Management of Transition betweenShut Down and Decommissioning of Research Reactor Cirus

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Abstract

Cirus, a vertical tank type 40 MW thermal research reactor, natural uranium fueled, heavy water moderated and light water cooled; is located in Bhabha atomic research centre, Mumbai, India. It achieved first criticality in July 1960 and was operated successfully for 50 years till permanent shut down in December, 2010. The core has been completely unloaded, heavy water has been removed and reactor systems have been brought to a safe state in preservation mode with minimum surveillance requirement to conserve manpower and save energy and effort.

A deferred dismantling (safe enclosure) has been chosen as the decommissioning strategy for the reactor. A detailed plan has been prepared for managing the transition between permanent shut down and deferred decommissioning and executed. Some of the jobs in progress include radiation mapping of reactor structure, estimation of radioactivity content and decay pattern; introduction of technical specifications and surveillance methodology, estimation of waste generation and its characterization; categorization of components for reuse in other facilities, release for unrestricted use and or scrap; Sampling for data generation on irradiation and corrosion damage suffered by materials, development of decontamination techniques, etc. A preliminary decommissioning plan has been prepared.

Thispaper covers all aspects of managing the transition and highlights experience gained in post permanent shut down management of Cirus.

Key Words: core management, deferred decommissioning, cleanout operations

1. Introduction: Cirus, a 40 MW (Thermal) Uranium metal fuelled, heavy water moderated, light water cooled research reactor achieved first criticality in July 1960. Since the early 1990s, Cirus started showing signs of ageing resulting in frequent breakdown and increased maintenance on equipment. Hence, detailed inspection and ageing studies of plant structures, systems and, components were undertaken for assessment of residual life. Based on these studies, performance review and current safety standards a plan for refurbishment and safety up-gradation of the reactor was prepared. The estimated residual life of reactor was 10-15 years. The reactor was shut down in Sept. 1997 for refurbishment. Refurbished reactor systems were re-commissioned and reactor operation was resumed in Oct. 2003. The reactor was shut down permanently on 31st December 2010 as per Indo-US civil nuclear deal.

2. Planning and Utilization of Time between Decision to Shut down and its Implementation:

2.1 By the middle of year 2008, Govt. of India took a decision to shut down the reactor permanently by the end of year 2010. A task force was created with the aim for its maximum utilization and to bring the reactor to a permanent safe shut down state. Several experiments such as neutron radiography, studies on fission fragments, re-irradiation of Thorium based fuel assembly,irradiationof Silicon wafer in the central hole of the reactor, etc. were to be conducted.These required planning, design, safety review and execution. Theexperimental set-ups of neutron radiography and tomography were erected and experiments were carried out. Re-irradiation of Thorium based fuel pins along with fresh fuel pins was carried out in pressurized water loop of the reactor. This involved development of special tools andprocedures. Assembly for irradiationSilicon wafer was designed, fabricated and tested out of pile. However the same could not be installed in the core as plug from the central hole could not be taken out as it was found jammed and it could not be removed before the end of year 2010.

There was huge demand for short term irradiations in self-serve facilities and pneumatic carrier facilities for research purposes. So was the case for production of radio-isotopes in irradiation assemblies. All could be achieved due to proper planning, active cooperation and excellent synergy between the various stake holders.

2.2 In-core Fuel Management: Optimum utilization of fuel before shutting down the reactor was one of the major challenges. It was decided to achieve average core irradiation level as high as feasible by December 31, 2010. During normal operation of reactor, the average core irradiation level used to remain around 50% of the stipulated irradiation level with 10-15% of the fuel assemblies remaining near the stipulated discharge irradiation level. Had the normal practice of refueling been followed during the approach period to permanent shut down, a large number of fuel assemblies would have got discharged at low irradiation levels. Therefore a fuel management scheme based upon shuffling of the fuel assemblies among the core positions was implemented to (i) maximize the irradiation level of fuel assemblies discharged from the core at the time of permanent shutdown, (ii) minimize the requirement of fresh fuel assemblies and iii) minimize the number of fuelling operations and thus person-Seivertconsumption.

2.3 Inventory management was an important aspect of planning of transition from operation to permanent shut down. Materials under procurement were reviewed for their utility during the intervening period. The components which were to be procured for replacement were reviewed based on the life assessment ofold components for long term operation of reactor. For economic considerations, some of the procurements were deferred after ensuring that availability and safety of reactor would not be compromised. Procurement of the components which were needed for industrial and radiation safety even after reactor shut down and those for operating the auxiliary and support systems during future decommissioning were kept out of ambit of this review.

2.4 Due care was given to human resource management aspects. Existing manpower profile for their professional competence including future decommissioning, age, health and future management roles was reviewed and found adequate. Based on this fresh recruitment was abandoned. Existing manpower was sensitized and trained for their new role during transition phase of reactor and future decommissioning.

3. Jobs Undertaken after Permanent Shut-Down:

3.1 Core Unloading: Preparations for core unloading were started in advance. Storage positions were created in wet storage block (a water tank with appropriate cooling arrangement) for temporary storage of spent fuel assemblies. Fuel assemblies were removed with normal mode of coolant recirculation as required by safety considerations. However number of operating pumps (normally four in parallel) for coolant recirculation was decreased gradually from four to one with progressive removal of fuel assemblies. Few assemblies were removed with shut down cooling when single pump operation was not feasible. Plugs were installed in empty positions to keep radiation background low in the working area. Few dummy fuel assemblies were installed to facilitate coolant recirculation to maintain water chemistry. Other assemblies such as isotope rods, shut-off rods, experimental fuel assembly in pressurized water loop, etc.; were also removed.

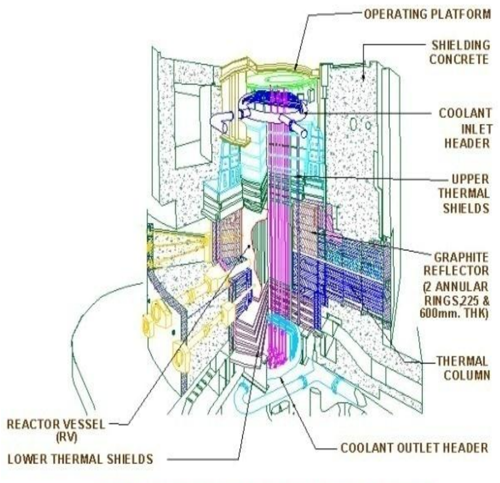
Person-Sievert Budgeting: Person-Sievert budgeting was one of the important aspects of the core unloading program. Based on actual person-Sievert consumption in recent years, a budget was prepared. To keep the radiation exposure to the minimum during the preparatory and execution stages of core unloading, thorough planning was done to identify the ways and means for the same. Hot spots were identified and removed. Additional shielding was provided in working areas. Actual person-Sievert consumption was only 39 % of the estimated one. This could be achieved by implementation of adequate radiological safety measures and starting core unloading operations with sufficient delay after reactor shut down.

3.2 Disposal of Irradiated Components: After sufficient decay of gaseous fission product activity and reduction in decay heat, fuel portions of fuel assemblies were cut underwater with appropriate tools and fuel sections were sent to reprocessing plant. Radio-isotopes were delivered for further processing and utilization. Irradiated assemblies were cut into pieces within a specially made Lead enclosure. These components along with active shielding sections of fuel assemblies were transferred to waste management facility for storage and disposal.

3.3 Removal of Moderator: Soon after reactor shut down, moderator (heavy water) from system was transferred to a storage tank which was physically isolated from rest of the system.An independent Helium venting was provided to the tank to maintain purity of heavy water. Subsequently entire heavy water was upgraded and transferred to Dhruva reactor for re-use. Residual heavy water lying in the pockets and instruments was recovered by drying with Helium (cover gas) and condensing in moisture recovery system. This was done to recover the precious heavy water as far as possible and to bring down tritium activity in the system which will be helpful during dismantling of piping and equipment of the system.

3.4 Radiation Mapping and Waste Characterization: Radiological characterizationis an important tool for safe and efficient decommissioning of nuclear facilities. The knowledge of levels of radiation fields and activity in various systems and structural components is useful in selecting the best decommissioning strategy and plan for handling, storage and disposal of radioactive waste. The need for shielding, remote handling and decontamination is based on the characterization data. With this aim, estimation of radiation dose rate levels in the reactor core structure of Cirus reactor after ten months of permanent shut down of the reactor was carried out.

3.4.1 Cirus reactor block consists of aluminumreactor vessel, graphite reflector, cast iron thermal shields, aluminum and steel thermal shields and concrete biological shields. Reactor Vessel (RV) is a cylindrical tank having cylindrical disk shaped top and bottom tube sheets. 199 vertical tubes of different diameter, arranged in a hexagonal lattice, are expanded and rolled in the tube sheets to permit insertion of in-pile assemblies.Inaccessible locations in the reactor structure were monitored for radiation dose rate using in-house designed and developed extendable cable type GM detector based high range radiation monitor and a diode based high range radiation monitor.Radiation dose rates were measured at 21 pre-selected elevations of reactor structure using radiation probe through empty reactor vessel tubes after removal of all irradiated fuel assemblies, shut off rods, tray rods and other assemblies from various core positions.



CIRUS REACTOR STRUCTURE CROSS SECTION

TABLE-1: PRELIMINARY RADIOLOGICAL CHARACTERIZATION

Reactor Structure	Co-60, Zn-65, Mn-54, Cd-109 Cs-137
Primary Coolant Water System	Eu-152, Ce-144, Sb-125, Cs-137, Ru-106, Mn-54, Co-60
Heavy Water System	Traces of Co-60 and ^{3}H in D2O and He lines
Pressurized Water Loop	Co-60, Ag-110m Cs-137 (trace)
Ventilation System	Co-60 and Eu-152 (in traces)
Waste Disposal System	Co-60, Cs-137, Sb-125

3.4.2 Radiation dose rate below lower tube sheet varied between 3.0 - 31 Gy/h. Radiation dose rate above upper tube sheet varied between 4.5 - 25 Gy/h. Radiation dose rates in the reactor vessel region varied between 1.25 – 3.0 Gy/h.Higher radiation dose rates were observed in the regions just above and below the tube sheets mainly due to presence of Co-60 in activated SS tubes running near above positions.

3.4.3 Radiation dose rates due to loose contamination were insignificant as compared to activation of structural components. In all horizontal beam hole positions, maximum radiation dose rates (0.7 - 0.9 Gy/h)was observed between outer graphite reflector and inner cast iron thermal shield due to activation of cast iron thermal shield.

3.4.4 A preliminary estimate of the metallic waste from various systems of Cirus reactor except the reactor core structure has been assessed and majority of the waste qualify for Category-I solid wastes. Appropriate waste volume reduction techniques have been identified for reducing the space requirement at disposal site.

4.0 Managing Transition from Permanent Shut Down to Decommissioning:

4.1 The principal objectives of the transition stage are to reduce hazards and to lower operations and maintenance costs. Equipment, thoseare no longer required to support the decommissioning phase, are deactivated. Systems for which the full capability is no longer required for decommissioning are modified to cope with the lower demands imposed by decommissioning. Cost savings are achieved by selective staff reductions, reduction in power and other services, reduced maintenance requirements, reduction in consumables and the recycling or resale of plant that is no longer required.

A number of preparatory works are carried out that typically include finalizing decommissioning plans and reducing or removing the more mobile nuclide inventory; for example, spent fuel removal, decontamination, operational waste treatment and the taking of measures to prevent the spread of contamination. Furthermore, a variety of other housekeeping tasks are tackled to reduce hazards and to prepare areas for later decommissioning. Installed systems are reviewed selectively for retention, de-activation or removal. Some of such activities undertaken at Cirus reactor are described as follows:

4.2 **Cleanout Operations of Systems:**

4.2.1 The high pressure high temperature experimental loop system water chemistry was preserved for about three years. In year 2014, coolant from the loop was drained and system was dried using process air. Some equipment (safety valves, recorders) have been removed and used in Dhruva research reactor. Zircaloy test section will be removed and examined for life assessment studies and database on irradiation and corrosion induced damage.

4.2.2 Moderator (heavy water) and Cover gas (Helium) system: Moderator is a relatively clean system with only traces of radioactivity. Tanks, made of SS will be decontaminated and used in an active facility. Plans are on hand to carry out corrosion related studies on Aluminum reactor vessel and tubes and on SS componentsof the system. Helium has been replaced with Nitrogen. Drying of HW pipelines, tanks and heat exchangersis in progress to recover traces of heavy water and to reduce tritium activity in the system to reduce person-Seivert consumption during dismantling in future. Nitrogen will be replaced with air after completion of drying of the system. Dismantling of components outside reactor core will commence shortly.

4.2.3 Primary Coolant activity has come down below detection limit. Coolant has not been drained so far from the system and chemistry of coolant is regularly monitored to assess change in chemistry parameters with respect to period of stagnation or low flow beyond six weeks (no significant change was noted up to six weeks of stagnancy during refurbishment outage). Sub-systems have been isolated including main coolant purification circuit. With only online polishing unit in service for emergency storage tank water recirculation, the system chemistry has not changed significantly. Draining of coolant from the system and drying of the system will commence shortly.

4.2.4 Steel and Aluminum Thermal Shields are under preservation mode. Chemistry of coolant is monitored / maintained regularly. There is no immediate plan to drain water as it provides shielding against high γ-radiation from reactor vessel region. Isolation and dismantling of redundant components like test section, purification circuit and heat exchangers will be taken up shortly.

4.2.5 Low Temperature Evaporation Desalination Plant which had been coupled with the reactor during refurbishment, was completely isolated from primary circuit of reactor, drained of coolant and dried with air. Useful components were salvaged for use in other facilities.

4.2.6 After removal of air cooled assemblies from core, process air requirement got drastically reduced. Two out of four main air compressors could easily meet requirement for instrumentation, breathing, services,etc. Two compressors have been declared surplus but retained keeping in mind the requirement during dismantling for pneumatic cutting tools.

4.2.7 Though there is no requirement for containment box up, the feature has been retained as a backup for radioactive work in future. The Ventilation system is operated at reduced speed to conserve energy and effort. This has resulted into reduced requirements of replacement of HEPA filters as well as reduction in waste generation. Iodine removal system has become redundant and its removal and disposal is on hand.

4.2.8 The safety classification of electrical power supply based on its reliability is no more relevant. Normal power supplyis sufficient except for radiation monitoring, fire alarm and control and instrumentation systems. Diesel Generators, Motor-Alternators, Battery Banks, switchgears, redundant supply panels and equipment arebeing disconnected in a phased manner to reduce surveillance, maintenance and fire hazards.

4.2.9 The experimental set-ups of researchers have been shifted to Dhruva beam lines. Also shielded flasks of self-serve irradiation facility have been transferred to Dhruva.

4.2.10 Review of Human Resources: After implementing measures for reduction of surveillance requirements without compromising industrial and radiological safety of the reactor, manpower at Cirus was downsized. Plant management structure was changed in line with the current requirements. Post of Reactor Superintendent and Assistant Reactor Superintendent were annulled and a new post of Decommissioning Superintendent was created. A skeleton maintenance staff has been retained for normal maintenance activities and merged with that of Dhruva. The surplus staff was redeployed within BARC. The staff retained for decommissioning activities is a mix of young and old and well trained.Services such as radiological and industrial safety, inspection, quality assurance, chemistry control, engineering support, etc. are common to all research reactors and are readily available.A two tier set-up of experts having experience in operation and maintenance of reactor, waste management and radiological and industrial safety and protection has been created to prepare documents for decommissioning of the reactor. The lower tier, headed by Decommissioning Superintendent, is entrusted with preparation of the documents and the upper tier, headed by Director, Reactor Group, reviews and approves the plans and policies.

4.2.11 Radiological and Industrial Safety: Though the radiological hazard potential has come down drastically, the radiological controls and practices have been maintained at same level as during reactor operation except reduction in manpower. Technical audit covers all aspects of safety and security.

4.2.12 Documentation: Documentation and record keeping aspects were reviewed in detail. Original copies of all relevant records and documents required for decommissioning were retained. The document which could be useful in future, were also retained. Documents not required were destructed as per prevalent practice. Several documents have been modified to meet the current surveillance and job requirements. The drafting of documentation for dismantling and disposal has been initiated.

4.2.13 Utilization of space: Space inside reactor and auxiliary buildings have been reorganized and radiation field has been brought down very close to the background level. Current utilization of space and infrastructure includes non-radioactive experimental set-ups and transit storage of materials. A prognostic health management laboratory is in advanced stage of commissioning. Future plans include exhibition centre for BARC programmes and technologies, storage of materials and equipment for upcoming projects and housing labs and experimental facilities.

4.3 Waste Management Plans for Decommissioning Phase: The waste management facilities exist within BARC to handle all kinds of solid and liquid wastes generated by all radiological facilities inside BARC campus. Gross estimation of radioactivity content in inaccessible components (mainly reactor structural components and some structures) has been completed using theoretical models for neutron activation of materials of construction. This has been refined based upon radiation field measurement data generated during refurbishment outage and after permanent shut down of the reactor. For rest of the systems, structures and components; the estimation has been carried out based upon data generated by actual measurements and estimates during normal operation and ageing studies. As an approximation about 500 cubic meter of category-I solid waste, 25 cubic meter of category-II solid waste and a few cubic meter of category-III solid waste would need to be managed. Preparatory work for this has been initiated.

No gaseous waste generation has been envisaged. Only moderate quantities of radioactive liquid waste are expected to be generated mainly during decontamination activities. The volume and activities expected are much below the capacities and capabilities existing within BARC.

4.4 Development of Decontamination Techniques: It is planned (a) to convert category-I or very low active or potentially active materials into inactive materials (fit for release into public domain as per IAEA guidelines endorsed by AERB) and (b) to convert category-III waste into category-II waste and category-II waste into category-I waste by a using suitable decontamination techniques. Some work in this regard has already been performed at laboratory scale. A set up has been created in auxiliary building of reactor for trials at actual scale. This aspect will be reviewed taking into consideration factors like generation of large quantities of secondary waste, overall economics and optimization of radiation exposure.

4.5 Technical Specifications for Permanently ShutdownCirus: In view of change in systems operational status and configuration, a new technical specification document named as “Technical Specifications for Permanently ShutdownCirus” was introduced after approval of regulatory authority. Technical Specifications related to nuclear safety issues such as core cooling, reactivity changes, reactor protection, moderator circulation, PWL, secondary coolant systems etc. were no more applicable and hence were not included in the Technical Specifications. Clauses related to Industrial and Radiological safety, fire protection, ventilation system, waste management, etc. were relevant and hence included in the new technical specifications after necessary modifications / changes. After about two years, due to shipment of all heavy water from reactor site and a few other changes in reactor systems, manning requirements of the reactor, etc, the ‘Technical Specifications for Permanently Shutdown’ was further revised in October 2013 and is currently in force. Manning of Cirus in round-the-clock shifts has been entrusted to duly licensed Shift Supervisors and licensed technicians.

5.0 Decommissioning Strategy:

5.1 For Cirus reactor, deferred dismantling (decommissioning) strategy seems to be the best option. Dismantling of reactor structure and core components is envisaged after about 30-35 years when the dominant radionuclide Co-60 will decay to negligible values for ease of dismantling and handling of radioactive components. Peripheral systems and components will be dismantled and disposed off in the initial years. Ventilation system and other auxiliary systems required for dismantling operations, radiological and industrial safety, security of reactor, etc will be kept operational. Optimum surveillance will be maintained. Required trained and experienced manpower will be retained. Presence of nearby Dhruva reactor which can contribute in long term surveillance requirements helps in deciding deferred decommissioning as a preferred decommissioning strategy. Site release for public after decommissioning is not envisaged. The site can be reused for a new laboratory / facility.

5.2 Short term activities which are planned to be executed in the next 3-4 years have been identified which include draining of coolant from various systems, isolation and truncation of systems to reduce surveillance requirements, disposal of inactive / low contaminated equipment / components to waste management facility, etc. The mid-term plan includes dismantling of peripheral systems and their disposal. Large amounts of primary coolant pipelines are buried under soil about 4mbelow grade level. The radioactivity content in these lines is quite low. A lot of excavation will be required to remove the lines and large storage space at waste management facility for their storage/disposal. This will incur large expenditure, and man-rem exposure in waste treatment. In view of these, feasibility of in-situ decontamination and in-situ permanent burial of these lines is being explored.

5.3 Efforts will be made to reuse and recycle the useful components to reduce waste generation as well as from economic point of view.

5.4 National Acts and Regulatory Aspects for Decommissioning: Atomic energy act 1962, Atomic energy factory rules 1996, Atomic energy radiation protection rules 2004, Atomic energy safe disposal of radioactive waste rules 1987 govern the radiation related activities in India. Atomic energy regulatory board (AERB) acts as regulator of radiation facilities other than BARC. BARC Safety Council is the regulator for BARC facilities. Reactor operation is carried out as per Tech. Specifications under authorization from regulatory body. Provisions are in place for Periodic Safety Review and extension of authorization. As of now, no separate license (authorization) for decommissioning exists. Decommissioning related activities will be carried out under operating license and will be regulated by the existing framework for reactor operation.

5.0 Conclusion: Cirus research reactor was well utilized since its first criticality in July 1960 and also after refurbishment. The period after permanent shut down also has been gainfully utilized for preparatory activities for deferred decommissioning of the reactor in future and generation of baseline data on corrosion and irradiation induced damage suffered by materials of systems, structures and components. Core has been unloaded and spent fuel has been reprocessed. Heavy water has been recovered and utilized well. Preliminary decommissioning management structure has been put in place. Delayed dismantling has been opted as the deferred decommissioning strategy for the reactor. Transition from operation to decommissioning phase has been managed well in a planned manner. Several measures have been taken for cost reduction without compromising with safety and security. Cirus being the first major nuclear facility under decommissioning in India, it will provide valuable experience feedback for decommissioning of similar facilities in future.