The OECD/NEA Fire Incidents Records Exchange Database – An Overview on Recent PSA Related Applications

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Abstract: Detailed information on fire events from fourteen member countries is collected in the FIRE (*F*ire *I*ncidents *R*ecords *E*xchange) Database as one of three databases on operational events in nuclear power plants (NPPs) operated under the auspices of the OECD Nuclear Energy Agency (NEA). In its seventh phase, the Database is mature enough for applications in probabilistic fire safety assessment (Fire PSA[1]). The actual database version covers more than 600 well documented and quality assured fire events during all plant operational states (POSs) of the entire plant life cycle from construction to decommissioning. Recent data application possibilities from the Database for Fire PSA are e.g., generic room and component type specific fire occurrence frequencies, or fire event tree specific data, particularly on fire detection and suppression success.

The FIRE Database has provided valuable insights on the contribution of fires induced by high energy arcing faults (HEAF) to Fire PSA. Furthermore, the non-negligible contribution of different types of combinations of fires and other internal and external hazards to the overall risk of NPPs was demonstrated. These insights have contributed considering combined hazards in national and international safety standards, e,g, revisions of the PSA related Safety Guides SSG-3 and SSG-4 by the International Atomic Energy Agency (IAEA).

Recent applications of the Database are related (i) to a comparison of available plant specific or generic national fire frequencies with generic data from the Database and the use of generic data as prior information in case of a lack of plant specific data, and (ii) to an analysis of fire barrier failures and their effects on plant damage. Another activity concerns core and/or fuel damage frequencies based on the type of room of fire occurrence or by a specific ignition category.

After a general introduction of recent FIRE Database features for risk analysis, some application examples of the Database are given.

Keywords: Fire occurrence frequency, Fire PSA, fire suppression success, generic data.

1. INTRODUCTION

Since plant internal fires represent a major contributor to risk for all nuclear installations, discussions started already during the 1980`s under the ORCD NEA Committee on the Safety of Nuclear Installations (CSNI) about challenging aspects of Level 1 PSA and the need to improve fire simulation codes. These discussions and follow-up activities led to the decision by eight countries in 2001 to develop a common operational events database containing as much as possible information about fire events in NPPs of the participating countries on a cost-sharing basis. The FIRE Database Project was then established as one of the Nuclear Safety Research Joint Projects conducted under the auspices of the OECD NEA.

This exchange of data and information allows the creation of a broad basis for deterministic and probabilistic fire safety assessments and for a better identification and analysis of trends aiming to develop mitigation measures. The FIRE Database was built on the Nordic Fire Database (NFDB) created by Sweden and Finland and is continuously being extended by information from meanwhile 14 member countries providing data for

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[1] In this paper, consistent with the usage across various countries, the abbreviations PSA (*P*robabilistic *S*afety *A*ssessment) and PRA (*P*robabilistic *R*isk *A*ssessment) are used interchangeably.

different types of reactors: Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, the Republic of Korea, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America (for further information and contact details see the FIRE website).

The main objectives of the FIRE Project are:

- the collection of fire event experience (by international exchange) in an appropriate format in a quality-assured and consistent database (the "OECD/NEA FIRE Database");
- the collection and analysis of fire events over the long-term to better understand such events and their causes, and to encourage their prevention;
- the generation of qualitative insights into the apparent and root causes of fire events in order to derive approaches or mechanisms for their prevention and to mitigate their consequences;
- to establish a mechanism for efficient operational feedback on fire event experience including the development of policies of prevention, such as indicators for risk-informed and performance-based inspections;
- to record characteristics of fire events to facilitate fire risk analysis, including quantification of fire frequencies.

While the FIRE Project is a long-term database project, it is conducted in a phased approach with a continuous update and extension of the work program. The seventh phase of the Project has started in January 2023, and it is intended to extend the Database beyond the operational phase of commercial nuclear power plants (NPPs) to the decommissioning and dismantling phase. Moreover, the data collection shall be extended to fire events from research reactors with a higher risk potential, typically reactors with a thermal power of 1 MW or more.

Discussions are ongoing if and how to include in the future information exchange on other installations of the nuclear fuel cycle, unique reactor designs, such as pilot and first-of-kind reactors, small modular reactors (SMRs) and other advanced nuclear technologies (ANTs) with non-water-cooled reactor modules.

2. OVERVIEW ON THE FIRE DATABASE

As of December 2021, the FIRE Database (see the most recent version 2021:01 [1]) includes more than 600 fire events from NPPs in fourteen member countries from Europe, Asia, and North America. This represents fire related operating experience from more than 10,435 reactor years (ry) of observation, approximately 7,995 years from commercial power operation including operating experience from full power as well as low power and shutdown states of NPP units important for Fire PSA. The FIRE Database is meanwhile mature enough for being used to identify all types of fire events and scenarios to be included in models ensuring that all mechanisms are accounted for, to support Fire PSA by real data from NPP operating experience, particularly to provide generic fire occurrence frequencies, and to compare national fire event data from Project member countries with the accumulated international data.

For organization and structure of the OECD/NEA FIRE Database Project, it was agreed in general that the event and plant specific data provided by the individual countries remain the property of their original owner: However, Project members have the right to access the data and to perform analytical activities with it. For increasing the value of the Database for member countries, an anonymized version of the Database is also prepared and made available to potential users in the FIRE member countries such as analysts from the nuclear installations having provided data and/or their consultants, from regulators involved in safety assessment and technical safety organizations (TSOs), subject to the required confidentiality agreements.

For each fire event being recorded in the Database detailed information is coded as far as available ranging from general information on the nuclear installation, over some general event data including a narrative description of the event sequence, data on the fire origin, up to the fire ignition phase and the causes of the event. Information on consequences and corrective actions taken after the event occurrence is also recorded (details see [1]).

3. FIRE DATABASE APPLICATIONS

Several applications of the FIRE Database have already supported fire safety analyses and provided input needed for further investigations. Major topics in this context were and are:

- High Energy Arcing Fault (HEAF) fire events (details see [2]) that resulted in a specific OECD/NEA CSNI experimental HEAF Project with two phases to overcome potential plant weaknesses,
- fire event sequences with combinations of plant internal fires and further (external and internal) hazards (see [3]),
- similarities and differences in member countries regarding the standards applied to fire barriers and their required functionalities (report in preparation [4]),
- the influence of the availability of on-site fire brigades on the event sequences, and
- trends observed from the different types of fires.

In the following, some insights from such past or more recent applications and in-depth investigations are provided.

3.1. Fires Induced by High Energy Arcing Faults

Already in the early 2010s it turned out that a non-negligible number of HEAF events had been recorded in the FIRE Database. Detailed investigations of HEAF fire events recorded in the Database provided already preliminary insights on the potential significance of this type of fire events (cf. [2]). As a result, in-depth investigations were carried out on a national basis, e.g., in Germany, Japan and the United States, but also on an international basis within an experimental program of the OECD/NEA [5]. In the United States, the observations from HEAF induced fires resulted in an Information Notice by the regulatory body[6][6][6][6] [6] and national U.S. research activities for updating the treatment of the risk from HEAF including ensuing fires [7]. The number of HEAF events in the FIRE Database has further increased in the recent past; meanwhile 67 fire events (13 % of all events in the Database during commercial operation) have been identified to be HEAF fires, 39 of these are event combinations of HEAF and fire hazards. An overview on the significance of HEAF induced ensuing fires in nuclear installations, the results of the corresponding analytical and experimental investigations and conclusions drawn for improving nuclear safety can be found in [6] and [8].

3.2. Combinations of Fires and Further Hazards

Another activity of the FIRE Database Project was an in-depth investigation of combinations of external and internal hazards with internal fire hazards (named combined fire events hereafter) observed in the operating experience [3]. As one of the results from the fire events compiled in the Database, the number of such combined fire events of the different types –fires occurring consequential to other external or internal hazards, internal hazards occurring consequential to plant internal hazards, fire and other hazards correlated by a common cause initiator and internal fires and other hazards occurring coincidentally is non-negligible representing approximately 12 % of all fire events recorded in the FIRE Database [1]. An actual update of an earlier published viewgraph [9] of all event combinations of fires and other hazards from the most recent Database version 2021:01 is provided in Figure 1 below.

This figure confirms the observation – well-known at least after the Fukushima nuclear accidents – that some external hazards have the potential to induce subsequent plant internal fires, at least for natural external hazards, such as seismic, hydrological, and various meteorological hazards. Furthermore, a variety of combinations of fires and other internal hazards has been observed. These combined fire events should be addressed in the regulations for the design and operation of NPPs and therefore, have been systematically addressed on an international basis by the IAEA in the Specific Safety Guides for the design and operation of internal and external hazards [10], [11], and Level 1 PSA [12]. Moreover, the figure supplements the observation that nearly half of all event combinations recorded in the Database are combinations of fire and HEAF supporting the need for further consideration of HEAF fires in deterministic and probabilistic safety analyses identified by several regulators and TSOs of member and non-member countries of the FIRE Database Project.

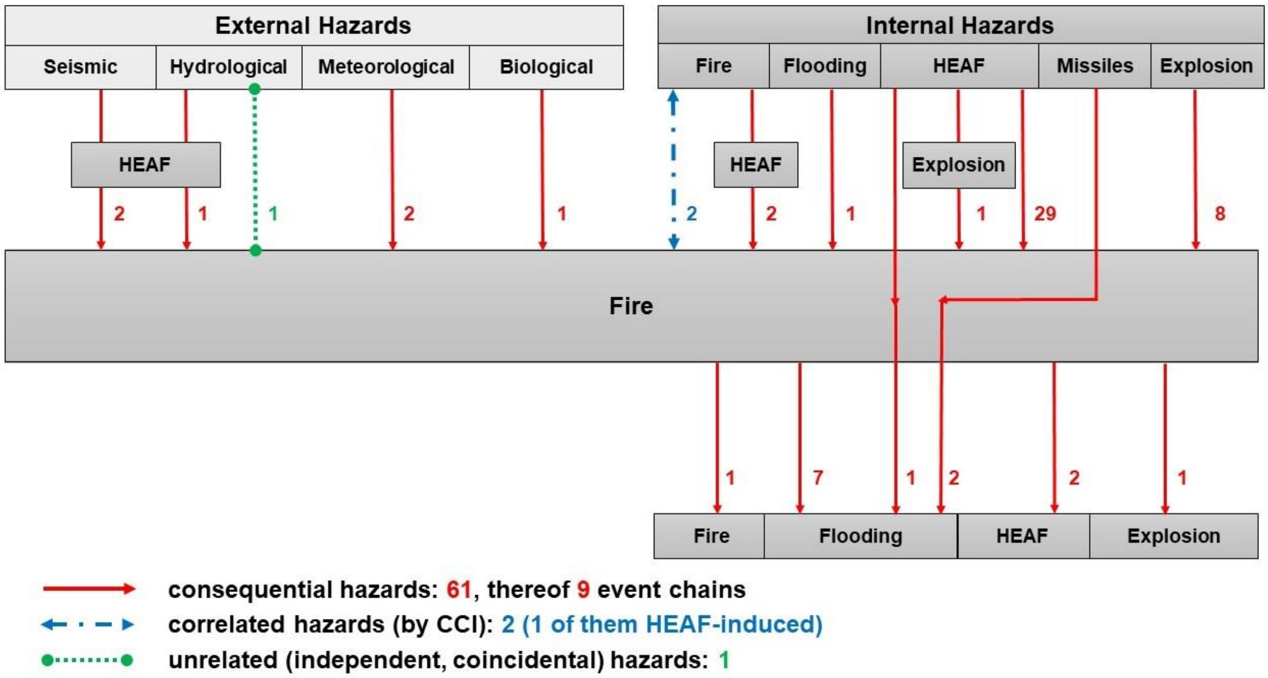

Figure 1. Combined fire hazards (from [1])

3.3. Application of Generic Data from the FIRE Database

A typical application of data from international data collections within PSA is the use of generic data from the operating experience if the available plant specific data are insufficient. This is internationally recommended by IAEA SSG-3, Rev. 1 [12]. Plant internal fires represent a significant contributor to plant damage frequencies (core and/or fuel damage frequency (CDF/FDF)). However, the NPP unit specific fire event data for different types of rooms (fire compartments) per buildings or components of fire ignition are often not sufficient and have high uncertainties due to the low statistics. For low event or failure data and a small data base of plant specific observation times the use of generic data is highly recommended for reducing the uncertainties of the plant specific Fire PSA, which will also increase the level of confidence in the results. Typically, a two-stages Bayesian approach is applied [13], [14], [15].

The FIRE Database can meanwhile serve to support the analyst in applying generic data in a Bayesian approach for calculating more reliable fire frequencies in case of insufficient plant and country specific data. In the following, two examples are presented.

3.3.1. Turbine Generator Fire Occurrence Frequencies for Full Power Operation

For a given single-unit NPP in a country with only limited plant operation periods of less than 50 ry participating in the FIRE Database Project with an observation period of 13.60 ry for the plant operational state (POS) full power and no fire event having occurred at the turbine generator (TG) during the observation period, the mean value of 3.68 E-02 /ry for the plant specific fire occurrence frequency applying a non-informative (Jeffrey) prior approach is high reflecting the insufficient data base. The respective uncertainty (5.2 E-02 /ry) is also high. Using the generic operating experience from the other FIRE member countries for the same component type with a total of 37 fire events at turbine generators for approx. 7981 years of turbine generator operation as prior information, the turbine fire frequency distribution shown in Figure 2 has been calculated.

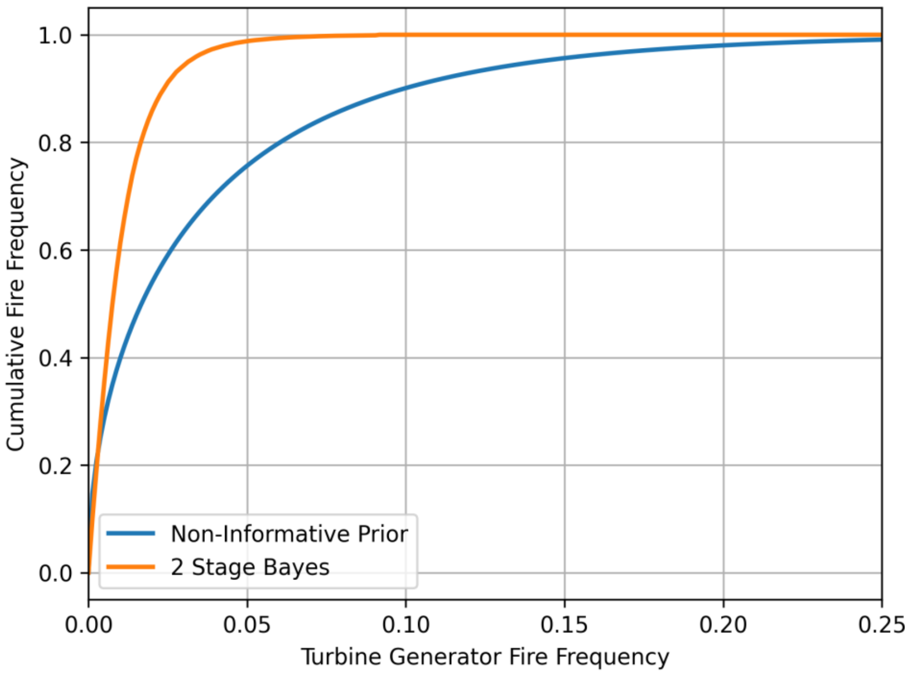

Figure 2. Distribution of turbine generator fire frequencies during full power POS for a selected NPP unit with an insufficient plant specific data base using generic FIRE Database data as prior information

The following frequencies have been calculated:

- The 5 % percentile is 5.70 E-04 /ry,
- the 50 % percentile is 7.61 E-03 /ry,
- the 95 % percentile is 3.17 E-02 /ry, and
- last not least, the mean value is 1.07 E-02 /ry.

The uncertainty range has decreased by including in the calculation the information from comparable operating experience and applying a 2-stage Bayesian approach while increasing the reliability of the overall results.

3.3.2. Diesel Generator Fire Occurrence Frequencies for a Nuclear Power Plant Site with Two Reactor Units

The second example is again a Bayesian calculation of the diesel generator fire frequency for two units of the same VVER type pressurized water reactors (PWRs) of a multi-unit NPP site with no fire events observed at the diesel generators during an observation period of 199.90 diesel operating years (doy). Two calculations have been performed to use the generically available operating experience from the FIRE Database:

- In a first calculation, only the operating experience from VVER type NPP units collected in the Database has been applied as generic prior information with a total of one event occurred within 929.91 doy.
- In a second calculation, the generic diesel operating experience from all countries with nearly all NPP units in the Database[2] has been applied with a total of 17 events in 36,052.97 doy.

Considering the VVER specific experience provides the following results per diesel observation year:

- The 5 % percentile is 6.45 E-06 /doy,
- the 50 % percentile is 1.96 E-03 /doy,
- the 95 % percentile is 8.71 E-03 /doy, and,
- last not least, the mean value is 2.80 E-03 /doy.

[2] Note that the numbers of diesel generators of five very old Canadian NPP units no more in operation for several years could not be made available in due time.

Considering the whole experience from all reactor units in all FIRE member countries provides the following results per diesel observation year including the calculated fire frequency distribution (see Figure 3):

- The 5 % percentile is 4.66 E-06 /doy,
- the 50 %: percentile is 7.51 E-04 /doy,
- the 95 % percentile is 5.84 E-03 /doy, and,
- last not least, the mean value is 1.54 E-03 /doy.

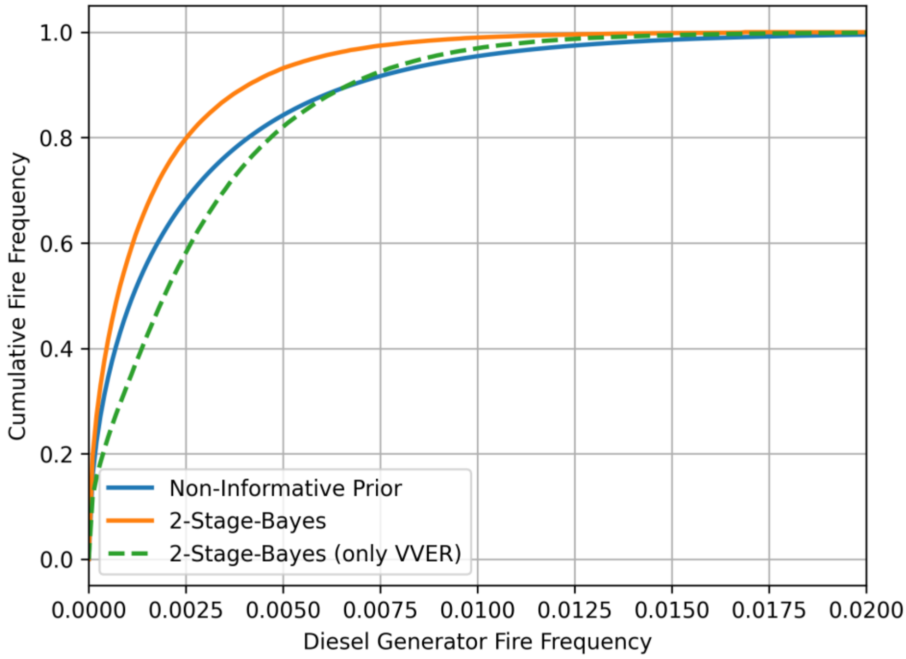

Figure 3. Distribution of diesel generator fire frequencies for a selected NPP applying prior information from reactor units of the same type and from all reactor units in the Database

Again, as in the previous example, the uncertainty range has decreased by the use of generic data applying a 2-stage Bayesian approach and the reliability of the overall results increased.

3.4. Significance of Reliable Passive Fire Protection Features for Fire Risk Assessment

Passive fire protection features, such as qualified fire barriers, aim to ensure the control and mitigation of fires in nuclear installations so that the level of redundancy required for safe plant operation or for safe shutdown of a reactor is maintained in the event of fire. The analysis of the events collected in the most recent FIRE Database version, in which the deterioration or failure of fire barriers took place, clearly demonstrates the significance of these fire events.

Although the percentage of events in this category only represents 4 % of all events included in the Database [1], the consequences of the fire events with a deterioration or failure of the required function of fire barriers, were considerably more severe than those of various other fire events in the Database.

The consequences are shown in the FIRE Database through diverse parameters. For example, in more than 60 % of the events, the POS changed (if the fire did not occur at "shutdown") as a result of the fire event. In addition, in case of more than 70 % of the analyzed fire events with barrier deterioration or failure, modifications of the design of the affected plant(s) were carried out as corrective actions. These corrective actions are documented, supporting licensees and regulators in FIRE member countries by using the operating experience for further enhancing fire safety.

All these parameters show the relevance of passive protection features and the need to ensure their appropriate performance during the commercial operational lifetime of the installation, also assuring that measures against adverse consequences from ageing of fire barriers are adequately implemented.

A Topical Report of the Database Project on the topic of fire barrier failures is in preparation and will be publicly available in early 2025.

3.5. Database Use for Trends Regarding Fire Suppression Success and Issues Concerning the Availability of a Dedicated Professional Fire Brigade on A Nuclear Site

Another activity is ongoing on the effects of the availability of a dedicated professional on-site fire brigade in any event of fire. A FIRE member survey on the (on-site and/or off-site) fire brigades involved in fighting fires at the different NPPs in member countries was conducted which included information on their staffing, skills, other duties to be performed, their training, the access to the fire scene, etc. Based on the responses to the member survey and indications from the reported fire events, potential conflicts of interest between fire suppression by the fire brigade and other tasks to be performed by the fire fighters have been observed in some member countries to adversely affect firefighting activities and timely fire suppression success.

The analysis is supported by a trend analysis of all well-documented fire events regarding fire suppression. The following Table 1 provides some preliminary insights on the timing and the suppression success of fires detected.

Table 1. Fire Suppression success data

Fire Detection and Alarm Period	No. of Events	Fire Suppression Start	No. of Events	Fire Suppression Period	No. of Events
Fire detection early	335	Early (≤ 15 min)	306	t ≤ 15 min	194
				15 min < t ≤ 30 min	40
				30 min < t ≤ 60 min	35
				60 min < t	37
		Late (> 15 min)	29	t ≤ 15 min	0
				15 min < t ≤ 30 min	4
				30 min < t ≤ 60 min	9
				60 min < t	16
Fire detection late	59	Early (≤ 15 min)	49	t ≤ 15 min	18
				15 min < t ≤ 30 min	13
				30 min < t ≤ 60 min	7
				60 min < t	11
		Late (> 15 min)	10	t ≤ 15 min	0
				15 min < t ≤ 30 min	2
				30 min < t ≤ 60 min	2
				60 min < t	6

From the 394 fire events in the Database with sufficient information on the periods for successful fire detection and suppression about 85 % were detected early resulting in a successful fire suppression of nearly 63 % within a short time if firefighting was started within 15 min. In case of a late detection and an early start of fire suppression again 37 % of the fires could be successfully suppressed within 15 min. This is an indication that the presence of a dedicated fire brigade is essential for the success of the fire protection means in place. An in-depth analysis is ongoing. The report with the final results from this ongoing activity should be publicly available by mid-2025.

4. RECENT FIRE DATABASE DEVELOPMENTS

Fire events during decommissioning of NPP units are meanwhile being included in the FIRE Database. Activities during decommissioning utilize an increase in hands-on activities, during the removal of plant operational and safety related, mainly redundant components and equipment. Techniques can include hot work including grinding, welding, and hot cutting techniques which, if poorly controlled, can lead to an increase in the occurrence of fire events. Transient teams are often involved in decommissioning which may also introduce potential organizational weaknesses. Fire detection and extinguishing systems at nuclear installations are often removed during the decommissioning phase and therefore safety measures reduced. Depending on the stage of decommissioning, fire events can still result in significant consequences from a nuclear safety perspective, and it remains important to consider the negative impact to the public perception of nuclear power due to a fire event at any stage of the lifecycle. In this context, an ongoing activity focuses on appropriately adapting the Coding Guidelines to take into account the nuclear safety significance of fires over the whole, long-duration decommissioning phase stepwise decreasing with the total removal of nuclear fuel, components from high radioactivity areas, etc. Decommissioning results in lower risk and a decrease of the fire brigade staffing and presence on-site and an increase of the fire protection focus on the non-nuclear protection goals. The inclusion of fires during the decommissioning phase in the FIRE Database will ensure that the Database will provide operating experience and statistical information in this area that regulators and operators will find useful.

Moreover, the data collection shall be extended to fire events from research and demonstration reactors as well as on other first-of-a-kind nuclear reactor installations with a non-negligible risk potential, typically nuclear reactors with a thermal power of more than 1 MW. Fire protection of research reactors is a focus area of the ongoing ENSREG (*E*uropean *N*uclear *S*afety *R*egulators *E*xperts *G*roup) second Topical Peer Review (TPR II) on “Fire Protection” (TPR II Technical Specification see [16]) with the three thematical areas “Fire Safety Analysis”, “Active Fire Protection” and “Fire Prevention and Passive Fire Protection” with a specific Topic of Interest on the use and application of the fire events operating experience in all the above-mentioned topical areas in the installations of the participating countries. There are already strong indications that feedback from different types of nuclear installations and exchange of information in a systematic manner, e.g. by data collection in the FIRE Database, will be beneficial also improving the fire safety of research reactors.

Moreover, the need for better addressing the operating experience in Fire PSA for unique reactor designs has already been identified and discussed within an international activity of the OECD/NEA CSNI Working Group on Risk Assessment (WGRISK) entitled “A Summary of Proceedings at the June 2022 Symposium on PSA for Reactors of Singular Designs”. The respective Report [17] is already in publication.

The members of the Database Project have therefore already started the respective activity for collecting fire events from research reactors, adapting the Coding Guidelines for NPPs in order to cover the specifics of research reactors in terms of their use and operation, their reduced risk compared to NPP units, their often quite unique designs, and often quite different environments compared to NPPs, etc.

5. CONCLUSIONS AND OUTLOOK

The OECD/NEA FIRE Database is mature enough to be used to provide collected data support for major parts of Fire PSA. It is possible to estimate generic building and compartment specific or component related fire occurrence frequencies for all plant operational states, for the main nuclear reactor types in use in member countries. Nevertheless, the data to be considered for real case applications may vary due to differences in reporting thresholds in the member countries. Collecting the information on the number of selected compartments and components at NPPs has been a long-term action in FIRE member countries and further information still expected will decrease the uncertainty in the associated fire frequency estimates.

The FIRE member countries have clearly indicated that there is a need for further fire event or fire protection related event data to be collected, shared between experts from different countries and discussed to extend the Database applicable to Fire PSA for existing NPPs in operation, for sites with reactors no longer being operated as well as for the design and future operation of new builds including SMRs. The current Project members strive for further extending the Project membership in order to develop a broader data base for the different analyses.

The ENSREG TPR II on fire protection at nuclear installations is currently underway, looking across the nuclear industry from a fire safety perspective. The key purpose of this review is to allow different countries, mainly from the European Union (EU), to share fire specific operating experience from various types of nuclear installations and to identify good practices, to consider common issues and challenges, and to define follow-up actions for addressing the challenges posed. Once the TPR has been concluded, the FIRE Database Project members will look at the conclusions and what can be learned from the peer review in relation to the Database.

The FIRE Database Project is continuously looking to learn and evolve. This ensures that the members keep up with developments in nuclear industry whilst striving to improve the Database and the information it collects. Looking to the future, the Project members have already started to consider SMRs and ANTs, and what the Database and Project team can offer in this area. Considering the unique fire safety challenges associated with SMR and ANT designs, a survey has been recently completed canvassing the opinions and interests of the members, including the potential to adapt the existing Database or to introduce a new database in the future for these technologies. The Project members agreed that the Database could be adapted to include fire events on SMRs/ANTs in the future but in the meantime, the group should focus on learning from each other with respect to:

- Current plans for introduction of SMRs/ANTs;
- Designs/technologies being considered;
- Experience of regulation of SMRs/ANTs (regulatory judgements);
- Thoughts on applicability of the FIRE Database;
- Fire related research needs for SMRs/ANTs.

The National Coordinators from the FIRE member countries, even if not currently pursuing SMRs/ANTs, also expressed an interest in learning from others.

Moreover, the FIRE Database is already envisaged to be further extended to other non-reactor nuclear installations as far as feasible. If the need for data from the operating experience of active and passive fire protection features will emerge for Fire PSA, such data could be collected as well in the future. The Fire Database members will discuss the potential to include fire events from fuel cycle facilities and other non-reactor installations in the future. Some non-reactor facilities are already making good use of the information, and it is important to remember that much of the equipment (pumps, generators, switchboards etc.) is often used on both reactor and non-reactor nuclear sites.

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