Regulatory Interventions Necessitated by Non-Conservative Operator Decisions

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Abstract. Presently, India has 15 nuclear power units in operation and 8 units under construction. Though the safety performance of the Nuclear Power Plants (NPPs) in India has been excellent, a few recent events indicate that conservative decision making process can possibly get affected by perceived production goals. In one of the events, a need for some maintenance work arose while reactor start-up was in progress. After it was realized that the maintenance would require considerable time, the proper course of action would have been to shutdown the reactor and add neutron poison to moderator to ensure sufficient sub criticality. This was not done, as it would have delayed the start up of the reactor on completion of maintenance. In another incident, an unintended slow increase in reactor power occurred due to the adjuster rods becoming inoperable on account of blowing-off of fuses in their power supply. Under this condition, the reactor should have been tripped which was not done. Further, the automatic addition of boron poison to the reactor was inhibited. Regulatory review showed that both the incidents were indicative of degradation in safety culture and reflected operator's overriding concern for keeping the units in operation. Appropriate corrective actions were taken to prevent recurrence of such events in the respective units as also in all other operating units of similar type. In the wake of improved production performance operators may develop a tendency to create new operational records and compete with other units. This aspect points out to a need for careful study of events to check the presence of any element of non-conservative decision-making and to identify leading indicators of degradation in safety performance.

1.0 Introduction

Presently 15 NPP units consisting of 2 X 160 MWe BWRs and 13 PHWRs (12 X 220 MWe and 1 X 540 MWe) are operating in India. Eight nuclear power units are under construction. In India, Nuclear Power Plants (NPPs) are owned and operated by the Nuclear Power Corporation of India Limited (NPCIL) and the Atomic Energy Regulatory Board (AERB) is entrusted with performing regulatory activities. The primary responsibility of operating the NPPs in a safe manner rests with the management of NPP. The responsibility of AERB is to ensure that the NPPs are operated according to the approved Technical Specifications and other conditions specified during issue of license.

2.0 Role of AERB in promoting operational safety in NPPs

Since the primary responsibility for safe operation of the NPP rests with the NPP management, AERB encourages a voluntary acceptance and implementation of measures to enhance safety culture without putting undue constraints on the NPP management. The plant management is required to demonstrate its commitment that it gives overriding priority to the common goal of safety.

AERB ensures that training, qualification and licensing of the operators is in accordance with the regulatory requirements. The operation and maintenance procedures are reviewed periodically and lessons learnt from operating experience are incorporated to prevent occurrence/ recurrence of events. AERB conducts periodic regulatory inspections to verify that all activities related to operations and maintenance of the NPPs are conducted in accordance with the Technical Specifications and other safety requirements. The inspectors also look for any signs of a weakening safety culture.

3.0 Safety concerns and regulatory actions

The safety performance of the NPPs in India has been excellent and their availability factors have also increased significantly over the past few years. The number of significant events requiring mandatory reporting has decreased. The radioactive discharges to the environment are a small fraction of the AERB specified limits. All these aspects indicate good safety performance. However, a couple of the recent events indicate that conservative decision making process can get affected due to perceived production goals and can have an adverse effect on safety. Salient aspects of these events are given in the following text.

3.1 Insufficient sub-criticality margin during suspended reactor start-up.

The event occurred in a 220 MWe Pressurized Heavy Water Reactor (PHWR). The reactor is provided with two fast acting shutdown systems. The Primary Shutdown System (PSS) consists of 14 shut off rods, which drop under gravity on a reactor trip signal. The Secondary Shutdown System (SSS) consists of 12 vertical poison tubes, divided into 4 banks. On actuation of SSS, liquid boron poison is injected into these tubes by helium pressure. The SSS gets actuated in case of slow actuation or total failure of PSS and also if certain process parameters exceed the preset thresholds. In addition, a Liquid Poison Injection System (LPIS) is provided for injection of boron into the moderator water. In case of normal reactor trip by PSS alone, LPIS adds boron in the moderator after a preset delay to cater to xenon decay and thus ensuring long-term shutdown safety. If SSS gets actuated during a reactor trip the boron addition from LPIS takes place without any delay.

The incident occurred when boron removal from moderator was in progress for reactor start-up. A leak developed from a valve in shutdown cooling circuit, a part of the main Primary Heat Transport (PHT) system. Boron removal from the moderator was suspended and maintenance on the valve was taken-up, after its isolation by ice plugging. The repair was expected to be completed within couple of hours but the actual maintenance time got extended. Under this condition, the correct and safe approach would have been to trip the reactor manually before commencement of maintenance work and to permit boron addition to moderator by LPIS after the preset time. This was not done, as it would have resulted in delay during restart of reactor after maintenance. Thus during the maintenance period when the reactor was held in suspended start-up condition, the sub-criticality margin was less than specified.

During regulatory review it was concluded that keeping the reactor start up suspended for such a extended period of time with insufficient shutdown margin was an unsafe practice as it could have led to inadvertent criticality in case of a human error or a system malfunction. The decision was not conservative and was probably made to minimize loss of production. It was also realized that the operating procedures did not explicitly cover the situation encountered. Utility was therefore asked to issue instructions to management of all NPPs (PHWR type) that reactor startup should not be kept in suspended state for extended periods and under such conditions the reactor should be brought to shutdown state with PSS IN and with addition of boron to the moderator system in order to ensure adequate shutdown margin.

3.2 Unintended reactor Power rise

This incident of unintended reactor power rise also occurred in a 220 MWe PHWR. The Reactor Regulation System (RRS) controls the reactor power by movement of adjuster rods and by controlled addition of boron poison to moderator if the difference between the Actual Power (AP) and Demand Power (DP) exceeds a set limit. There are 16 adjuster rods at 8 locations. These are divided in three groups depending upon their function. Regulating Rods (4 Nos.) the control power during normal operation, Shim Rods (4 Nos.) that normally remain fully out and move in for reactor setback and Absorber Rods (8 Nos.) that normally remain inserted in the core to compensate for excess reactivity.

The Controlled Addition Mode (CAM) of Automatic Liquid Poison Addition System (ALPAS) gets actuated during operation when AP exceeds the DP by a preset value and injects boron shots to moderator system at prefixed intervals. The CAM also actuates if after a reactor setback the shim rods do not come out fully in 10 seconds. A hand switch is provided in Control Room to permit manual injection of boron when needed, as well as for blocking of the system by operator. The feature to manually block boron addition is provided to cater to situations when boron addition has to be stopped due to shim rod stuck while inside the reactor or if required boron addition has already taken place.

On the day of the incident, reactor was operating at about 75% Full Power (FP). Power supply to Reactor Regulating System (RRS) failed due to blowing of the fuses in their control unit. At that instant, one of the regulating rods was in slightly withdrawn position corresponding to the signal generated by RRS. The small positive reactivity existing led to increase of the reactor power. When "AP exceeded DP" alarm annunciated in control room, operator took a decision to block CAM to prevent addition of boron to moderator in order to prevent reduction in reactor power that might have led to possible poisoning out. Reactor power continued to rise slowly and 'Coolant Channel Outlet Temperature (COT) very high alarm' registered to actuate reactor setback. However, the setback was not effective, as shim rods had lost power supply and could not move. At 98%FP, the reactor tripped on ' high differential temperature across primary side of steam generator'.

During the previous few months, reactor was being operated at lower than rated power level, and in peaked flux configuration to optimize fuel burnup. In this configuration, the neutron flux peaks at the center and hence even at reduced reactor power level the central channels produce the same power as they would when operating at rated reactor power in the normal flat flux configuration. Thus in this configuration, the reactor power trip settings are required to be adjusted to 10% higher than the operating power. In this case the reactor overpower trip settings were not adjusted in accordance with the operating power level of 75% FP. Consequently when the reactor tripped at 98% FP, the central channels exceeded the specified limit by about 30% though it was within the safety limit. No failure of fuel took place.

During initial review of the incident, as the exact cause of the observed power rise could not be explained satisfactorily, the regulatory body asked the utility to shutdown the plant. Subsequently the various feedback coefficients were evaluated using the IAEA 69 neutron group cross-section library. This detailed analysis could explain the power rise observed during the incident and the reactor behavior during the incident. Reactivity devices worth's were also reevaluated using this library and were found to be conservative. Loss of Coolant Accident (LOCA) analysis for limiting critical breaks was also done, which indicated conservative results in terms of, reduced peak power and peak fuel clad temperature.

The regulatory body also directed the utility to carry out required modifications in the power supply system of adjuster rods to eliminate the possibility of common mode failure. The Utility was also asked to remove the provision of manual inhibition of ALPAS-CAM by the operator. Since these modifications were also applicable to the other unit of the power plant, the regulatory body asked utility to shutdown the other unit also to incorporate the modifications accordingly.

While the primary cause of the event was inadequate appreciation of safety aspects of operating the reactor at reduced power with peaked flux configuration, the other contributors were inappropriate reactor trip settings and inappropriate operator action. The incident was indicative of degradation in safety culture and reflected the operator's overriding concern for keeping the unit in operation. Therefore the regulatory body stipulated formal retraining followed by relicensing of all the frontline operating staff and the plant management personnel before restart of the units.

It was also observed during regulatory review that scheme of power supply to adjuster rods in the reactors constructed subsequently had been modified appropriately and was not prone to common mode failure. The utility was asked to strengthen the management systems pertaining to safety related matters and experience feedback, for ensuring that the design improvements made in any unit are checked for their applicability to all other units also.

Conclusions and recommendations

The fact that availability factors have increased significantly and the number of events requiring reporting has reduced does not necessarily indicate improved safety performance. The recent events as described in the paper indicate non-conservative decision making by operators coupled with lack of appreciation of the modified operating configurations of the reactor core. These events are characterized by factors like; operation beyond Technical Specifications, plant restart after an incident without complete analysis and without implementation of corrective actions, departure from approved procedures and inadequate attention to available plant information. While these factors relate directly to the events presented in the paper, it is possible to identify other factors also that may be indicative of non-conservative decision-making. Such factors can possibly be used as leading indicators to detect any decline in safety performance of the NPP.

The decline in safety performance can be caused because of actual or even perceived production pressures. This gradual degradation may go unnoticed in the wake of improved production performance. It is therefore suggested that events indicating non-conservative decision-making be studied in detail to identify leading indicators of degrading safety culture and safety performance. Also, the utility management and regulatory bodies should maintain enhanced vigilance, even when the operating plants show consistently high production performance.