Safety Enhancement of Dhruva Reactor through Periodic Safety Review

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Abstract- Dhruva is a natural uranium metal fuelled, heavy water moderated, cooled and reflected research reactor of 100 MW^{th} capacity. Dhruva attained first criticality on August 8, 1985. As part of the regulatory requirement every operating facility including research reactors, shall carry out a Periodic Safety Review (PSR) once in every 10 years. A comprehensive Periodic Safety review of plant was carried out to continue operation beyond May 2014, taking into account the cumulative effects of plant ageing, modifications carried out over the years and the feedback of operating experience. The review was carried out based on safety factors suggested in safety manual BSCS/SM/2010/1 Edition; R-0, March-2010 issued by the apex safety body of BARC. Before a PSR is started, an agreement between the operating organisation and the regulatory body indicating the scope and objectives of the PSR, its schedule and expected outcome was made. Based on these reviews, certain mid-term safety up grades in various systems of Dhruva Reactor was carried out. This paper provides an overview of overall safety enhancement of the research reactor carried out following PSR.

1. Introduction

First criticality of Dhruva was attained on August 8, 1985 after due approval of regulatory body. Stage wise approvals of regulatory body were obtained for light water commissioning, heavy water addition, fuel loading and power operation of the reactor. Since then, regular operation of the reactor was continued, with due safety reviews at regular intervals and periodic regulatory inspections by regulatory body. First PSR was carried out and submitted to regulatory body in the year 2014. Based on PSR, Dhruva got authorization for operation up to May 2019.

2. Procedure for PSR

Following are the salient features of the safety guide, provided by BARC Safety Council (BSC) for conducting PSR.

- The operating plant management should initiate comprehensive PSR **two years** prior to expiry of the authorization for operation.
- Operating organization should work out **the specific requirements of PSR** for their facility following a **graded approach**.
- The mutually agreed upon scope and requirements for PSR would constitute a **reference level** for the review and will remain unchanged for the duration of PSR.
- An application for renewal of authorization for operation shall be submitted to regulatory body at least **three months** before the expiry of operation.
- **Starting point** of PSR is the time of agreement between operating organization and regulatory body on the general scope of requirements of PSR and its expected outcome. The **end point** of PSR is the approval by regulatory body of an integrated of corrective actions and/or safety improvements.

- In order that PSR is completed within the agreed schedule, a detailed **action plan** should be prepared.
- Before the start of reviews, the **senior management** should **approve** the action plan.

PSR was started with an agreement with regulatory body. Following points were fixed in the agreement as a reference level:

- Scope
- Objective
- Time schedule
- Expected outcome from PSR

2.1 Scope of PSR

PSR was prepared based on the plant data for ten years, from 2003-2012. Following operational safety aspects for ten years were reviewed:

- Adherence to technical specifications for operation
- Review of annual plant performance reports
- Review of Anomaly reports, Event Reports & Significant Event Reports
- Radioactive releases to the environment
- Radiation exposures
- Technical and procedural modifications
- Industrial safety
- Safety committee recommendations and compliance to same
- Reports of periodic Internal Regulatory Inspection
- Reports of Regulatory inspections and compliance to their recommendations

Beyond the review of above documents, PSR of Dhruva was intended to take into account:

- The cumulative effects of plant ageing
- Modifications carried out over the years
- The feedback of operating experience

For a comprehensive review of safety, **applicable safety factors** based on the guide lines provided in safety manual issued by the regulatory body were considered.

2.2 Time schedule

Based on the guidelines provided in the safety manual, the time schedule for conducting PSR was made in such a way that every committee will get sufficient time for review and for giving recommendations. Time schedule subsequent to submission of proposal to Plant Level Safety Committee (PLSC) was as follows:

Sr.	Event	Date
1	Submission of PSR proposal to Unit Level Safety Committee (ULSC)	18 months before final submission
2	Submission of PSR proposal to Operating Pant Safety Review Committee (OPSRC)	17 months before final submission
3	Submission of PSR proposal to regulatory body (BSC)	16 months before final submission
4	Submission of PSR report to PLSC	9 months before final submission
5	Submission of PSR report to ULSC	6 months before final submission
5	Submission of PSR report to OPSRC	3 months before final submission
6	Submission of PSR report to regulatory body (BSC)	1st week of February 2014

2.3 Objective of PSR and its expected outcome

- The review of documents of operational safety aspects will provide necessary inputs for concluding **overall safety culture** of plant, trends of radiation exposure and release of radioactivity to environment.
- The PSR is intended to find out **weakness in structure, system and components (SSCs) due to ageing** and suggest corrective action towards ensuring safe and uninterrupted operation of reactor, considering the plant modifications carried out and corrective actions taken by the plant.
- The PSR of Dhruva Reactor is intended to be utilized for **reauthorization of Dhruva Reactor for operation.**
- PSR will also address issues related **residual life of SSCs**, ageing studies to be conducted and refurbishment requirements.
- It is also expected to generate monthly report / annual reporting format for each division, which will become input for conducting PSR such that to minimize time required for conducting next PSR.

In order to complete PSR in agreed schedule, detailed **action plans** were prepared which identifies all the activities to be performed for the PSR time frame and responsibilities. The action plans were submitted to senior plant management and necessary approvals were obtained. A **task force** was constituted to conduct PSR and to prepare report on PSR of Dhruva reactor.

3. Safety factors review

For a comprehensive review of safety, the following **fourteen safety factors** were selected and considered sufficient. These safety factors are divided into five subject areas to facilitate the review. For PSR; all safety factors have been addressed and reviewed. For each factor, necessary applicable inputs were considered and outputs were reviewed.

Plant
- Plant design
- Actual condition of SSCs
- Equipment Qualification
- Ageing

Safety Analysis
- Hazard Analysis
- Deterministic / Probabilistic Safety Analysis

Performance and Feedback of Experience
- Safety Performance
- Radiological protection
- Use of experience from other plant and research findings

Management
- Organization and administration
- Safety documents and Procedures
- The human factor
- Emergency planning

Environment
- Radiological impact on the environment

Quality and safety culture are not considered to be separate safety factors as these should be an integral part of every activity affecting safety.

3.1 Plant design

Review: Dhruva Reactor was designed and constructed as per prevailing standards and guides for Nuclear Reactor at that time. Design documents were reviewed. Over a period of time, various modifications carried out in plant design were checked. The records after carrying out modifications were noted to be updated appropriately. Plant performance/safety factors like availability factor, capacity factor, number of reactor trips and number of planned as well as unplanned shutdowns were reviewed. The present plant design was compared with safety standard **IAEA NSR-4**. Each requirement of this safety standard have been scrutinised and observed to have implemented for Dhruva.

Conclusion: Several modifications implemented by the plant have enhanced the safety. Trending of performance indicators depicted that plant health was in good condition for the period of PSR.Based on revised seismic standards and Beyond Design Basis Flood Level (BDBFL), safety margins for these conditions are to be enhanced. Mitigatory planning has been done. Work towards these, has been started and under progress.

3.2 Actual condition of System, Structure and Components (SSCs)

Review: Ageing is a natural phenomenon and due to this it is well understood that SSCs will undergo deterioration with time. To determine actual physical condition of SSCs as far as possible, status records with respect to inspection, modification, developments and maintenance were checked and reviewed. No abnormality was noticed. After adopting elaborate methodology, list of components important to safety was prepared. The results of various surveillances tests on safety related systems were reviewed and no abnormality was noticed. Their performance was satisfactory. Maintenance records of the SSCs were checked and found normal. Dhruva was ensured to be operated within limiting conditions of operations (LCOs) which ensure safety in all operational states. For assuring healthy condition of SSCs, a comprehensive surveillance programme exists in the Dhruva.
Conclusion: Based on review it is concluded that the plant systems, structures and components are performing as intended. Plant has adequate number of procedures, schedules and resources to physically assess their conditions and restore them to desired state, should the need arise. Based on various surveillance tests conducted on different safety related systems during the reporting period, it is concluded that the performance of safety related systems is satisfactory.

3.3 Equipment qualification

Review: All the equipment and components important to safety are required to perform intended safety functions under postulated service conditions including those arising out of natural events and accidents e.g., floods, earthquake, loss of coolant accidents, etc. Thus equipment and components important to safety are qualified to ensure their capability to perform their intended functions under normal as well as accident conditions as stated above. It is also ensured that the Qualification is preserved throughout its installed life. In case of Dhruva reactor, equipment & component important to safety are identified and there qualification is done at the material stage, fabrication stage, erection & commissioning stage and Operation & Maintenance (O&M) stage. Qualification status is reviewed and documented at the pre-determined periodicity to gain confidence about its intended performance. All the equipment important to safety has been considered for equipment qualification. Equipment qualification methodology was reviewed. Preservation of equipment qualification in the form of Maintenance records, in-service inspection records, testing, calibration, repair & replacement records were reviewed. Equipment qualification of various systems like reactor protection system, Primary Shutdown System, Back up shutdown system, Main coolant system, Emergency Core Cooling System, Control & Instrumentation Systems and Emergency Cooling Systems were reviewed.
Conclusion: Based on performance of all the equipment and components important to safety, it is concluded that these systems and components performed as intended.

3.4 Ageing management

Review: Ageing management is one of the most important safety factors for the plant which has seen more of operation. List of all important SSCs have been prepared. Ageing mechanism for SSCs and its impact on safety function was reviewed. In-service Inspection programme was reviewed.

Conclusion: Ageing monitoring methods and procedures to replace aged components exist in the plant for taking timely mitigating measures. Technological obsolescence had been overcome by installing new components of latest technology. The performance of the systems has been maintained/ improved over the years. This has been possible due to several modifications and upgradations. In-service Inspection programme and inspection/analysis programme based on ageing management review assure adequate confidence to operate the plant safely in the coming years. Various corrective actions have been taken and some have been planned based on ageing indicators. Non Destructive Testing (NDT) of Dhruva Civil structure has been initiated for assessment of health of civil structure and to predict residual life of structure by checking half potential and carbonization. Ageing Management Program will be formulated.

3.5 Hazard analysis

Review: Hazard analysis for Dhruva reactor due to internal hazards like fire, internal flooding, and explosion, missile attack due to detachment of main coolant pump flywheel, toxic gas release from internal sources and criticality was carried out. Hazard analysis due to external hazard flooding (due to rains or tsunami), seismic hazard, and toxic explosion was carried out.
Conclusion: Plant preparedness to mitigate the consequences of internal hazards is found to be adequate. Plant preparedness to mitigate the consequences due to external hazards such as beyond design basis flooding and seismic hazard is being enhanced as per current standards and safety requirements.

3.6 Deterministic/probabilistic safety analysis

Review: Deterministic safety analysis and probabilistic safety analysis for Dhruva have been carried out. All possible Postulated Imitating Events (PIEs) have been considered during deterministic analysis. Level-1 PSA for full power operation with internal initiating events has been performed. Overall core damage frequency (CDF) for Dhruva is 4.8 X 10^{-5}/year. Level -1 PSA analysis extended to a limited scope of level-2 analysis considering LOCA and containment failure. As a part of this, containment event tree was modelled.This analysis along with deterministic insight available at Dhruva indicated that likelihood of this scenario is 3.4 X 10^{-6}/year. Consistency of the accident management programme for Beyond Design Basis Accident with PSA results was reviewed. BDBAs due to both internal and external events have been reviewed. Internal events like Class-IV failure along with failure of class-III +class-II + shutdown cooling system, Loss Of Regulation Accident with failure of main cooling system + shutdown cooling system, Class-IV failure along with failure of primary shutdown system + back up shutdown system, Loss of coolant accident(LOCA) along with failure of Emergency Core Cooling System (ECCS) were considered for estimating CDF.External events like earthquake, flooding due to rains /due to tsunami , storm surge, air craft crash were considered.
Conclusion: Radiation doses during accidental conditions following LOCA accident with ECCS available found to be within limit. Plant is having well prepared and easy Emergency Operating Procedures (EOPs) to be carried out to take care of Severe Accident conditions. Plant is capable of mitigating the consequences of severe accident and long term stable state of reactor is achievable.

3.7 Safety performance

Review: The objective of the review was to determine Safety Performance of the plant and its trend from the records of operating experience. Plant found to have adequate system for identifying, Classifying and Reporting of Safety Related Incidents. Events and Significant Events happened in the plant have been reported in the proper formants of the reports. There has been adequate mechanism for Root Cause Analysis (RCA) and feedback of its result. Trend analyses of safety related data from 2003-2012 was carried out. Trend analysis of Chemistry related safety data was carried out. Analysis of frequency of Safety System demands and actuations was carried out. Trend analysis of frequency of unplanned trips was carried out.
Conclusion: Review indicated trips and unplanned shutdown decreased. The demand of safety system was observed to have decreased indicating improvement in plant performance. Safety system was available during all the time. Trend of chemistry parameters indicated that except on few occasions with known cause, there were no Technical Specifications violations. In nut shell plant performance was excellent.

3.8 Radiological protection

Review: During review of this factor, plant doses for the period of 2003-2012 were checked. Internal and external exposure data of plant personnel was reviewed. Plant dose consumption showed a reducing trend over the years. Plant dose was well within the budget estimate.In 2008, the neutron dose was highest. Formal investigation was carried out by RHC unit. In year 2010 the tritium dose consumption was highest. It was due to a planned job in Main Coolant System. Overexposure investigation is carried out as per the exiting procedures. There were no cases of genuine exposure.
Conclusion: Review indicated that plant has operated safely without any radiological hazard to the plant personnel.

3.9 Use of experience from other plants and research findings

Review: Information from national and international agencies on Operating Experience from Nuclear Power Plants and Research Organizations in India and abroad is obtained at Dhruva Reactor in the form of reports issued by these plants and through various other channels of communications as well as visits to the facilities by the plant personnel. Information of operating experience is being disseminated all levels through meetings and colloquiums. Based on incidents and accidents in nuclear power plants of India and abroad, plants have taken various corrective actions and some actions are under progress to avoid recurrence of such incident in Dhruva.
Conclusion: This safety factor indicated that plant management is very well aware about operating experience review elsewhere as well as for removing latent Safety Weakness which might result in undesirable impact. An informal system of information sharing is present and various actions have been taken in the plant based on incidences those have been taken place in Indian Nuclear Power Plants, such as Fire in Narora Atomic Power Station (NAPS), tripping on Kakrapar Atomic Power Station (KAPS) on high thermal power and Fukushima Nuclear Accident. Hence though a formal set up is not in place, lessons learnt are well implemented at Dhruva. A formal system for obtaining information from Atomic Energy

Regulatory Body (AERB)/Nuclear Power Corporation of India Limited (NPCIL) will be introduced.

3.10 Organization and administration

Review: Document consisting of roles and responsibilities of individuals and groups was reviewed. Responsibilities/roles are clearly mentioned. Functional organization chart is available and found up-to-date.
Conclusion: Functional responsibilities and powers of various management positions of the organization to conduct safe, orderly and efficient operation of the reactor is well recorded in Technical specification of Dhruva.

3.11 Procedures

Review: Adequate plant procedures & documents are available in the plant. The revision of these documents is carried out as per the plant policies. Adherence to procedures is strictly ensured for all the activities at Dhruva. The procedures which do not have changes are approved as Standard Operating Procedures (SOPs). All the Operation and Maintenance activities are carried out as per approved procedures which are issued as and when the job is planned. Plant is having well maintained and revised Technical Specification, Safety Analysis Report (SAR), operating & design manual and Quality Assurance manual. The plant is having normal Operation & Maintenance (O&M) procedures, Quality Control and Inspection Procedures and Work Permit Procedures. The plant has Emergency Operating Procedures (EOPs). Periodic review and revision frequency of these documents have been fixed and found to be adequate. All the procedures at Dhruva found to be clear, unambiguous, well-structured and understood by concerned O&M staff.
Conclusion: It is concluded that adequate plant procedures and documents are available in the plant. The revisions of these documents are carried out as per the plant policies.

3.12 Human factors

Review: The objective of the review was to determine the status of various human factors essential for safe operation of the reactor, as these factors influence the safe operation of reactor. The status of human factors was reviewed so that these factors do not contribute to an unacceptable level of risk. The review included staffing, selection, training and the man-machine interface. The plant is having adequate qualified staff. Licensing procedure found to be adequate. Interview for licensing and relicensing are being arranged as per guidelines and requirements. Training and refresher training are being arranged. Man-machine interface was well considered while carrying out Main Control Room upgradation and control & instrumentation upgradation. All plant staff has been sent for medical check for the reporting period.
Conclusion: During review it was felt that implementation of Supplementary Control Panel (SCP) and Simulator will enhance plant safety and operators output. So, in nut shell it can be inferred that human Factors are well considered by plant and plant will continue to ensure/enhance these aspects for safety of plant and personnel

3.13 Emergency planning

Review: During review of this safety factor; all the related documents and records were checked. The documents include Standing fire order, plant radiation emergency procedure and radiation protection manual. The document found to be up-to-date and revised as and when required. The plant has well defined strategy and organization spelt out in a Plant Radiation Emergency Procedure. The effectiveness of the procedure is checked during Emergency Exercises and these have been found to be adequate which are verified from Emergency Exercises Reports. Training and Retraining is being given to all the plant/ site personnel regarding familiarization of the procedure. Transportation and communication facilities found to be adequate. Adequacy of all on-site Equipment for emergencies was checked and found okay.
Conclusion: Based on review of emergency preparedness of the plant, it is concluded that plant is having required emergency planning, procedures, documents, training and emergency exercise to provide adequate protection against accidental release of radioactivity.

3.14 Environment

Review: During review of this safety factor, no deviation or abnormality was noticed. Gaseous release from Dhruva stack during the period was well within the limit and there was no adverse consequence on the environment. Solid and liquid waste disposal was within the authorized limit. The bore well data for the period was checked and found normal. All environmental data was noted to be collected as per schedule to ensure no abnormal effect on environment.
Conclusion: It is concluded that plant has operated safely and there was no unplanned discharge of radioactive effluent from plant to environment. All discharges were well within the limit.

4. Safety culture

Based on review it is concluded that safety has been ensured at regular intervals by following mechanism:

1. Monitoring of plant performance on annual basis and analyzed to understand weakness in any area, if any. Corrective actions are initiated as and when required.
2. Plant is operated within Limiting Conditions of Operations as per technical specifications.
3. Performance of safety systems and safety related systems are monitored at regular intervals.
4. Physical condition of plant is assessed at regular interval by functional testing, In Service Inspection programme, ageing management programme.
5. Radiation protection and release of activity to environment is monitored at regular intervals.
6. Plant has emergency plans, qualified staff and equipment for preparedness.
7. Plant is having required Organization & Administrative structure and their responsibilities are well defined.
8. All safety factors (fourteen in numbers) have been addressed which provide assurance that Dhruva can be operated safely for the next ten years.

5. Outcome of PSR

Based on PSR and various standards and directives given by safety committees, following are the action plans implemented by plant to enhance safety further and some actions plan will be implemented in given fixed time frame:

1. Following regulatory body recommendations post Fukushima event, Unit Level Safety Committee recommended installation of seismic instrumentation and **incorporation of seismic trip in Dhruva.** Based on heavy flooding in Mumbai, 2005 and tsunami, two number of trolley mounted **Engine Driven Pumps** were installed and commissioned in 2011 for making up of OHST water to ensure uninterrupted shutdown core cooling, during knocking out of all supply sources. One trolley mounted pump will be installed at higher elevation to safeguard against **Beyond Design Basis Flood Level (BDBFL).**
2. Underground dump tank vent pipes will be suitably modified to avoid entry water due to BDB flooding.
3. Replacement of all diesel generators sets to combat technical obsolescence is planned to keep one diesel generator set at higher elevation to take care of flooding in view of new **BDBFL**. Also this will take care of the failure of all DG sets due to common cause failure. Seismically qualified Building construction is under progress and will be completed shortly.
4. As a result of PSR, **supplementary Control Panel (SCP)** was commissioned. It is back up to **Main Control Room (MCR)** and will carry out all safety functions during inhabitability of MCR. It is physically isolated from MCR. It provides protection against fire or any other reason of inhabitability in MCR and is in different fire zone.
5. As a result of PSR, **new BDB flood proof pump** house was constructed which housed additional two motor driven makeup pumps with separate line for Over Head Storage Tank (OHST) makeup to ensure uninterrupted core cooling.
6. Provision of **Hook up points** has been given for direct connections of fire tenders in case of unavailability of elevated pipelines/ OHST or water degradation.
7. Provision of fire hydrant water connection has been given in Spent Fuel Storable Building (SFSB) for bay make up.
8. Preparation of equipment qualification list and completion of required qualification of equipment for **Loss of Coolant Accident (LOCA)** condition was identified and is being implemented.
9. Dhruva reactor seismic analysis was carried out during design stage as per IS-1893-1975. Seismic qualification of system structural components as per current standard using Tarapur site spectra is in progress. New equipment is being seismically qualified. Task force has been constituted. It will complete seismic qualification and retrofitting action if required. It will be done in one year time.
10. Provision of submersible pump to pump out dump tank water to Overhead storage Tank (OHST) is being considered.
11. Provision of solar powered lighting in view of knocking down of all power supply sources during seismic as well as flooding events.
12. As a result of PSR; to enhance confidence of operating personnel for reactor operation, **a Dhruva Simulator** was designed, installed and is being commissioned.
13. Plant capacity to withstand air craft crash will be evaluated and action plan will be submitted to regulatory body.

6. Conclusion

Based on review as discussed above, the plant preparedness and capabilities to perform safe operations within specified operational limits and actual condition of SSCs important to safety, it is concluded that the plant was operated safely. In view of safety culture adopted by plant, plant can be operated safely for next ten years without any risk to members of public, plant personnel and plant.

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