Statistical Analysis for NPP Fire Events in the OECD FIRE DB

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1. Introduction

The purpose of the OECD FIRE (Fire Incidents Records Exchange) Project is to encourage multilateral co-operation in the collection and analysis of data relating to fire events in NPPs [1]. It includes improving the safety of NPPs by better accounting for feedback from operating experience and by providing common resources for analytical work in the frame of deterministic and probabilistic assessment. The OECD FIRE Project was launched in January 2003, with nine countries. The project was successfully continued with five additional member countries through each Phase (Phase1: 2003-2005, Phase2: 2006-2009, Phase3: 2010-2013, Phase4: 2014-2015) under an agreed set of Terms and Conditions. The project is currently in the Fifth Project Phase (2016-2019) with fourteen countries (Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, United States, and United Kingdom) participating. In Korea, four related organizations (KINS, KAERI, KHNP, KEPCO E&C) established the fire protection consortium and joined the project since 2007. In this study, the statistical analysis for fire events in the OECD FIRE database (DB) was performed to generate qualitative insights into fire events in NPPs.

2. Methods and Results

2.1 OECD FIRE DB and Statistical Analysis

The latest OECD FIRE DB (2016:01) released August 2017 [2]. The total of 491 fire events was reported by the member countries up until the end of 2016. Only 479 fire events are available for statistical analysis because the information of some fire events (12 events) has not been quality assured. The statistics of fire events collected by each country are shown in Table I. Table I shows that most of fire events occurred in pressurized water reactors (248 events), boiling water reactors (151 events) and pressurized heavy water reactors (75 events). Only five events occurred in the other type of plants (gas cooled reactors). The main elements of the fire events reported in the database were analyzed statistically by classifying the phase from the fire growth to the consequence of fire. The information provided in each phase is as follows.

- Ignition phase: location where the fire started, ignition mechanism, etc.
- Detection phase: confirmation time, type of detection, etc.
- Suppression phase: suppression time, type of suppression, etc.
- Functional consequences and corrective actions: impact on safety trains, corrective actions, etc.

The statistical analysis of 479 fire events was performed and events with missing relevant information ("unknown") were excluded from the analysis (e.g. the information of the ignition mechanism for 17 fire events were unknown). If more than one information was included in single fire event such as the type of detection (e.g. the fire was detected by plant personnel and fire alarm system), it is classified as "more than one".

Table I: The Number of Reported Fire events in OECD FIRE DB

Country	Fire events	Reactor type	Observation starting time
Belgium	1	PWR: 1	2015
Canada	73	PHWR: 73	2000
Czech	14	PWR: 14	1991
Finland	22	BWR: 12 PWR: 10	1991
France	96	GCR: 3 HWGCR: 1 PWR: 92	1999
Germany	36	BWR: 15 PWR: 21	1987
Japan	12	BWR: 11 PWR: 1	1976
Korea	12	PHWR: 2 PWR: 10	2003
Netherlands	2	PWR: 2	2006
Spain	29	BWR: 5 GCR: 1 PWR: 23	1987
Sweden	103	BWR: 81 PWR: 22	1981
Switzerland	7	BWR: 3 PWR: 4	1984
United States	72	BWR: 24 PWR: 48	1997
Total	479	BWR: 151 PWR: 248 PHWR: 75 GCR: 4 HWGCR: 1	

Abbreviations
BWR: Boiling Water Reactor
PWR: Pressurized Water Reactor
PHWR: Pressurized Heavy Water Reactor
GCR: Gas Cooled Reactor
HWGCR: Heavy Water Gas Cooled Reactor

2.2 Ignition Phase

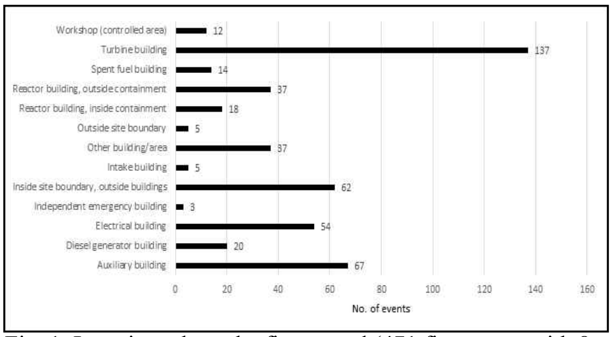

Fig. 1. Location where the fire started (471 fire events with 8 "unknown" events)

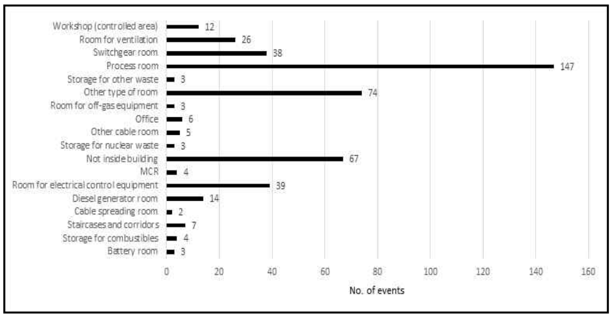

Fig. 2. Type of room/area inside building where the fire started (457 fire events with 22 "unknown" events)

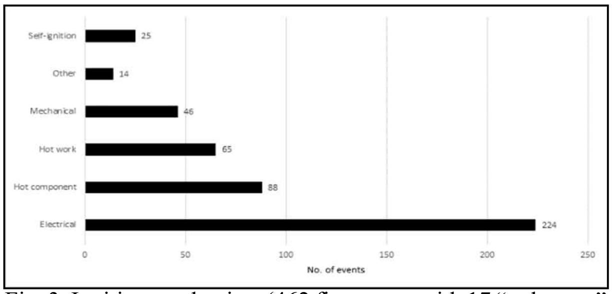

Fig. 3. Ignition mechanism (462 fire events with 17 "unknown" events)

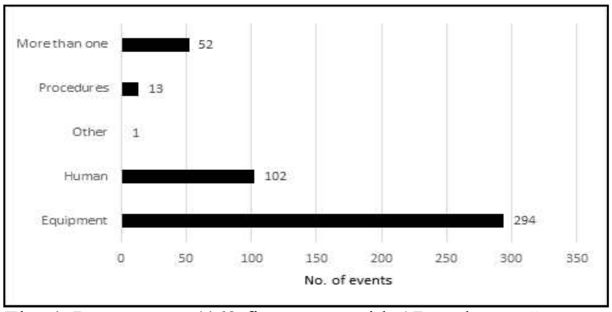

Fig. 4. Root causes (462 fire events with 17 "unknown" events)

Fig. 1 shows that fire events in turbine building account for 29.1% of all events and fire events in auxiliary building takes 14.2%. Since the number of fire events in turbine building is the highest, it should be considered in the fire protection activities. Fig. 2 shows that fire events in process room account for 32.2% of all events. The fire events in the process room takes a large part of fire events in the turbine building because approximate 60% of process room in NPPs is generally located in the turbine building [3]. Fig. 3 shows that electrical factor accounts for 48.5% and it means that electrical factor is the major contributor of fire events. Fig. 4 shows that equipment (design, operational failure and maintenance) accounts for 63.6% of root causes of fire events and it is found to be the largest part. The fire caused by human (non-observance of procedures, e.g., related to welding, cutting, not-appropriate treatment of flammable / combustible materials, etc.) takes the second major part (22.1%) of root causes.

2.3 Detection Phase

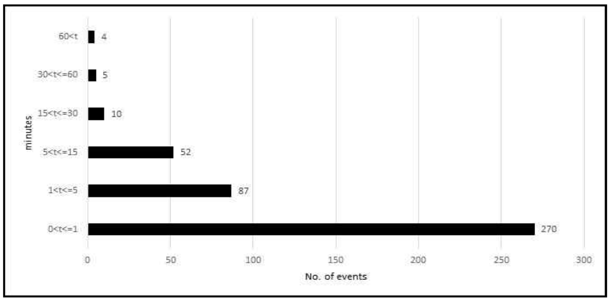

Fig. 5. Confirmation time (428 fire events with 51 "unknown" events)

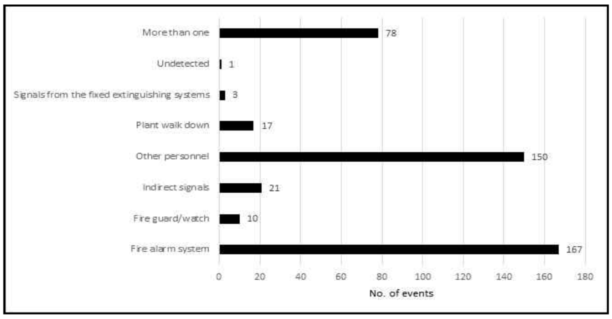

Fig. 6. Type of fire detection (447 fire events with 32 "unknown" events)

Fig. 5 shows the time interval between time of detection and time of confirmation of the fire, i.e. verification of the occurrence of a fire and identification of its location. The most of fire events were confirmed within one minute (63.1 %), while 16.6% of fire events needed more than five minutes to be confirmed. Some of fire events took long times to identify the component where the fire started because the corridor of turbine building was filled with smoke.

Fig. 6 shows that 37.4% of fire events were detected by the fire alarm system, while 33.6% of fire events were detected by personnel excluding fire guard and fire watch. Since the proportion of fire events detected by the personnel at the site is also high, it is necessary to establish fire protection training plan so that the personnel at the site can respond effectively in case of fire.

2.4 Suppression Phase

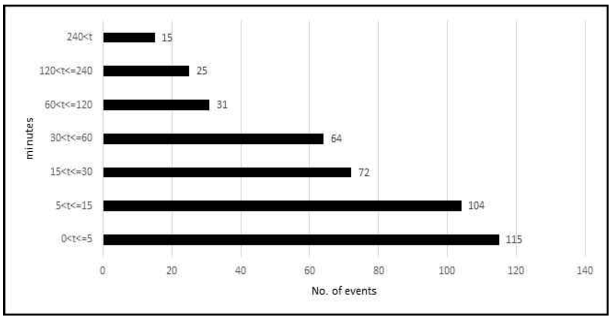

Fig. 7. Suppression time (426 fire events with 53 "unknown" events)

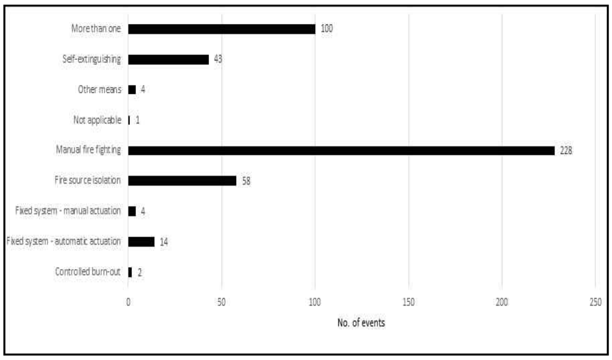

Fig. 8. Type of fire suppression (462 fire events with 17 "unknown" events)

Fig. 7 shows the time interval between time of detection and time of suppression of the fire. Only 16.7% of fire events needed suppression times in excess of one hour. Some of fire events that needed long suppression times were transformer fires [3]. 51.4% of fire events were suppressed within 15 minutes and it indicates that about half of fire events succeeded to suppress early. Fig. 8 shows that 50.2% of the fire were suppressed by manual firefighting, while only 4% of the fire were suppressed by fixed fire suppression system (manual or automatic action). 100 of fire events are classified as "more than one" and it contains the more than one fire suppression types like fixed fire suppression system automatically actuated and manual firefighting. In this reason, the suppression by fixed system takes only 4%.

2.5 Functional consequences and corrective actions

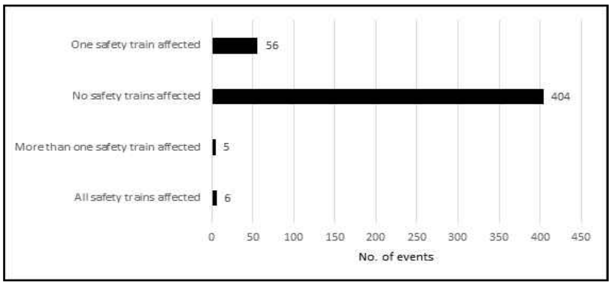

Fig. 9. Impact on Safety trains (471 fire events with 8 "unknown" events)

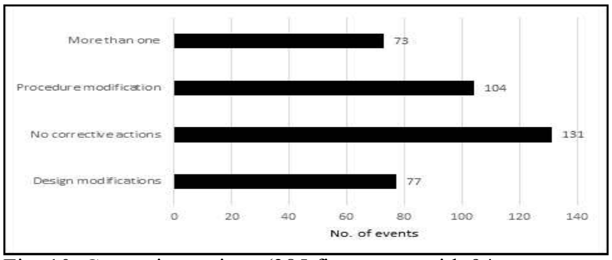

Fig. 10. Corrective actions (385 fire events with 94 "unknown" events)

Fig. 9 shows that most of fire events (85.8%) did not affect the safety trains and only 2.3% of fire events affected more than one safety trains including all safety train affected. Since NPPs are designed with physical separation of each safety trains to maintain the safe shutdown functions after the fire, it has been identified that more than one safety trains are unlikely to be affected by the fire. Fig. 10 shows that the proportion of fire events implemented the corrective actions was 66%. The corrective actions related to procedures modification includes the modifications to general administrative controls or procedure controls and the modifications to specific maintenance or operation practices. Design modifications includes the modification of fire detection and suppression equipment, physical separation, etc.

3. Conclusions

The statistical analysis of the OECD FIRE DB conducted in this study provides a qualitative understanding of the major fire protection variables at each phase of the fire (ignition, detection, suppression and consequence). In the ignition phase, the process room in the turbine building was identified as the room where fire occurred most frequently. Electrical factors were identified as the major causes of fire events and the deficiencies in the design, operation and maintenance were identified as the major root causes of fire events. In the detection phase, most of fire events were confirmed early and the ratio of fire detection by fire alarm system and personnel was similar. It indicates that not only the fire alarm system but also the role of the personnel is important to detect the fire. In the suppression phase, about half of fire events succeeded to suppress early and most of fire events was suppressed by manual firefighting. It indicates the importance of fire drills to extinguish the fire effectively. In the consequence phase, most of fire events did not affect the safety trains and approx. two-thirds of them had led to the procedures or design modifications.

The OECD FIRE DB is useful tool for evaluating the operating experience from member countries with fire events in NPPs. Although it has some limitation like differing reporting thresholds and criteria in the member countries, it is expected to be improved. At the end of the Fifth Project Phase, we expect more data to be gathered and it will provide more meaningful information to improve the fire protection in NPPs.

Acknowledgements

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