

Safety Management and Effective Utilization of Indian Research Reactors APSARA, CIRUS and DHRUVA

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Abstract: Research Reactors Apsara, Cirus and Dhruva are located at Bhabha Atomic Research Centre, Mumbai, India. These research reactors have played very important role in developing India's nuclear energy programme and in establishing the safety basis for the related activities. Due to diversity in their design, operating power levels and utilization aspects, a slightly flexible and graded approach is necessary for managing safety in these research reactors. Special attention is necessary on account of several irradiations and experiments that are carried out in these facilities. For ensuring continued safety during the operating life of the research reactors a well planned safety management system is in place. The paper outlines the safety management system practised in these research reactors with details of its essential elements. Some important utilization of research reactors Apsara, Cirus and Dhruva, modifications incorporated and up gradation proposed to enhance utilization are also described.

Introduction:

Research Reactors Apsara, Cirus and Dhruva are located at Bhabha Atomic Research Centre, Mumbai, India. Apsara, a swimming pool type reactor with maximum design power of 1MWth is in operation since 1956. Cirus (40MWth) and Dhruva (100MWth), both tank type reactors were commissioned in 1960 and 1985 respectively. These research reactors have played very important role in developing India's nuclear energy programme and in establishing the safety basis for the related activities. Apart from utilization of neutron beams for conduct of research in many areas, these research reactors have also provided basic and essential facilities for training scientists and engineers for our nuclear power programme and for production and application of radio-isotopes in the field of medicine, agriculture and Industry. Development of our research centre, Bhabha Atomic Research Centre, took place around these research reactors and led to the generation of expertise in several other related fields such as radio-isotope processing, management of radioactive waste, fuel chemistry and radiochemistry, radiation protection and emergency preparedness. Research reactors Cirus and Dhruva have nearly all important features of a power reactor excepting steam generating equipment and thus provided experience in design construction and operation which could be gainfully used in our nuclear power plants.

Operating experience of Apsara and Cirus enabled Indian engineers and scientists to gain an in depth understanding of the intricacies of controlling fission chain reaction and safe management of a large nuclear reactor plant. Safety has been given paramount importance in operation and maintenance of these research reactors. Our safety management programme started with the commissioning of Apsara. In the initial days, weekly meetings were conducted at Apsara for scheduling irradiations and clearing proposed experiments. Concept of safety committees and safety reports (used to be called Hazard Evaluation Report at that time) started with Apsara. Development of a formal safety management programme was one of the parallel activities during construction and commissioning of Cirus. By the time work on Dhruva project started, a strong safety management system, evolved over the years, was already in place. Operating experience gained in commissioning and operation of Dhruva was further

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utilized in fine tuning the safety management system for our research reactors. Salient features of Apsara, Cirus and Dhruva are produced in table-1

Table 1. BASIC FEATURES OF RESEARCH REACTORS AT BARC

No.	ITEM	APSARA	CIRUS	DHRUVA
1.	Reactor type	Pool type	Tank	Tank
2.	Date of criticality	Aug 4, 1956	July 10, 1960	Aug 8, 1985
3.	Nominal thermal power	1 MWt	40 MWt	100 MWt
4.	Fuel	HEU in U-Al Alloy form-Al Clad Flat plate	Nat. U metal rods clad in Al	7 element cluster of Nat. U metal rods in Al clad
5.	Fuel inventory	4.5 kg of U-235	10 Te	6.5 Te
6.	Thermal neutron flux (n/cm ² /s)	1 x 10 ¹³	6.5 x 10 ¹³	1.8 x 10 ¹⁴
7.	Moderator / coolant	Light water	Heavy water / Light Water	Heavy water
8.	Shutdown / Control devices	Cadmium plates	B ₄ C filled rods	Cadmium rods

Safe Management of Apsara, Cirus and Dhruva:

Principal goal of research reactor safety is to keep radiation exposure of plant personnel and members of public as low as reasonably achievable in all operational states and accident conditions. To achieve this goal, nuclear reactors are designed, constructed and operated to a very high level of quality to minimize the likelihood of failures which could lead to the escape of significant quantities of radioactive material. The design process incorporates defense in depth philosophy through multiple levels of protection. To incorporate defense in depth, provision of multiple means for ensuring each of the basic safety functions, i.e. reactivity control, heat removal and the confinement of radioactivity are made. Escape of radioactive material is restricted by providing successive physical barriers such as fuel cladding, reactor coolant boundary and containment or confinement.

Design, manufacturing, and commissioning inspections/tests are carried out to provide an adequately defect free product at start up of the reactor. To ensure that the research reactors are operated within the design limits and provisions for safe operation made in the design, do not degrade during the life of the research reactor a safety management system is established. A well evolved and time tested system is in place for safe management of Apsara, Cirus and Dhruva. The main constituents of the system are briefly described here. Safety culture does not figure as constituent as each constituent of our safety management programme aims towards enhancing safety culture.

Operating Organization:

A well structured organization set-up with clearly defined roles and responsibilities of its constituents is an important ingredient of safety management system. Reactor Group, BARC has the over all responsibility of operational safety of the research reactors located at Trombay. There exists a well defined hierarchical structure and line of communication, authority and regulation among operating organization, regulatory agency, health and safety organization, maintenance and services organization and quality groups, and experimenters, to facilitate smooth and safe functioning of the research reactors at BARC. Each research reactor is headed by a reactor superintendent, who is responsible for safe and orderly operation of the respective research reactor in accordance with the Technical Specifications. Organization chart for each research reactor clearly shows the lines of authority, communication and regulation among various agencies.

Documentation:

The documentation is a vital part of the operational safety management of our research reactors. The documents such as Design Basis reports covering design aspects, Safety Analysis Report giving the results of safety analysis, Technical Specification, Quality Assurance manual, In-Service Inspection Programme, Emergency Operating Procedures, Radiation Emergency Procedures, Plan for the regular emergency exercises and tests, Operating & maintenance procedures for normal operation, Process & Instrumentation Diagram for all the process and safety systems form part of regular operating documents. These documents are reviewed and updated periodically.

The Technical Specifications for operation of the respective research reactor is the most important document. The various documents listed above provide the bases for the clauses of the technical specification. This document contains the safety policy, Operational Limits and Conditions (OLCs) for reactor systems, surveillance requirements and administrative controls. The administrative controls cover functional organization chart, requirements of licensing for operating staff, O&M procedures, plant records, reporting, and functions of safety review committees. This document is reviewed and approved by the regulatory body. Any change in this document requires approval of regulatory body. Strict adherence to the technical specification ensures operational safety of the research reactor. Any violation of the technical specification clause is taken seriously and reported promptly (within 24 hours) to the regulatory body.

Procedures and practices:

Several good operating practices like special work permits for maintenance activities including jumpering of interlocks, issuance of written valve slips for effecting valve status changes, checklists for routine jobs requiring number of sequential activities, window form for routine jobs, issuance of transfer slips for fuel movement, pile irradiation requests for irradiation of samples, approved refueling agenda for reactor refueling, close attention to chemistry of fluid systems are practiced. These practices led to development of a strong safety culture wherein all plant personnel are conscious about safety importance of their actions and are proactive about maintaining and enhancing safety.

Approved Emergency Operating Procedures for postulated off-normal conditions are available. These procedures are reviewed and revised periodically. Duly approved special procedures for non-routine safety significant activities are issued before taking up the activity. Care is taken in selecting such procedures to keep their number to a bare minimum to avoid dilution of their significance and the involvement of personnel in carrying out the procedures. Depending upon their safety significance some of these procedures are reviewed and approved by safety committees.

Our experience is that simple procedures written in collaboration with plant personnel highlighting the safety significance of each step are valued and are less likely to be bypassed compared to cumbersome procedures prepared in isolation.

Emergency preparedness

In line with international practice, two types of radiation emergencies are considered for research reactors at Trombay, namely, plant emergency and site emergency. A detailed radiation emergency preparedness plan is prepared bringing out the responsibilities of various agencies, including the site emergency control centre, security staff, transport section, BARC fire services section, medical division etc., and the follow-up actions required are unambiguously laid down. The instructions in concise form with key elements are also displayed at strategic locations. Periodic plant radiation emergency exercises and fire drills are carried out (once a year) with an objective to assess the response of various agencies including plant staff and to ensure that the emergency provisions are in 'Ready' state to cater to the possible emergency scenario. Based on the feed back of these exercises emergency procedures are revised appropriately and training / retraining programme is further strengthened.

Radioactive waste management

Management of radioactive waste forms an important aspect in the operation of research reactors. Provision exists for segregation and storage of solid and liquid radioactive waste based on their activity / radiation levels. The solid, liquid wastes are treated and discharged only after ensuring that the authorized limits as set by the regulatory authority are adhered to. The gaseous wastes are treated by effective filtration before they are released through the stack. All discharges are monitored and recorded to estimate the dose to public which is maintained well below the prescribed limits. All the activities related to radioactive waste management are recorded and communicated to the regulatory authority periodically.

Radiation safety

Occupational health and safety is given prime importance towards ensuring that the radiation exposure to plant personnel, members of public and environment is kept well within prescribed limit and as low as achievable.

Area radiation monitors have been provided in each research reactors in various areas of the plant and the status is displayed in the control room. The areas around the plant are monitored by taking periodic samples of air, soil and plantation. A number of bore-holes are provided to monitor any ingress and transport. All radiation workers are monitored for keeping their exposure to radiations well within stipulated limits. An annual person mSv budget is prepared in advance and is approved by regulatory body. Assessment of the station dose is carried out periodically by Operation Review Committee to ensure dose consumption to be within budget.

Reactor Utilization and modifications

Research reactors are utilized for many applications, which include radioisotope production, basic research using neutron beams, neutron activation analysis and testing of experimental fuel and other assemblies. Some specific utilization may require introduction of experimental devices into or near the core or reflector region of the reactor. In some cases it may be necessary to carry out design modifications to permit conduct of experiments

Experimental requirements are given special consideration because they can cause direct hazards from their failure or indirect hazard by affecting the safe operation of the research reactor or increase the hazard from an initiating event by their impact on the event sequence. Hence, the design of every proposed experiment and associated modification is done in accordance with the same principles that apply to the design of the reactor itself.

Utilization and modification proposals having major safety significance are subjected to an initial safety analysis to determine whether the change is within the operational limits and conditions. Depending on the results of the initial evaluation, a more detailed and comprehensive safety

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assessment is carried out and approval of safety authorities is obtained before implementation. The procedure to be followed for raising and processing of modification proposals in APSARA, CIRUS and Dhruva is well documented.

Routine irradiations such as irradiation of target materials for isotope production or neutron activation analysis are carried out as per established procedures through Pile Irradiation Requests. Evaluation of the requests takes into account the effect of the proposed irradiation on core reactivity, sample cooling requirements during irradiation and shielding requirements during post-irradiation handling.

A register is kept in the control room of each reactor for recording any suggestion on improvement of systems from O&M convenience and/ or radiation and industrial safety consideration. These suggestions are discussed in the respective plant safety committee and required modifications proposals are raised.

Chemistry control

Chemistry control in various systems of nuclear reactors plays a very important role in their safe and smooth operation. Stringent chemistry control of coolant and moderator system in our research reactors has minimized corrosion of systems and components and consequent neutron activation of corrosion products and their deposition in the low velocity zones of system piping and components. Keeping corrosion products low has also helped in maintaining low levels of radioactivity in operational areas resulting in lower dose to the operating personnel. Excellent condition of the pipelines in various systems of Cirus after 4 decades of service is credited to meticulous control of process systems chemistry.

Training, Licensing and Re-Licensing:

Realizing the fact that all safety provisions/ procedures/ practices could be fully effective provided the personnel undertaking the job are aware of “What is being done?” and ‘Why is it being done so?’ strong emphasis is laid on formal training and licensing of personnel in research reactors right from their inception. To ensure that competent and safety conscious personnel are made available on a continuous basis at all levels to man the research reactors the recruitment is carried out at three levels namely professionals, supervisory staff and plant operators / maintenance technicians.

The staff in the above categories, after recruitment on competitive basis, is put through a structured training programme of one to three years designed to introduce the staff to their work environment in a systematic and consistent manner. The programme consists of class room lectures given by senior and well qualified O & M staff members and on- the-job training in different plant areas. During the training process, trainees are required to get respective systems checklists (a set of questions) signed by the authorized personnel. This process allows one to one interaction of trainees with experienced field personnel. This is a vital part of the training as it provides most effective communication opportunity for propagating safety culture. Once a trainee successfully completes the training, he is put through a licensing process, so that the individual can be authorized to perform specified duties in the operating organization. The licensing process consists of three stages, viz., written examination, walk-through test, and assessment interview by an expert committee. The license is valid for three years after which the person needs to be re-licensed by the expert committee. In case a person remains absent from his licensed position for more than 35 days, he/she is required to get re-certified as per the established procedure before resuming his licensed position. This ensures that the research reactor employee is abreast with the latest plant status and operation, especially with design modifications and changes in operating procedures carried out during period of his absence.

For motivating plant personnel to attain higher levels of safety awareness weightage is given by the plant management to their safety awareness level during their assessment. Besides, incentives are given to the qualified staff under Qualification Incentive scheme of the department.

Incident Reporting:

The incident reporting system of our research reactors caters to the requirements of reporting of operational anomalies and safety significant incidents. For all operational events, a first information report is prepared immediately and is followed by a detailed report supplemented with Root Cause Analysis (RCA). Based on the RCA and subsequent reviews of the event by the safety authorities, necessary recommendations are formulated for implementation of measures that can prevent recurrence of such event.

Besides the incidents reporting, reactor fault reports and system/equipment fault reports are also prepared in appropriate format for effective performance evaluation and initiation of timely corrective action to avoid translation of precursors into events/significant events. These reports after due investigation and incorporation of comments by the plant management are returned back to the O&M staff for discussion in crew meetings. This helps significantly in avoiding the recurrence and also provides feed back to the plant personnel regarding importance of their reporting. It also encourages the staff to report all the faults irrespective of their apparent triviality.

Quality assurance and Internal Regulatory Inspection:

A comprehensive quality assurance programme covering all the operational and maintenance activities is implemented to strengthen the safety culture and enhancement of safety through self-assessment of operational performance. The quality assurance programme includes monthly technical audits of operational and maintenance activities, performance review of systems and equipments, checking compliance with technical specifications for all activities with specific emphasis on surveillance schedules, ensuring implementation of recommendation of various safety committees and compliance with radiological and industrial safety measures in all O&M activities.

Periodic Internal Regulatory Inspections (IRI) are carried out by services agency (not reporting to O&M). The findings of IRI are given due importance and corrective actions are effected promptly.

Ageing Management and Safety Upgrades:

Ageing management aims at identifying refurbishment requirements and retrofit upgrades that need to be implemented to qualify systems, structures and components to current safety standards. After over 30 years of service, signs of ageing started showing in Cirus resulting in reduced availability and excessive efforts for maintenance. Detailed ageing studies were therefore conducted in a systematic manner for all systems, structures and components. Based on these studies, refurbishing requirements were identified and an extended refurbishing outage of the reactor was taken from end 1997. After unloading fuel from the core, further inspections were undertaken which led to identification of several more refurbishing needs. Extensive refurbishing was then carried out and the reactor was made operational again in October 2002.

CIRUS Refurbishment and safety upgradation

The refurbishment outage was utilized for carrying out several safety upgrades to comply with current standards. Certain areas of the ball tank structure were stressed beyond permissible limits under maximum envisaged ground motion. Coincidentally, this area was also having minor water seepage problem. Both problems were tackled by steel jacketing the required portion of the structure. Epoxy was pressure injected between the steel jacket and concrete to make the repaired structure monolithic. Similarly, appropriate modifications were incorporated for the class I power supply battery banks for seismic qualification.

Detailed theoretical as well as experimental assessment of the graphite reflector was done for stored wigner energy. It was concluded that there is no concern for thermal safety of the reflector during reactor operation. Continuous monitoring of temperatures at number of locations in the reflector was

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incorporated for collection of data and follow-up of its thermal safety. Some of the other safety improvements made include the following:

- Replacement and rerouting of waste transfer lines to permit their periodic inspection and monitoring.
- Installation of fire detection system and other fire safety upgrades.
- Up-gradation of heavy water leak detection system
- Provision of bore holes for monitoring of underground piping for any leakage.
- Physical separation of safety related equipment
- Modification of failed fuel detection (FFD) system for improved performance based on experience in Dhruva.
- Replacement of old caustic scrubber based Iodine removal system in the emergency ventilation exhaust by modern activated charcoal and HEPA filter based system.

Plan for Apsara refurbishment and up gradation

Since Apsara reactor has completed more than 50 years of service, it is planned to carryout extensive refurbishment of the reactor so as to extend its useful life and to meet the current safety standards. During refurbishment, it is also planned to upgrade the reactor to a 2 MW reactor in order to enhance the maximum available thermal neutron flux to 6.5×10^{13} n/cm²/s. The core will be loaded with LEU plate type fuel in the form of U₃Si₂ dispersed in aluminium. Pool water will act as coolant and moderator. Beryllium oxide will be used as the reflector. The reactor building and associated structure will be strengthened to meet the current seismic standards. The upgraded Apsara reactor will provide enhanced facilities for basic research, production of radio-isotopes, shielding experiments, neutron radiography, calibration and testing of neutron detectors etc.

Regulatory Review and Control:

A multi-tier regulatory framework with clear assignment of responsibilities exists for regulatory review and control of research reactors Apsara, Cirus and Dhruva. The first review of research reactors performance, special procedures, system modifications, changes in approved procedures, incidents, or other related safety matters is performed at a common forum known as Reactor Group -Operations Review Committee (RG-ORC). ORC consists of members of research reactors middle management. While reviewing the incident in one reactor, possibility of occurrence of such incident in other reactors is also checked and recommendations are made for taking advance measures. ORC is an important forum for our research reactor specialists for sharing the operating experience and lessons learned.

The next level of safety review is performed by Research Reactors Safety Committee (RRSC) based on the recommendations of the ORC. RRSC is also responsible for carrying out periodical regulatory inspections of research reactors. RRSC is headed by Director, Reactor Group and supported by top management of the reactor group, specialist members from other groups of BARC and nominees of next higher committee, OPSRC. The observations and the details including the recommendations on safety significant matters are forwarded to Operating Plant Safety Review Committee (OPSRC) for further review. OPSRC a committee, consisting of senior experts in the field, reviews the issues and makes stipulation for implementation by the research reactors. OPSRC is empowered to order curtailment or suspension of reactor operation and impose such other restrictions as felt necessary in the interest of safety. The final stage of review is done by the apex committee called BARC Safety Council (BSC) which has overall responsibility for safety review of all BARC facilities. BSC issues safety directives and ensures their compliance.

Effective Utilization of Apsara, Cirus and Dhruva:

All the three research reactors have been well utilized for basic and applied research, neutron radiography, nuclear detectors testing, radioisotope production, material testing and human resource training and development. A large number of user groups are available within BARC. A users committee coordinates the utilization programme for our research reactors.

The National Facility for Neutron Beam Research (NFNBR) has been created at BARC during early nineties to cater to the needs of the Indian scientific community. Scientists from, universities and national laboratories also use these facilities in research reactors through collaborative research projects. Many of these collaborations are being supported by University Grant Commission - DAE Consortium for Scientific Research (UGC-DAE CSR), Board of Research in Nuclear Sciences (BRNS), and other agencies. Besides conventional uses, these research reactors have been utilized for conducting various engineering experiments also. Since utilization of these research reactors is covered in another paper by Dr. S.L.Chaplot in detail, only some important experiments performed in our research reactors which provided vital inputs for the development work for power reactors and other industrial applications are listed here:

- Experiments with different combinations of shield models were carried out at Apsara for optimizing the in-core shielding of the intermediate sodium heat exchanger of Prototype Fast Breeder Reactor. Results obtained from these experiments have also been utilized for validation of various computer codes used for shielding calculations. A large number of shielding experiments were also carried out for radiation streaming studies through penetrations and ducts of various shapes and sizes for the proposed 300 MWe Advanced Heavy Water Reactor (AHWR).
- Flow pattern transition instability studies were carried out in Apsara by constructing a loop similar to the geometry of Advanced Heavy Water Reactor (AHWR) coolant circuit. The neutron radiography facility was utilized to visualize the flow pattern and also to measure the void fraction which is an important parameter causing the flow pattern transition.
- Irradiation of various biological samples like plants, seeds, etc. was carried out in Apsara. The experiments carried out at Apsara in the field of biosciences relate to systematic studies on different biological crop plants and ornamentals. Many of these experiments and the subsequent ones initiated with the aim of inducing genetic variability led to the development of high yielding varieties both in food crops and pigeon pea and in ornamentals.
- At Cirus special irradiation assemblies were used for irradiation of piston rings and silicon samples. Piston rings up to diameter of 85 mm were irradiated to study the wear rates in rings and Silicon samples were irradiated to study transmutation doping of silicon.
- Towards development of Mixed Oxide (MOX) fuel, $\text{UO}_2\text{-PuO}_2$ fuel pins were test irradiated for stipulated burn up in Pressurized Water Loop (PWL) of Cirus reactor. Various design and manufacturing parameters were assessed through these tests. Towards utilization of Thoria based fuel in PHWRs, an experimental assembly containing $\text{ThO}_2\text{-PuO}_2$ fuel pellets was successfully irradiated to a burn up of more than 15000 MWD/Te in PWL. Irradiation of intentionally defected fuel pin was carried out for activity transport studies. These studies have contributed significantly to the development of Nat U oxide and Nat U-Pu MOX fuels for power reactors.
- Several pins of Antimony were irradiated at Cirus for developing start-up source for Tarapur Atomic Power Station and Fast Breeder Test Reactor, Kalpakkam.
- During the refurbishing outage of Cirus, a desalination unit of 30 tonne/day capacity, based on low temperature vacuum evaporation process had been integrated with primary coolant system of the reactor towards demonstration program for utilization of waste heat from nuclear reactor. The product water is used after polishing for the reactor systems.
- Zircaloy calandria tubes manufactured by different routes were test irradiated in Dhruva reactor to study their comparative In-pile growth behaviour. Assessment of radiation induced creep of

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Zirconium materials has been carried out along with radiation embrittlement studies of various structural materials used in Indian PHWRs. These studies resulted in finalization of manufacturing route for the PHWR pressure tubes and calandria tubes

- Towards assessing the adaptability of the neutron noise measurement technique for monitoring healthiness of the in-core components in PHWRs, an experimental assembly with number of self-powered detectors was irradiated in Dhruva.
- An instrumented fuel assembly was irradiated in Dhruva for validating the theoretical model used for estimating fuel clad temperature.

Concluding remarks:

Safety management system practised in Apsara, Cirus and Dhruva is evolved with experience and is updated from time to time based on operational experience and new knowledge acquired. The excellent safety track record of research reactors in India proves the effectiveness of our safety management system. Ageing of old reactors has been managed by systematic assessments and refurbishing actions. The refurbishing outage has been also utilized for making several safety upgrades to meet present safety standards, as in the case of refurbishment of the Cirus reactor. Safety improvements have been made on a continuing basis based on operating experience and new knowledge. At times, these improvements have gone beyond the requirements of design and safety analysis giving credence to the slogan **AHARA “Safety – As High As Reasonably Achievable”**.

ACKNOWLEDGEMENTS

Author is grateful to Shri V.K.Raina, Director, Reactor Group and Shri K.Sasidharan, Head, RRD&PD of Bhabha Atomic Research Centre for their support and guidance in preparation of the paper.

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