determining fire induced core damage frequencies by means of the simulation code CRAVEX.

Up to now, the Fire PSA database has not yet been completely adapted from full power plant modes to low power and shutdown modes. Investigations, which data have to be changed or added for these states, are still ongoing.

Another recent development focuses on fire induced cable failures and circuit faults, which are broadly discussed on an international level (EPRI, 2005). In this context, a cable failure mode and effect analysis (FMEA) for all the PSA related cables has been developed (Herb & Piljugin, 2008) and tested for a fire compartment, which had been identified as significant in the frame of the Fire PSA. This leads to the requirement to enlarge the Fire PSA database considering additional data needed for a cable FMEA and/or combining the compartment inventory matrix with the cable database of the FMEA. The activities for implementation of the cable FMEA approach in the Fire PSA methodology are ongoing.

A further development will cover the characteristics of compartments and components for supplementing the automatic data supply, such as data on the room heights for fire simulations with the zone model CFAST or the description of the ventilation systems for assessing smoke propagation.

In addition, an uncertainty and sensitivity analysis has been performed for the reference plant Fire PSA providing not only mean values for fire induced CDF but also for quantifying major uncertainties. This will increase the level of confidence of the Fire PSA results.

It has to be pointed out with respect to the statistical data applied in the frame of an as far as possible realistic Fire PSA that the existing national database, in particular data on compartment specific as well as component specific fire occurrence frequencies and on the reliability of fire protection features, has to be further improved and expanded. Moreover, the human influence has to be considered carefully.

The use of internationally available generic data (e.g. for fire occurrence frequencies), mainly from the U.S. and France, is not always appropriate for application within Fire PSA for German plants due to differences in design, inspection and maintenance. However, the German data being presently available do not always allow providing a verified database because only a very small amount of approx. 30 fire events had to be obligatory reported to the national supervisory authorities. Therefore, the OECD FIRE Database Project which was started by OECD/NEA in 2003 to collect fire event data and meanwhile comprises more than 340 fire events from twelve NEA member countries (OECD, 2009) may supplement performing Fire PSA for German NPP by further input data.. First test applications of this database with up to the end of 2008 in total 343 fire events have been successfully performed (Berg et al., 2009; Berg et al., 2010).

7. References

American Nuclear Society (ANS) (2007). *Fire PRA Methodology*, ANSI/ANS-58.23-2007

Berg, H. P.; Forell, B.; Fritze, N. & Röwekamp, M. (2009). First National Applications of the OECD FIRE Database. *Proceedings of SMiRT 20, 11th International Seminar on Fire Safety in Nuclear Power Plants and Installations*, August 17-19, 2009, Helsinki, Finland

Berg, H. P.; Frey, W.; Röwekamp, M. & Türschmann, M. (2009). Fire PSA for a German BWR-Enhanced Results and Potential Plant Specific Improvements, *Proceedings of the ESREL Conference 2009, Prague*, Taylor & Francis Group, London, pp. 2123–2130, GRS-A-3496

Berg, H. P.; Fritze, N.; Forell, B. & Röwekamp, M. (2010). Risk oriented insights in transformer fires at nuclear installations. *Proceedings of the ESREL Conference 2010, Rhodes*, September 5 – 9, 2010, in press

Berg, H. P. & Röwekamp, M. (2000). Reliability Data Collection for Fire Protection Features, *Kerntechnik* 65, No 2-3 (May 2000) 102-107, ISSN 0932-3902

Berry, D. L.; Minor, E.E. (1979). *Nuclear Power Plant Fire Protection, Fire Hazard Analysis*, NUREG/CR-0654, SAND 79-0324, September 1979

Bundesminister des Innern (BMI) (1977). *Sicherheitskriterien für Kernkraftwerke vom 21.10.1977*, Bekanntmachung des Bundesministers des Innern, Bundesanzeiger Nr. 206 vom 3.11.1977

Bundesminister des Innern (BMI) (1994). *Leitlinien zur Beurteilung der Auslegung von Kernkraftwerken mit Druckwasserreaktoren gegen Störfälle im Sinne des § 28 Abs. 3 der Strahlenschutzverordnung – Störfall-Leitlinien*, Bekanntmachung vom 18. Oktober 1983 mit Neufassung des Kap. 4 vom 21./22. April 1994

EPRI/NRC-RES (2005). *Fire PRA: Methodology for Nuclear Power Facilities - Final Report*, NUREG/CR-6850, September 2005

Facharbeitskreis (FAK PSA) (2005a). *Probabilistische Sicherheitsanalyse für Kernkraftwerke: Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke, Stand: August 2005*, BfS-SCHR-37/05, Salzgitter, October 2005

Facharbeitskreis (FAK PSA) (2005b). *Probabilistische Sicherheitsanalyse für Kernkraftwerke: Daten zur probabilistischen Sicherheitsanalyse für Kernkraftwerke, Stand: August 2005*, BfS-SCHR-38/05, Salzgitter, October 2005

Frey, W.; Herb, J.; von Linden, J.; Piljugin, E.; Röwekamp, M.; Türschmann, M.; Hosser, D. & Riese, O. (2008). *Methoden zur Abschätzung des Risikobeitrags redundanzübergreifender Brandschäden*, Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH, GRS-A-3425, Köln

Herb, J. & Piljugin, E. (2008). FMEA of Cable Failures within Fire PSA, *Proceedings of the 9th International Probabilistic Safety Assessment and Management Conference (PSAM 9)*, May 2008, Hong Kong, China, on CD

Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA) (2000). *Fire Safety in Nuclear Power Plants.*

Part 1: *Basic Requirements*, KTA 2101.1 (12/2000),
Part 2: *Fire Protection of Structural Plant Components*, KTA 2101.2 (12/2000)
Part 3: *Fire Protection of Mechanical and Electrical Plant Components*, KTA 2101.3 (12/2000)

Organization for Economic Cooperation and Development (OECD) OECD/NEA/CSNI (2009). FIRE Project Report: "Collection and Analysis of Fire Events (2002-2008) – First Applications and Expected Further Developments". *NEA/CSNI/R(2009)6*, Paris

Röwekamp, M.; Türschmann, M.; von Linden, J.; Kirchner, J. W. & Berg, H. P. (2006). Fire PSA for a German BWR (BWR-69 type) – methodology applied and results, *Proceedings of the 8th International Probabilistic Safety Assessment and Management Conference (PSAM 8)*, New Orleans, May 2006, paper 0052, on CD

Röwekamp, M.; Türschmann, M.; Piljugin, E.; Riese, O. & Hosser, D. (2008). Actual Developments in the Advanced German Fire PSA Methodology, *Proceedings of ANS PSA 2008*, Knoxville, TN, USA, September 7 – 11, on CD

Röwekamp, M.; Riese, O. & Berg, H. P. (2009). Improvements in the German Fire PSA Methodology Demonstrated at a German BWR Built to Earlier Standards, *Proceedings 17th International Conference on Nuclear Engineering (ICONE-17),* paper 75595, Brussels, July 2009, on CD

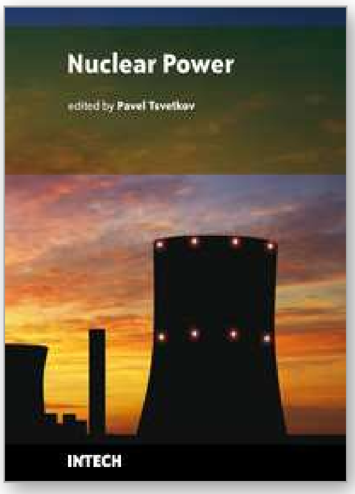
Röwekamp, M.; Türschmann, M.; Schwarz, M. & Berg, H. P. (2010). Database for A Comprehensive Fire PSA. *Proceedings of the 10th International Probabilistic Safety Assessment and Management Conference (PSAM 10)*, June 7 – 11, paper 113, Seattle, USA, on CD

Türschmann, M.; von Linden, J. & Röwekamp, M. (2005). Systematisches Auswahlverfahren für probabilistische Brandanalysen, *Schriftenreihe Reaktorsicherheit und Strahlenschutz*, BMU-2005-667, ISSN 0724-3316

Türschmann, M.; Röwekamp, M & Berg, H. P. (2006). Durchführung einer Brand-PSA mit aktuellen Methoden, *Tagungsbericht Jahrestagung Kerntechnik 2006*, *Aachen,* May 2006, pp 208 – 212, INFORUM-Verlag (Ed.), Deutsches Atomforum, Bonn, ISSN 0720-9207

von Linden, J., Klein-Heßling, W.; Piljugin, E.; Röwekamp, M. & Türschmann, M. (2005). Ausgewählte probabilistische Brandanalysen für den Leistungs- und Nichtleistungsbetrieb einer Referenzanlage mit Siedewasserreaktor älterer Bauart, *Schriftenreihe Reaktorsicherheit und Strahlenschutz,* BMU-2005-666, ISSN 0724-3316

von Linden, J.; Röwekamp, M.; Türschmann, M. & Berg, H. P. (2009). Methods for a Fire PSA Exemplary Applied to a German BWR-69 Type Nuclear Power Plant, *Kerntechnik*, Vol. 74, No. 3 (May 2009) 106–110, ISSN 0932-3902



Nuclear Power
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The world of the twenty first century is an energy consuming society. Due to increasing population and living standards, each year the world requires more energy and new efficient systems for delivering it. Furthermore, the new systems must be inherently safe and environmentally benign. These realities of today's world are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. Today's nuclear reactors are safe and highly efficient energy systems that offer electricity and a multitude of co-generation energy products ranging from potable water to heat for industrial applications. The goal of the book is to show the current state-of-the-art in the covered technical areas as well as to demonstrate how general engineering principles and methods can be applied to nuclear power systems.

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