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Statistical Analysis of Fire in NPP and the Regulatory Requirements to Fire Safety for Pressurized Water Reactor (PWR)

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Abstract:

Nuclear power plant operation experience over the past three decades indicates that fires at NPPs may constitute a real and significant threat to nuclear safety in addition to the conventional fire hazards to life and property. Fire Hazard Analyses (FHA) and Probabilistic Fire Safety Analyses (Fire PSA), have shown that fire may be of an important contribution to fault trees leading to core damage and other major plant damage states, particularly for older nuclear power plants (NPP). Yet, realistic modelling of fire scenarios within Fire PSA is considered difficult, due to the scarcity of reliable data for fire analysis. Design deficiencies and human factors are large contributors to the events. Thus initiators, propagators and mitigates is needed to be considered. The motivation of the present work was under taken to statistical evaluation of the reported fire accidents in the period from 1990 to 2015. The present study describe the major fire accidents that have been happened in NPPs, which provides assessment of associated hazards, Economical coasts and lessons learned have also been introduced and discussed. This will help Regulatory Authority to introduce fire safety requirements capable to avoid the recurrence of similar events in future.

Keywords: Fire safety, statistical analysis, fire safety requirements in PWR

Introduction:

Fire is a major hazard at nuclear power plants. A fire in a nuclear power station could be one of the reasons for the spread of radioactive contamination and release of radioactive materials to the environment. Through the early 1970s, nuclear power plants generally followed the same local fire protection codes which governed the other industrial facilities. However, After the Browns Ferry fire accident on March 22, 1975, fire at a nuclear power plant seriously challenged safety systems of the plant. In order to evaluate the potential fire hazards and the appropriate fire protection systems as well as the features used to mitigate the fire hazards, fire hazard analysis (FHA) is going to be performed. The shortage of fire analysis data was considered one of the major deficiencies in the present fire risk assessment. The database thus obtained allows generating qualitative insights into the root causes of fire events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences [1].

The international experience of nuclear power plants (NPP) shows that fire induced cable failure play a significant role for nuclear safety [2]. With respect to the buildings and rooms or plant areas where fires initiate, the observation from the FIRE Database is that fires are most likely to occur in process rooms and in turbine buildings (about one third each of all events stored in the database), approximately twenty percent of the fires having occurred in process rooms inside a turbine building. This is generally in accordance with observations from international event databases such as IRS and INES. Auxiliary buildings and electrical buildings, as well as rooms for electrical control equipment and switchgear rooms also represent significant locations of fire ignition with contributions of about ten percent or more [3]. A number of fires have occurred that had severe impact, and a few of those caused the failure of a large number of safety systems. Because of those experiences, we have done much to protect the nuclear power plants from fires. We have improved the quality of the materials, incorporated strict physical separation and enhanced the fire detection and suppression capabilities. Thus, we have reduced the likelihood of ignition and spread of a fire, increased the likelihood of discovery and mitigation, and reduced it for a fire to fail a minimal cut set of equipment. The core damage frequency from fires estimated in fire risk studies for a number of plants within the USA ranges between 10^{-6} and 10^{-4} per reactor year [4].A fire risk analysis, using probabilistic methods, attempts to model fire scenarios that can be described in terms of the following elements: ignition of fire, growth of the fire, detection and suppression processes, impact on cables and other equipment, and response of the automatic safety and control systems and plant operators[5] . The fire PSA methodology developed in NUPEC consists of three stages, namely, "spatial interaction analysis", "screening analysis" and "detailed analysis",. Spatial interaction analysis makes fire scenarios based on plant information. Screening analysis identifies risk significant fire scenarios under conservative assumptions. Detailed scenario analysis makes sub-scenarios without the conservative assumptions and quantifies core damage frequencies for the sub-scenarios. the quality of a Fire PSA strongly depends on the one hand on careful modelling and, on the other hand, on reliable data; the latter one can and will be achieved by further expanding the OECD FIRE Database supported by a continuous and consistent reporting of events by the project members. The OECD FIRE Database currently provides a valuable tool for facilitating the use of fire experience of nuclear power plants in the member countries for Fire PSA containing 438 fire events up to the end of 2013, the wide majority of them quality assured. Although the reporting of events is not yet exhaustive according to limitations by different reporting criteria and thresholds in the project member countries, the database provides a good platform for starting the analytical phase [3]. The French fire protection concept is based on a principle of three levels of defence in depth: fire prevention, fire containing and fire controlling. Fire prevention is based on arrangements which prevent the fire from starting or which make difficult for the fire to start. Fire containing is based on design measures so that the fire will have no impact on the safety of the installation. For fire controlling, equipment and personnel are on duty in order to detect, to fight and to gain control over the fire as early as possible. The French fire protection concept gives priority to fire containing based on passive structural measures. All buildings containing safety equipment are divided into fire compartments (or fire areas) and fire cells (or fire zones). Basically, a compartment houses safety equipment belonging to one division (or train) so that the other division is always available to reach the plant safe shut down or to mitigate an accident [6] .

-STATISTICAL NALYSIS OF REPORTED FIRE ACIDENTS:

Operational experience throughout the world has shown that fire in nuclear power plants is a significant threat to plant safety among internal hazards because of the frequency of its occurrence and because of the severity and unpredictability of its development. For commercially operating NPP in Germany with a an overall operating experience of approximately 594 reactor years, up to the end of May 2001 only 25 fire incidents out of approximately 4860 incidents obligatory reported overall to the licensing and supervisory authorities since 1971 have been identified [7] . These 25 fires represent an amount of approximately 0,5 % of the overall 4860 obligatory reportable incidents from NPP in Germany. Nearly all of the fires resulted either from minor deficiencies in the fire protection

means available at the time of the occurrence or represented single events which cannot

totally be excluded even by a well balanced fire safety concept. All of the fires extinguished themselves or were extinguished successfully within an adequate period to be limited to the fire compartment or the ignition area itself. A total of 67 fire incidents

(most of them insignificant) were reported from the India nuclear power plants in the period from 1990-1997 except large' fire incident, which occurred at one of its Plant (Narora unit #1) in March 1993 due to failure of turbine generator level 3 at INES scale. An analysis of these incidents to understand their general characteristics and specific fire prevention methods adopted to prevent such incidents. The total number of fires reported 1998–2000 were 6 i.e., 3,2 and 1 respectively[8] . This is a remarkable improvement from an average of incidents/year during the previous 7 years. As a result of the study on fire events at NPPs in Japan, the number of fire events with generating fire or smoke is only nine events in the period 1966-2004, which means fire protection has been appropriately taken [9]. The feedback of French operating experience is based on data available to IPSN. From their first commercial operation up to the first of March 1994, the French 900 MWe and 1300 MWe PWRs accumulated an operating time of 508,2 reactor-years and a total of 279 fires were recorded. These data concern all the fires that occurred in the PWRs which were reported by Electricite de France to the French Safety Authority [10]. Experience shows that electrical faults (short circuits, arcing, poor contacts) are the main cause of fires. The significant contribution of maintenance operations (grinding, cutting, welding, cleaning with solvents), which represent 22,7% of overall fire events, should also be noted. Fires with mechanical origin are less frequent (around 11%); they result, to a large extent, from contact of flammable material with hot surfaces. Since 1995 there have been over 150 fires at U.S. nuclear plants [11]. Approximately 50% of fires were caused by electrical equipment. One third of the fires were caused by leaking oil and hydrogen. Although the IRS database covers nearly 7000 reactor years of operating experience and more than 2200 events, the reported fire events constitute only a fraction (66 identified fires) of all fire events that actually occurred. Moreover, the role of explosions, suspected to be significant, needs to be further examined [7]. The Swedish nuclear industry has a system for exchanging information that might be generic. This includes all events and failures of safety equipment. Each site has a local organization for transferring reports about incidents to the functions it might concern. Far from all reports result in any administrative or technical changes. But when the people involved have knowledge about incidents, this apparently reduces the risk of making the same mistake at another site [12]. The use of internationally available generic data, mainly from US and France, in particular fire occurrence frequency data, is not always appropriate for application within fire PSA for German NPP due to design, inspection and maintenance differences. On the other hand, the presently available German data do not always allow providing a verified database [13].

Material and Methods

As from September 1990 to 23 September 2015, the USIE contained a total of 34 fire incidents reported by participating States represented [12]. The 34 confirmed incidents are categorized as follows: 15 event under INES rates out of scale,13 event below scale , 3 incident at rate1,2incident at rate 2 and 1 incidents at rate 3. The percentage of each are represented at figure 1. The incident under rate 2 was in Slovak Republic Power Reactor and Finland Power Reactor, where the incident under rat 3 was at Narora Atomic Power Station India. For the fire events below and out scale was extinguished by the fire-fighting system assisted by the plant fire brigade. All the safety functions were complete and the event did not affect any safety systems. India-Nararo incident caused damaging the heavy water reactor and almost leading to a meltdown. The worst to ever occur in India the loss cost was about 220 million $. Cattenom-2, Lorraine, France Power Reactor, Fire on electric cables Sub-standard electrical cables fire cause an electricity funnel, damaging safety systems triggered the on-site emergency plan and has shut down the unit 2. Firemen have intervened and have considered the fire extinguished after about 2-hours. There are neither people injured nor consequence to the environment, the loss cost was about 12 million $. The entire reported incident did not cause any radiation doses or radioactive releases. It is clear that most of fire incident due to electrical causes with is no fatalities. From the reported incident the number of fire in the period between 2000 -2015 less than the number in the period between 1990-1999 that because of the development of the fire protection system and fire safety training policy' fire hazard analysis of critical areas. Figure 2 represent the number of fire incident reported in every participated country. It is clear that the largest number of recurrences fire at USA with no significant accidents all of them below the scale.

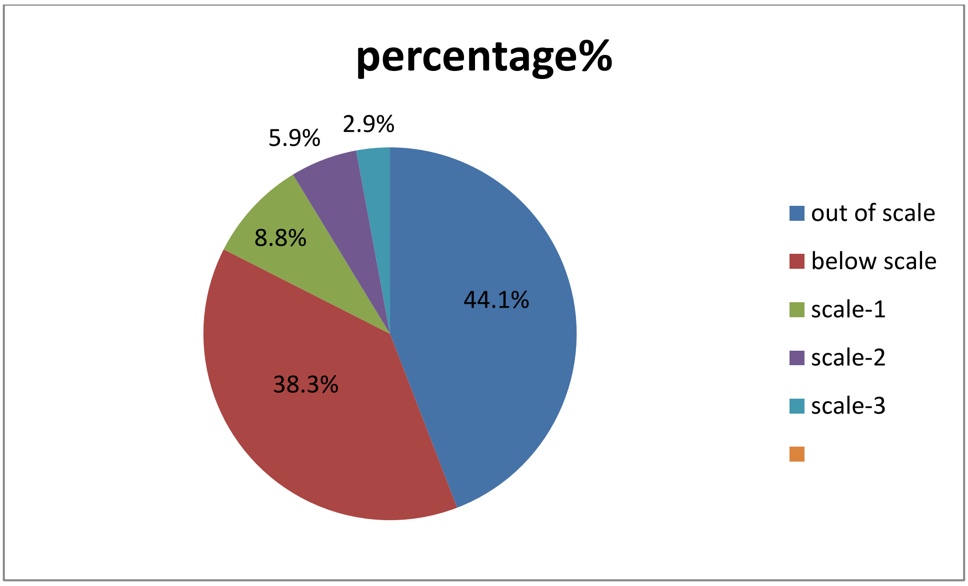

Figure (1) the percentage of the incident under INES scale

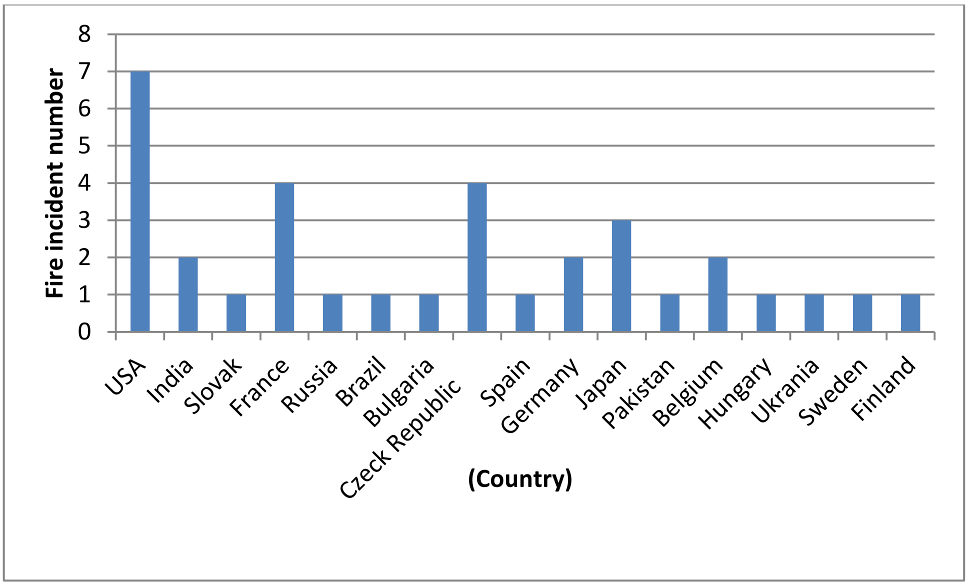

Figure (2) Reported incident in the period between (1990-2015)

Roll of the regulatory authority and lessons learning:

Regulatory authorities have developed requirements to establish minimum levels of fire safety which must be provided in nuclear plants. In response to this accident, the NRC developed fire regulations in 1980 that were intended to configure nuclear plants in ways to avoid problems like those at Browns Ferry. These regulations, require reactors to have fire walls, automatic fire detection and suppression systems (e.g., water sprinklers or carbon dioxide discharges), and separation or insulation of electrical cables for primary safety systems and their backups. The goal is to keep a single fire from knocking out redundant systems of electrical cables, equipment, and emergency systems needed to safely shut down a nuclear reactor. Cables can either be physically separated (e.g., by keeping cables at least 20 feet apart) or if they are closer together one or both cables can be wrapped in a fire retardant material designed to protect against fire for one to three hours, depending on what other safety features are installed [14]. In 2004, the NRC added a second set of fire protection regulations, called the NFPA 805 option. Under the NFPA 805 option, plant owners would instead use plant-specific information, such as the amount of combustible material in different areas of the plant and what fire detection and suppression systems are available, to conduct risk analyses. The risk analyses estimate how long it would take to detect and extinguish a fire in each area, what equipment would be disabled by the fire, and whether sufficient equipment remains intact to cool the reactor core. The goal is to determine what protection is needed in specific plant areas and reduce the costs of the one-size fits-all approach of the 1980 regulations without reducing protection. The fire hazard analysis (FHA) should cover all relevant areas of the plant to clearly demonstrate there is a sufficient level of protection. It should be performed by qualified fire protection and reactor systems engineers and include the following [15]:

1. The evaluation of physical construction and layout of buildings and equipment (including electrical cables) within fire compartments or fire cells.

2. An inventory of combustibles, including maximum transient combustibles within each fire compartment or cell.

3. A description of fire protection equipment, including detection systems and manual and automatic extinguishing systems in each fire compartment or cell.

4. An analysis to assure a single fire event (in any compartment or cell) cannot impair required safe shutdown functions or result in the uncontrolled release of radioactive contamination to the environment. The fire hazard analysis should be reviewed and updated following any plant modification that could affect fire safety, periodically and at times as may be specified by the regulatory body. STUK's inspections of fire protection at nuclear power plants and nuclear facilities are timed in accordance with the stages of the licensing process: a. during the decision-in-principle stage, STUK’s statement on an application for a decision-in-principle also covers the principles of fire protection. b. During the construction licence stage, STUK evaluates the Preliminary Safety Analysis Report (PSAR) and the supplementary topical reports, system descriptions, fire compartmentation drawings as well as the preliminary design and quality assurance procedures. The acceptability and feasibility of implementation of the fire protection principles are verified based on them. During the construction licence phase, STUK also reviews the plant’s design phase fire PRA. During construction STUK ensures that the principles presented in the construction licence stage are implemented in the plant’s detailed design and implementation. STUK oversees and inspects the plant construction, in accordance with the construction inspection programme. During the operating licence stage, STUK inspects the Final Safety Analysis Report, (FSAR) and related system descriptions, the fire PRA and topical reports, including the final analysis reports and commissioning inspection records drawn up by the license applicant and inspection bodies approved by TUKES. STUK conducts the commissioning inspections of fire protection systems as part of the commissioning inspections of buildings before the plant’s commissioning [16]. The inspection frequency should be sufficient to ensure administrative controls are effective. The frequency should be increased during major maintenance operations. The results of walk-through inspections should be documented and deficiencies should be corrected promptly. - Inspection and testing procedures should address system aging. Performance tests of fire pumps and fire mains should be conducted to demonstrate flow and pressure design requirements are being met. Fire sprinkler systems should be inspected for the presence of foreign material, pinhole leaks, and/or obstructed strainers. Other suppression and detection systems should be evaluated based on performance and obsolescence. Passive systems should be inspected for signs of damage due to aging. Follow-up actions and correction of deficiencies detected during testing and inspection should be performed promptly and documented. Improved emergency procedures including emergency communications should be required to reduce the causes relevant to human factors.

Fire safety requirements:

-Every NP plant's introduce fire protection plan must meet regulatory body requirements

- The plan should document management's fire protection program policy and goals to prevent fires from starting and spreading,

-The organisational responsibilities and lines of communication for fire protection should be defined through the use of organizational charts and functional descriptions of each position's responsibilities. The fire protection program manager directly responsible for the day-to-day implementation of the fire protection program

-Written emergency procedures that clearly define the responsibility and actions of staff in responding to any fire in the plant should be established and kept up to date.

-Plants map out the types of fire hazards at the plant and the location of fire fighting equipment in the event of a fire.

-Regular fire exercises should be held to ensure that staff have a proper understanding of their responsibilities in the event of a fire. Records should be maintained of all exercises and of the lessons to be learned from them. Full consultation and liaison should be maintained with any off-site organizations that have responsibilities in relation to fire fighting.

- A written procedure should be established to address impairments to fire protection systems and features and to other plant systems that directly impact fire risk (e.g., ventilation systems, plant emergency communication systems, egress and access routes, passive systems such as barriers). This procedure should include identification of impaired systems, notifications (e.g., plant operations, station fire brigade, external agencies) and provision for compensatory measures (including restricted station activities).

-There should be an on-site station fire brigade with a minimum strength of five members (qualified fire-fighters) available at all times.Fire brigade members should be physically able to perform all anticipated duties and tasks throughout their period of service. In addition to an annual medical examination, members should be given regular checks to demonstrate that they can use and operate the appropriate personal protective equipment.

- A fully automatic water-based fire suppression system designed to protect all areas around the turbine-generator group where oil can be released or can accumulate or A manual water-based fire suppression system designed to protect all areas around the turbine-generator group where oil can be released or can accumulate. System actuation should be from either of two remote locations, one of which should be the MCR. Operating and training procedures should be prepared to minimize delays between detection of the fire and operation of the suppression system

-Plant documentation should provide a clear description of the manual fire fighting capability provided for those areas of the plant identified as important to safety. The manual fire fighting capability may be provided by a suitably trained and equipped on-site fire brigade, by a qualified off-site service or by a co-ordinated combination of the two, as appropriate for the plant and in accordance with national practice.

Nuclear power plants train their staff on fire safety, including regular drills on responding to possible fires.

-The control room and the emergency control room shall be provided with overpressure ventilation to prevent smoke from entering the control room or the emergency control room in case of a fire outside the room in question.

-The regulatory body ́s resident inspectors monitor daily plant activities and perform specific fire safety inspections every 3 months, plus an additional yearly inspection.

-Implementation of the defence in depth approach to fire protection shall be assessed

-The adequacy of fire protection shall be demonstrated by deterministic fire hazard analyses. It is especially important to demonstrate that the safety functions of the facility can be reliably accomplished during any potential fire situation. Fire hazard analyses shall also examine design basis extension events (common cause failures in systems related to fire protection). The results of deterministic fire hazards analyses are used as input data in drawing up a fire PRA.

-The significance of the results of fire hazard analyses used as the basis of risk-informed design shall be assessed by accident modelling methods approved in accordance with the licensing stages

-The nuclear facility shall feature an adequate number of appropriate, sufficiently spacious and easy-to-use access routes to enable safe exit from the facility.

- Fast detection of the fire is very important. Automatic detection and alarm systems should particularly be provided in unoccupied rooms. These systems should be reliable and be regularly tested and maintained.

The regulatory authority shall at the same time reviews the results of periodic inspections conducted by the licensee and other organisations. Oversees on-site deems necessary the periodic inspections conducted by the licensee.

Discussion and Conclusion:

Human factors are considered large contributors to the events. Nevertheless, the statistics have showed also that a majority of reportable fires typically occur at electric and/or electronic equipment. The equipment items and maintenance operations are the principal ignition sources for PWRs. The fire compartment cable space under the control desk shall be equipped with effective and reliable fire detection systems as well as fire- extinguishing systems. All accidents or incidents must report and be available. The databases internationally available, such as IRS by OECD and INES by IAEA or the SANDIA fire database, are also very small and to some extent not directly applicable to the specific plant. Experience exchanges with nuclear facility are very important. Leadership and control of fire and rescue services, as well as the availability and quality of its services, rests with the Ministry of the Interior; the Ministry is also responsible for the preparation and arrangements of fire and rescue services at national level so the fire fighter must take training and perform drill exercise on the radiation fire fighting to can protect them. Nuclear power plants today use multiple layers of fire protection features to protect plant safety systems. Every plant must have a fire protection plan outlining the fire protection program, installed fire protection systems, and the means to assure that the reactor can be safely shutdown in the event of a fire.

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