Frequencies and trends of significant characteristics of reported events in Germany

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Abstract: In the frame of its support to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety the GRS continuously performs in-depth technical analyses of reported events at operating nuclear power reactors in Germany which can be used for the determination of plant weaknesses with regard to reactor safety. During the last 18 months, in addition to those activities, the GRS has developed a data bank model for the statistical assessment of events. This model is based on a hierarchically structured, detailed coding system with respect to technical and safety relevant characteristics of the plants and the systematic characterization of plant-specific events. The data bank model is ready for practical application. Results of a first statistical evaluation, taking into account the data sets from the time period 1996 to 1999, are meanwhile available. By increasing the amount of data it will become possible to herewith improve the statements concerning trends of safety aspects.

This report describes the coding system, the evaluation model, the data input and the evaluations performed during the period beginning in April 2000.

1. INTRODUCTION

The use of the feedback from operating experience is indispensable for maintaining the safety of nuclear power plants (NPP). Particularly due to this reason the NPP licensees have to report all safety significant events. In the Federal Republic of Germany, the event reporting is carried out according to criteria specified in the "Nuclear Safety Officer and Reporting Ordinance" /1/.

The Ordinance in its current version came into effect in October 1992. Approximately 1100 events have been reported from the operating NPPs in Germany up to the time being, representing a relatively good basis for a statistical evaluation of the events. Such evaluations are more and more performed by GRS to investigate generic or type-specific safety related trends and to identify distinctive safety aspects.

Basically, the events included in the database are coded by GRS with respect to their safety characteristics in combination with characteristics on the plant technology and the corresponding operating conditions. The intention is to identify and quantify by means of the statistical treatment the relevant generic deficiencies in nuclear safety, e.g. in plant operation, safety and general management, maintenance, etc. However, prior to any generic conclusions, the event reports from the individual plants require a plant-specific evaluation.
The database may be used to group events according to the event consequences, the potential generic relevance, or the realistic occurrence frequency of safety characteristics.

Thus, deteriorations of or deficiencies in the normal plant operation can be observed and statistically analysed. The trends can be easily and quickly received and reproduced transparently. The statistical results inevitably become more reliable with an extension of the data sets by including more events.

Last not least, the frequencies of different characteristics can also be used to establish relations between the differing NPP generations, construction lines and individual plants.

2. KEYWORD SYSTEM

In order to record the reported events in a standardized, systematic and detailed way, a directory of numerous safety-related and operational characteristics was worked out. The safety-related charac-teristics are mainly focussed on the recording of the kind of event or failure details, the cause of the event or failure and what caused it, the kind of event detection, the degree of damage that has occurred, the actual and the potential effect of the event or failure, possible safety goal violations or weakening of protection measures intended to insure fulfillment of the safety goals, and the levels of the defense-in-depth concept affected. For the description of the operating situation, the operating condition of the plant, the operating condition of the system affected and the nominal operating condition of the affected components at the start of the event are encoded. In addition, the classification of the event is encoded according to the INES scale as well as according to the reporting category and the reporting criteria of the Reporting Ordinance applicable in Germany.

Table 1: Directories for the characterisation of events

Main characteristics of the central keyword catalogue	**Numbers of keywords**
State of plant operation (at the moment of event detection)	31
System affiliation of effected component	119
Operation mode of effected system (at the moment of event detection)	6
Planned operation mode of effected component (at the moment of event detection)	5
Kind of event detection	11
Place of installation of the component respectively of the component sub-unit	10
Degree of damage (with regard to the smallest unit under consideration)	17
Kind of event / failure (with regard to component and component sub-unit)	53
Event / failure consequences (except radiological consequences)	40
Radiological consequences	13
Safety goal interference or violation	35
Safety level relation	41
Classification of event (as of the Nuclear Safety Standards Commission)	70
Cause(s) of event	103
Personnel causing the event	7
Measures taken after the event	41
Failure with relevance to aging	9
Design characteristics and groups of material of the effected pressurized parts	27
	638

Additional keyword lists		Numbers of keywords
For systems	Uniform list as used by the utilities (KKS)	1538
For components	Uniform list as used by the utilities (KKS)	253
For component sub-units	Uniform list as used by the utilities (KKS)	253
For parts	Elaborated by GRS (still incomplete)	124
For materials	Elaborated by GRS	103
For replacement materials	Elaborated by GRS (see above)	103
		2374

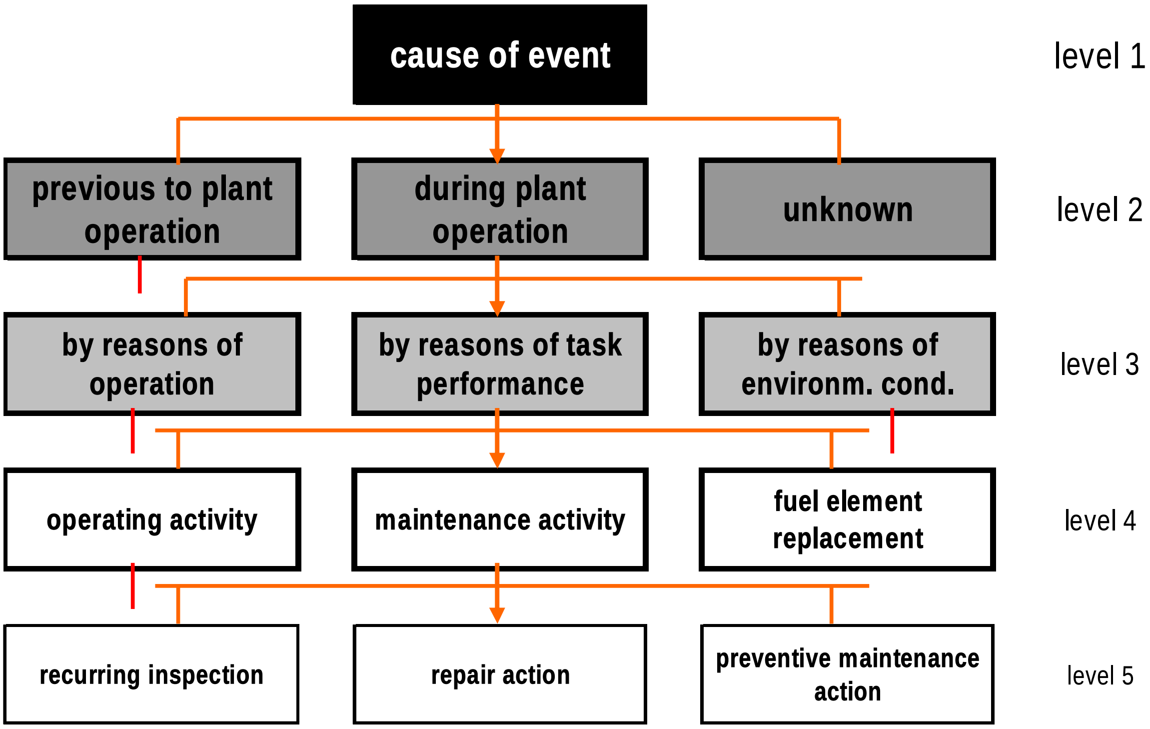
This directory was supplemented by comprehensive lists to identify the systems, functional units, components, component sub-units (self-functioning exchangeable modules of a component consisting of several constituents), parts, materials, and replacement materials. For the systems, functional units, components and component sub-units it was possible to use the KKS identification system developed by the utilities; for the parts, materials and replacement materials, the lists drawn up by GRS were used.

The directory of keywords developed by GRS consists of 19 groups of main characteristics, with at present 638 individual characteristics on up to 5 hierarchic levels. The additional lists for the charac-terization of the individual features in view of technical design details contain a further 2374 values. Table 1 gives an idea of how the keywords are distributed over the different groups of the coding system.

Figure 1 shows an example of the hierarchical structure. With this structure it is possible to achieve that

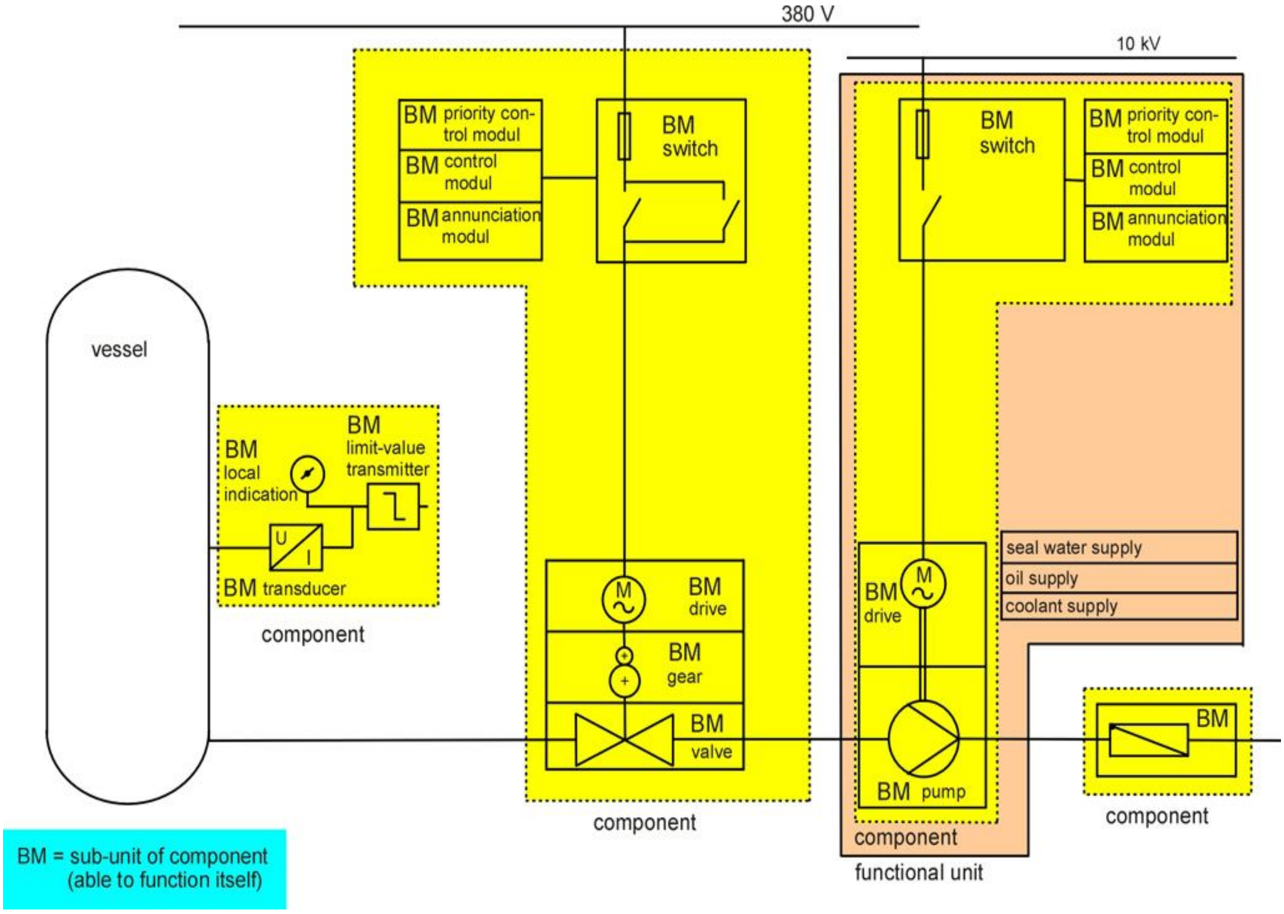
- the coding can be adapted to the respective available depth of information,
- evaluations can easily be adapted to the information depth that is common to the events,
- any frequencies worth mentioning can be generated according to general aspects,
- the depth of evaluation can be chosen freely for different groups of characteristics.

Fig 1: Examples for the hierarchical keyword structure



The component affected by the respective event is referred to as major item under consideration. Generally, the evaluation concentrates on components. The component sub-units affected – in case of adequate depth of information also the constituent – is also taken in. Together with its associated protective device and its auxiliary and supply systems, the component forms a functional unit. Large components may consist of a number of smaller components and can form functional units together with the associated protective devices and the auxiliary and support systems. To keep the system unambiguous, clear definitions of technical terms are necessary in this context. These definitions ensue especially from the boundaries of the items under consideration. The most important examples of the boundaries of component sub-units, components and functional units are shown in Figure 2. The system boundaries also have to be defined systematically and in a uniform manner.

Fig. 2: Boundaries of component and functional unit



3. DATA INPUT

For the keywording of the events, only those members of the personnel are used who are in charge of or familiar with the evaluation of operating experience and/or who dispose of their own commissioning or operating experience. Depending on the complexity of the event, they revert to various different information sources:

- the text of the licensee´s report itself,
- entries in other GRS databases dedicated to the evaluation of events,
- any possibly existing Information Notices,
- the GRS file about the event, i. a. vendor reports, results of inquiries, analyses and reviews
- the computerized technical documentation system of GRS, e. g. technical drawings, operating manuals.

Initially, it has to be established from the information available for the events that have been reported how many failures or impairments of the function of components or component sub-units have occurred.

The events are divided into more than one events if there has been more than one functional failure and the functional failures have been independent from each other. This ensures that all independent functional failures of components or component sub-units that have occurred in an event are statistically recorded.
Consequential failures occur as a result of primary events and are therefore not treated as events as such. Since the consequences of primary events are also recorded and evaluated, the information about consequential failures is not lost.

In case there has been any damage to a component or component sub-unit, the first question will be about the effects of the damage. These occur predominantly in case of challenge. If there has been such an case, the reported event correspondingly is a critical one. In case any damage has been detected on a component or component sub-unit even though there was no activation, there usually will be no damage consequences beyond the item under consideration. The event thus appears to be less relevant to safety even though there would have been significant consequences if the system concerned had been activated. This is why details about the consequences of damage are not only provided if there has actually been a challenge, but likely damage consequences are also encoded that would have occurred if there had been a potential challenge.

For a better understanding of the database and of the results of the statistical evaluation presented in Chapter 5, the most important principles of data encoding are explained in the following.

After entering the fulfilled reporting criterion and the reporting category as well as the INES reporting level, the user initially encodes, with the help of the special keyword directories, the details about the system, functional unit, component, component sub-unit, constituent, material (if necessary also the replacement material). All other encoding is done by means of the central catalogue of keywords by simply clicking on the characteristics applying to the respective event on the respective lowest hierarchy level for which encoding is possible due to the state of knowledge. The associated characteristics on the above-lying levels of the hierarchy are generated automatically. To avoid different interpretations on attributing characteristics, the user is also offered on-screen explanations for a better understanding of the keywords.

The user encodes the specified condition of the component affected as well as the operating condition of the associated system and the plant prevailing at the time the event was detected.

The degree of damage is encoded for the respective smallest item under consideration. This may be a constituent, a component sub-unit or a component. The degree of damage is divided into indication, fault, and functional failure. The item under consideration does not always have to be characterized by a degree of damage. "No damage" would e. g. have to be used as encoding characteristic if the failure was caused by an operator error.

The encoding of the failure mode, e. g. as mechanical failure or as electrical failure, is largely determined by the delimitation of components. Different failure modes may occur for a component and an associated component sub-unit, e. g. component "valve" does not open (mechanical failure), component sub-unit "control interface module" has no output signal (electrical failure). If possible, the failure mode is therefore determined for the component as well as for the component sub-unit.

The determination of the cause of the event is difficult in so far as that it depends on how far a cause was or could be traced. The depth of information provided in the event reports in this respect varies a great deal. In connection with the data acquisition at GRS, only the causes identified as direct causes are encoded. However, it is not always possible to define exactly what a direct cause is. If several causes are identified, (e. g. flow effect on the one hand and corrosion on the other), there subsequently will be multiple entries.

A difference is made between operational, execution-related, task-related and environmental event causes. A task-related cause is inevitably also an execution-related cause, so that there are always two entries here, e. g. task-related cause "repair" and execution-related cause "wrong measure". By the simultaneous encoding under both groups of characteristics, a better event characterization with regard to the causes becomes possible.

As to the cause originators, a distinction has to be made between own and contract personnel. Encoding is particularly difficult in the case of contract personnel as it depends on how far a cause was or could be traced back. Faults during preventive maintenance - which is performed with varying degrees involvement of own and contract personnel from plant to plant - usually cannot be allocated clearly by the information available at GRS. In these cases, the characteristic "originator unknown" is entered. As regards the operating personnel, there is a division into different groups of persons.

As regards event detection, a distinction is mainly made between detection incase of activation, detection by operational monitoring, during walk-downs/at-the-face observations, and during maintenance. Experience shows that events can be detected this way or the other. If necessary, multiple encoding is carried out. Detection by operational monitoring is divided into detection by the monitoring of parameters, fault alarms or the actuation of protection systems. What is mainly interesting here is by which detection possibility the event was first detected, so that no multiple encoding is allowed within this group of characteristics.

Concerning the *failure consequence that has actually occurred*, a distinction is made between single failure and consequential failure.

As in the case of a single failure, only the respective greatest function-related failure consequence, i. e. the single failure of either the component sub-unit, component, functional unit, redundancy or system, is encoded. If the failure of e. g. a system is due to the failure of a component, it is obvious that the functional unit and the redundancy have also failed.

A consequential failure presupposes by nature a single failure or a CCF and can occur in various forms:

- Not function-related consequential failure.
  This is a failure which has occurred due to environmental or impact-related causes, e. g. as a result of a fire or through jet forces. It is double-encoded as single failure (single failure of either the component, functional unit, partial train, whole train or system) and as consequential failure (either single consequential failure or more than one consequential failure).

- Functional consequential failure due to the failure of an auxiliary system belonging only to the component affected.
  An auxiliary system belonging only to the component affected is allocated (in line with the delimitation of components , see Figure 2) to the component with which it forms a functional unit. If the component fails due to the failure of this auxiliary system, the failure effect is encoded as single failure because with respect to the functional unit as such, this is not a consequential failure. The failure of the component manifests itself as the single failure of the functional unit, redundancy or system.

- Consequential failure due to functional dependence on separate systems.
  Auxiliary systems supplying more than one component – as e. g. the power supply system - are considered as separate systems. Process-based systems, especially the systems of cooling chains, are also considered as separate systems. Typical such systems are the nuclear residual-heat removal system, closed cooling water system, and service water system. If e. g. the failure of a service water pump leads to the failure of a redundancy of the service water system and to a consequential failure in the residual-heat removal chain, this will be double-encoded as a single failure (e. g. redundancy or system) and as a consequential failure.

On the one hand, the double-encoding characterizes in more detail which effects the failure of a component in the system to which it belongs have entailed. On the other hand, it characterizes the effects of the failure on other systems.

For the *potential effect* in the assumed challenge case, the encoding of single failure and consequential failure is principally done in the same way as for the actually occurred effect. However, this is only done if the potential effect is more serious that the actually occurred effect.

For CCF events and also in case of potential CCF, there is no double-encoding. What is encoded in case of CCS is whether there has been 1 failure + additional findings/faults or if there have been several failures happening at different times, 2 failures, or more than 2 failures.

The radiological consequences of the real event are divided into activity release, discharge of radioactive materials, contamination, the carrying-off of radioactive materials, radiation and exposure. As regards the potential radiological consequences in the assumed but not actually occurred operating/challenge case, no such division was made, so that it only has to be indicated whether there would have been radiological consequences, but not of which kind they would have been.

The integrity of the barriers for the confinement of the radioactive materials in nuclear power plants is achieved by the defense-in-depth concept which has several levels of safety. This concept consists of a combination of protection measures for the prevention of anticipated operational occurrences and design basis accidents, measures for their control, and finally accident management measures for the prevention of core damage and the mitigation of the effects on the surrounding environment in the event of an accident involving core damage. This concept stipulates that the safety objectives of reactivity control, fuel cooling and activity retention be fulfilled in line with the requirements for the individual levels.

Checks are made upon data input in how far the specified safety objectives have been violated. A violation of a safety objective is defined by the fact that the minimum requirements for the respective protection measures have not been fulfilled. If the safety objectives have been fulfilled, it is checked whether there has been a reduction in the reliability or effectiveness (in short "weakening") of protection measures.

As to the protection goals of reactivity control and core cooling, only one entry is made, relating to the respective protection measure originally concerned. For the safety objective of activity retention, multiple encoding of the protection measures concerned may be admissible.

Depending on whether a protection measure has been challenged or not due to an event, there may have been an actual or latent violation of safety objectives or weakening of protection measures. Exceptions are the fuel cladding tubes and the passive parts of the reactor coolant pressure boundary and the containment. Their protection measures must always be in place, so that any weakening of the protection measure of violation of the safety objective has to be encoded. A case of damage or a failure in the safety system that is detected at a time when the protection measure is irrelevant – e. g. during an outage – is encoded as a latent weakening of the protection measure or as a latent safety objective violation. The reason for this is that this damage or failure may already have existed at a time when the protection measure might have been challenged due to an accident.

In principle, the safety objectives have to be fulfilled on each safety level. The corresponding safety measures have to fulfil requirements related to the safety levels, e. g. with respect to redundancy and diversity. Encoding is done in such a way that the corresponding safety level is determined from the system function required at the start of the event to perform the protection measures (e. g. residual-heat removal during normal specified operation or during emergency cooling operation).

Upon encoding, reference is only made to the event that has actually occurred and its effects. All safety levels affected are encoded, because from the point of view of reactor safety it is of particular interest whether there have been any transgressions of safety levels during the cause of the event and which they were. Such transgressions may occur in the case of consequential failures and CCFs.
The pressurized parts are characterized according to type, diameter, material and damage localization. Apart from various pipes, these parts are mainly vessels, valve bodies, and heat exchanger and steam generator tubes.

Cases of damage with aging relevance can be characterized according to different damage criteria and are allocated to certain groups of systems. The application of damage criteria may be difficult as the information available to GRS often provides little insight in this respect and because the database project does not provide for own analyses in this respect. Therefore entries are only made here if one of the damage criteria has obviously been fulfilled and can thus not claim to be exhaustive with regard to the frequency of these cases.

The measures taken by the utility to restore correct plant conditions are also encoded. These may be far-reaching measures against the repeat of an event or straightforward measures for damage reme-diation. Depending on the kind and scope of the measures taken, there will be single encoding (e.g. component sub-unit exchange) or multiple encoding (e. g. component exchange, examination of comparable items under consideration, change in operation, modification of operating documentation, personnel training).

After the implementation of the database concept, the data sets for the years 1996 to 2000 were generated. The input of data from before and after that period is underway. To control data input, automatic consistency checks were developed in order to avoid to the largest possible degree encoding that is

- incomplete, e. g. consequential failure without prior single failure,
- inadmissible, e. g. potential failure effects equal actual failure effects,
- contradictory, e. g. installation location "emergency diesel building" and functional unit "piston pump".

In supplement to the automatic consistency checking, measures were also taken to assure the technical quality of the data sets. When this was completed for the events of 1996 until 2000, the corresponding data sets were saved as quality-assured read-only files. In this form they are available for statistical evaluation. In all, they comprise 475 events and 449 reports.

4. DATA EVALUATION

The database concept allows a fast and full survey of the existing data as well of frequencies, distinctive features and trends. It also makes it possible to select data by indicating

- any desired time periods under consideration,
- facility, power plant generation and power plant type,
- any desired individual or group characteristics according to the central keyword directory,
- any desired individual values according to the additional keyword lists.

It allows any desired combinations of characteristics and values in "AND", "AND NOT" or "OR" logic. For the evaluation it may under certain circumstances also be useful to relate the frequencies of the characteristics to availabilities instead of certain periods of years, e. g. in the case of comparative evaluations for plants with large backfitting- or modernization-related differences regarding their shutdown periods. This option has also already been realized.

For the reliability of the results of statistical evaluations it is important how the criteria for the reporting of events by the licensee are treated /1/. According to these criteria, what has to be reported in particular is functional disturbances, damage or failures in the safety system (including the associated auxiliary and ancillary systems), but also

- crack indications in the pressure boundary of the primary and secondary system,
- findings that indicate systematic failures in the safety system or in other safety-relevant systems and parts of the plant.

Crack indications and findings pointing at systematic failures (potential CCFs) are mainly just above or below the reporting threshold. Analyses carried out by GRS have shown that in this range – i. e. concerning events with comparatively low safety relevance – reporting criteria may be handled differently. The reasons for this are i. a. imprecise, lacking or contradictory definitions of technical terms as well as sometimes generalizing specifications. The order of magnitude of the uncertainties caused by this has been estimated (as far as the database allowed) and is in total less than 20 %.

The results of the data evaluation can be represented in practically any desired form in tables or directly in graphs, with different options for presentation available. The evaluation results can be shown per year or for the overall period.

RESULTS

By means of selected results of the data evaluation performed by now, it shall be generally illustrated how the reported events are represented in total numbers. Moreover, the potential of the data base shall be presented, but also the limits given due to the amount of data which is still small at present. As far as distinctive features or indications to trends could have been identified, these are shown.

Fig. 3: Distribution of event frequencies and component failures (1996 - 1999)

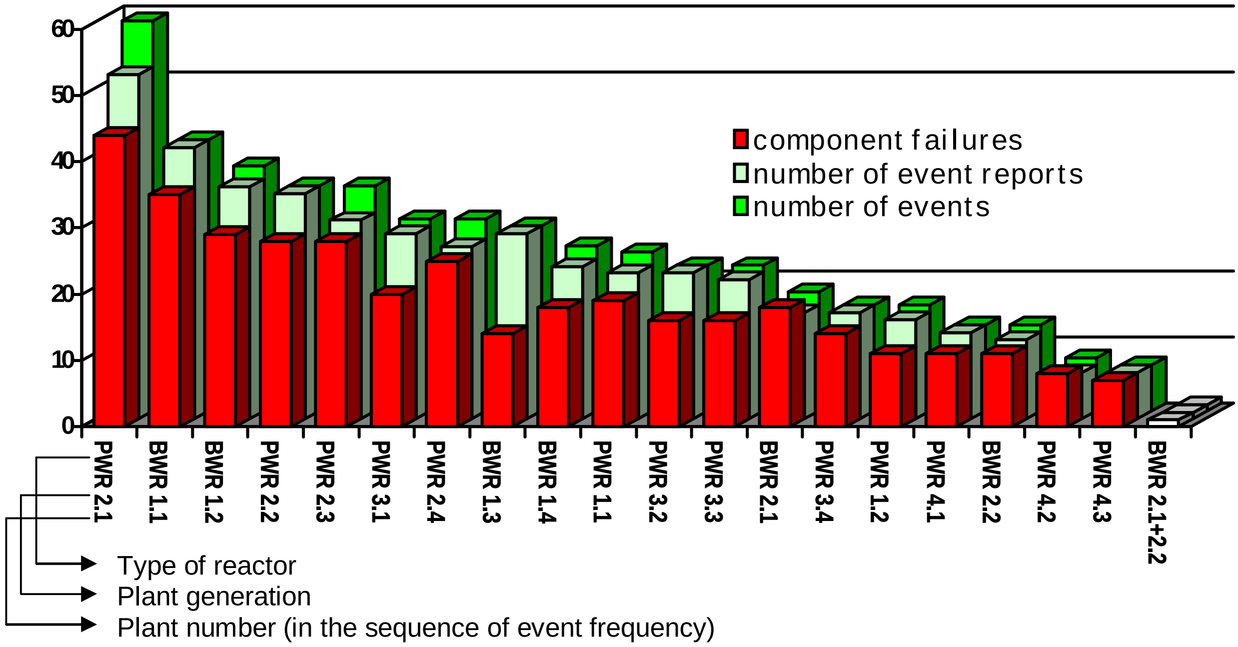


Fig. 3 shows the plant-specific frequencies of the event reports, the corresponding events and the component failures occurred. In nearly 79% of the reported events, there were component failures.

The failure frequencies of the components are determined on the basis of the criteria for event reports. According to these, component failures in the safety system or other safety-relevant systems or parts of the plant mainly have to be reported. They do not give information on how often the entire safety system has been affected by a certain event in comparison with the operational system, but only on how often a reportable event occurred at itself.

At some plants, the number of component failures is extremely low and at some plants relatively high. They differ by a factor of up to six. Altogether, a similar picture is displayed as in the case of the event frequencies. Both the retroactive and progressing upgrade of the database will show whether the distribution determined so far will be confirmed.

The following evaluations, practically without exceptions, concentrate on the component failures. The uncertainties discussed at the end of chapter 4 are not existent here.
More than 90% of the reported component failures

- have either occurred in the safety system, including related auxiliary systems (degradation of protection measures at Safety Level 3),
- or they have led to an activation of protection measures at Safety Level 3.

The other component failures occurred at the fire protection systems, emergency systems and auxiliary systems, and can partly also be assigned to Safety Level 3. It would be possible to determine the exact percentage of these events by in-depth plant-specific considerations, which, however, has not been done within the framework of this first evaluation.

After the preceding estimation, statistical evaluation separated according to the safety levels becomes unnecessary. In the first approximation, the results are representative for results at Safety Level 3.

Fig. 4: Failures of special safety relevance (1996 - 1999)

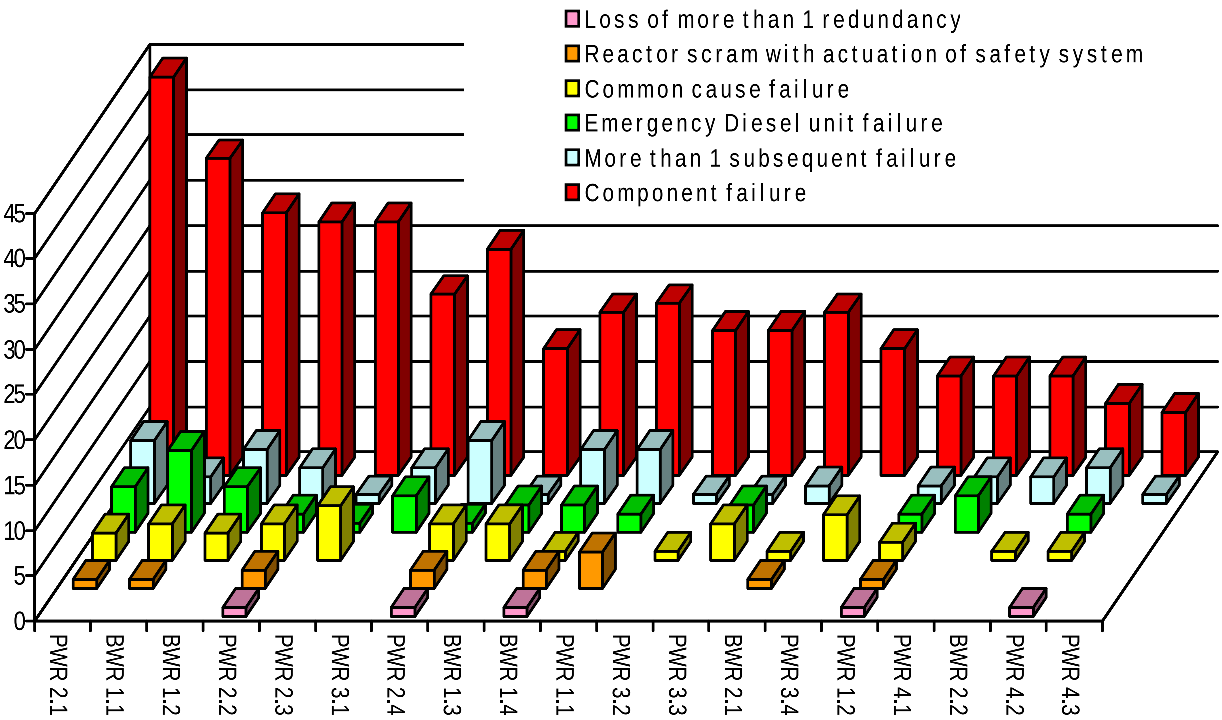


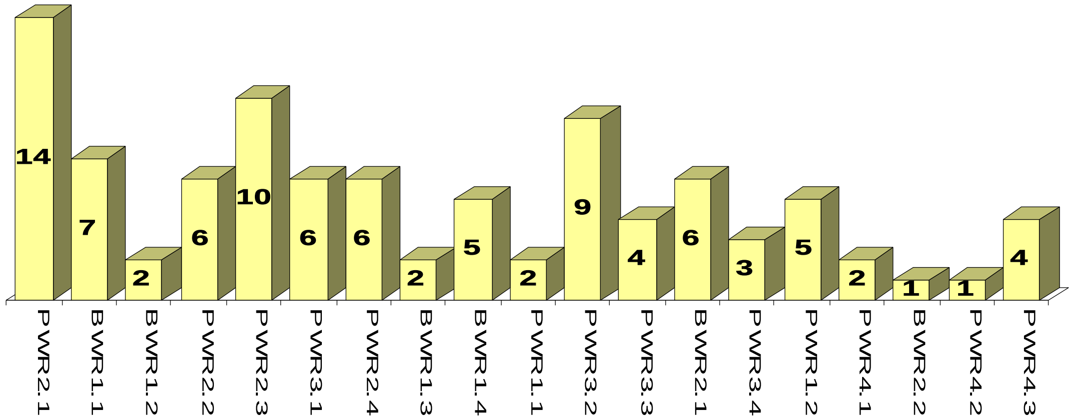
Fig 4 presents further distributions of events with special safety relevance corresponding with the encoding characteristics "more than one consequential failure", "Diesel failure", "common cause failure" (without potential CCF), "reactor scram with actuation of a safety device" and "loss of several redundancies". It has to be noted that several encoding characteristics can be fulfilled simultaneously. For this reason, it would not be reasonable to make a summation of the plant-specific characteristic frequencies. Globally seen, it shows that the plant-specific frequencies of events with special safety relevance do not increase proportionally compared to the number of plant-specific component failures. Postulating that the special safety relevance is characterized appropriately by the selected characteristics, plants with a larger failure frequency of components do not show a corresponding increase of events with special safety relevance. As a result of the preceding evaluation it cannot be confirmed that plants with a relatively low frequency of reportings mainly report events with a higher degree of safety relevance.

The plant technical condition can the easiest be characterized by means of the component failures and their consequences. The component failures can be classified according to their superordinate causes as follows:

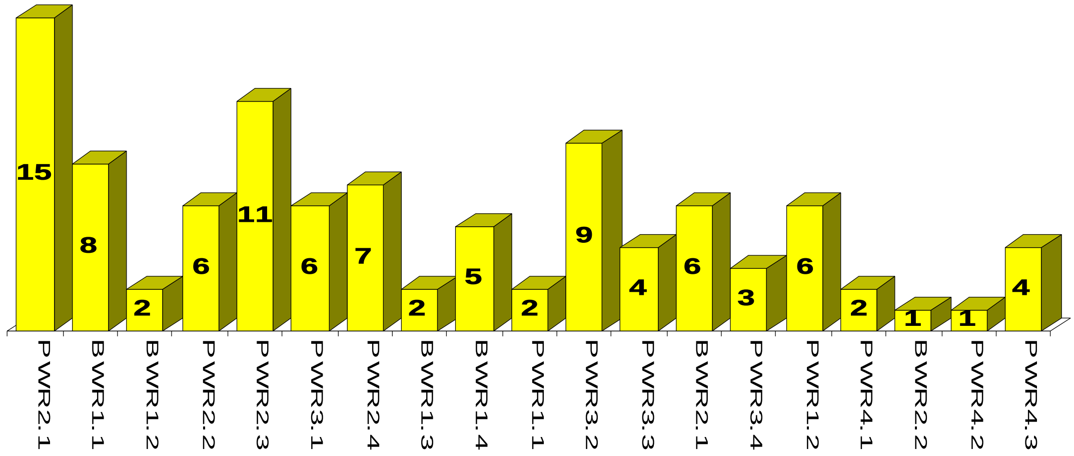
- pre-operational causes,
- operational causes, i.e. due to mode of operation,
- task-related or execution-related causes,
- environmental causes.

Fig. 5: Causes of component failures (1996 - 1999)

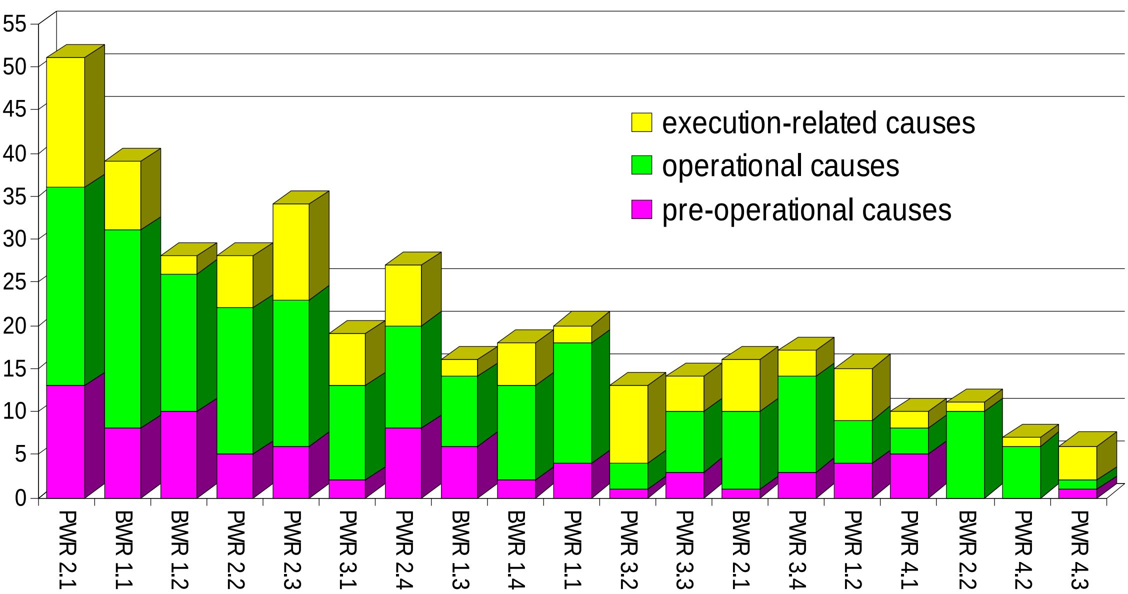
a) Task-related causes of component failures



b) Execution-related causes of component failures



c) Execution-related, operational and pre-operational causes



The total of the events, i.e. events with and without functional failure is not suited for the characterization of the plant technical condition, since this would also include human errors and also due to the uncertainties discussed at the end of chapter 4.
21% of the component failures were due to pre-operational causes. From these, projecting/planning/ specification and manufacturing/fabrication accounted for nearly the same percentage, and erection/ assembly and transport were of minor statistical significance.

53% were due to operational causes, mainly and, with decreasing tendency, resulting from shortcomings regarding electrical engineering, I&C, corrosion, fatigue, dirt and wear. Regarding some of the latter characteristics it is difficult to distinguish whether it is actually an operational or a pre-operational cause, so that they cannot be assigned to the one or the other explicitly.

24% of the functional failures were task-related and mainly caused by preventive maintenance, repair, in-service inspections and plant operation. Each task-related cause is corresponding with an execution-related one. The execution characteristics "wrong measure", "omitted measure" and "non-observance of plant operating procedures" occurred dominantly.

With 2%, the environmental causes were statistically insignificant.
Pre-operational causes can hardly be detected during plant operation, and events due these causes can hardly be prevented. Regarding the identification of operational causes and prevention of events resulting from them, there are, generally seen, better possibilities. The number of task-related and execution-related component failures can be influenced by the utility to the greatest extent. In so far, it is likely to be the best criterion for possible problems in the fields of administration/organization/quality assurance.

The plant-specific number of component failures due to task-related causes is represented in Fig. 5a. The distribution clearly deviates from the frequency distribution of all plant-specific functional failures.

In general, several works have to be executed for the performance of tasks, e.g. for in-service inspection. For this reason, it may be that a functional failure due to the performance of a task is due to several execution-related causes, e.g. "wrong measure" and "non-observance of plant operating procedures". The plant-specific number of execution-related causes is given in Fig. 5b.

Fig. 5c shows the execution-related, operational and pre-operational causes of component failures for each plant. It can be seen that at plants with high event frequencies generally more component failures occur due to pre-operational plus operational causes compared to plants with low event frequencies. For some plants, the percentage of the execution-related causes from the sum of all causes for component failures is relatively low (in the extreme case 9 %), and for others relatively high (in the extreme case 69 %).

An exemplary performed comparison of the absolute values of the plant-specific causes für the plants PWR 2.1 und BWR 1.2 has led to the following results:

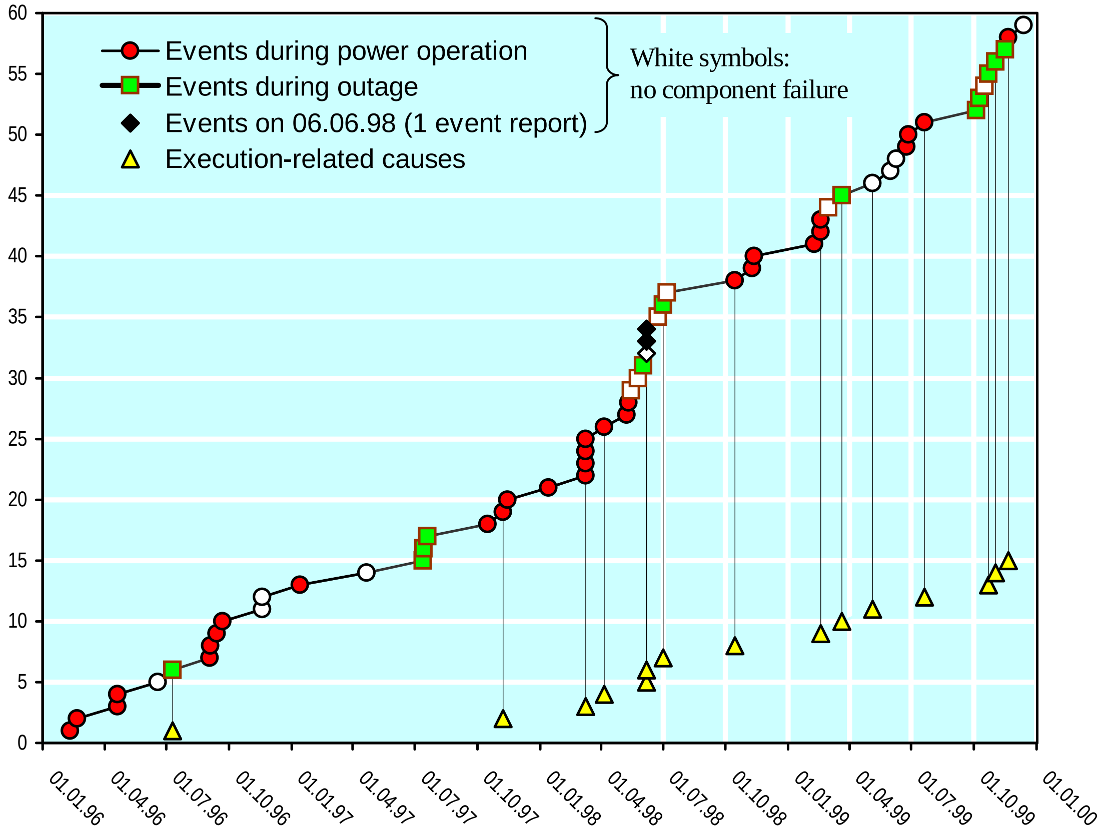
- Both plants have an above-average frequency of pre-operational causes in common. Regarding these frequencies, they only differ by three hits.

- Both plants have an above-average frequency of operational causes in common. Regarding these frequencies, they only differ by seven hits.

- PWR 2.1 has a frequency of 15 regarding execution-related causes for component failures, whereas BWR 1.2 has a frequency of two. This indicates a different relevance of these causes in the administrative/organizational area of the plants.

When examining the events at PWR 2.1 in their time sequences, the following picture is obtained.

Fig. 6: Cumulative representation of events and execution-related causes at PWR 2.1



On 6th June 1998, an event classified at the International Nuclear Event Scale (INES) at Level 2 occurred in this plant. The investigations showed that the causes for the event were solely related to the organization/administration and personnel behavior. Therefore, the recognized deficiencies should be removed by a comprehensive catalogue of measures. By means of the data sets, it is checked whether or to which extent the implementation of the measures influenced the plant operation.

The cumulative representation in Fig. 6 shows

- at which dates two or more events have occurred,
- which events are due to execution-related causes,
- a clear increase of the event frequencies for the first six months of 1998,
- an increase particularly in the execution-related causes after the first six months of 1998,
- which events occurred during outage of the plant
(a total of 11 of the events occurred after the 6th June 1998).

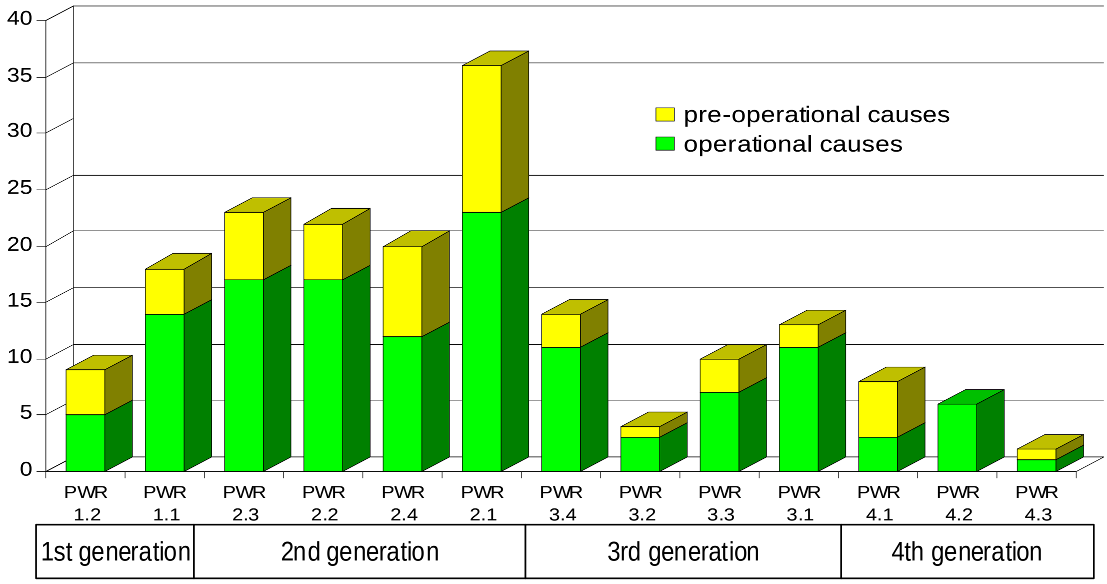
In summary, it can be stated that the catalogue of measures has not proven to be effective yet until the end of 1999 with regard to the removal of deficiencies in the field of organization/administration.

Since the operational and pre-operational causes for component failures are comparatively most suitable to give information on the plant condition and this plant condition probably differs according to power plant generation, the causes were assigned correspondingly in Fig. 7a and Fig. 7b. It can be seen that the PWRs of the second generation give a less favorable picture compared to those of the other generations. Regarding BWRs of the first generation in comparison with those of the second generation this does not apply correspondingly, but only with reference to the plants BWR 1.1 and BWR 1.2. With regard to PWR-plants, the low frequency of the operational and pre-operational failure causes for a plant of the first generation is also noticeable.

As it is the case for the other evaluations, the reliability of the results has to be corroborated by means of extended sets of event data.

Fig. 7: Causes of component failures in dependency on power plant generation (1996 - 1999)

a) Operational and pre-operational causes of component failures (PWR)



b) Operational and pre-operational causes of component failures (BWR)

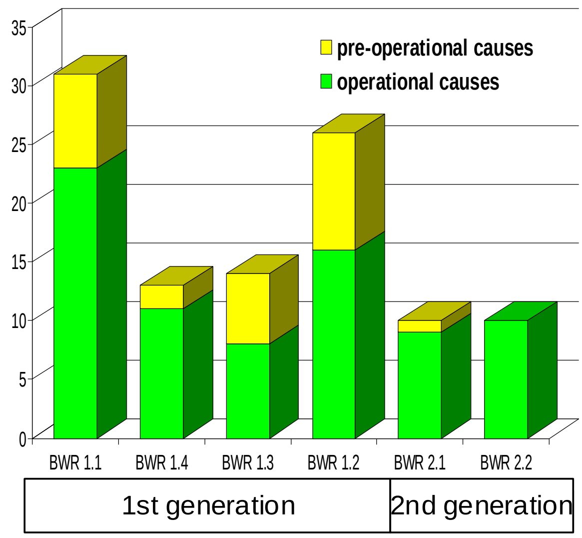


Fig. 8a exemplary shows the respective percentages of the component failures and average unavailabilities for the PWR and BWR generations for the period 1996 to 1999.

The power plant generations with a relatively large number of reported functional failures also show correspondingly high unavailabilities. With the extension of the sets of event data and the accurate consideration of other causes for outages, the correlation between the frequency of component failures and the unavailabilities becomes quantifiable.

A first impression of the dependency is given by Fig. 8b. Due to the proximity of the frequency values to the regression straight line, it seems to be reasonable to further analyze to which extent there is a converse linear correlation between the frequency of component failures and the average availabilities (plant-specific, related to power plant generations, type-specific or generic) by means of further sets of event data.

The deviation from linearity is also given by the correlation coefficient, which had a value of -0.894. At a value of -1.0, the converse linear dependency would fully be reached.

Fig. 8a: Component failures and plant unavailabilities (1996 - 1999)

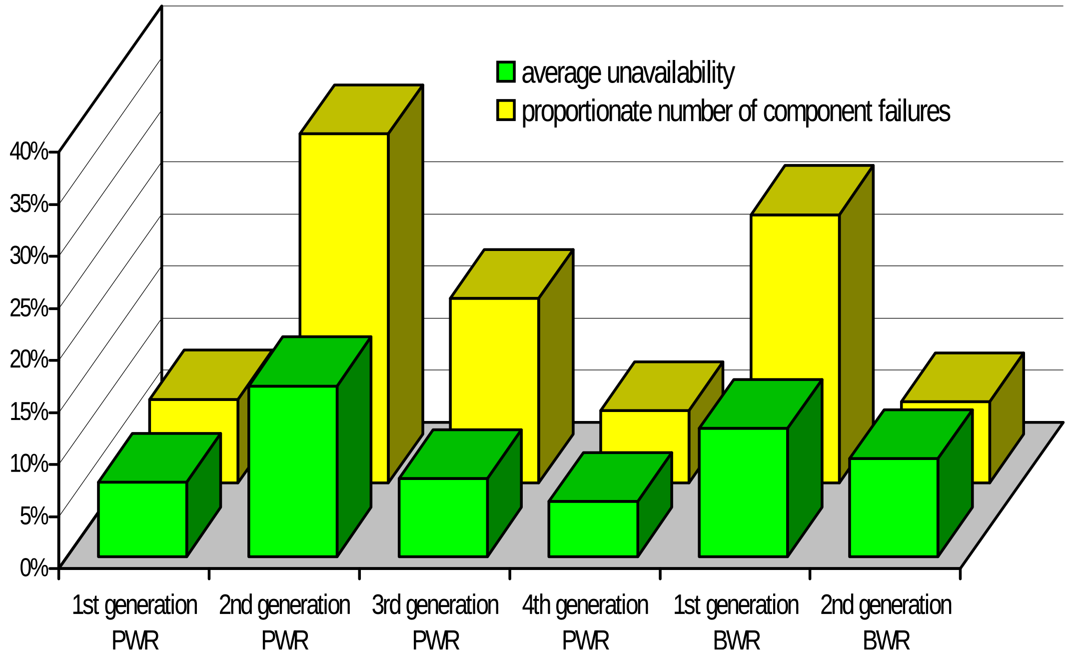
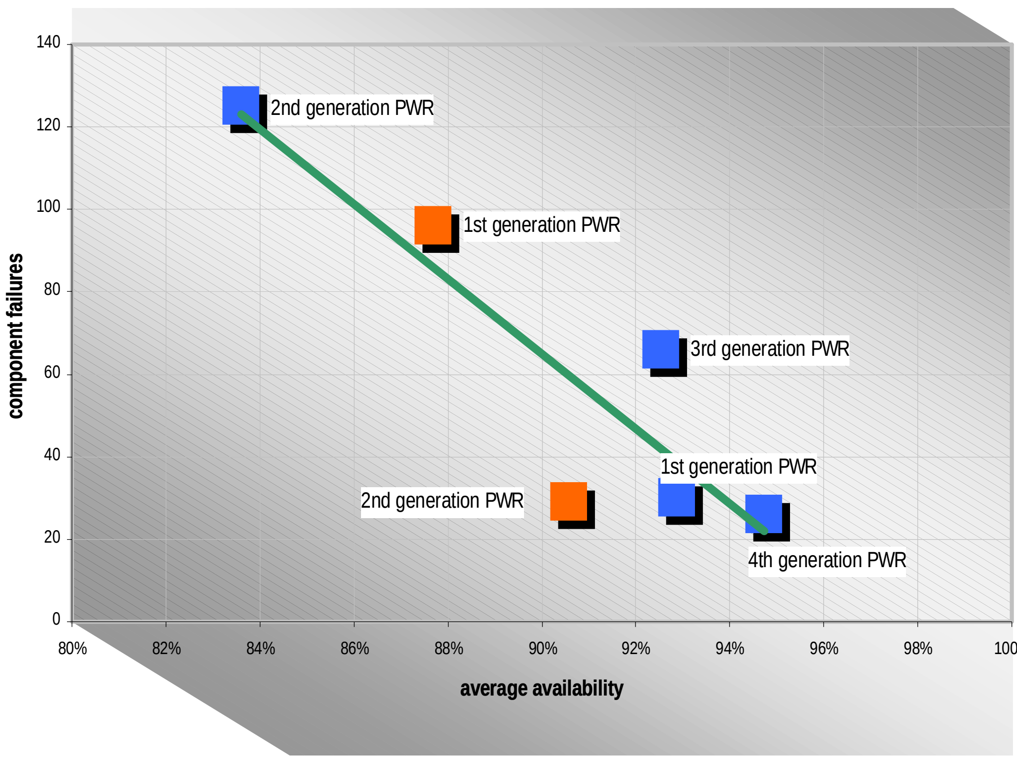
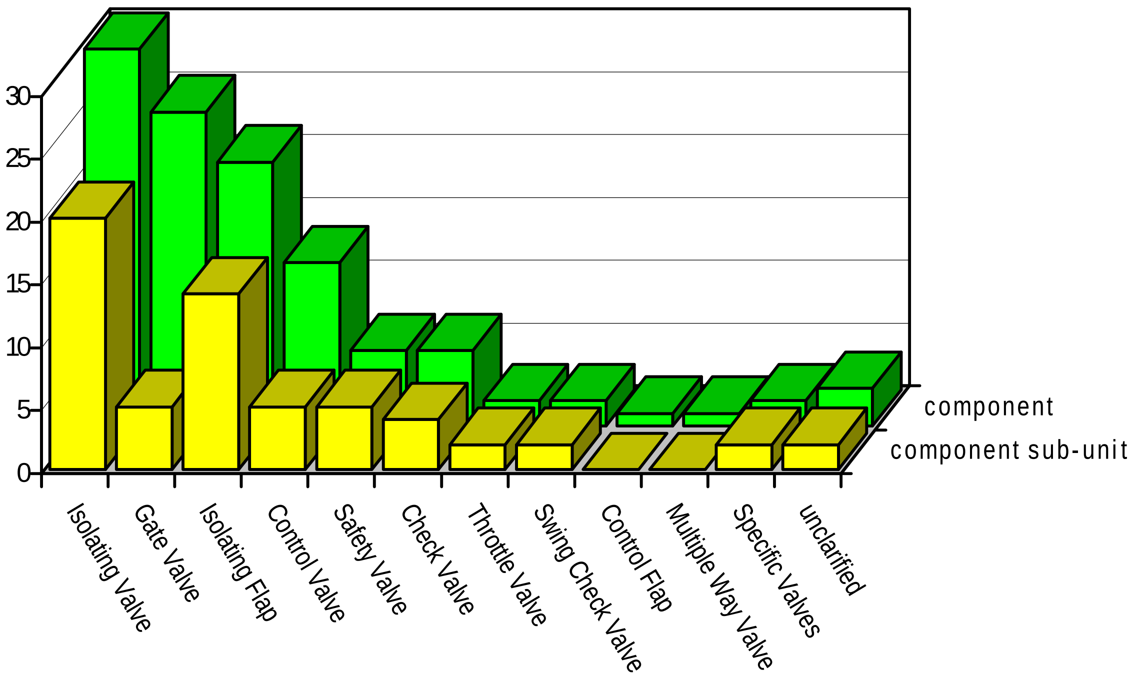


Fig. 8b: Component failures and plant availabilities (1996 - 1999)



With the following example, another possibility is presented, how distinctive features in the statistics can be identified by means of the database.

If subdividing the component group of the valves and flaps according to their construction principle, the respective functional failures are obtained according to Fig. 9. The component type "isolating valve" proves to be dominant, followed by "gate valve" and "isolating flap".
Fig. 9: Failure frequencies for different types of valves and flaps (1996 - 1999, all NPPs)



Components, i.e. also valves and flaps, consist of one or several component sub-units, one of them giving its name to the component. In case of component failures, the question arises to which percentage these were caused by which component sub-unit. The directly concerned component sub-units can be identified by means of the database. Fig. 9 (front row) exemplary shows the frequency distribution for the respective name-giving component sub-unit. A failure frequency of 30 for the isolating valve results in a failure frequency of 20 for the name-giving component sub-unit, i.e. the event was caused to 67% by the component sub-unit isolating valve and only to 33% by the other component sub-units (e.g. gear, drive, switch, actuation module, control module, annunciation module).

The failure frequency of the name-giving component sub-units is also dominating regarding most of the other valves and flaps. One exception to it is the gate valve where the name-giving component sub-unit was only affected up to 18% and up to 82% the other not name-giving component sub-units. It is noteworthy that a failure of the drive units generally occurred due to the actuation of the drive overload protection. The problem is known to the utilities and to GRS for some time and object of thorough investigation and assessment. By means of the data evaluation, it could easily be reproduced.

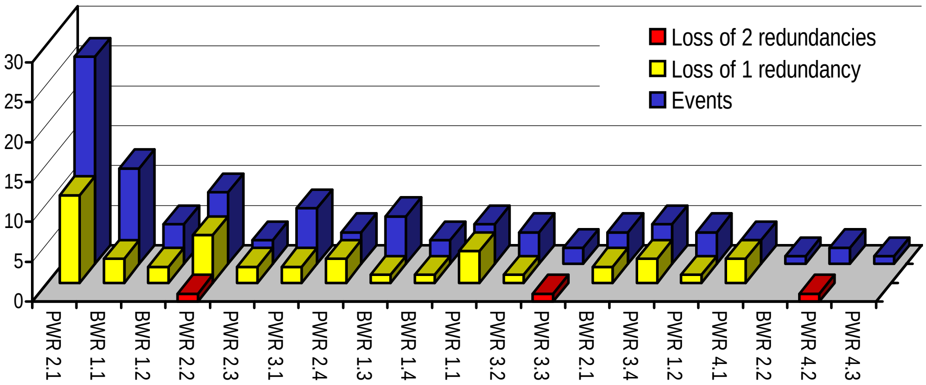
A last application example shows the distribution of the direct plant-specific event and failure frequencies of redundancies to the system chains for residual heat removal.

Fig.10a shows the sum of the redundancy losses in the emergency core cooling and residual heat removal system, in the intermediate and secured (closed) cooling system, and in the secured auxiliary service water system. During the period 1996 to 1999, there was no redundancy loss of the mentioned systems at two plants (BWR 2.2 and PWR 4.3). Three plants had a loss of two redundancies each (PWR 2.2, PWR 3.3 and PWR 4.2).

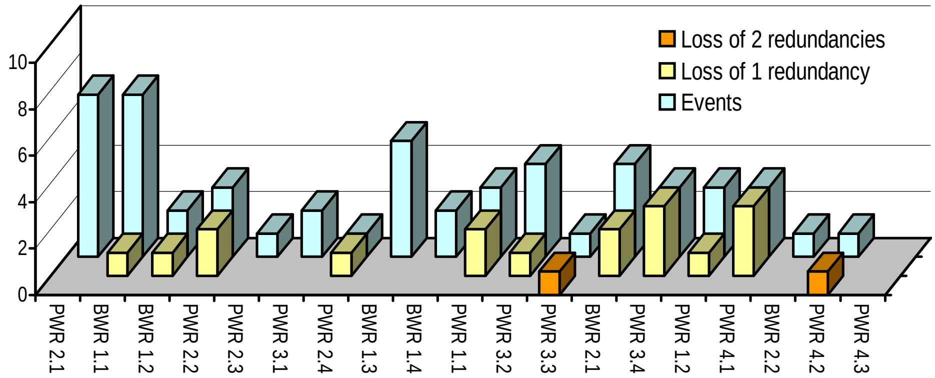
Considering the emergency core cooling and residual heat removal system separately (Fig. 10b), there is a distribution of redundancy losses over 12 of the 19 plants. Two of the above-mentioned losses of two redundancies concerned the emergency core cooling and residual heat removal system.

Fig. 10: Direct event and failure frequencies at the residual heat removal system chain

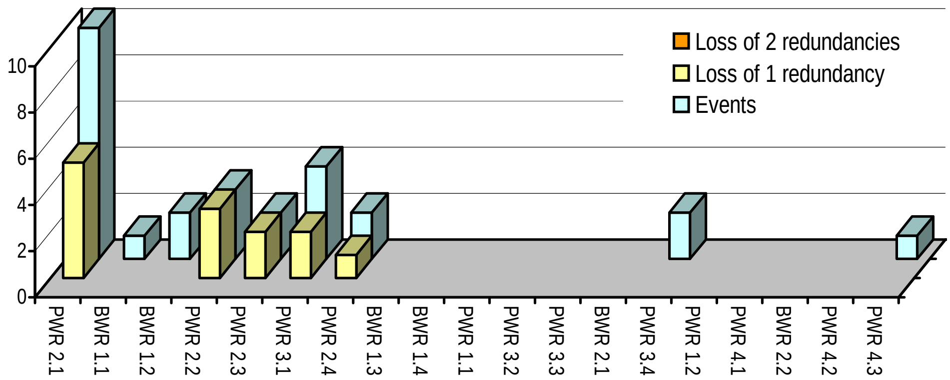
a) Residual heat removal system chain



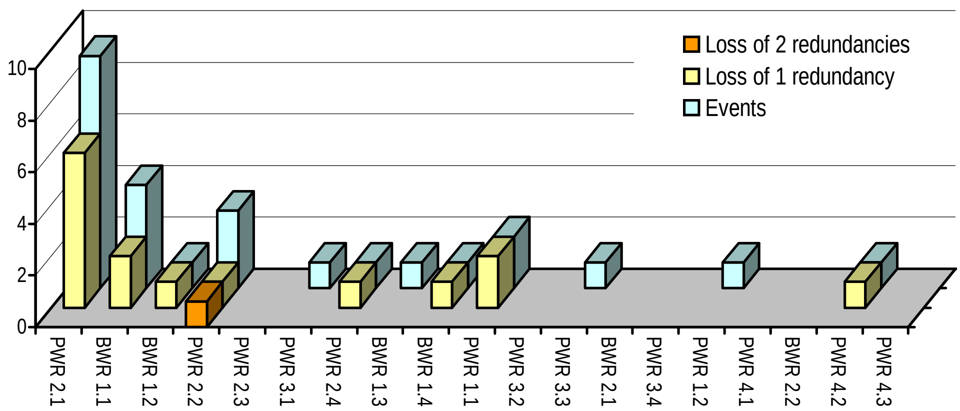
b) Emergency core cooling and residual heat removal system



c) Intermediate and secured (closed) cooling system



d) Secured auxiliary service water system



Considering the intermediate and secured (closed) cooling system, there redundancy losses are only distributed over five of the 19 plants. 11 of a total of 13 system failures concerned the PWRs of the second generation. "Corrosion" was mainly encoded as cause, and "surface heat exchanger" as affected component. None of the BWRs showed a redundancy loss with regard to this system.

Considering the secured auxiliary service water system separately, the redundancy losses are distributed over eight of the 19 plants.

SUMMARY

This paper gives an overview on the GRS activities in the field of statistical analysis of events obligatory reported from NPPs in Germany in accordance with the Nuclear Reporting Ordinance including a few selected results. The statistical evaluation covers the frequencies for certain safety related characteristics and their respective time related sequences.

A coding system has been developed for the events reported, consisting of 19 groups of hierarchically organized characteristics (up to five levels of characteristics with stepwise more depth of information). This system enables a standardized registration of the events according to their safety characteristics. Furthermore, this system is supplemented by comprehensive lists of technical details of the affected technical equipment.

The coded plant, operation, action and event features are collected within a database developed on the basis of the information management system ORACLE providing direct access to information from other GRS databases additionally used for the coding of the reportable events.

For the reporting period from 1996 to 1999, 475 event data sets from in total 19 operating pressurized and boiling water reactor units were included in the database. The coding of events from previous years as well as from the year 2000 has been started. Each data set consists in average of 70 characteristics being selected from the key directories with in total approx. 3,300 characteristics.

The data input was accompanied by various quality assurance measures in order to exclude potential subjective influences in the engineering assignment of characteristic features as far as possible, including an automatic consistency check of the individual data.

The data sets within the database can be sorted, combined and filtered to use them, by suitable specifications, for the determination of frequencies of individual or group features or combinations. The completed data evaluation user surface gives the possibility of a direct survey of the available data inventories, the respective event frequencies and trends, as well as a data selection by indicating any desired periods under consideration, plants or plant groups. Meanwhile it is possible to choose any selection of characteristics, in up to six desired "AND", "AND NOT" or "OR" combinations each.

In addition to an adequate number of quality assured data sets, it is extremely important to the reliability of the results of statistical evaluations that the reporting criteria are easily manageable by the licensees. GRS investigations have shown that in case of events with low safety significance which might not be obligatory reportable in any case (so-called events close to the minimum reporting level) the criteria are used inconsistently. The potential reasons are, among other things, not very precise, missing or inconsistent definitions of terms.

The resulting uncertainties in the assessment mainly concern two types of events which do not lead to a functional equipment unavailability, i.e. the potential CCF (Common Cause Failures) and the crack indications. These uncertainties have been estimated to be in total approx. 20% based on the available data The analyses performed so far, mainly focus on events with component failure. For this type of events, uncertainties due to the reporting criteria are not given.

Due to the specifications given by the reporting criteria, a separate statistical evaluation according to the levels of the defense-in-depth concept is not needed. As a first approach, the results are representative for level 3 events.

For the period 1996 to 1999 the statistical evaluations have been performed, for practical reasons, such that plant specific occurrence frequencies and their changes over the time have been determined for selected characteristics and their combinations. By means of the frequency distributions over the plants it has been studied to what extent plant type or plant generation specific characteristic features or trends have occurred. By this approach it was possible to ensure that generic statements or conclusions are only given if this is tolerable from the viewpoint of the frequencies of the plant specific characteristics.

During the time period analyzed, the number of event reports from the different plants varies between 0 and 18 per year; the number of independent events between 0 and 21 per year, respectively. Besides a few exceptions, the distribution of the component failures over the plants is similar to the distribution of the event frequencies. The plant-specific component failures observed during the whole time period varied from 7 to 44; thus, they differ by a factor of six. 79% of all events are related to component failures, which mainly resulted in system failures.

If the frequency of component failures at a specific plant is large, that does not necessarily mean that many component failures occurred having a relatively high safety significance. According to the statistical evaluation, the number of plant specific component failures with a particular safety significance (e.g. more than one consequential failure, diesel failure, actual CCF, reactor scram with actuation of a safety device, functional failure of several redundancies, etc.) is not proportional to the complete number of plant-specific component failures.

Considering the CCF frequencies as one characteristic feature, the generic characteristic observation is that their distribution over the plants is nearly independent of the plant specific number of the reported events and/or component failures. According to an estimation of GRS, about 14% of the events with component failures are CCF.

The functional failures can be subdivided according to their overriding causes. Primarily, these are pre-operational causes, operational causes (due to the operation of systems and devices) and causes by human actions (execution-related causes). In average, 21% are functional failures with pre-operational causes, which can hardly be detected or influenced by the operating personnel. Approximately 53% are functional failures with operational causes, which can be more or less avoided by the operating personnel. About 24% are human action-related functional failures, i.e. caused by the operating personnel.

With regard to the major causes of functional failures, generic or type specific distinctive features or trends could not be found.

The comparison of the pre-operational and operational causes show very low frequencies for the PWRs of the most recent (fourth) plant generation as well as for PWRs of the third generation. In comparison, the most unfavorable results were obtained for the PWRs of the second generation, in particular with a very high frequency for one specific plant.

From viewpoint of the two plants of the first PWR generation, it has been observed that the frequency for one of these is in the same range as for the fourth PWR-generation.

Regarding the BWR type plants, for two plants of the first generation relatively unfavorable results were obtained. The respective frequency values approximately correspond to those of the PWRs of the second plant generation.
It was been exemplary demonstrated by the problems related to the "gate valves" how component- and system-specific deficiencies can be identified systematically. For this purpose, the failure frequencies of various valves and flaps were compared to the failure frequencies of the associated component sub-units. With one exception, the failures of all types of valves and flaps result from the respective name-giving component sub-unit. For the gate valves, however, it has been determined that the events at the component sub-unit "drive (motor)" dominate clearly with an amount of 82% and that they resulted in the actuation of the drive overload protection.

The example of a particular event which occurred in June 1998 at a PWR of the second generation, demonstrated clearly how deficiencies and the effectiveness of corrective actions can be analyzed systematically. The evaluation has shown that by the end of 1999, the administrative measures taken on the basis of the event above have not yet proven to be effective.

The analysis of the event data from 1996 to 1999 performed up to now do not indicate any generic deficiencies in the NPP safety concepts. With respect to the event frequencies of specific safety characteristics indicating a generic component- or system-specific deficiency, this affects those systems or components which have already been subjected to an in-depth engineering assessment (see gate valve problems). During the period from 1996 to 1999, the number of events reported from all plants per year was in the range of 104 to 119 showing no trend with respect to the event frequency.

In summary, it can be stated that the coding system and the concept of the database have proven to be worthwhile. By means of the analyses performed up to now, it is possible to demonstrate the variety of the database applications, although the results are not yet as reliable as intended because of the still very limited number of data sets.

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