Indian Society for
Non-Destructive Testing
Hyderabad Chapter

NDE-2006

Proc. National Seminar on
Non-Destructive Evaluation
Dec. 7 - 9, 2006, Hyderabad

Quality Assurance in BHAVINI

Prabhat Kumar
Project Director, PFBR &
Director (Construction), BHAVINI
Kalpakkam – 603 102, India

1. Abstract:

Fast Breeder Test Reactor (FBTR) operating at IGCAR since 1985 is testimony of maturity India has attained in Fast Breeder Technology. The reactor has operated exceedingly well thus established the competence of Indian engineers in handling this difficult technology where large quantity of sodium is used for cooling of reactors. INDIA took quantum leap from 40 MWe FBTR to launch of 500 MWe Fast Breeder Reactor. This was possible with strong R&D backbone that DAE has established and manufacturing infrastructure that Indian Industries have developed. Competence of Indian scientists and engineers is second to none in taking on any challenge. Quality of construction presently in progress at PFBR is the outcome of this technological excellence Indians have attained at all fronts.

The First of its type technology for PFBR has many first of its type materials to be processed, several new manufacturing techniques to be used, and novel construction techniques to be deployed besides commissioning challenges to be met for the first commercial fast breeder reactor. Being commercial venture, the first of its type Fast Breeder Reactor itself has requirement of meeting time and cost targets in parallel to meeting technological challenges.

At BHAVINI R&D and construction professionals work together in mission mode to accomplish the technological needs within stringent time and cost targets. PFBR is thus a role model in handling new technologies where experts have been drawn from different organizations to work together with their organizational backing to work in mission mode and to take fast Breeder technology to success. This experimentation is expected to be a trend setter for future commercial exploitation of advance technologies.

Quality is the key to success for this new technology. Planned and systematic actions towards QA provide adequate confidence that an item/facility will perform satisfactorily in service. QA in PFBR is not limited to construction or commissioning. QA has been the buzzword at all stages right from R&D, technology development, manufacturing and fabrication, documentation to training and qualification of man power.

2. Introduction:

India launched research and development programme in nuclear science and technology in early fifties. Tarapur Atomic Power Station was the first commercial venture for producing electricity through boiling water reactor. In parallel Pressurized Heavy Water Reactor (PHWR) programme was launched for better utilization of uranium, the fuel for nuclear reactors. Rajasthan Atomic Power Station, Madras Atomic Power Station, Narora Atomic Power Station, Kakrapar Atomic Power Station, Kaiga Atomic Power Station and two new units of Tarapur Atomic Power Station are based on the PHWR technology. Kudan Kulam Atomic Power Project under advance stage deploys Pressurized Water Technology. All these reactors are thermal reactors and form part of India's first stage of nuclear power programme. Nuclear Power Corporation of India Limited (NPCIL) is responsible for construction and commissioning of Atomic Power plants in India. NPCIL has attained excellence in construction, commissioning and operation. Encouraged with performance by Indians, Govt. launched second generation of India's nuclear power programme i.e. fast breeder reactors in commercial mode by allowing construction of Prototype Fast Breeder Reactor (PFBR) itself in commercial mode.

Bhartiya Nabhikiya Vidyut Nigam (BHAVINI) is fifth public sector undertaking under Department of Atomic Energy (DAE) of India. This company formed on October 22, 2003 has mandate to construct and operate Prototype Fast Breeder Reactor (PFBR) and future Fast Breeder Reactors in commercial mode.

2.1 First of its type technology:

The first of its type technology for PFBR has many technological challenges. Every thing has to be conceived fresh, new procedures/methodologies have to be developed for construction and commissioning of the plant. Novel construction techniques are to be developed.

3. Quality in Every action and Activity in BHAVINI:

Quality is planned to be achieved in BHAVINI through planned and systematic action in every activity of the project. "Fit for purpose" and "Do it right the first time", is BHAVINI's determination. Towards Quality Assurance, regulation of quality of raw materials, assemblies, products, components, services related to production and management, production and inspection processes are bench marked. The main goal of QA is to ensure that the product fulfills or exceeds the user expectation.

Concerning quality it could be said that, quality of something depends on the criteria being applied to it. Quality has no specific meaning unless related to a specific function and /or object. In the industry of any kind in general and manufacturing industries in particular, quality drives productivity. Improved productivity is a source of higher revenues, enhanced employment opportunity and technology advances.

3.1 Quality in Excavation for Nuclear Island:

The excavation for nuclear island in PFBR over a plan area of 216mX268 m was upto 24 meter depth. This resulted into creation of pit up to 18m below the mean sea level at a distance of only 150 to 200m from the shore line. Excavation covered sandy soil, clay, weathered rock and hard rock excavation. This was followed by elaborate geo-technical investigation, many of which were done for the first time in a nuclear power plant. The concrete laying below the raft (mud mat/leveling course) too underwent design reviews, regulatory clearances, restrictions on spans and thickness of the layer and control on quality of concreting. Mud mat was followed by four stage grouting including primary, secondary, tertiary and curtain and injection grouting. Bone dry condition was achieved after grouting to enable laying of water proofing. Quality had apex place in all these operations and compliance to specification was strictly adhered to.

3.2 Quality in Water Proofing:

NICB has a deep underground structure. In our endeavour to avoid any water seepage in the underground structure the entire raft and perimeter wall was wrapped in state of art water proofing. The water proofing below raft included 12mm concrete plaster, followed by APP membranes of 4 mm thick, two layers, in perpendicular directions, followed by 50 mm thick screed concrete. For the transition area and the vertical surfaces, Liquid membrane water proofing system using Tapelastic and Elastothane was used. This is followed by a protective layer of block masonry. These operations required care in applications, compliance to all QC parameters for the water proofing materials, supervision for entire processing and recording as per QA programme.

3.3 Quality of Ingredients of Concrete/ Placement Record:

PFBR has a large raft of around 100mX 100m dimensions. Thickness of the raft is 3.5 meter, in a trough shape. 35000 cubic meter of concrete with 7000 tones of reinforcement steel was required for the raft. The very first pour of the raft was 2900 cubic meter, largest first pour in any Indian nuclear reactor. New national record of 5000 cubic meter pour was set by PFBR around May 2005. The project exceeded its own record by doing 5800 cubic meter of continuous concreting in August 2005.These two landmark achievements speak volumes about the capabilities of Indian contractors as regards meeting quality and schedule requirements.

Quality of ingredients of concrete, concrete production controls, quality of reinforcement bars, laying of RE bars, transportation of concrete from batching plant to construction site, mode of concrete placement, vibrating the new concrete, green cutting in large span are only few elements of raft construction that required planning, monitoring for effective quality controls. Construction of raft of PFBR could be a model where excellence in productivity has been achieved through meticulous planning and thus the quality and productivity found its way without much effort.

3.3.1 Quality Control in Production of Concrete:

Even before awarding contract for civil construction BHAVINI engineers collected aggregate, sand and cement from all possible sources around Kalpakkam and carried out qualification of materials. Ground water samples were also collected and analysed for their acceptability for concrete and for ice production. Having established the right quality of concrete ingredients, preliminary mix design was also carried out for various grades of concrete. These advance planning saved substantial time for contractors after the work order was released and they could quickly produce acceptable mix using already approved ingredients. The mix design involved qualification not only as per IS 456 but also the rigorous requirements of RCC-G (French specification).

Preliminary trials were conducted in the concrete laboratory with various brands of cement, various cement contents and different chemical admixtures to arrive at optimum mix of minimum cement content to meet the requirement of workability, strength and low permeability conditions required for coastal environmental conditions. Similarly trials were conducted with various brands of chemical admixtures for cement-admixture compatibility and optimization of dosage.

To start with mix design of N45 and N30 grade concrete, the first step is prequalification of cement; in this we have considered the following points

- Quality system procedure of cement manufacturers by inspection of cement factories.

- All the physical & chemical requirements should satisfy the requirements specified in IS 8112
- C_3A content should be in the range of 5% to 8%

- C_3S of cement should be in the range of 35% to 45%

- Fineness should be less than 290 m^2/kg

- Heat of hydration of cement at 1 day, 3days, 7 days and 28 days.

As a second step, coarse aggregate& fine aggregate were checked as per IS requirements.

We have taken approximately 120 trials to arrive at optimum mix which satisfied all the specification requirements i.e workability, strength and low permeability by Rapid chloride penetration tests (RCPT) which shown as low permeable concrete.

After qualifying the mix, to gain additional confidence,

- We have taken 30 cube strengths which have shown standard deviation of only 1.71N/mm2, where we have considered is 5 N/mm2.

- As a qualification of RCC-G we have taken trials with less cement content by 25 kg/m3, with more water cement ratio, with 10% additional sand content to check the worst conditions, but even then mix has given satisfactory strengths.

- To check the rise of temperature in concrete we have done Heat of hydration studies by casting 1.0M X 1.0M X 1.0M concrete mould keeping thermocouples at the centre and the top surface. The temperature gradient between centre core and at surface is less than 20ºC which is satisfactory.

- To measure the permeability of concrete lot of RCPT were done which have shown the concrete is low permeable.

State of art batching plants of adequate capacities (two of 60 cubic meter per hour and one of 30 cubic meter per hour) were available at site for concrete production speed to meet the placement at the rate of 60 cubic meter per hour. This ensured un-interrupted concreting, despite preventive maintenance.

3.4 Quality assurance in fabrication:

PFBR uses several unconventional materials. This includes 316LN, D9, 9Cr-1Mo. Since these materials are not conventionally used by the industries many challenges are faced in commercial exploitation of these materials. The first being availability of these materials at industrial scale to stipulated quality requirements. The material specification are even stringent to ASTM standards. This demands specific processing of these special materials for ordered quantities for PFBR. Yet there is a pressing need to contain time and cost for the project, this there emerges a challenge to contain cost and time and quality for new technological venture.

Reactor equipment in PFBR are huge in size and low in wall thickness. This poses challenge in maintaining dimensional tolerances which are stringent for reactor equipment. Safety Vessel made of SS

316LN plates of 16 mm thickness is requires to be fabricated within a tolerance band of 12mm. This equipment has hemispherical bottom and cylindrical top of 13.5 m diameter. Thus the vessel of diameter and height of around 13.5m are required to be fabricated within 12 mm tolerance. To establish feasibility of fabrication of component to such accuracy, a sector was fabricated as a pre-project activity and then only design drawings were frozen. Yet extensive experimentation was done at site before actual welding was done.

At least 50 test coupons were prepared to qualify welding for the safety vessels itself. The welding sequence to reduce distortions was finalized by highly experienced welding engineers.

The steam generators under fabrication are form water to sodium boundary. Sodium on the shell side enters at 530 deg K and exits at 480 degree Kelvin. Since sodium and water react vigorously, the integrity of tube material and tube to tube sheet joint have to be of defect free without any concessions

Roof slab and safety vessel have carbon steel to Stainless steel welding too ring extensive qualifying tessting.

3.6 Quality measures post tsunami rehabilitation:

While laying second layer of raft concrete, tsunami struck on 26th December 2004 flooding the pit with 3.5 lakh cubic meter of sea water, sludge and muck. While the pit was cleared in one month's time, decision making for acceptability of already completed concrete raft required numerous considerations. The already concreted raft was thoroughly analysed by taking about 50 core samples. The concrete cores were tested for chloride, sulphate, cement content and compressive strength. The chloride contamination was found concentrated only in the top 5 to 10mm layer. As part pf rehabilitation process, even though the raft was meeting all the requirements, quality took higher position as compared to cost and thus it was decided to discard the concrete and treat as mud mat after clearing the contaminated layer up to 15mm by chipping and lime washing. This was followed by 100mm PCC, water proofing etc as per the original design.

As part of rehabilitation process as suggested by CESC/AERB it was required to assess the compressive strength of the raft and the chloride penetration at various locations. Subsequently analysis of Sulphate content and cement content was also done.

3.6.1 Details of tests carried out:

Initially, 100mm diameter core samples were taken from 3 locations of pour-I over which pour-II was not laid and 35 locations on pour-II to depths varying from 400 to 850mm.

Parallely CECRI scientists carried out Schmidt rebound hammer test at 10 locations. Electrical resistively measurements were also taken and concrete was also chipped up to 25mm depth at same locations for chloride analysis.

Chloride penetration was checked for 0 to 25mm, 26 to 50mm, 51 to 75mm depth from the top surface. Chloride levels varying from 3.23 kg/m3 to 9.11 kg/m3 in the top 25mm layer of concrete. An additional exercise was carried out by CECRI, which shows that the chloride concentration was high in the top 5mm layer.

Sulpahate contents were also checked. Sulphate levels are varying from 6.47kg/m3 to 10.01kg/m3. These are with in the acceptable limit of 4% by weight of cement content (400kg/m3) in concrete i.e., 16kg/m3.

Cement contents were also checked at different locations. Cement content levels were found satisfactory and are comparable with the mix design requirement of 400kg/m3 as per clause 8.8 of SP-23.

Compressive strength results obtained from the initial lot of 100mm diameter core samples and those obtained from the second lot of 150mm core samples are analyzed in detail. The results of 1st lot of cores (100mm dia) are on the lower side and are attributable to testing details like capping, moisture content, size effect etc. The results of 2nd lot of cores (150mm dia) show values, which are commensurate with the requirement of N45 grade concrete.

Quality took higher position as compared to cost and thus it was decided to discard the 5000 cubic meter of concrete already laid and the water proofing below the concrete. The already laid concrete was

The tsunami has not only flooded the pit but destroyed almost every construction machinery and equipment. Concrete pumps, concrete placement pipe, dewatering pumps, transit mixers, tippers, compressors, generators all were submerged in water and destroyed beyond repair. All approaches were washed away, all slopes of the excavated pit were damaged, bore well dewatering system was completely destroyed. In addition there were several safety concerns requiring. The tsunami rehabilitation task was not possible to be planned effectively due to ever changing scenarios during rehabilitation and due to industrial safety concerns with large no of persons deployed in unpredictable scenarios of working. Hour to hour planning, extensive supervision, quick and bold decisions are steps towards attainment of .quality. A decision was taken after tsunami to discard the sea water contacted concrete even though it was established that the concrete chloride and sulphate content in concrete are within acceptable limits once top 10 mm layer of concrete is chipped off. It was decided not to leave any lingering doubt in the minds that there could be a sea water affected sub standard concrete in PFBR raft. The pre-tsunami concrete layer was discarded and treated as PCC. Yet 10 mm top layer of the concrete was chipped off. In addition a fresh layer of 100 mm impermeable fly ash concrete was laid above chipped off concreted layer. Fresh water proofing layers were laid over this. Thus the already laid concrete was completely isolated from sea water affected concrete in interest of quality.

3.7 Manufacturing techniques:

Several new manufacturing techniques are required to be developed and deployed to perfection. Highly specialized materials such as 316LN, D9, 9Cr-1Mo are extensively used in PFBR. These materials require special care to maintain desired specification of finished products.

Reactor equipment of PFBR are large size thin walled vessels required to be fabricated to close tolerances.

Safety vessel is a vessel with dished end bottom and cylindrical shells. 13.5m dia and 13.5 m high vessel is made of 16 mm 316LN material. Several ingenious technique has been made use of while fabricating Safety vessel.

The circumferential seam of 42500 mm long on 25 mm thick SS316 LN grade SS plate with 3D configuration could be weled at site with 99.83% sound weld joint (requiring repairs in only 77.15 mm length). This percentage has`further improved to cross 99.9% of sound weld joint. Mismatch on the outside dia of 13540 mm has been controlled within the allowed tolerance of $\pm$ 3 mm.

3.8 Mock ups:

Similarly in the construction activities several full scale mock ups are also carried out to establish the constructability of the design. These measures help in achieving the quality envisaged in design without any rejection/ repair in the actual construction.

3.9 Cleanliness and House Keeping:

Maintenance of cleanliness during manufacture of equipment, their erection and house keeping during construction play a major role in performance of system at a later date. When large no of contractors, with different responsibilities work together in same area, maintenance of cleanliness and house keeping may not be maintained by any one of them. Effective administrative controls have to be exercised to remove clutter and maintain working area in orderly fashion. Proper stacking of materials, removal of scrap on daily basis, and control on water leakage is key to success in house keeping. Quality of the construction results in quality operation emphasis on house keeping and cleanliness in large in BHAVINI. In site assembly shop where stainless steel reactor equipment such as safety vessel, main vessel, inner vessel, thermal baffle etc are manufactured, no carbon steel fabrication is permitted and nuclear clean room conditions are maintained.

3.10 Selction of Equipment:

Selection of equipment is vital for future operation performance. Off the shelf items where quality control during production is not controlled by purchaser can end up in poor quality of plant. A shopping list has been prepared identifying off the shelf items of proven performance. Decisions are taken in interest of quality and not on the basis of cost alone.

3.11 Quality Audits:

Quality assurance in BHAVINI is governed by Atomic Energy Regulatory Board (AERB) code on QA. All its elements are followed in totality. Organisation structure for starting any action, systematic planning and monitoring and documentation have special emphasis in PFBR. All the activities of PFBR project are governed by QA manual of BHAVINI. All the activities are audited by an expert senior level quality audit team. The audit team not only ensures compliance to BHAVINI QA manual for project site activities but also at manufactures shop. Audits are well documented.

3.12 Quality of human resources:

Quality of human resources is strength in PFBR. Experts have been drawn from different units of DAE. Technology .developers and sodium experts from IGCAR and construction experts fro NPCIL have been brought on a common platform to construct PFBR reactor. Training of manpower is planned meticulously to develop required skills. The training extends to all disciplines of the project including administration, finance, contracts and material management personnel. The engineers of BHAVINI are exposed to various technical courses, seminars, workshops, discussion meets and technical qualification programmes.

NPCIL provides expert man power support to PFBR as per needs of the project Design skills of IGCAR are well recognized. IGCAR has scientists, engineers and metallurgists of international repute. They have not only done R&D and developed design but continue to provide regular design support to PFBR.

3.13 Operation Training:

For operation training, a systematic training and qualification programme has been worked out with syllabus, checklists, durations for classroom and practical training. The training for operating crew is imparted in FBTR to provide knowledge of sodium handling and NPCIL power stations to impart knowledge of operation under pressure of production and profit generation.

4. Conclusion:

Besides this, there are several challenges to be met during the commissioning phase for which meticulous planning, training of man power, trials are carried out. Being a commercial venture, the first of its type Fast Breeder Reactor itself has requirement of meeting time and cost targets in parallel in addition to meeting technological challenges.

Thus PFBR which is going to be the fore runner for the next generation of reactor is expected to be a marvel of technology and an epitome of quality.

References:

QA documents,
Production records
and site QC formats