Review of Narora Unit 1 Fire Event of March 1993

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Abstract: ***On 31st March 1993, a major fire broke out in NAPS unit 1 while it was generating 185 MWe power level. The fire had been triggered by sudden rupture at the roots of the 5th stage blades in the low pressure turbine leading to leakage of hydrogen from the generator cooling circuit. It led to deflagration in the turbine building which propagated along the cable ducts through several barriers to the control room and emergency control room. This fire disabled emergency power supply in about 7 minutes. Explosive sounds were experienced, and blue flames was observed in the turbine building by an operator. The ensuing fire propagated via power and control cables to the control room and emergency control room disabling all power supply sources, from class I to class IV types. This beyond-SBO situation lasted around 17 hours. It disabled all safety functions after the initial scram. Hence, the safety functions to actuate long term sub-criticality by poison injection, and residual heat removal were actuated manually, at great personal risk. The fire was brought under control in 90 minutes and was extinguished manually by use of portable fire pumps, in around 9 hours. This fire event ranked third after Chernobyl and Fukushima fire events in terms of severity. However, despite manifest signs of common cause failures and weak safety culture in the utility (NPCIL) and failure of all power sources from class I to class IV, this event was ranked at level 3 on INES scale, namely, a simple incident. The utility (NPCIL) had undertaken measures, including strengthened systems and procedures for fire control to address weaknesses that were dormant for over a decade in its NPPs. In this study, this event is reviewed and strengths and weaknesses of Indian NPP program and its regulatory control as they existed at the time of the event are described. Those strengths are weaknesses are also described. Suggestions are offered to weed out any dormant weaknesses.***

Keywords: fire; explosion; beyond SBO; common cause failures; weak safety culture;

1. Description of the Fire Event

On 31st March 1993, a major fire broke out in NAPS unit 1 while it was generating 185 MWe power level. The fire had been triggered by sudden rupture at the roots of 5th stage blades in the low pressure turbine and leakage of hydrogen from the generator cooling circuit. It led to deflagration in the turbine building which propagated along the cable ducts through several barriers and disabled emergency power supply in about 7 minutes. This was loss of all power was more severe than the Station Black Out situation (SBO).

The sequence of events have been graphically described in reference [1] as follows:

QUOTE. *Simultaneously, a strong and powerful sound resembling an explosion was heard by control room staff on duty inside and outside the turbine building. Vibrations on the floor were also experienced by the control room staff. On investigation, a huge fire was observed on the operating floor and below near the slip ring end of the generator. Fire near the turbo-generator (TG) set of Unit 1 with bluish flames was also observed by the crane operator from his crane cabin parked on the side of Unit 2.*UNQUOTE.

Reference [2] describes the further sequence as follows:

QUOTE *The incident was a "Beyond Design Basis Accident", as SBO including class I and II failure was not considered during the design stage. Due to the ineffective fire barriers, fire spread rapidly and finally a large amount of smoke ingressed into the control room, so the staff had to leave. . It was not possible to take charge of the situation from the emergency control room, as by reason of the loss of control power supply no indications on Narora-1 panel were available. Important parameters had to be directly measured from field. This resulted in the blind operation of the plant. Firefighting was started by using two diesel engine driven fire water pumps. To establish the heat sink diesel driven fire water pumps were started to feed the secondary side of the steam generators and cooling was maintained during this time by natural circulation (thermo-siphoning effect), the heat being released in the atmosphere through the Atmospheric Steam Discharge Valves, and the steam generators being fed by the diesel-powered fire water pumps.*

The Narora-1 event represents loss of several safety systems and operational systems due to an internal hazard (internal fire). The main systems lost were the AC and DC buses, the control room and the emergency control room. The effective barriers were the successful emergency actions by the personnel, several passive design features (including the low thermal power) and a third EDG placed sufficiently physically separated from the plant. UNQUOTE

The reactor was manually tripped. However, due to complete loss of power, other safety functions had to be performed manually, in the dark, at great personal risk. For long term shut down, the Gravity Addition of Boron System was actuated by operators entering the stream generator room around 2 hours into the incident.

Due to loss of power, the engineered emergency core cooling system could not be activated. The reactor decay heat was being removed through action of the steam relief valves, which opened in about 7 minutes into the incident. The reactor coolant circuit entered a thermo-syphon mode and the steam generators, which were at 48 bars pressure initially, removed the transferred heat even without water make-up for about 5 hours. After 5 hours, the steam generators were down to atmospheric pressure on the shell side. This would indicate that core cooling via steam generator relief valves was getting depleted with time and was not far from being dry on the shell side after 5 hours. It also indicated that sustained steam-relief was achieved manually. The injection of fire water by external fire-fighting pumps saved the reactor unit from major release of radio-active materials from the PHT system.

The beyond-SBO situation lasted around 17 hours, and core cooling was restored in 19 hours.

The initiator of this accident was sudden failure of two turbine blades in the 5th stage of the low pressure turbine. The consequent unbalance of the generator shaft caused its oil lubricated seals to rupture and the hydrogen, which was used as coolant for the generator leaked out, causing explosions and secondary fire.

This fire lit the cables insulation and spread from the turbine room through cable joints to the Control Equipment Room, Control Room and Emergency Control Room, forcing their evacuation. These cables lacked fire-resistant insulation and the cable penetrations were not qualified to resist standard fires.

Summary of similar fire events in nuclear power stations from 1988 to 1996 [3]

Reference [3] gives descriptions and evaluations of 25 fire incidents in nuclear power plants from 1988 to 1996.Of these 25 events, involving fires,8 events cover turbine oil leakage leading to the fire, including 4 incidents wherein the fire was initiated by rupture of turbine blades, leading to hydrogen fire. These reactor units, in chronological order, are as follows:

Muhleberg, PWR, Switzerland, 1971 – first known large turbine building fire

Browns Ferry BWR units 1 and 2, USA -large scale cable fire damaged control building and panels, led to SBO

Beloyarsk PWR 1978 – Russia - large scale cable fire damaged control building and panels

Armenia PWR, Armenia 1982 – large cable gallery fire, led to SBO

Maanshan PWR unit 1, Taiwan 1985 – turbine blade ejection & large scale turbine building fire

Vandelos PWR, Spain 1989 - turbine blade ejection and large scale turbine building fire

Salem PWR units 1 and 2, USA 1991 - turbine blade failure and large scale turbine building fire

Narora PHWR unit 1, India 1993 - turbine blade failure and large scale turbine building fire led to SBO

Table 1 shows the in NPPs listed above and nature of consequences of these fire events.

Table 1: List of similar fire events and their consequences in NPPs - [C]

NPPs Fire effects	Muhleberg PWR	Browns Ferry BWR	Beloyarsk PWR unit 2	Armenia PWR	Maanshan Unit 1 PWR	Vandelos Unit 1 PWR	Salem PWR units 1 & 2	Narora unit 1 PHWR
Severe fire	No	no	Yes	Yes	Yes	Yes	Yes	Yes
Fire propagated	No	yes	Yes	Yes	No	No	No	Yes
Smoke propagated	No	yes	Yes	Yes	No	Yes	No	Yes
Smoke in control room	No	yes	Yes	Yes	No	Yes	No	Yes
Control room vacated	No	No	Yes	No	No	No	No	Yes
Challenging fire	No	yes	Yes	Yes	No	Yes	No	Yes
Multi systems impacted	No	yes	Yes	Yes	No	Yes	No	Yes
Loss of core cooling	No	No	Not known	Yes	No	No	No	Yes
Loss of instrumentation	No	no	Yes	Yes	No	No	No	Yes
Time to control fire	Not known	6:55 hrs.	17:05 hrs.	6:05 hrs.	Not known	3:51 hrs.	Not known	1:30 hrs.
Time to put out fire	2:07 hrs.	7:25 hrs.	21:40 hrs.	7:03	10 hrs.	6:21 hrs.	0:15 hrs.	9:00 hrs.

2. Corrective and repair actions by the utility (NPCIL) [4]

The utility NPCIL have undertaken several measures to minimize the chances of occurrences of fires and of limiting their effects should any fires occur. These include the following: (quoted text is shown in italics)

(1) Storage of combustible materials has been limited to bare minimum in operating areas and where such materials can be eliminated it has been done. This has been ensured through `work permits' and regular field surveys.

(2) Preventive maintenance and energy conservation measures have been initiated to prevent electrical accidents.

(3) Regular measurements of bearing temperature of motors are done to avoid fire due to overheating. Condition monitoring of equipment is also done to minimize fire risk due to overheating, friction and jamming of internal parts.

(4) Smoking inside operating island is strictly prohibited at all sites.

(5) A number of training and awareness programs are initiated on fire safety aspects.

NPCIL have also made important changes to equipment, including the following:

(6) Mineral wool insulation, which used to catch fire due to oil leakage, has been replaced by calcium silicate as an insulation material on steam pipelines and below turbine. Similarly in hot, active and inaccessible places the insulation material has been changed to 'reflective metallic mirror insulation'.

(7) Hydrogen leak detectors have been provided near generator hydrogen addition station, generator bearing and near hydrogen dryer areas.

(8) Installation and testing of fire detectors and installation of additional fire detectors insensitive areas like cable vaults and cable galleries.

(9) Fire watch during `hot work' in sensitive areas and special work permits for carrying out such jobs.

(10) Investigation and analysis of fire incidents.

(11) Segregation of power and control cables and application of fire retardant coating on cables,

The following steps for training of fire-fighting personnel have been instituted:

(12) Systematic training of fire staff to familiarize them of all critical areas of the plant.

(13) Periodic fire emergency drills and review of the results under a standard format.

(15) All operation and maintenance staff was trained on fire-fighting operations and on the use of Self-Contained Breathing Apparatus.

(11) Fire squads have been formed at all stations to cover all three shifts and all areas of the plant to attack any fire at its initial stage itself before arrival of Fire Station Personnel.
These fire squad personnel have been given detailed fire safety training.

Classification of the event on INES scale

This incident had been classified as level 3 on the INES scale, i.e. an event wherein echelons of defence in depth, engineered barriers and systems had been degraded. This was an obvious understatement, as all echelons, barriers and systems for reactor protection remained disabled for nearly 19 hours of SBO duration. This event was marked by common cause failures of most safety systems and reactor protection systems, and showed weak safety culture as well as weak QA. As per INES, events showing any of these weaknesses should be marked one level above the basic level. Hence, this event should have been ranked as level 4 on the INES scale.

Observations and conclusions on review of Narora fire event

In comparison of NAPS fire with fire events in other NPPs listed above, it is clear that the NAPS fire event was the most intense and severe. Only the fires in Chernobyl and Fukushima events (both at level 7) were more severe than the NAPS fire event. The Beloyarsk event listed showed similar failures and consequential effects, though it did not involve fire in the turbine building. The events in Maanshan, Vandelos and Salem involved turbine blades rupture and consequential fires, though the consequential effects were not as severe as those in NAPS. However, fire control actions on NAPS, even though manual, were quicker than on other reactor units.

This accident brought to light the strengths and weaknesses of Indian nuclear power program and its regulatory program for safety, at that time. The root cause of the fire, namely, blade ruptures, and their effects, namely, hydrogen leaks leading to detonation and fire propagation causing beyond SBO conditions highlighted their weaknesses. The actions in manually activating the GRAB system, manually activating the steam relief actions, and in manual linking of external fire water supply to the steam generators highlighted inherent strengths.

The incorporation and testing of the GRAB system, and testing of the thermo-syphon system during commissioning was done at the instance of the regulatory body, showing its effectiveness.

It is also noteworthy that the thermo-syphon mode of cooling was effective even with a diminishing heat sink in form of shell-side water in the steam generators. This was possible since this mode of cooling, with healthy heat sink, was designed and tested during commissioning, and sufficient margins of safety were demonstrated. These margins were depended upon when steam relief valves were opened by operators for about 5 hours before portable fire water pumps could be aligned to the steam generators. Aligning the portable fire pumps to the steam generators also involved manual actions in the reactor building, in complete dark.

The actions of the operators in activating the GRAB system about 2 hours into the event, in controlling the fire in 90 minutes and extinguishing in 9 hours, and in lining up the portable fire water supply in around 5 hours is indeed noteworthy. It testifies to their qualification, training and dedication to their duties, even in circumstances of grave personal risk.

The fire event in NAPS and its consequences were the result of lapses and oversights in several areas of its design, construction as well as in internal and regulatory reviews of this NPP unit. The comprehensive nature of technical and administrative measures and changes in equipment by NPCIL after this fire accident indicate that these weaknesses were dormant in the design, construction, commissioning and operational processes for over a decade. These weaknesses had not been addressed adequately in internal and regulatory reviews of the NAPS project, indicating slack safety culture in the area of fire prevention and suppression.

The location of hydrogen tank inside the turbine building was responsible for the intensity of the hydrogen combustion (possibly explosion) as reported in reference [3]. It would have been appropriate if the hydrogen tanks had been located in separate rooms that are designed to withstand and suppress hydrogen fires. In addition, provisions for quick isolation on the lines leading out of the hydrogen tanks should be incorporated if abnormal low pressure is sensed in the tank. It is not clear from reference [3] if these precautions had been taken. Extensive use of flammable insulation materials and filler materials for penetration joints was the direct cause of loss of all sources of electric power from class I to class IV i.e. beyond SBO event. Similarly, sharing of power and control cables in the same cable ducts also contributed to the beyond SBO accident. Either evidence of weak safety culture or common cause failures causing the incident are grounds for increasing its INES level by 1. In order to provide assurance of safety in our nuclear projects, it is recommended that the regulatory body conduct safety audits during design, construction and commissioning to assure that its recommendations are being acted upon. These safety audits should be complemented by inclusion of subject experts drawn from outside the department of atomic energy. Likewise, whenever any event rated at first sight at level 3 or higher on the INES scale, opinion of subject experts drawn from outside the department of atomic energy should be sought and considered when finalizing its level on the INES scale.

References

[1] TECDOC-1112 Root Cause Analysis – Fire Events
[2] CEA/CNRA/R(2014)1 "FUKUSHIMA DAIICHI NPP PRECURSOR EVENTS"
[3] NUREG/CR/6738 -Risks Method Insights From Fire Incidents
[4] TECDOC-1421 –Experience gained from Fires in NPPs