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A Review of Representative Fire Incidents in Nuclear Power Plants

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1. Introduction

Recently, Zaporizhzhya Nuclear Power Plant (NPP) in Ukraine was hit by a projectile causing a localized fire when the site was taken over by Russian forces. Also, Hanul NPP in Korea was threatened by the proximity of the severe wildfire events. This paper is intended to provide risk insights by analyzing representative fire incident that have occurred worldwide considering the importance of fire protection and the aspect of fire event Probabilistic Safety Assessment (PSA).

2. Fire Incidents Summary

A report is referenced to analysis representative fire incident that have occurred historically [1]. This study is conducted based on the review of a specific set of 25 fire incidents including fire at both U.S. and foreign reactors summarized in NUREG/CR-6738[1]. In this section five among them are briefly discussed.

2.1 Browns Ferry Units 1 & 2 Fire on March 22, 1975

Browns Ferry NPP is located near Decatur, Alabama. At the time of the fire, Unit 1 & 2 were in the very last stages of obtaining their operating licenses. Unit 1 & 2 have a shared control room and cable spreading room (CSR).

A fire ignited on the polyurethane foam inside a cable penetration between the CSR and the Unit 1 Reactor Building (RB) at 12:20p.m. The ignition source was a candle that was being used to check for existence of air currents. The fire spread to the RB by the flow of air. The operators activated the fixed CO2 system late because this was initially discharged. This certainly affected the progression of the fire at the CSR. At 01:15p.m. Alabama fire brigade arrived at the scene and recommended use of water to extinguish the fire at the RB. But this was rejected by plant personnel on the scene. When reactor was in a stable state, permission was given to use water to fight the fire. And then the fire was declared as completely extinguished at 07:45p.m.

2.2 Beloyarsk Unit 2 Fire on December 31, 1978

Beloyarsk NPP is located near Ekaterinburg, Rissia. Unit 2 was operating at 100% power when plant personnel noticed a fire.

A fire was noticed at 01:50a.m. on the Unit 2 side of the Turbine Building (TB). The fire was caused by a break in the lubricating oil piping system. The fire brigade was immediately notified by the plant manager. But the plant personnel were unable to take any actions to fight the fire before the arrival of the fire brigade because of the rapid growth of fire. The TB roof near #2 turbine-generator collapsed and the fire propagated from the TB into the Control Building via open cable penetrations and other openings. The installed foam system at the fire location could not be activated because the cables for the system were damaged. A portable foam system was not used because the fire area was filled with smoke and the personnel could not reach the fire location. At 11:30p.m. fire was declared as completely extinguished. The fire fighting involved 35 brigades and a total of 270 fire fighters including 150 who were trained in using SCBA.

2.3 Zaporizhzhya Unit 1 Fire on January 27, 1984

Zaporizhzhya NPP is located near Energodar, Ukraine. At the time of the fire, Unit 1 was in the last stages of construction and apparently the reactor was not activated yet.

A fire was observed at elevation 13.2m of the Control Building at 05:15p.m. The ignition source was a short in terminal box. The fire propagated via cables coming out of the terminal box and into a cable shaft. As soon as the operators received news about the fire, they tripped the electrical system, including the DC power system. Fire brigade arrived at the plant and they sprayed water at different points of the Control Building. However, since the fire brigade personnel were not familiar with building layout and because of the heavy smoke in the building, they failed to be effective and fire continued to propagate. The fire eventually spread through practically all elevations of the Control Building. The fire was finally declared as completely out about 17hours and 50minutes after the fire broke out. More than 115 fire fighters were involved in this effort.

2.4 Vandellos Unit 1 Fire on October 19, 1989

Vandellos NPP is located near south of Barcelona, Spain. Unit 1, which is currently decommissioned because of fire incident, was a graphite moderated reactor.

The ignition source was Turbine blade ejection. The control room had a window overseeing the turbine generators. A flash was seen in the control room and the shift operator manually tripped the reactor at 09:39p.m. Of the four coolant loops of the reactor, two (No.3 and

4) failed because of fire-induced cable failures. In addition to the turbo-blowers, the fire caused the shutdown heat exchanger to fail as well. Core cooling capability remained available through steam generator No.1 and 2, their associated feedwater pumps and turbo-blowers. And the control air supply was lost because hot gases under the ceiling of the TB damaged the copper piping of the air system. Operators, using SCBAs and portable lighting, entered darkened and smoke filled valve rooms to manually adjust the flow control valves. The turbine lube oil, as it was burning, cascaded down to the lower floors of the TB and created a pool of burning oil underneath the turbine. It eventually ruptured at the point that was closest to the wall. The rupture allowed seawater to spill into the basement of the TB. The fire was declared as completely extinguished at 04:00a.m.

2.5 Narora Unit 1 Fire on March 31, 1993

Narora NPP is located in Utal Pradesh, India.

At 03:32a.m. a turbine blade failure took place on the Unit 1 turbine-generator set that led to severe vibrations, rupture of oil lines and the release of hydrogen. These fuels ignited causing an explosion and fire in TB. A reactor trip was immediately, manually initiated upon turbine failure. The fire spread to control and power cables. A large quantity of smoke entered the Main Control Room (MCR). The operators were forced to leave the MCR. As the result, it caused a station blackout. The diesel generators started automatically, but tripped because of loss of control power supply. The operators manually started two diesel-driven fire water pumps. These pumps provided fire water and were later used to pump water into the steam generators. This established fire water flow into the steam generators that served as a heat sink for decay heat removal by maintaining natural-circulation cooling of the core. The fire was completely extinguished at 12:32p.m. About 17 hours after the fire broke out, one of the shutdown cooling pumps was started. This is considered by the plant operators to represent termination of the station blackout condition.

3. Fire Incidents Analysis

Of the 25 fire incidents, most of the causes of the fire were related to cable, Turbine oil system failure and blade ejection. TBs had the most fire locations. Not only the turbine oil system failure that occurred in the TB, but also the turbine blade ejection that causes the turbine oil system failure caused severe fire. In most fire incidents, automatic suppression system did not overwhelm the fire and manual suppression was used. It means automatic suppression system did not function effectively.

Table I: Summary of Incident Review Results

Plant	Ignition source	Location (Room or Building)	Severe fire
San Onofre	Cable	Switchgear	NO
Muhleberg	Turbine oil	TB	YES
Browns Ferry	Transient	CSR & Control Building	NO
Greifswald	Cable	Switchgear room	YES
Beloyarsk	Turbine oil	TB	YES
North Anna	Transformer	TB	YES
Armenia	Cable	Yard	YES
Rancho Seco	Hydrogen	Cable Tunnel & TB	YES
South Ukraine	Cable	Containment	YES
Zaporizhzhya	Cable	Control Building	YES
Kalinin	Cable	Control & TB	YES
Maanshan	Turbine blade	TB	YES
Waterford	Main feedwater pump	Service water pump area	YES
Fort St. Vrain	Turbine oil	TB	NO
Ignalina	Cable	CSR	YES
Oconee	Cable	Switchgear room	NO
H.B. Robinson	Transient	TB	NO
Calvert Cliffs	Cable	MCR	NO
Shearon Harris	Bus duct	TB & Yard	NO
Vandellos	Turbine blade	TB	YES
Chernobyl	Cable	TB	YES
Salem	Turbine blade	TB	YES
Narora	Turbine blade	TB	YES
Waterford	Transformer	Switchgear room	NO
Palo Verde	Cable	MCR & AUX building	NO

3.1 Browns Ferry Units 1 & 2 Fire on March 22, 1975

The Browns Ferry fire is quite typical of the “classical” fire PSA risk scenario. It was actually a relatively modest fire in classical fire protection terms. The fire remained confined to a relatively small part of two adjacent rooms and did not present a significant challenge to plant structures. However, the fire led to loss of numerous and redundant plant safety systems. It is the biggest incident in the U.S. except for TMI accident. The control room was contacted about 15minutes after the fire was ignited and the fire affected two units. In the PSA, it is commonly assumed that a fire alarm will be sounded immediately upon any personnel detecting any fire anywhere in the plant and common practice of PSA is to analyze fires as impacting a single unit only. These assumptions may be optimistic and the need of multi-unit PSA is raised. Although adequate core cooling was maintained at all times, the fire did present a significant challenge to plant operators in their attempts to stabilize Unit 1 in particular.

Brown Ferry unit 1&2 fire incident CCDP is 0.20.[2] This figure is historically the highest value in fire incidents.

3.2 Beloyarsk Unit 2 Fire on December 31, 1978

The Beloyarsk fire is illustrative of a severe turbine hall fire and one of the longest-lasting fire incidents in the history of NPP fire. The lack of separation between redundant cables and extensive fire spread led to numerous common mode failures making the control of the plant extremely difficult. A fixed manual fire suppression system near the fire origin could not be manually activated because the fire had already damaged system cables. Fire protection system cables are not typically traced as a part of a fire PSA. As soon as the fire is ignited, the TB roof is collapsed in just a few minutes. The collapsed TB roof caused secondary damage. This secondary damage is not also traced as a part of a fire PSA. Fortunately, adequate core cooling was maintained at all time.

3.3 Zaporizhzhya Unit 1 Fire on January 27, 1984

Fortunately, Zaporizhzhya unit 1 was not activated yet. If it was in operation, the impact on plant operations would have been severe. There was no apparent delay in calling out the fire brigade. But, it was not effective. Because the fire brigade personnel were not familiar with building layout and the heavy smoke interrupted them. In fire PSA, the impact of smoke on the fire fighters is not generally modeled explicitly. It is commonly assumed that once fire fighters arrive on-scene, they will quickly and effectively control and suppress the fire. Here, the need for periodic training of the fire brigade in charge of NPP is raised.

3.4 Vandellos Unit 1 Fire on October 19, 1989

The Vandellos fire is considered a major fire from the classical fire protection perspective. The fire also presented a modest challenge to nuclear safety. The fire caused extensive damage, failed several key safe shutdown related components, created an adverse environment for the operators in the control room and in other areas of the plant, and ultimately led to the permanent shutdown of the plant. Seawater spilled into the basement of the TB because of the rupture. In fire PSA, the possibility of secondary effects, such as this flooding, is not typically considered. And automatic sprinkler and deluge systems were activated but, because of lack of coverage in the area of fire proved to be ineffective in controlling the fire. In fire PSA, it is assumed that the fire protection system is properly designed to handle all possible fire scenarios of the area.

3.5 Narora Unit 1 Fire on March 31, 1993

The turbine building fire at Narora unit 1 caused and extended station blackout and extensive damage. In fire PSA, it is common to model such fires by postulating that and oil spill occurs and is ignited. This, of course, is intended to cover a large spectrum of possible incidents, including blade ejection. In this incident, the blade ejection caused the shaft to overheat presenting an ignition source that is not normally present in the plant. This was also seen at Vandellos, for example. The possibility of an accident creating and ignition source is not generally modeled. In fire PSA an overall fire initiation frequency is used to represent a large spectrum of possible fire scenarios. And in fire PSA upon the presence of smoke or other adverse conditions in the MCR, it is assumed that the operators will not be able to function properly and will have to leave the MCR. This incident demonstrates that smoke alone (i.e., there is no fire in the MCR and no direct fire damage to MCR circuits) can lead to MCR abandonment. It is also of interest to note that upon arrival at the emergency control room, operators for unit 1 were still unable to control the reactor because the station blackout had rendered the emergency control panels inoperable as well. This incident demonstrates the possibility of a common cause failure for the two control rooms.

3. Conclusions

As mentioned above, turbine oil system failure causes severe fire. Because turbine blade ejection causes turbine oil system, turbine blade ejection also causes severe fire. And the most fire incidents are historically in TBs. In particular, caution is needed to prevent fires in TBs.

Automatic fire suppression system could not overwhelm the fire in the most fire incidents. In fire PSA, it is assumed that the fire protection system is properly designed to handle all possible fire scenarios of the area. The possibility of the suppression system being overwhelmed is not considered. It is necessary to design effective automatic fire suppression system closely to control the fire.

There were fire incidents in which smoke entered the MCR and leaded to MCR abandonment. It is important to take appropriate measures because the smoke entering the MCR is not specific to the fire in the TB and occurs sufficiently in other places.

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