ENHANCING SAFETY PERFORMANCE OF RESEARCH REACTORS AT TROMBAY

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Abstract

Based on various national requirements of basic research, material testing, isotope production, criticality experiments and research related to future power reactor program, Indian research reactor program encompasses a variety of reactors from simple pool type reactor Apsara to complex 100 MW reactor like Dhruva. To meet the varied and complex safety requirements of research reactors, a strong safety management system has also been evolved and nurtured. With over 150 reactor years of operating feedback, wealth of experience has been gained and safety enhancement has been kept as a continuously evolving process at Trombay. The 100 MW_{th} research reactor Dhruva has now completed more than two and half decades of operation. Based on a systematic In-Service Inspection (ISI) program, structured system performance monitoring & review and Periodic Safety Review (PSR) certain incipient failures in the system could be noted and corrected in time. Based on these reviews, certain mid-term safety upgrades in various systems of Dhruva were carried out. This paper will provide an overview of overall safety enhancement of research reactors, through refurbishment, and engineering changes.

1. INTRODUCTION

India has a three stage nuclear power program, with the ultimate target of thorium utilization for large scale energy generation. Research reactors have played a vital role in the development of national nuclear program. They have provided invaluable support in many ways, viz. testing of structural and fuel material, testing of equipment, shielding experiments, validation of codes etc. During the course of construction of these reactors several new technologies were also developed and adopted, which turned out to be the fore runners, for use in power reactors. In addition to the above these reactors have also provided lot of societal benefits, by way of radioisotope production. These isotopes have opened new vistas in the field of medicine, industry and agriculture in India.

1.1. Apsara [1]

Apsara was a swimming pool type, 1 MW reactor, fuelled with enriched uranium as Uranium–Aluminum alloy, clad with Aluminum. The core was suspended from a movable trolley in a SS lined pool 8.4 m long, 2.9 m wide and 8.0 m deep, filled with de-mineralized light water. It produced an average neutron flux of 10^{12} $cm^{-2}s^{-1}$. It attained first criticality on August 4, 1956. In view of the long service tenure of Apsara, it is planned to carry out extensive refurbishment and up-gradation of the reactor. For this, reactor has been shut down and de-fuelled.

Reactor will be upgraded to a 2 MW research reactor with a peak thermal flux of 6.2×10^{13} $cm^{-2}s^{-1}$ and fast flux of 1.3×10^{13} $cm^{-2}s^{-1}$. It is likely to commence operation by the end of 2012.

1.2. Cirus [1]

Cirus was a vertical tank type 40 MW_{th} reactor. The reactor was natural uranium fuelled, heavy water moderated, graphite reflected and light water cooled. It produced a neutron flux of 6.5×10^{13} $cm^{-2}s^{-1}$. It became operational in July 1960.

After four decades of successful operation, it started showing some signs of ageing. Hence, detailed ageing studies were carried out, which indicated possibility of substantial life enhancement by carrying out refurbishment of identified systems, structures and components. Refurbishment of the reactor was carried out from 1997 to 2002. Along with this, major safety upgrades were also carried out to meet present safety standards. Cirus has been permanently shut down in December 2010.

1.3. Dhruva [1]

Dhruva is a 100 MW_{th} tank type reactor, with metallic natural uranium as fuel, heavy water as moderator, coolant and reflector, giving a maximum thermal neutron flux of $1.8\times10^{14}\,cm^{-2}s^{-1}$. Reactor became operational on 8th August 1985.

Systematic In-Service Inspection (ISI), structured system performance monitoring & review and Periodic Safety Review (PSR), have been carried out. Based on these reviews, certain mid-term safety upgrades in various systems of Dhruva were executed. To combat obsolescence and aging, extensive refurbishment of certain reactor systems has been undertaken recently, without significantly affecting the reactor availability.

1.4. AHWR CF [1]

Advanced Heavy Water Reactor (AHWR) [1] is a proposed 300 MW_e power reactor. It is aimed at early utilization of thorium in the three stage nuclear program. For conducting lattice physics experiments for validating Advanced Heavy Water Reactor (AHWR) core design parameters, a 400 W reactor called Advanced Heavy Water Reactor Critical Facility (AHWR CF) has been commissioned in 2008.

2. SAFETY MANAGEMENT

Due to multiple objectives, research reactors have become more complex over the years. To meet the varied and complex safety requirements of research reactors, a strong safety management system has been evolved. Following important safety management principles are adhered to:

- Well structured operating organization;
- Detailed documentation;
- Adopting good practices and procedures for carrying out any activity;
- Quality assurance, technical audit and internal and external regulatory inspection;
- Authorizations for waste disposals with detailed reporting to the regulatory bodies;
- Periodic authorization to operate based on safety performance of the facility;
- Radiation safety with prompt investigations of exposures beyond investigation limits as per radiation protection rules;
- Engineering change management;
- Safety review of every reactor utilization experiment, in line with norms for new reactors and approval commensurate with the safety significance of the experiment;
- Event reporting and prompt reporting of violation of “Technical Specifications” (*within 24 hours*) to the regulatory body;
- Emergency preparedness and regular “Mock Emergency Exercises;”
- A multitier regulatory review.

3. ENHANCING THE SAFETY BY ENGINEERING CHANGE MANAGEMENT

Safety enhancement is a continuous process and introspection is required on regular basis. An effective change management system is necessary to identify weaknesses and to take corrective actions in time. There can be several weaknesses in the operating plant viz. weakness in the system configuration, material degradation and cultural degradation. Timely identification of these trends is necessary. Following are the important tools used for this viz:

- Systematically gained experience, with the reactor systems:
    - System and plant performance review by low level event reporting and analysis;
    - In Service Inspection (ISI);
    - Probabilistic Safety Assessments (PSA);
    - Dose Budgets;
- Experiences of other reactors and improvement in the safety norms:
    - Periodic Safety Review (PSR).

3.1. System and plant performance review by low level event reporting and analysis

Anomaly reports are a simple system of reporting events, which has been in existence in Cirus and Dhruva since their inception. The purpose of these reports was to highlight any deviation with in the permissible limit of the system or components from its intended design function, for important systems. Though these events do not fall in the category of ER (Event Reports) or SER (Significant Event Reports), analysis of these reports have indicated some incipient system deficiencies in time, so that significant events could be averted or significant improvements could be brought about in system performance or procedures.

As application of this approach, involves processing large volume of reported events, it is necessary to deal with them in an efficient manner, with graded approach. A quick screening of event information is necessary to ensure that all significant safety relevant matters are considered and that all applicable lessons learned are taken into account. The screening process should select events for further detailed investigation and analysis. However, for certain events which are either complicated or are having higher safety significance, a detailed analysis or additional investigation may be necessary in the form of diagnosis report. Classification and trending of data generated is carried out based on the circumstances under which the fault occurred and the causes which are responsible for these faults. This forms the basis for the system performance review. Other than the material or the process degradation, analyses of these anomaly reports also bring out cultural degradation in the plant. Reactor building air treatment plant, Main air compressors, machinery cooling water cooling towers, Class-II power supply motor alternator sets and various circuit breakers have been refurbished based on analysis of these anomaly reports. Some examples as to how, reporting and analysis of anomaly reports help in improving system performance are given below.

3.1.1. DG heater circuit and starting problem

For starting diesel generator, engine cranking is done with the help of air bottles holding compressed air maintained at 30 kg/cm^2. Three starting kicks are given to the diesel generators, of five second duration each. It was noted that, at times during the surveillance testing, the diesel generator would start only on the third kick. Since a detailed data base was available in form of anomaly reports, trending for the same was done to see if they had any common feature. Trend analysis indicated that most of the anomalies were seen only in winter season. The engine had a provision for heating its jacket cooling water, which was earlier considered to be redundant for Mumbai climate. However, on seeing this data the heater circuit was commissioned to maintain the jacket temperature at 35°C, since then DG are noted to be starting on first kick.

3.1.2. Simplification of fueling machine extractor and isotope rod locking mechanism

In Dhruva reactor, refueling operations are carried out during shut down. However, to fulfill the requirements of weekly delivery of radioisotopes for health care, the isotope tray rods are handled on power, for which certain innovative design features have been developed. Weight of isotope tray rod assemblies was increased by lead-filled shielding section to counter the up-thrust due to coolant flow. With this provision, the tray rod cannot get driven out from the channel even if it remains unlocked in pile with main coolant pumps operating. After incorporating this passive safety feature, tray rods are handled every week with reactor in operating condition. To enhance the reliability of the locking/unlocking, the locking mechanism of the tray rod, and extractor design was modified from pressing and rotating type to lock and unlock, to, pressing to unlock and releasing (*by spring*) to lock. With this feature the operation of the fuelling machine extractors and tray rod locking mechanism has become simple and more reliable.

3.1.3. Up-gradation of control & instrumentation for reactor and fuelling machine

The pneumatic instrumentation which was designed in mid-seventies was facing problem of obsolescence. Hence, all the control room and fuelling machine panels were replaced. Old pneumatic transmitters and indicators were replaced with electronics transmitters and chartless recorders. Also the alarm windows in control room were replaced from lamp type to LED type, for better service life. About 396 fuel channel direct reading flow gauges were replaced with electronic flow gauges for better maintainability.

3.2. In service inspection (ISI)

In service inspection (ISI) of SSCs is carried out as per approved ISI program at specified intervals. This helps in ensuring the healthiness of SSCs for continued operation or indicating the need for timely corrective action.

3.3. Probabilistic safety assessments (PSA)

Level#1 Probabilistic Safety Assessment (PSA) of Dhruva has been carried out to assess the reliability of safety systems, estimation of failure frequency of the initiating events and modeling of accident sequences towards giving the statement of core damage frequency. One of the areas where PSA has also helped in freezing the final scheme is up-gradation of the “Emergency Core Cooling System” (ECCS).

ECCS of Dhruva was up-graded to improve its reliability. Emergency Core Cooling System (ECCS) is provided, to ensure core cooling under Loss of Coolant Accident (LOCA). The earlier scheme of ECCS consisted of Sequence dump tanks (SDTs) for collecting leaked out heavy water, two SDT pumps, set of rupture discs and motorized injection valves for providing forward and reverse injection in the core on “Auto” or “Manual” following a completed LOCA signal. It also had provision for taking light water in SDT and injecting it in the core using SDT pumps, in case there was mismatch between the inflow and out flow in the SDT. This was done by remotely operated light water injection valve connected to Over Head Storage Tank (OHST).

Operation of ECCS had been very satisfactory over the years and there were no failures observed during the routine quarterly surveillance. It was upgraded to enhance its reliability by improving redundancy and diversity of the equipment such as SDT pumps and light water injection valve. Provision was also made for passive light water injection from OHST directly into the core, remotely from control room.

3.4. Dose budgets

Dose Budgets help in identification of areas prone to high dose consumption. One of the areas identified was the SFSB purification system resin handling facility. Design of Spent Fuel Storage Bay (SFSB) purification system is being upgraded to achieve reduction in plant dose consumption.

At the time of commissioning of this facility, it was designed as a regenerative system, and hence was not designed for handling high activity. However, due to change in the policy, to avoid generation of high activity level liquid waste, it was decided to stop regeneration of these resin beds. Fluidization and ejection of the exhausted resin through bare pipes was causing increased background field. Though these activities are remotely done, possibilities cannot be obviated of exposing the operating staff, in case of a problem. To circumvent this, completely standalone stainless steel hopper enclosed in a shielded cask has been designed, which is handled as a single unit. It is coupled with the system with help of quick disconnect couplings. Once the resin gets exhausted, resin hopper and the shielded cask together will be transferred to the waste management facility. The resin will be ejected, to another carbon steel hopper in a hot cell, polymer fixed and disposed in a tile holes. Resin hopper along with the shielded cask will be returned back to the plant for further use.

3.5. Periodic safety review

PSR is an important tool, for identifying weakness in the system configuration with respect to the latest safety norms in the nuclear industry. Based on these reviews, certain mid-term safety up grades in various systems of Dhruva Reactor were carried out, one of the major changes, an additional provision to take care of a prolonged station blackout condition, will now be described.

Shut down core cooling in Dhruva is maintained at the desired rate by three Auxiliary coolant pumps.These pumps are installed in parallel to the main coolant pumps.They cut in automatically on failure of all the main coolant pumps. Each Auxiliary coolant pump is provided with two prime movers, coupled on the same shaft. One is an AC motor with class II power supply and the other is a water turbine. The motive power for the turbine is the gravity flow of water from an OHST. This water after driving the turbine passes through the secondary side of the respective heat exchangers and subsequently is collected in the Underground Dump Tank (UGDT). Class-III driven make up pumps are used to maintain the OHST water level. Commissioning experience has indicated that OHST and UGDT itself can act as ultimate heat sink. Adequate inventory of water is maintained in OHST, to allow uninterrupted core cooling for a period of eight hours without any makeup.

To take care of an extended class IV and class III failure (*Station Black out*) due to any common cause, two independently located 125 kW DG sets were commissioned in the year 2000. They provide dedicated supply to OHST make up pumps, which can cater to shut down cooling requirements on the primary and secondary side indefinitely. Normally these DG sets are kept isolated from the regular class III system and are brought on line by manipulation of certain isolators. In addition, in 2009, two more emergency portable diesel engine driven pumps of 60 kW capacity have also been procured and commissioned, to augment the diversity and redundancy of OHST make up capability, through an independent line.

4. MANAGING THE ENGINEERING CHANGE

Managing the engineering change is a very important and multidimensional problem, with issues ranging from familiarity of the operator to the change, safety issues involved in the execution of the change and testing. Though these changes are carried out with reactor in shut down state, core un-loading is usually not considered while carrying out many of these changes for obvious reasons. While implementing these changes in the reactor systems, though the initial and the final system configuration are well analyzed and established, during the transition phase adequate care has to be exercised to ensure that the system configuration does not lead to an unsafe state, taking into account various possible failures of the system under commissioning. To ensure this requirement, the system change protocol follows a multitier review and approved procedure with adequate quality control in execution of the changes.

Important issues which were addressed, while managing these changes are as follows:

- As the actions expected from the operating staff have to be completed in a limited time frame, their experience and suggestions were given due importance. Feed back of the operators was considered from the conceptual design stage itself;
- Adequate interactive sessions were held with the operating staff to emphasize all the changes and benefits likely to accrue from these modifications to familiarize them, before implementing these changes. A detailed document highlighting all the changes was made available to the operating staff to increase their awareness. In certain cases, a mock facility was provided, which became more helpful in place of discussion and documents;
- Draft modified documents related to change; including EOPs, SARs, drawings and operating policies & manuals were made available to the operating staff before implementing the modification. Final documents were made available on completion of the modification, before reactor startup;
- Formal authorization sessions were held to check the proficiency of the operators based on the nature and extent of the changes being carried out;
- Safety approval for the design of the new system was obtained from plant management and various regulatory authorities based on the safety significance of the system being modified;
- Detailed procedures were prepared, giving sequential steps for the execution of the change, including perquisites for initiating the job, verification by third party and a test plan. Based on the safety significance of the changes being executed, change implementation schemes were approved by the plant management or by regulatory body.

Following issues were considered for preparation of detailed procedure giving sequential steps for the execution of the change:

- Systems, Structures and Components (SSCs) likely to get affected during execution of these changes, their safety significance, based on the role of these SSCs in Safety Analysis Report (SAR), Emergency Operating Procedures (EOPs) or minimum monitoring requirement of the technical specifications;
- Time duration for the unavailability of the respective SSCs, alternative arrangements and the class of these arrangements, vis-à-vis the class of the original SSC. Commissioning of the alternate arrangements, confirming that the alternate arrangement is performing satisfactorily;
- Action plan to deal with Anticipated Operational Occurrences (AOOs), while these changes were being incorporated, considering failure of the systems to perform under commissioning. Advance checking of the SSCs required for mitigating these situations;

- Detailed qualification tests to be carried out and acceptance criterion;
- Adequacy of the simulation tests and their differences with respect to the actual testing required.

5. CONCLUSION

Experience has shown that the precursors of a significant event are present long before the significant events occur. Many of the precursors present, as vary gradual degrading safety culture and plant material condition. Effective trending and analysis provides early identification of the accumulating less significant, low impact events and provide opportunity to take effective corrective actions prior to the occurrence of more significant events, this is an important contributor in improving safety.

Periodic Safety Review helps in identification of weaknesses in the plant configuration. Though on many occasions, complete adaptation of new system designs is not possible in an existing reactor, however, if the concepts are understood and the system configuration are suitably modified to adopt the spirit of these changes, substantial improvement in the safety performance of the plant can be brought about.

Regular ISI, PSR and analysis and trending of the low level events are very effective tools for improvements in the safety performance of the plant.

REFERENCES

[1] “India's Reactors: Past, Present, Future,” Nuclear Engineering and Design **236** 7–8 (2006) 681–930.