Technical Reliability of Active Fire Protection Features – Generic Database Derived from German Nuclear Power Plants

Burkhard Forell*, Svante Einarsson, Marina Roewekamp
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Köln, Germany

Abstract: In the frame of Probabilistic Fire Safety Analysis fire event and fault trees specific to the conditions of the nuclear power plant under consideration need to be established for estimating the corresponding branch point probabilities and end states for core or fuel damage frequency. That also requires applying technical and human reliability data for fire specific event sequences. The technical reliability of fire detection systems, fire and smoke extraction dampers, fire doors and fire extinguishing systems and equipment including extinguishing media supplies has been estimated.
The data has been evaluated by analyzing the documentation of periodic in-service inspections as well as additional information and reports which resulted from the inspection findings. For more complex systems, in addition to the components' reliability data, fault trees are presented to calculate the system's reliability.
This type of data already published 2005 in the document on PSA Data supplementing the German PSA Guideline and has now been extended to cover 111 plant operational years of six power reactor units of different age and type. The generic data may also be applied as a-priori information for estimating the reliability of components with similar design and equivalent inspection and maintenance practice for nuclear power plants abroad.

Keywords: Fire PSA, reliability data, failure rate per hours of plant operation, fault trees for technical component failures

1. INTRODUCTION

The German Regulatory Guide for safety reviews of nuclear power plants (NPP) requires Level 1 Probabilistic Safety Analyses (PSA) for all plant operational states including plant internal fires (Fire PSA). Guidance on the recommended methods and data for PSA is provided in supplementary technical documents [1], [2] to this Guide including tables with generic reliability data for active fire protection features. For performing Fire PSA, a variety of different data is needed to quantify the fire specific event trees and to calculate the corresponding branch point probabilities and end states for core damage. These include fire occurrence frequencies, fire spreading parameters, unavailability of active and passive fire protection features, and failure rates of human actions in case of fire.

In order to model the plant specific fire event trees in an as far as possible realistic manner, failure rates and resulting unavailabilities per demand for fire protection features are needed. In the past, reliability data was already established within different projects [3] to [5]. In a recently finished project [6] the existing database was extended and improved, covering now 111 reactor years from six German NPP units. The systems and components analyzed are:

- Fire detection systems consisting of main fire alarm panel and subsidiary alarm boards, detection drawers inside such boards, as well as detection lines with connected automatic fire detectors or manual fire alarm buttons,
- Fire dampers in the ventilation systems,
- Smoke extraction dampers in ventilation ducts and smoke vents in roofs and walls,
- Fire doors, partly equipped with devices to keep them in open position (hold-open devices),

* Corresponding author: Burkhard.Forell@grs.de

- Fire extinguishing systems and equipment such as water pumps, remote controlled valve stations of water deluge systems, and hydrants (field hydrants, wall hydrants, and foam wall hydrants).

2. APPROACH FOR ESTIMATING TECHNICAL RELIABILITY DATA FOR ACTIVE FIRE PROTETION FEATURES

The technical reliability data is derived from results of in-service inspections carried out for active fire protection features in the power plants under consideration. In German NPP, the active function of all systems and components is inspected regularly via a component specific inspection program. The observed findings of these inspections, i.e. anticipated functional deteriorations and failures are documented in the inspection records. In addition to the records of periodic in-service inspections (including the inspection procedures), resulting deviation reports, maintenance orders, and repair reports were analyzed. Based on these documents and by consultation of the plant staff involved in inspection and maintenance of the corresponding fire protection features, each finding of an in-service inspection has been analyzed regarding its required function in case of fire. In this context, it is distinguished between findings representing only a deficiency not deteriorating the required function of the component in case of fire and those findings representing a failure of the required function. The latter are those findings accounted for in the statistical analysis.

Self-signaling deficiencies or failures observed independently of an in-service inspection are not accounted for in the analysis. It is known from the operation experience that plant operators usually do react on self-signaled failures by compensational measures and carry out repair work at these components quite fast.

For a consistent assessment of the raw data suitable definitions of “failure” and “deficiency” are necessary to receive realistic values for failure rates to be applied in Fire PSA. Considering the relevance of the affected components or systems in the event trees, a careful assessment by engineering judgment based on expert knowledge is needed to determine, if the documented findings can be estimated as functional failures (“unavailability”) or only as deficiencies. In this context, detailed knowledge of plant specific boundary conditions is evident for the assessment. This requires a plant walk-through for all plant locations where the fire protection features to be investigated are installed. In addition, close co-operation with the plant staff in charge of inspections and maintenance of the different systems and components is needed for a meaningful and consistent assessment.

In addition to the number of failures k, the number of equal components, the cumulated observation period T and the inspection interval of the components are collected. In the past [3] to [6], failure rate as well as unavailability per demand were calculated from the raw data for the fire protection features. However, the most recent data collection and processing covers only failure rates per hours of plant operation $\lambda(t)$, because it is assumed that the fire protection features´ failure behavior correlates well with the time. The expected value of the failure rate becomes

$$E(\lambda)=\frac{k+0.5}{T}$$

For calculating generic reliability data, it has to be decided if the components of different plants under consideration can be considered as components with almost the same characteristics and equivalent inspection practice. These components are binned together in a common data pool and treated as if belonging to one plant. For most of the fire protection features analyzed the components have not been pooled, because each plant has individually installed components from different supplier, with individual history, maintenance strategy, etc. If this is the case, the plant specific reliability have been calculated by a superpopulation approach [7] considering differences in the characteristics of components from different plants which increases the uncertainties of the estimated failure rates.

For electric and electronic equipment which is pre-manufactured externally by one manufacturer and which is only configured in the different plants, the data are pooled together for deriving generic data sets. This procedure is applied for fire detection features with the exception of aspirating smoke detectors (ASD) and manual call points (push buttons). In this procedure, the distribution ranges of the estimated values are computed by a statistical estimation based on the approach of Bayes. The procedure is performed in two steps, first generating a gamma distribution via the Bayes non-informative approach and a second one applying an algorithm [8], [9] to consider additional sources of epistemic uncertainties. The result is a non-parametric distribution of the estimates with the relevant quantile, mean values, and standard deviations.

Since in-service inspections do not address system design, the collected and evaluated data does not reflect possible design failures. Examples for design failures might be a fire door with insufficient fire resistance rating or a smoke detector located too close to an air inlet vent.

3. GENERIC TECHNICAL RELIABILITY DATA FROM SIX REFERENCE REACTOR UNITS

The generic reliability data has been collected from six reactor units of different design and age. The active systems and components investigated are sub-divided into

- automatically actuated fire detection systems (Table 1),
- fire dampers, smoke vents, and fire doors (Table 2), and
- fire extinguishing systems and equipment (Table 3).

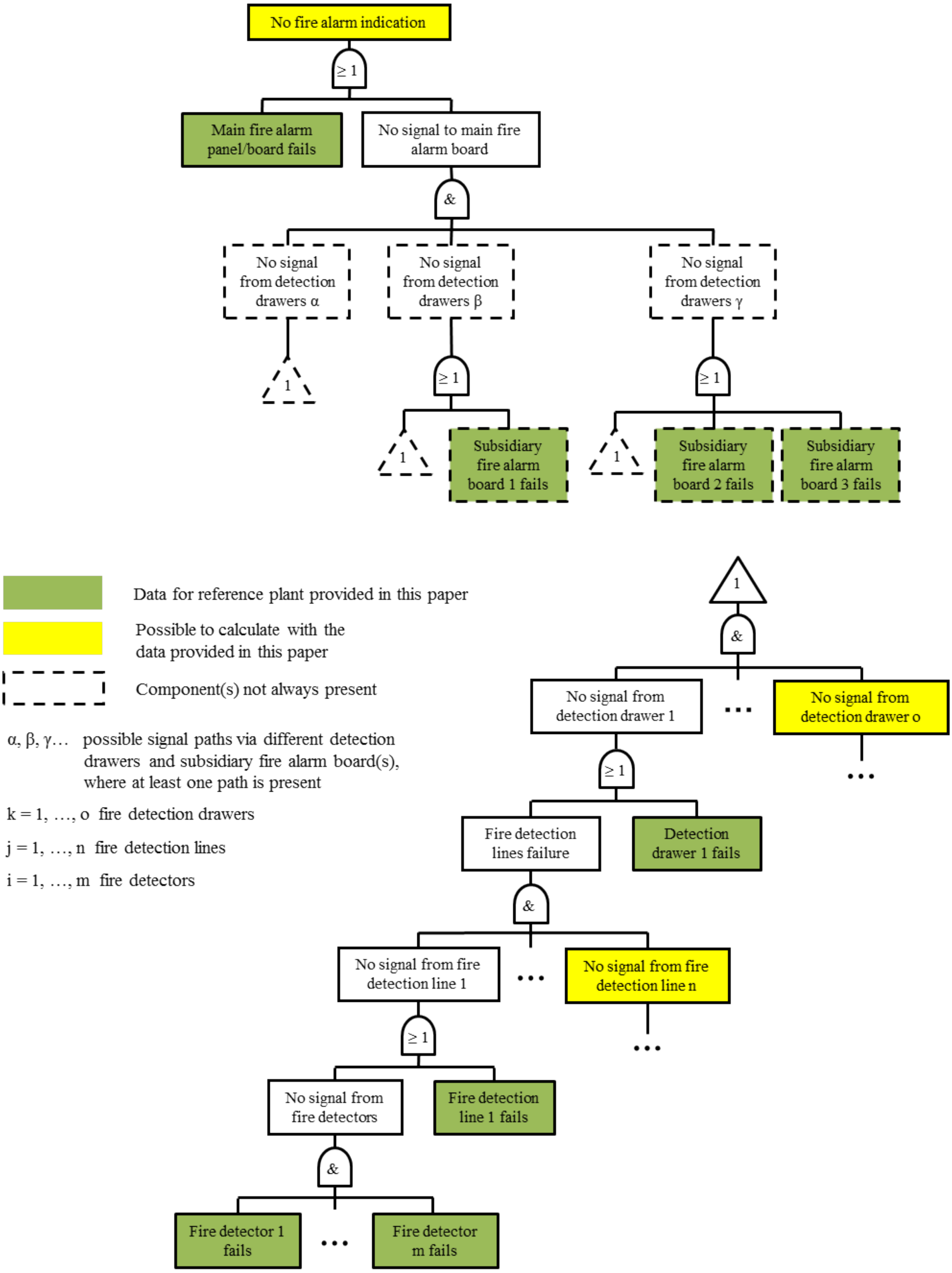
Each table contains the component/system name and type, the number of components observed, their associated test intervals, the cumulated observation periods of all components, the observed number of failures, and the resulting failure rates with their 5 %, 50 % and 95 % quantiles, their mean value and the corresponding standard deviations. The results of the data collection and statistical processing are explained in detail in the following paragraphs.

3.1. Automatic Fire Detection Systems

An automatic fire detection system is sub-divided into several components which are considered in the exemplary fault tree in Figure 1. This fault tree is representative for an automatic fire detection system of a German NPP. In some cases also more redundancies may be present. The fault tree covers technical failures only. With the data presented in Table 1 it is possible to calculate the top event “no fire alarm indication” of the fault tree. On the bottom of the tree the end state that one or more fire detectors in one fire compartment do fail is portrayed. The fire detectors give a signal being transmitted via the fire detection lines. If the fire detection line or all its associated fire detectors in the fire compartment fail, there will be no further transmission of the fire detection signal. However, there may be other fire detectors installed in the same fire compartment not connected to the same fire detection line. In case of a failure of all detection lines or of their connected fire detectors the fire detector signal will not be transmitted to the detection drawer.

Another possibility of a non-successful signal transmission is a detection drawer malfunction. Similar to the detection lines, there may be several detection drawers transmitting an alarm signal from the same fire compartment. The signal may be transmitted via the detection drawers α directly to the main fire alarm panel or being further processed through a subsidiary fire alarm board. Similarly, the signal may be transmitted via different detection drawers α, β, γ, etc. and additionally through one or several subsidiary fire alarm boards. If one of these boards or the detection drawers α, β, γ, etc. fail (if all present), the signal is discontinued.

Figure 1: Exemplary fault tree for technical failures of a fire detection system [10]



The components of the fire detection system are distinguished according to their system generation:

- The first generation of fire detection systems was based on analog technique, which has been taken out of operation now,
- the second generation was based on the digital technique newly introduced at that time,

- fire detection systems of the third generation being in place from the mid-1990es used more powerful processors then the second generation, and
- the fourth generation of fire detection systems is meanwhile available on the market, however operating experience from German NPP is not yet available.

Table 1 provides results for components in particular of the generations II and III. A graphical illustration of the data is given in Figure 2. Concerning the aspiration smoke detectors (ASD), a major development resulted from the replacement of the specifications of the Comité Européen des Assurances (now: Insurance Europe) [11] (generation 1) by the European Standard EN 54 Part 20 [12] (generation 2). With the new specification, changes in the aspirated volume flow of ± 20 % need to be recognized by an ASD, whereas the old systems recognized changes of ± 50 %. Flow changes occur due to clogging of the inlets or due to leaks in the pipework of an ASD and are the primary cause of failures. However, up to now the zero-failure statistics of the newer ASD does not result in a lower mean failure rate, since the time observed for generation 2 ASD is much smaller than for generation 1. For manual call points no distinction in the generations was made since the basic principle is the same for all types over the whole assessment period.

Table 1: Failure rates of components of the fire detection system

Active Fire Protection Systems and Components	Number of components	Test interval [years]	Time observed [h]	Number of failures	Failure rate [1/h]				
					5 % quantile	50 % quantile	95 % quantile	Mean value	Standard deviation
- Main fire alarm panels (gen. II)	9	1/4	1 049 581	0	1.10E-09	1.50E-07	2.04E-06	4.77E-07	9.14E-07
- Main fire alarm panels (gen. III)	7	1/4	350 784	0	3.29E-09	4.49E-07	6.11E-06	1.43E-06	2.74E-06
- Subsidiary alarm boards (gen. II)	39	1/4	4 189 836	0	2.76E-10	3.76E-08	5.12E-07	1.20E-07	2.29E-07
- Subsidiary alarm boards (gen. III)	44	1/4	1 234 478	0	9.36E-10	1.28E-07	1.74E-06	4.06E-07	7.77E-07
- Detection drawers (gen. II)	307	1/4	32 898 804	0	3.51E-11	4.78E-09	6.52E-08	1.52E-08	2.92E-08
- Detection drawers (gen. III)	240	1/4	4 861 247	0	2.38E-10	3.24E-08	4.41E-07	1.03E-07	1.97E-07
- Detection lines (gen. II)	2501	1/4[a]	237 268 345	0	4.87E-12	6.63E-10	9.03E-09	2.11E-09	4.05E-09
- Detection lines (gen. III)	3110	1/4[a]	179 788 565	0	6.42E-12	8.75E-10	1.19E-08	2.79E-09	5.34E-09
- Automatic fire detectors									
- Ionization smoke detectors (gen. II, type A)	3375	1[a]	478 737 759	2	4.28E-10	3.42E-09	1.61E-08	5.22E-09	5.66E-09
- Ionization smoke detectors (gen. II, type B)	710	1[a]	66 141 808	2	3.10E-09	2.47E-08	1.17E-07	3.78E-08	4.10E-08
- Optical smoke detectors (gen. II, type A)	4839	1[a]	478 920 649	0	2.41E-12	3.29E-10	4.48E-09	1.05E-09	2.00E-09
- Optical smoke detectors (gen. III, type A)	97	1[a]	8 896 488	0	1.30E-10	1.77E-08	2.41E-07	5.63E-08	1.08E-07
- Rate-of-rise heat detectors (gen. II, type A)	137	1[a]	16 111 533	0	7.17E-11	9.77E-09	1.33E-07	3.11E-08	5.96E-08
- IR-flame detectors (gen. III, type A)	400	1[a]	24 240 000	1	3.15E-09	3.58E-08	2.09E-07	6.19E-08	7.81E-08
- Multi-criteria detectors (gen. IV, type A)	3017	1[a]	95 656 721	0	1.21E-11	1.65E-09	2.24E-08	5.24E-09	1.00E-08
- Multi-criteria detectors (gen. IV, type B)	251	1[a]	27 348 650	0	4.22E-11	5.75E-09	7.84E-08	1.83E-08	3.51E-08
- Aspirating smoke detectors (gen. 1)[b]	151	1[a]	9 219 942	5	7.33E-08	6.93E-07	2.63E-06	1.01E-06	1.62E-06
- Aspirating smoke detectors (gen. 2)[b]	99	1[a]	2 971 602	0	8.66E-09	5.65E-07	1.41E-05	9.02E-06	6.12E-05
- Manual call points (push buttons)[b]	1234	1[a]	142 050 755	0	2.39E-10	1.40E-07	3.53E-06	7.04E-07	1.25E-06

[a] Some fire detection lines and fire detectors are located inside restricted areas, where the tes interval is extended to one fuel cycle (≈ 15 months).

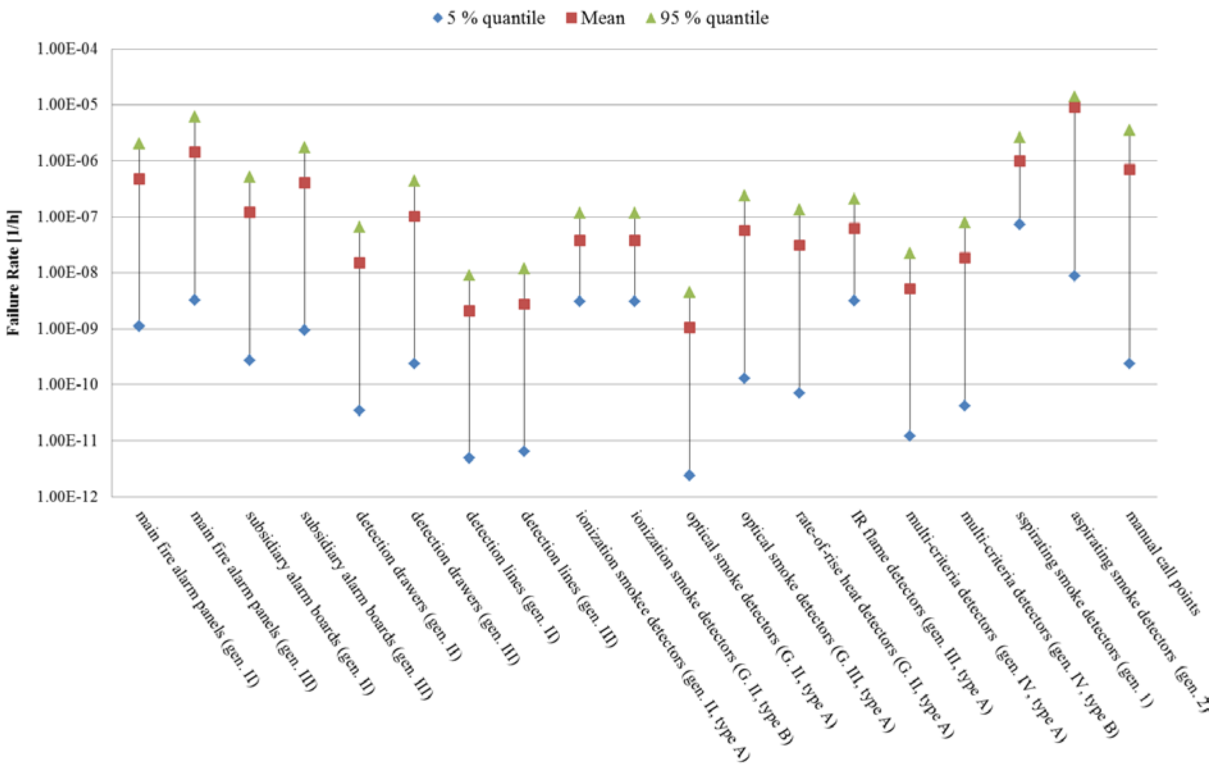
[b] In contrary to the other components of the fire detection system, aspirating smoke detectors and manual call points have not been pooled for generic failure rates, but a superpopulation approach has been used.

For many components of the fire detection system no failures were observed in the frame of the in-service inspections for the plants under consideration, on the one hand according to the higher reliability of electric equipment compared to mechanical components such as dampers, etc. Moreover, the majority of failure types observed at components for fire detection is self-signaling and therefore cannot be accounted for in the unavailability statistics for the required function in case of fire, because were observed independently of in-service inspections. In addition to the overall observed five functional failures of ASD, which are attributed to clogging or leaks in the aspiration tubes, another five failures occurred at automatically actuated fire detectors.

The system's unavailability by self-signaling failures could not be quantified yet, but it is assumed to be quite small. Therefore, the ratio between unavailability from self-signaling failures and unavailability from inspection-related failures is not known. The lower the unavailability calculated based on the results from in-service inspection is, the more an in-depth analysis of the system's unavailability by self-signaling failures is needed.

Another applicability limitation of the presented data is the reliability of the power supply; more details see [13]. Fire detection systems are connected to the emergency power system and are equipped with an additional battery, which makes the power supply reliable and redundant.

Figure 2: Failure rates of components of the fire detection system



3.2. Fire Dampers, Smoke Control Equipment, and Fire Doors

The failure rates estimated for fire dampers, smoke control equipment and fire doors are listed in Table 2. A graphical illustration of the data is given in Figure 3. Fire dampers are designed to close in case of fire. Most of them are connected to a ventilation duct; very few are installed in walls or ceilings as overflow opening between two rooms. Smoke control equipment, in contrary, refers to dampers and vents that are designed to open in case of fire. Dampers are installed in smoke extraction ducts or in inlet air ducts to extract smoke and increase air inlet flow. Vents are installed in roofs or walls and lead directly outside. They are not attached to ducts.

Different types of fire dampers are used in the German reference NPP. All fire dampers are equipped with thermal actuation, the wide majority of them by a fusible link. Dampers in safety related plant areas can additionally be remote controlled actuated. The following remote controlled actuation types are in place in the NPP units, for which reliability data have been estimated:

- electro-magnetic valves which release air-pressure from pneumatic system to close the dampers (closed-circuit principle) (type 1),
- lifting magnets which draw back a bolt when being actuated to close the dampers (open-circuit principle) additionally equipped with a pneumatic support to reopen the blade (type 2),
- lifting magnets which move back a bolt when being actuated to close the dampers (open-circuit principle) partly equipped with a crank lever to reopen the blade (type 3), and
- magnetic clamps (closed-circuit principle) that release the blade when deactivated (type 4).

Remote controlled actuation and thermal actuation are redundant and diverse actuation mechanisms. In addition to the actuation, in case of fire the blade has to move to the “closed” position and remain structurally intact to fulfill its required function of separating redundant train, called ‘closing/barrier function’. The corresponding fault tree for technical failures of fire dampers is shown in Figure 4. Since the remote controlled actuation mechanism is not present for all dampers, it is marked with a dashed line. All dampers can be manually operated on one side of the fire barrier penetrated by the damper by means of a test button. However, this actuation mechanism is not accessible in many cases during plant operation and is therefore marked with a dotted line in Figure 4. A failure of the fire damper occurs in case of failure of either all present actuation mechanisms or failure of the closing/barrier function.

Table 2: Failure rates of fire dampers, smoke control equipment and fire doors

Active Fire Protection Systems and Components	Number of components	Test interval [years]	Time observed [h]	Number of failures	Failure rate [1/h]				
					5 % quantile	50 % quantile	95 % quantile	Mean value	Standard deviation
Fire dampers [a]									
- Closing/Barrier function (all dampers)	3799	1/2 / 1[b]	500 581 612	117	3.91E-08	2.10E-07	6.07E-07	2.51E-07	8.88E-08
- Actuation:									
- Remote controlled									
- Electro-pneumatic (type 1)	505	1[b]	72 262 028	10	2.93E-09	4.75E-07	6.12E-06	1.66E-06	4.75E-06
- Lifting magnet plus pneumatic reopening (type 2)	539	1[b]	61 423 362	148	3.69E-07	1.98E-06	5.96E-06	2.42E-06	1.81E-06
- Lifting magnet (type 3)	1308	1[b]	185 930 706	74	3.75E-08	5.55E-07	2.66E-06	8.22E-07	5.79E-07
- Magnetic clamp (type 4)		1[b]	6 354 822	4	9.09E-09	7.52E-07	7.99E-06	4.82E-06	2.99E-05
- Thermal (fusible link)	3370	1 , 10[c]	321 640 836	125	1.54E-09	2.07E-07	2.00E-06	4.83E-07	5.85E-07
Smoke control equipment									
- Smoke extraction dampers in ducts	324	1	51 853 043	53	3.95E-08	1.22E-06	6.58E-06	1.92E-06	1.45E-06
- Smoke extraction vents (roof-installed)	46	1	8 415 600	20	3.97E-07	2.35E-06	6.39E-06	2.80E-06	2.37E-06
- Smoke extraction vents (wall-installed)	10	1	1 139 568	1	9.46E-08	2.00E-06	1.49E-05	5.17E-06	1.57E-05
Fire doors [a]									
- Barrier function	914	1/2 , 1[d]	102 803 958	3	2.13E-09	4.77E-08	4.26E-07	1.60E-07	6.36E-07
- Self-closing function	1055	1/2 , 1[d]	118 186 632	134	2.53E-07	1.04E-06	2.77E-06	1.22E-06	7.90E-07
- Self-latching function	1055	1/2 , 1[d]	118 186 632	113	1.14E-07	8.32E-07	3.16E-06	1.18E-06	1.51E-06
- Door-coordinator function	141	1/2 , 1[d]	15 382 674	29	9.39E-07	2.00E-06	4.13E-06	2.18E-06	6.68E-07
- Release by hold-open device	436	1/12, 1/4[d]	75 180 812	31	3.27E-08	8.29E-07	4.99E-06	1.39E-06	1.11E-06

[a] Some of the fire dampers and fire doors are located inside restricted areas, where the testing interval is extended to one fuel cycle (≈ 15 months).

[b] The most common test interval for fire dampers is 1 year, sometimes it is 6 months. In some plants manual and remote controlled testing are separated such that on average the blade is moved every 6 months.

[c] In some plants, the fusible link is removed from the damper every year, other plants do destructive tests with a hot air dryer every 10 years

[d] The most common test interval for fire doors is 1 year, sometimes it is 6 months. The most common test interval for hold-open devices is 3 months, sometimes with additional short tests it is 1 month. In tests at doors with hold-open devices, also others failures may be recognized.

The most common test interval for fire dampers is one year, in some cases six months. In some plants functional testing of manual and remote controlled actuation is separated, that on average the damper blade is moved every six months. For fire dampers installed in plant areas important to safety, the thermal actuation mechanism by fusible link has been included in the in-service inspection program due to a German Information Notice sent out by the regulators as a result of findings at fire dampers in the mid-nineties. Meanwhile, in some plants these inspections are carried out periodically every ten years through a destructive inspection, where the fusible link is molten by a hot air dryer. In other plants, within the yearly inspections the fusible link is removed out of the damper.

Concerning the closing/barrier function 117 failures were observed. The majority of these failures occurred because of dust deposit or resinified oil on the mobile inner parts of the dampers which blocked the closing function. A small number of failures were caused by significant damages of the damper blades.

Regarding the remote controlled actuation, the complete signal line from the trigger (e.g. the main control room, the fire detection system or a local control place) to the damper is covered. Typical failure modes were ‘jammed’, ‘stiff”, or ‘did not close’. Failures are always assigned to the dampers, even if the failure is located at the trigger, because the trigger is not modelled. Although the actuation mechanism types 2 and 3 are based on the outdated open-circuit principle, there was no significant difference in the failure rates of all four types observed; all failure rate mean values are within one order of magnitude. Moreover, the functional unavailability of the thermal actuation via fusible link is in the same order of magnitude. A mean failure rate of λ = 4.83 E-07 /h was estimated, which is the lowest value of the entire mean failure rates for the different types of actuation. However, as the test interval is about ten times longer than that for remote controlled actuation, the resulting unavailability per demand may increase up to the upper boundary in comparison to all other actuation mechanisms.

Figure 3: Failure rates of fire dampers, smoke control equipment, and fire doors

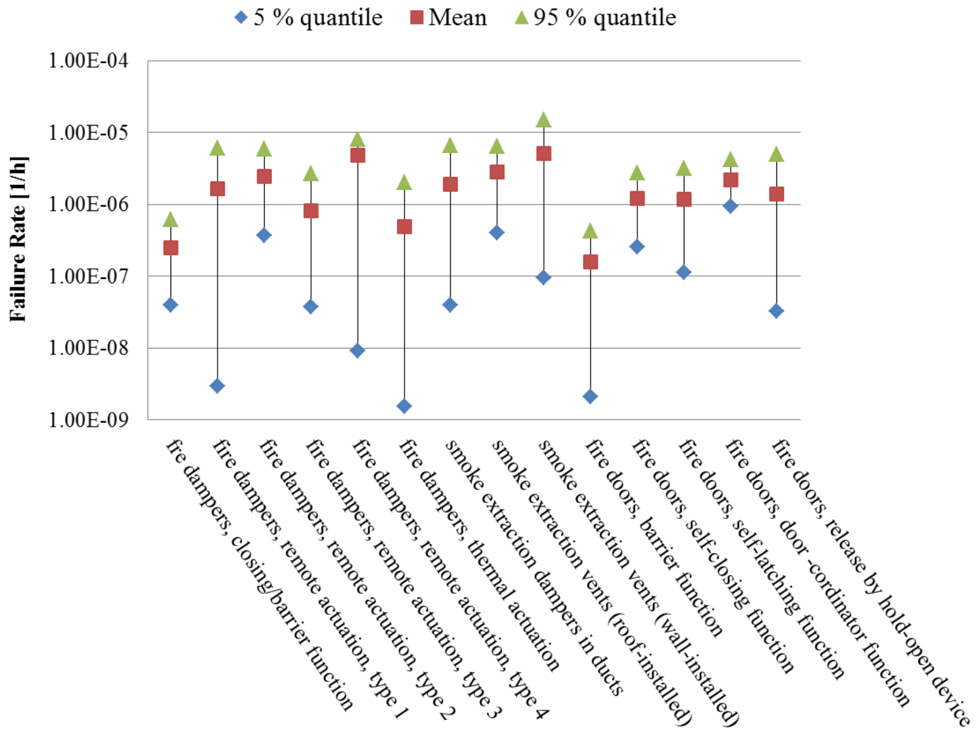
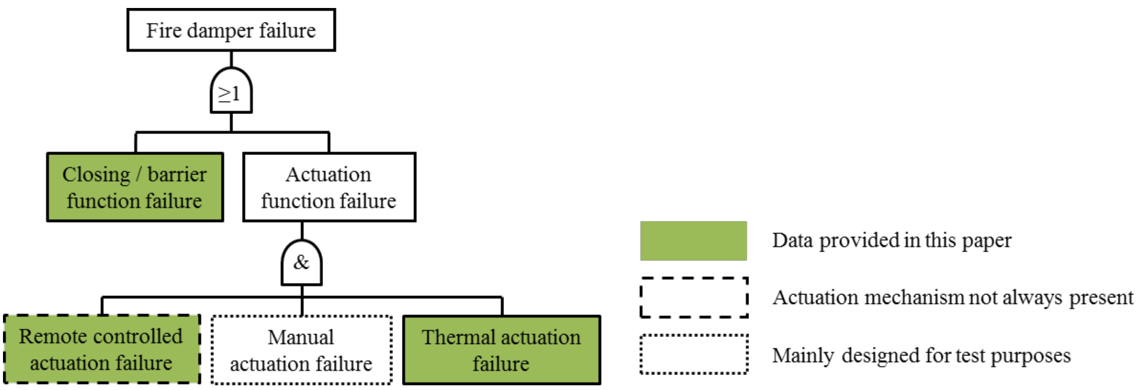


Figure 4: Fault tree for technical failures of fire dampers [10]

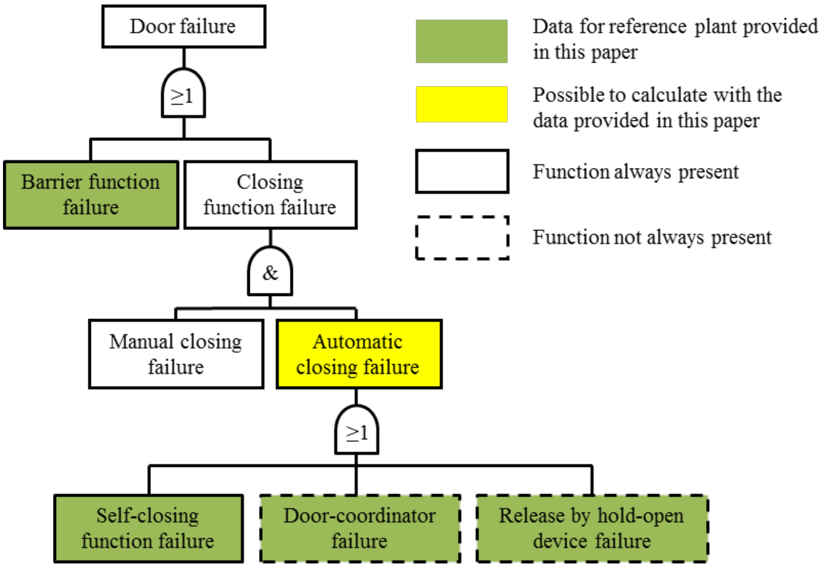


With regard to the reliability of smoke extraction equipment no fault tree was developed, since the majority of these components do not have redundant actuations and the possibility of a manual opening by the fire brigade cannot be assessed by statistical means. Regarding smoke extraction dampers in ducts, which are mostly modified fire dampers, the observed failure types were similar to those of the fire dampers, too. A failure of the required function of a smoke extraction damper was assumed if it did not open. In case it opened but did not latch in open position, this observation was only interpreted as a deficiency. It was further distinguished between installation in roofs or in walls. Typical failure types of the vents were empty CO_2 cartridges or leakages at the pneumatic pipework. A stiff frame and damaged wire ropes also occurred and were interpreted as failure.

A notable limitation in the application of the data for remote controlled fire dampers as well as for smoke extraction dampers concerns the already mentioned fact that the observed failures were not assigned to the triggers, but only to the dampers themselves. That implies that realistic data for the event that more than one damper of a fire compartment does not operate as designed cannot be provided yet.

Because of the different combinations of types of fire doors, e.g. single and double winged doors with additional door-coordinator, and doors equipped with or without hold-open device, again a fault tree (cf. Figure 5) has been developed. This faults tree is very similar to that for fire dampers (see Figure 4), however barrier and closing function are separated, and closing can be achieved manually or automatically. For manual closing no data has been provided. The automatic closing depends on the availability of the door closer(s), for double winged doors on that of the door-coordinator and, if present, on the availability of the automatic (magnetic) release function of the hold-open device. For all functions failure rates are given in Table 2 and Figure 3.

Figure 5: Fault tree for technical failures of fire doors



3.3. Fire Extinguishing Systems and Equipment

The plant units under consideration do rely on stationary water deluge systems (in the following called deluge systems) with fire pumps fed by river water and other ones supplied by fresh water. There are five different types of remote controlled actuated deluge system valve stations installed in the plants being considered with the following characteristics:

- hydraulically actuated butterfly valves controlled (open/close) via a magnetic (4/2-way) valve,
- hydraulically operated poppet valves controlled (open/close) via a magnetic valve,
- electromagnetically controlled (only open) valves with manual override,
- electric motor operated valves with manual override, and
- pneumatically preserved valves, which are controlled (only open) on the discharge of the trigger line.

The numbers of remote controlled actuated deluge system valve stations installed in the plant units to be considered are 192 of type 1, 3 of type 2, 30 of type 3, 4 of type 4 and 9 of type 5. The most common test interval for each type is six months, although longer and shorter test intervals have also been used during the observation period (see also Table 3). During the complete observation period 121 findings for type 1 were interpreted as functional failures of the remote controlled actuation. The corresponding numbers of failures were 0 for type 2, 2 for type 3, 4 for type 4, and 0 for type 5 respectively. In this context, it has to be mentioned that the availability of the manual deluge systems´ actuation was not evaluated. Details can be found in [13].

Table 3: Failure rates for fire extinguishing systems and equipment

Active Fire Protection Systems and Components	Number of components	Test interval [years]	Time observed [h]	Number of failures	Failure rate [1/h]				
					5 % quantile	50 % quantile	95 % quantile	Mean value	Standard deviation
Water deluge systems:									
- Remote controlled valve stations, type 1	192	1/2[a]	34 952 424	121	6.39E-08	2.58E-06	1.71E-05	4.96E-06	7.51E-06
- Remote controlled valve stations, type 2	3	1/2[b]	262 980	0	4.39E-09	5.98E-07	8.15E-06	1.90E-06	3.65E-06
- Remote controlled valve stations, type 3	30	1/2[b]	2 636 484	2	7.78E-08	6.21E-07	2.92E-06	9.48E-07	1.03E-06
- Remote controlled valve stations, type 4	21	1/2[c]	3 497 256	4	1.44E-07	9.22E-07	3.66E-06	1.29E-06	1.22E-06
- Remote controlled valve stations, type 5	4	1/2[d]	666 144	0	1.73E-09	2.36E-07	3.22E-06	7.52E-07	1.44E-06
Water pumps:									
- Pump (incl. motor)	21	1/2[e]	3 345 756	4	4.15E-08	2.27E-06	1.63E-05	4.29E-06	4.38E-06
- Remote actuation	21	1/2[e]	3 345 756	2	5.71E-08	1.67E-06	1.03E-05	2.84E-06	2.42E-06
Hydrants:									
- Field hydrants	158	1[f]	26 393 665	5	6.68E-09	4.04E-07	3.34E-06	8.42E-07	9.36E-07
- Wall hydrants	709	1[f]	111 905 641	1	8.28E-10	4.52E-08	3.94E-07	9.93E-08	1.22E-07
- Foam wall hydrants, foam mixing function	63	1	6 660 480	10	2.11E-07	2.00E-06	8.39E-06	2.82E-06	2.39E-06

[a] The most common test intervals for water deluge systems, type 1 are 6 months, sometimes 6 weeks or 3 months.

[b] The most common test intervals for water deluge systems, type 2 and 3 are 6 months, sometimes 3 months.

[c] The most common test intervals for water deluge systems, type 4 are 6 months, sometimes 3 months or 1 year.

[d] The most common test intervals for water deluge systems, type 5 are 6 months, sometimes 1 week or 1, 2 or 5 years.

[e] The most common test intervals for water pumps are 6 months, sometimes 1 week, 1 month or 3 months.

[f] The most common test intervals for hydrants are 1 year, sometimes 6 months.

Observations that have been interpreted as failures of the remote controlled actuation include that the pilot valve was not actuated or did not open or that the main valve did not open. Delayed opening (few seconds), leakages or findings on the closing function after opening of the main valve were assessed as deficiencies. Mean values, standard deviations and quantiles for the different types of the remote controlled actuated deluge system valve stations are presented in Table 3 and graphically displayed in Figure 6.

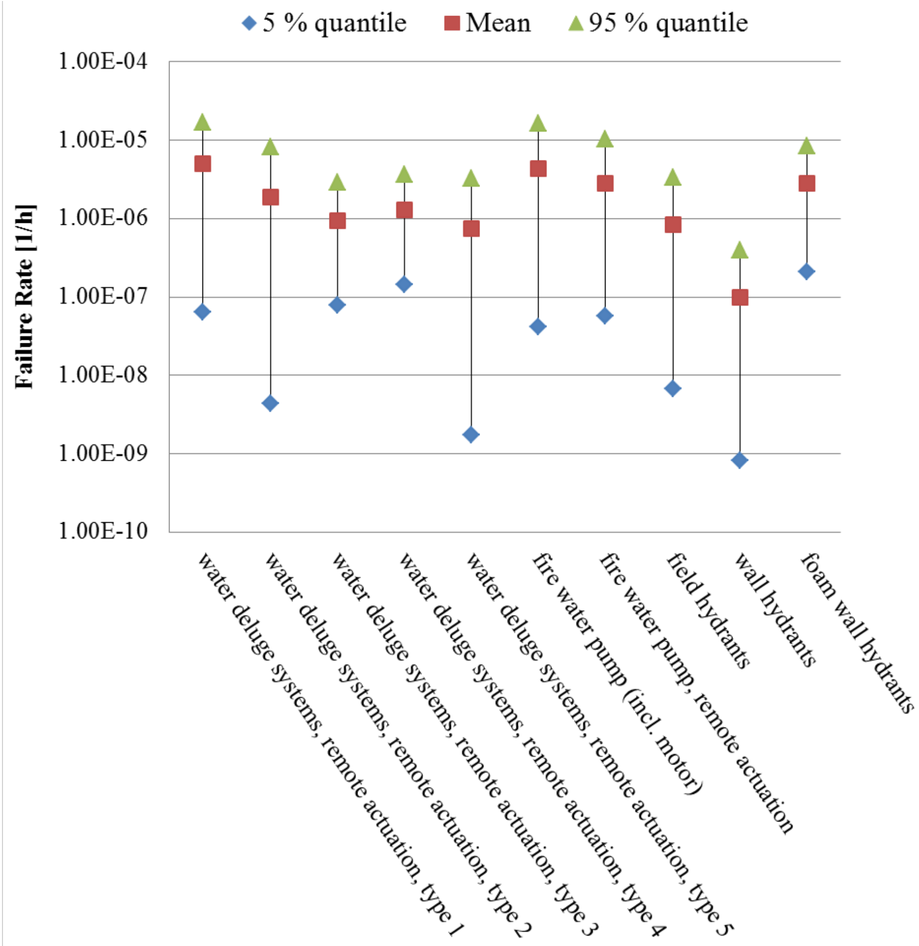
The plants under consideration have got a main ring for the water supply of the deluge systems and the hydrants. The reliability of the main ring, including (if present) flooding valves as well as building closing and clearing fittings are to be regarded separately. To achieve the necessary water supply the plant main ring is connected to a number of water pumps. The following types of failures of the water pumps been observed:
The plants under consideration have got a main ring for the water supply of the deluge systems and the hydrants. The reliability of the main ring, including (if present) flooding valves as well as building closing and clearing fittings are to be regarded separately. To achieve the necessary water supply the fire water main ring of a plant is connected to a number of water pumps. The following types of failures of the water pumps have been observed:

- for the remote controlled actuation of the pumps: the safety hatch of the actuation drawer standing in an intermediate position, when being interrupted on command/request, and
- for the operation of the pumps: insufficient water volume or water pressure.

During the evaluation period four findings were observed at the water pumps where the pumps did not reach sufficient water pressure/flow, and two findings where the remote actuation from the main control room failed. Accordingly, the mean failure rate for the water pumps (operation) is 4.29 E-06 /h with a standard deviation of 4.38 E-06 /h and the mean failure rate for the remote controlled actuation of the pumps is 2.84 E-06 /h with a standard deviation of 2.42 E-06 /h respectively.

A total of 867 hydrants are installed in the reference plants, 158 of these are field hydrants outside in the yard and 709 wall hydrants inside buildings, 63 of them are equipped with a device to add foam. In the inspections carried out five findings that can be interpreted as failures of the required function of field hydrants and one failure of wall hydrants were observed. Such failures were stuck drop jacket or main valve. In addition, the foam mixing function was assessed for the relevant wall hydrants with a total of ten findings that could be interpreted as failures of the required function. For the resulting generic failure rates mean values of 8.42 E-07 /h, 9.93 E-08 /h and 2.82 E-06 /h were calculated with standard deviations of 3.34 E-06 /h, 3.94 E-07 /h and 2.82 E-06 /h correspondingly for field hydrants, wall hydrants and foam mixing function respectively.

Figure 6: Failure rates of fire extinguishing systems and equipment



4. CONCLUSIONS

The technical reliability data for active fire protection systems and components established in the past for six nuclear power plant units of different reactor types and plant generations has been recently updated and extended. The entire data has been evaluated by analyzing results of periodic in-service inspections, covering approx. 111 plant operational years of in total six NPP units. Plant specific [13] and generic data has been calculated. The updated and extended reliability database [6] will be included in an additional document supplementing the existing technical document on PSA Data [2] to be issued in 2014. Furthermore, this database may also be internationally applicable to Fire PSA for NPP.

The data is based on results of in-service inspections, therefore the given failure rates do not cover design failures or failures that occurred and were repaired in-between two inspections. Design failures may concern the selection of suitable fire detectors, a sufficient rating of fire barrier elements, or the correct selection of fire extinguishing agents.

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