OECD FIRE Database Applications and Challenges – A Recent Perspective

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Abstract: As one of the OECD NEA databases the FIRE Database has been upgraded and extended applicable as a source of generic event data for Fire PRA. The updated Database structure facilitates statistical analysis needed for providing generic fire frequencies for nuclear power plants. Valuable queries can be made based on reactor type, plant operational state, selection of countries, from which events are reported depending on reporting criteria and thresholds, etc.

Moreover, for a given generic fire event tree various branch point probabilities can be calculated based on the plant specific operating experience, which may be statistically not meaningful, and generic probabilities derived from the FIRE Database. Meanwhile, twelve member countries are involved in the collection of fire event data from almost 400 reactor units. For the time being, a few thousands of reactor years are covered and more than 420 fire events have been reported in total.

In addition, the FIRE Database has provided first insights on causal as event combinations of fire events and other anticipated events. One of the lessons learned from the Fukushima Dai-ichi reactor accidents was that such event combinations have to be adequately addressed in PRA. The most recent analyses of event combinations with fires support the ongoing PSA improvements in this direction.

Keywords: Fire PRA, OECD FIRE Database, fire event tree, fire occurrence frequency.

1. INTRODUCTION

As one of the OECD Nuclear Energy Agency (NEA) databases related to probabilistic risk assessment the FIRE Database has been widely upgraded and extended in its third project phase (2010-2013) applicable as a source of generic fire event data for Fire PRA. Major goals of the improvements with respect to the statistical use and application for performing probabilistic fire risk analysis were to enable the applicant to receive reactor type specific generic fire occurrence frequencies and to develop generic fire event trees from the operating experience collected from nuclear power reactors in member countries.

At the time being, the already fourth phase of this database project has started. The collection of fire events data covers up to the end of 2013 in total 5746 reactor years of nuclear power plant (NPP) operation from almost 400 reactor units in twelve member countries (Canada, Czech Republic, Finland, France, Germany, Japan, Korea, the Netherlands, Spain, Sweden Switzerland, and United States of America) with more than 420 fire events having been reported [1].

2. ACTUAL CHANGES IN THE DATABASE

The updated Database structure shall facilitate statistical analysis needed for providing generic fire frequencies for nuclear power plants (NPP). A variety of queries can be made based on reactor type,

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plant operational state (power operation, low power and shutdown, decommissioning), selection of countries, from which events are reported depending on reporting criteria and thresholds, etc. to make the query as meaningful as possible for the task to be performed.

In particular, the function '*Search Fire Events*' has been substantially improved and the functions '*Evaluate*' and '*Operation times*' have been recently added to the FIRE Database [1] (see also Figure 1) in response to requests by the FIRE Program Review Group (PRG).

Figure 1: Screenshot of OECD FIRE Database Entry Page [1]

By means of the '*Search fire events*' function, either the whole Database (default) can be used as basis for the query or already existing subsets generated by earlier queries can be applied as basis for new queries. Four different types of fields do exist:

- Fields permitting to select one attribute from a pull down menu;
- Fields permitting to select multiple attributes connected by logical '*OR*' within the field; these are '*Operation mode*', '*Country*', and '*Reactor type*';
- Fields permitting to select multiple attributes connected by logical '*AND*' or '*OR*' or '*EXCLUDE*' within the field;
- Fields permitting text string searches in comments fields.

All fields are connected by logical 'AND'. The result of any search can be stored as a subset and used as basis for further queries.

With respect to the '*Evaluate*' function, three different analysis modes can be examined:

1. Single selection fields and mutually exclusive multiple selections fields (reactor type, country, operation mode),
2. Pairs of single selection fields (cross tables),
3. Fields in which multiple attributes can be selected.

The same input form is used for all three options. For each of the three options the evaluation can either be based on the whole data set or on subsets. This is illustrated by two examples. The first example shows the input format for single selection fields or mutually exclusive multiple selections fields. The search for "all ignition mechanisms" provides the following result (cf. Figure 2):

Figure 2: Result of query in example 1 “evaluation of all ignition mechanisms”, from [1]

Electrical	198
Hot component	77
Hot work	60
Mechanical	36
Other	13
Self ignition	22
Unknown	17

The second example (cf. Figure 3) shows the input format for pairs of single selection fields (cross tables) providing the result presented in Figure 4.

Figure 3: Screenshot for query in example 2

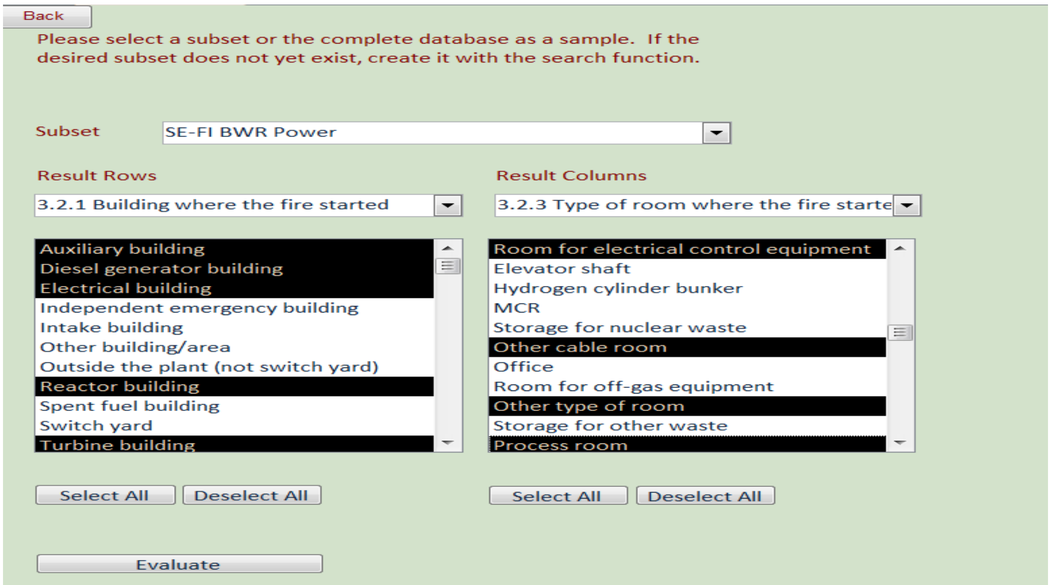
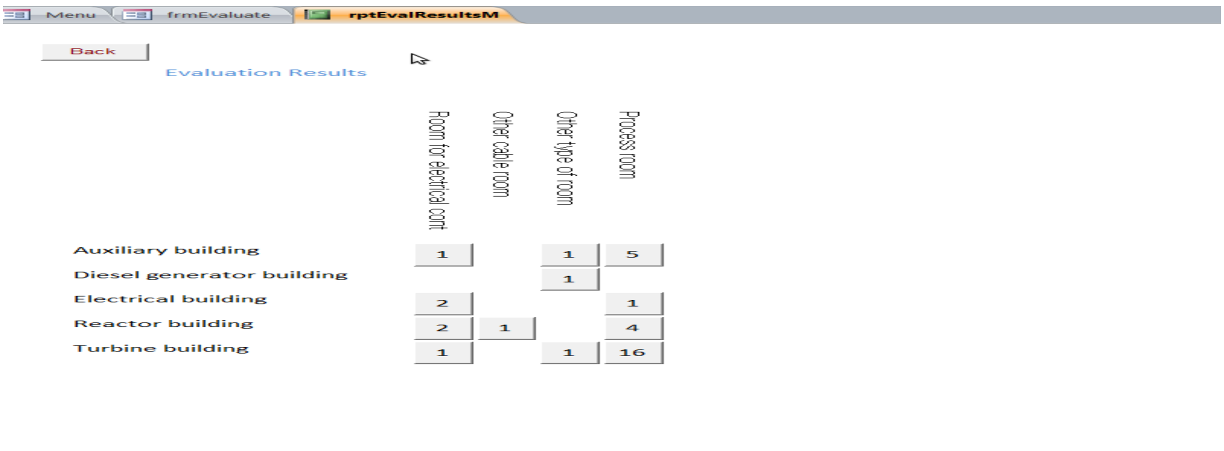


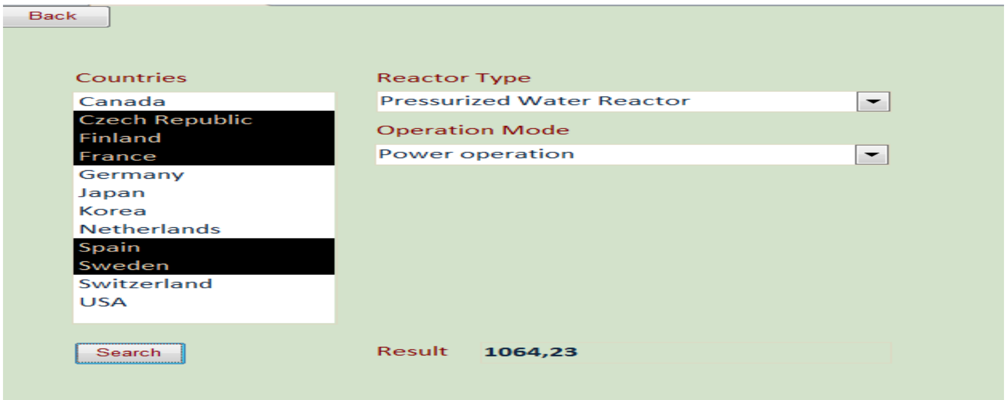
Figure 4: Result of the query in example 2, from [1]



	Room for electrical cont	Other cable room	Other type of room	Process room
Auxiliary building	1		1	5
Diesel generator building			1	
Electrical building	2			1
Reactor building	2	1		4
Turbine building	1		1	16

The *’Observation times*’ function provides (see screenshot in Figure 5) anonymized plant operational times for the different OECD member countries, reactor types and the different plant modes, as power operation, low power and shutdown, and decommissioning phase.

Figure 5: Screenshot of search by ’*Observation times*’ function, from [1]



3. RECENT APPLICATIONS OF THE OECD FIRE DATABASE

3.1. Compartment Specific Fire Frequency Estimation

In the following, results obtained by queries that strongly utilized the new ‘*Evaluation’* function of the OECD FIRE Database are presented. The term “*countries reporting all events*” used in this context refers to Czech Republic, Finland, France, and Sweden for pressurized water reactors (PWR) and Finland and Sweden for boiling water reactors (BWR). Figure 6 shows exemplary search results on compartment specific occurrences of fire events for selected buildings during power operation (FP, referring to more than 5 % of full power level) and, in comparison, also for low power and shutdown (LPSD) states. Table 1 provides, as an example, for PWR from those countries reporting all events the average numbers of selected compartments for a selection of buildings relevant for PSA. The correspondingly determined fire occurrence frequencies are given in Table 2 for FP as well as for LPSD. Figure 7 provides the same type of information on fire occurrences per selected compartments and buildings from BWR in countries reporting all events. The corresponding average compartment numbers for BWR are given in Table 3, the respective fire frequencies are provided in Table 4.

Figure 6: Building and compartment specific number of fire events from PWR units in FIRE member countries reporting all events (left: FP, right: LPSD)

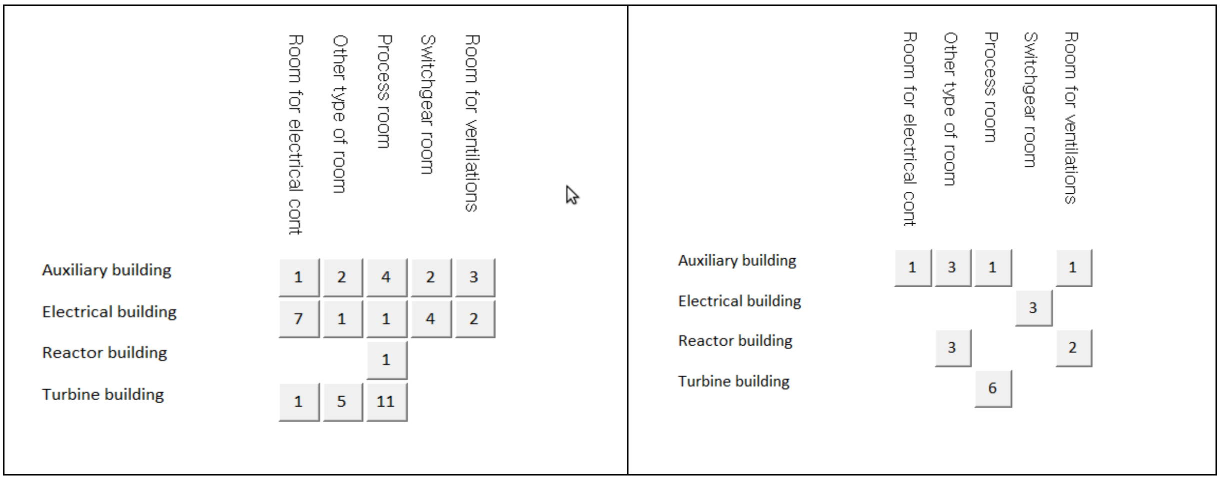


Table 1: Average numbers of compartments for selected buildings in PWR units from FIRE member countries reporting all events

Building \ Compartment Type	Process rooms	Rooms for electrical control equipment (including MCR)	Rooms for ventilation	Other types of rooms	Switchgear rooms
Turbine Building	45	8	7	51	4
Auxiliary Building	34	4	40	45	9
Reactor Building	32	16	6	11	12
Electrical Building	18	22	9	14	5

Table 2: Compartment specific fire frequencies for selected buildings in PWR units from FIRE member countries reporting all events (FP and LPSD)

Building \ Compartment Type	POS	Process rooms	Rooms for electrical control equipment (including MCR)	Rooms for ventilation	Other types of rooms	Switchgear rooms
Turbine Building	FP	2,6 E-04/a	1.3 E-04 /a	*	1.0 E-04 /a	*
	LP/SD	1.3 E-03 /a	*	*	no event	*
Auxiliary Building	FP	1.2 E-04 /a	2.7 E-04 /a	8.1 E-05 /a	4.9 E-05 /a	2.4 E-04 /a
	LP/SD	2.9 E-04 /a	2.5 E-03 /a	2.5 E-04 /a	6.7 E-04 /a	*
Reactor Building	FP	3.4 E-05 /a	*	*	*	*
	LP/SD	*	*	3.4 E-03 /a	2.7 E-03 /a	*
Electrical Building	FP	6.0 E-05/a	3.4 E-04 /a	2.4 E-04 /a	7.7 E-05/a	8.6 E-04 /a
	LP/SD	*	*	*	*	6.0 E-03 /a

Remarks:
POS: plant operational state
FP: power operational states - 923 reactor years in total
LP/SD: low power and shutdown states - 99 reactor years in total
*: no fire event observed, therefore no frequency estimate

Figure 7: Building and compartment specific number of fire events from BWR units in FIRE member countries reporting all events (left: FP, right: LPSD)

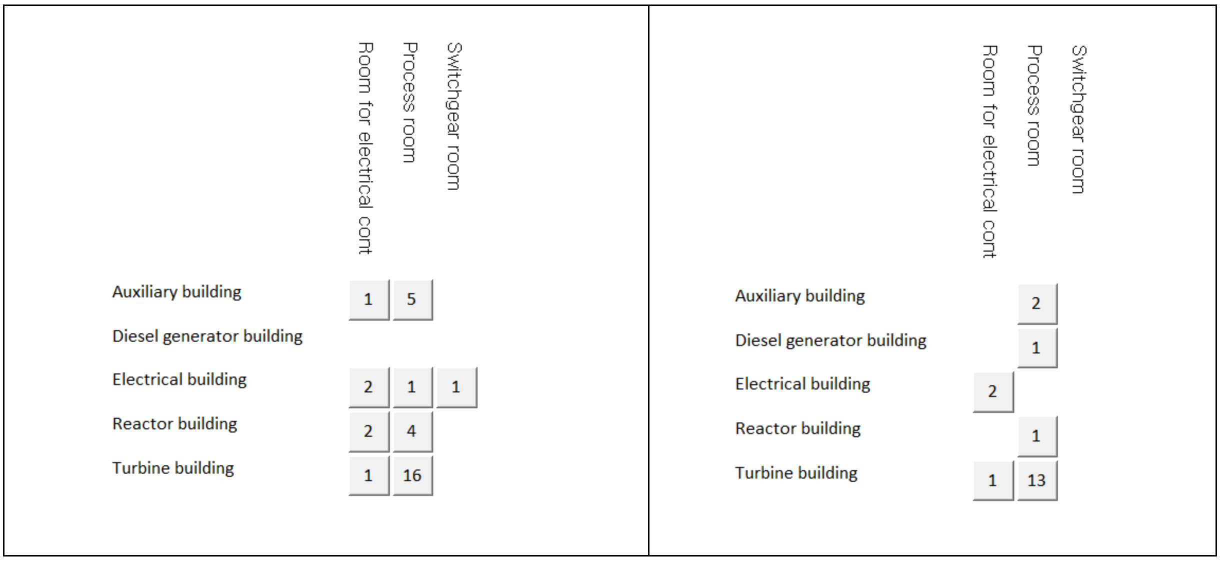


Table 3: Average numbers of compartments for selected buildings in BWR units from FIRE member countries reporting all events

Building \ Compartment Type	Process rooms	Rooms for electrical control equipment (including MCR)	Switchgear rooms
Turbine Building	70	8	16
Diesel Generator Building	11	12	4
Auxiliary Building	30	16	4
Reactor Building	81	18	21
Electrical Building	10	18	11

Table 4: Compartment specific fire frequencies for selected buildings in BWR units from FIRE member countries reporting all events (FP and LPSD)

Building \ Compartment Type	POS	Process rooms	Rooms for electrical control equipment (including MCR)	Switchgear rooms
Turbine Building	FP	8.6 E-04 /a	2.3 E-04 /a	*
	LP/SD	3.2 E-03 /a	1.0 E-03 /a	*
Diesel Generator Building	FP	*	*	*
	LP/SD	1.5 E-03 /a	*	*
Auxiliary Building	FP	6.3 E-04 /a	9.4 E-04 /a	*
	LP/SD	2.5 E-04 /a	*	*
Reactor Building	FP	9.2 E-05 /a	3.6 E-04 /a	*
	LP/SD	2.1 E-03 /a	*	*
Electrical Building	FP	3.8 E-04 /a	6.8 E-04 /a	2.1 E-04 /a
	LP/SD	*	3.1 E-03 /a	*

Remarks:
POS: plant operational state
FP: power operational states - 266 reactor years in total
LP/SD: low power and shutdown states - 58 reactor years in total
*: no fire event observed, therefore no frequency estimate

3.2. Generic Fire Event Trees

A key element of performing Fire PSA is the determination of fire induced failure probabilities of components and cables for those fire sources identified as relevant, typically by means of fire event trees. The Fire PSA analyst derives specific fire event trees for all possible fire sequences taking into account plant characteristics (e.g. on-site plant internal or only external fire brigade), the compartment specific situation and boundary conditions (e.g. compartment volume and ventilation conditions), potential fire sources (e.g. location, fuel) and safety targets (e.g. components, cables). Generic event trees are a valuable tool for the analysis, however have to be adapted within a plant specific Fire PSA, e.g. branch points to reflect the plant characteristics, and branch point probabilities needed to be determined by applying plant specific data.

Generic event trees can also be applied for another purpose. A set of standardized generic event trees can be used to describe the main fire specific characteristics of fire events observed from the operating experience (see also [2]). In the frame of an ongoing research and development project the following set of generic fire event trees has been developed:

– a time dependent event tree which sub-divides a fire event into different phases,
– an event tree specifically addressing fire detection, and
– an event tree specifically addressing fire suppression.

The set of generic fire event trees characterizes all the possibilities of the phases of fire initiation, fire development and propagation as a stochastic process. Each fire event having occurred represents a realization of this process and can be described by a corresponding sequence number.

The above mentioned set of generic fire event trees can be used to analyze fire events reported to the OECD FIRE Database. For the entity of fire events observed from the operating experience collected from nuclear power plants in FIRE member countries the corresponding sequence numbers of the generic fire event trees can be determined. The triplet of sequence numbers represents an additional attribute of each reported fire event, which can be stored in the OECD FIRE Database as additional information in the future.

3.3. Combinations of Fires and Other Anticipated Events

Operating experience from nuclear installations has shown that combinations of fires and other anticipated events do occur during the entire lifetime of these installations. The required function of structures, systems and components important to safety may be impaired in case of the occurrence of such event combinations resulting in degradation or even loss of their intended functions.

Combinations of hazards, with either a causal relationship or an independently occurrence, have been discussed in detail as a lesson learned from the Fukushima Dai-ichi reactor accidents, in particular regarding the necessity to be covered within the PSA framework. This was the reason for the decision to systematically investigate combinations of fires and other anticipated events including hazards. For that purpose, three types of combinations have to be distinguished:

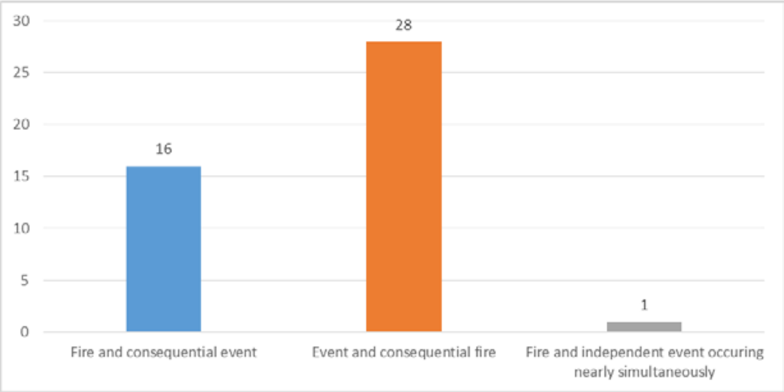
- Fire and consequential event,
- Event and consequential fire, and
- Fire and independent event occurring nearly simultaneously.

For each of these event combinations, it has to be systematically checked, which types of internal or external hazards can be correlated to fire events. This approach is in line with international recommendations, e.g. [3]. The general answer to this question is that only internal hazards may occur as a consequence of a plant internal fire, while fires may be induced by several internal or external hazards. This consideration revealed a list of possible combinations, only some of them have been observed in the operating experience reported to the OECD FIRE Database.

Basis for such a first investigation was the OECD FIRE Database in its version 2012:1 [4] containing in total 415 fire events up to the end of 2012. 45 out of these 415 fire events have been identified as event combinations of fires and other events in the OECD FIRE Database representing a contribution of approx. 10.8 %, which is rather small but not negligible. The distribution of the 45 events with respect to the type of combinations is provided in Figure 8.

The investigation has provided the result that the number of event combinations of the same type is typically very low, most of the combined event sequences have occurred so far only one, two or four time. There are only two types of causally related event combinations, for which the FIRE Database contains significantly more events: Fires consequential to an explosion constituted the vast majority of event combinations already in the 2012 version of the FIRE Database [4] with 24 events. Ten fire events resulted in an internal flooding, mostly due to the necessary fire extinguishing activities. Three event combinations show a domino effect (earthquake resulting in a high energy arcing fault (HEAF) and a consequential fire as well as fire resulting in an explosion and a consequential fire). Combinations of fires and independently occurring hazards were expected to be practically excluded. Nevertheless, such an event combination of a fire and an independently occurring event (flooding) was found in the Database underlining that such combinations do occur in reality.

Figure 8: Types of event combinations as observed from OECD FIRE Database



Moreover, the investigation has shown that in case of several event combinations observed the plant operational state changed from full power to low power and/or shutdown, in some cases safety trains were lost during the event sequence.

Regarding the use of the OECD FIRE Database for analyzing event combinations in PSA there are still limitations resulting from inconsistencies due to different reporting criteria in the participating member countries. However, the available data provide valuable insights and allow at least probabilistic considerations.

A Topical Report on results from the FIRE Database on event combinations of fires with other anticipated events or hazards is intended to be issued. Basis for this Topical Report will be the most recently updated version of the OECD FIRE Database [1]. Lists of the event combinations identified with details regarding plant operational state, equipment/component where the fire started, fuel, plant area, root causes, fire duration and extinguishing means used will be presented in tables. Moreover, consequences of the events with respect to plant operational state and, if possible, good practices to efficiently prevent such types of event combinations in the future will be addressed. Some exemplary event combinations will be depicted in more detail. Moreover, already existing national regulations how to deal with event combinations will additionally be provided.

4. CHALLENGES

4.1. Component Specific Fire Occurrence Frequencies

In the recent past, first attempts have been made to collect component numbers for components at which fires have occurred. The list of components is given in the FIRE Database Coding Guideline (cf. [1]). First estimates of component fire frequencies are presented in Table 5. Many of these components are significant contributors to Fire PSA results. Cables, which are also important contributors, are not yet included because of the differing ways of their recording in the various NPPs (by segments or by length, using a cable management system or not, etc.) and the resulting - still unresolved - data collection issues.

The list of components in the Database does still contain approx. 30 items for which the average component numbers have to be collected and assessed. This activity is ongoing.

Table 5: Example for average numbers of components, numbers of fire events and corresponding fire frequencies for selected components from PWR and BWR in FIRE member countries having provided component numbers (FP and LPSD)

<table>
<tr><th rowspan="2">Component type</th><th rowspan="2">Average number of components per NPP unit</th><th colspan="2">Number of fires</th><th colspan="2">Estimated fire frequency [1/a] per component</th></tr>
<tr><th>FP</th><th>LPSD</th><th>FP</th><th>LPSD</th></tr>
<tr><td>High voltage transformer</td><td>6.90</td><td>3</td><td>0</td><td>3.3 E-04</td><td>*</td></tr>
<tr><td>Turbine generator</td><td>1.06</td><td>8</td><td>0</td><td>5.8 E-03</td><td>*</td></tr>
<tr><td>Diesel generator</td><td>3.73</td><td>2</td><td>3</td><td>4.2 E-04</td><td>3.1 E-03</td></tr>
<tr><td>Medium or low voltage transformer</td><td>41.20</td><td>3</td><td>2</td><td>5.6 E-05</td><td>1.9 E-04</td></tr>
<tr><td>High or medium voltage electrical cabinet (> 1 kV)</td><td rowspan="2">1436</td><td rowspan="2">14</td><td rowspan="2">2</td><td rowspan="2">7.0 E-06</td><td rowspan="2">5.0 E-06</td></tr>
<tr><td>Low voltage electrical cabinet (< 1 kV)</td></tr>
<tr><td>Electrically driven pump</td><td>266</td><td>3</td><td>3</td><td>8.7 E-06</td><td>4.3 E-05</td></tr>
<tr><td>Rectifiers and inverters</td><td>46.26</td><td>2</td><td>0</td><td>3.3 E-05</td><td>*</td></tr>
<tr><td>Heater</td><td>473</td><td>4</td><td>6</td><td>6.5 E-06</td><td>4.9 E-05</td></tr>
<tr><td>Fan</td><td>196</td><td>7</td><td>3</td><td>2.7 E-05</td><td>5.9 E-05</td></tr>
<tr><td>Battery</td><td>28</td><td>0</td><td>0</td><td>*</td><td>*</td></tr>
<tr><td colspan="6">Remark:
* no fire event observed, therefore no frequency estimate</td></tr>
</table>

4.2. Database Consolidation Challenges

In July 2013, the Electric Power Research Institute (EPRI), in coordination with the U.S. NRC's Office of Nuclear Regulatory Research (RES) under a Memorandum of Understanding issued EPRI 1025284 entitled, "The Updated Fire Events Database: Description of Content and Fire Event Classification Guidance. This report provides a description of the updated and enhanced Fire Events Database (FEDB) and will become the principal source of fire incident data for use in U.S. fire probabilistic risk assessments (FPRAs) as described in EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities (EPRI report 1011989 and NUREG/CR-6850 [5]). It provides a comprehensive and consolidated source of fire incident information for nuclear power plants operating in the United States that covers experience from 1990 through 2009. The database classification scheme identifies important attributes of fire incidents to characterize their nature, causal factors, and severity consistent with available data. The database provides sufficient detail to delineate important plant specific attributes of the incidents to the extent that these details were obtainable.

The updated FEDB is intended to capture fire event history up through 2009 and includes a total of roughly 2000 fire events at varying severity levels. These events have been pre-screened and severity classifications have been thoroughly reviewed through several NRC audits. In addition to providing more current data, the updated FEDB has expanded and improved data fields, coding consistency, incident detail, data review fields, and reference data source traceability. The improvement is designed to better support several Fire PRA (FPRA) uses. The project has an additional objective of updating fire ignition frequency trends and bin frequencies. That task is currently under development and should be completed by the summer of 2014. Once that task is completed the OECD will evaluate the merit of merging the two databases.

There are several challenges associated with merging the OECD FIRE Database and the FEDB. The first of which will be aligning the information into a usable format. The OECD FIRE Database shares similar input fields as the FEDB, but significant work will need to be performed in order to ensure consistency between the two. For example, the FIRE Database generally aligns with the ignition bins found in Chapter 6 of NUREG/CR-6850 [5] but it is not a one to one match. Each event in the FEDB database will have to be reviewed in order to assure consistency with the OECD binning methodology and considering the number of events this will not be a trivial task.

Furthermore, a large portion of the supplementary information contained within the FEDB database remains proprietary plant information. A brief description of the event will be able to be presented but the supporting documentation will be lost. While the brief description will be satisfactory for the generation of frequencies and suppression data, the supporting documentation is invaluable while attempting to gain insight into the fire event for fields which require interpretation and an understanding of the fire event timeline is a necessity.

In addition to the logistical challenges with merging the OECD FIRE Database and the FEDB, there should be an investigation into the applicability of merging the databases. That is, do the same trends exist in the FEDB as in the current version of the OECD FIRE Database? The FEDB database contains a much larger pool of events, approx. 2000 in FEDB compared to approx.425 in the FIRE Database. By merging the two databases without performing a sensitivity study, country specific variations may be overwhelmed by the large number of FEDB contributions.

The addition, the FEDB events would significantly increase the total number of events which currently make up the OECD FIRE Database and add further evidence to support realistic frequency calculations. The OECD Fire Incident Records Exchange Project (OECD FIRE) will evaluate the additional data and make recommendations for use in the fourth phase of the Project, which will end on December 31, 2015.

4.3. Further Challenges to Reduce Uncertainties

In many cases the event descriptions provided in the OECD FIRE database have no words for conditions inside the compartment, where the fire occurred. For example, information on compartment dimensions, components installed, and amount of combustibles inside the compartment is needed to apply the fire event coding of the FIRE Database for statistical purposes and to avoid possibly misleading conclusions.

An effort is ongoing to estimate fire frequencies for selected types of compartments based on the average number of such compartments, plant operational years and number of fire events involved. In this case, the average fire frequency is representative for an average compartment; however the average compartment is not specified by any measures. Knowledge on components installed in the compartment as well as floor area and/or volume of the compartment, where the fire occurred, would be useful to better realize what the average conditions represent for given types of compartments. Additional information might be traced from member countries for an important pilot case, e.g. considering fires in switchgear rooms, I&C cabinet rooms, or cable rooms.

The FIRE Database includes coding of fire impact and consequences. The lack of knowledge on components installed in the fire compartment as well as on the amount of combustibles present causes several uncertainties in conclusions. For example, the impact of a pump fire can be coded as loss of single component despite of fire propagation, if the pump is the only component vulnerable to fire in that fire compartment. Similarly, fire impact and consequences should be applied carefully while assessing “other ignition sources” in process rooms, because the conditions in such compartments strongly differ. Additional information may be gained from member countries considering the number of components present inside the process room where the fire occurred, in particular considering events where fire affected only a single component or no damage resulted. Moreover, clarification of the overall amount of oil inside the system or component would be useful, considering fires in the process rooms where oil has been coded as combustible, to better realize the potential of fire propagation and fire impact in such events.

5. CONCLUSIONS

As one of the ongoing OECD NEA database projects the *F*ire *I*ncidents *R*ecords *E*xchange (FIRE) Database Project is meanwhile in its fourth phase up to the end of 2015. Containing meanwhile more than 420 fire events from almost 400 reactor units in twelve OECD member countries this Database represents a valuable tool for facilitating the use of nuclear power plants fire experience and applicable as a source of generic event data for Fire PRA.

In the recent past, the structure of the FIRE Database has been upgraded and extended to facilitate statistical analysis needed for providing generic fire frequencies for nuclear power plants. A variety of applications has already been started making use of the enhanced statistical possibilities. Although the reporting of events is not yet exhaustive, the Database provides already a suitable platform for starting the analytical phase.

It is meanwhile possible to make queries based on reactor type, plant operational state, a pre-selection selection of countries to be considered depending on their reporting criteria and thresholds, etc. By this means, in particular compartment specific fire frequencies can be estimated for those buildings relevant for analysis within Fire PRA. Gaining estimates of component specific fire initiation frequencies is still challenging, since the component numbers needed for that purpose are difficult to receive and not yet provided completely.

Data collection is continuously ongoing with in average approx. 30 events to be expected per year to be included. This will increase significantly as soon as the already announced larger amounts of several hundreds of fire events records from the United States will be submitted.

Acknowledgements

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