5

KUDANKULAM NUCLEAR POWER PROJECT

The three-stage power program of India based on Bhabha's vision which was aimed at utilizing the natural uranium in the first stage and the abundantly available thorium in the final stage did not rightly include the deployment of light water reactors (LWRs) requiring enriched uranium. But then around the year 1987 to meet the increasing demand for energy, DAE decided to go in for large capacity (1000 MWe) reactors. DAE opted to go in for Pressurized Water Reactors (PWRs) in view of the large worldwide operating experience for these reactors. After detailed evaluation, VVER type Russian reactors of 1000MWe capacity were chosen to be located at the earlier selected site of Kudankulam, near Kanyakumari in Tamilnadu. VVER–412 specially designed for India was a slightly modified version of VVER–320 which met all the licensing requirements of the Russian regulatory body, then called as Gosatomnadzor (GAN).

For AERB, which had just then completed the establishment of a well structured scheme of regulatory review for the PHWR type of reactors, the induction of VVERs posed a big challenge for many reasons. Even though the plant had a proven design which was licensable in the Russian Federation, AERB needed to carry out detailed safety review as part of consenting process for construction, commissioning and operation. For the first time an LWR design of a high capacity was being reviewed. AERB did not have its own codes and guides for PWRs and hence had to use relevant standards of IAEA and other international standards.

Cooperation between AERB and Russian Regulatory Body

It was well recognized that intense interaction between AERB and GAN, the Russian regulatory body would be essential to ensure a smooth and proper process of licensing the Kudankulam Nuclear Power Plant (KKNPP). First formal contacts between AERB and

GAN began during November 1988, when a team of Russian officials from GAN visited India and exchanged information with AERB. Subsequently, following a brief period of lull due to break up of USSR, project activities at KK did not start. Contacts restarted between AERB and GAN from 1999 onwards when a team of officials led by G.R. Srinivasan, the then Vice-Chairman, AERB visited the Russian Federation and had discussions with the GAN authorities. As desired by GAN, a formal agreement for cooperation in safety and regulatory areas was formulated during 1999. During the year 2001, a team of AERB officials led by S.K. Mehta, Chairman ACPSR-LWR visited the Russian Federation to have a direct discussion with the principal designers and visit the prototype plant Balakova Unit-4. During the year 2002, action was initiated by AERB to finalize the agreement for cooperation between the regulatory bodies, as the construction was in progress and the necessary regulatory clearances were being granted to the KKNPP. A team led by Yuri G. Vishnevsky, the then Chairman, GAN visited India in January, 2003. During the visit, he and S.P. Sukhatme, Chairman, AERB signed the final agreement on January 15, 2003.

The agreement provided for cooperation in the field of safety regulation in the peaceful uses of nuclear energy. The regulatory agencies agreed to familiarize themselves with the practices followed by the counterparts to ensure the safety of nuclear power plant personnel and the public and protection of the environment against any possible harmful effects of radiation. Mutual exchange of information and experience would cover regulatory documents used for design and for all subsequent phases of the nuclear power project, methodology adopted to validate computer codes and comparison of results against international verification programmes and requirements for qualifications, training and licensing of power plant personnel. Method of acceptance of design and its analysis with regard to seismic stability and environmental qualification, methodology of selection of materials for critical components, regulatory positions on other matters related to the safety of nuclear power plants are some of the other issues, where AERB and the Russian regulatory authority would exchange information and experience.

In February 2005, a workshop was organized by AERB on "Information Exchange on Nuclear Safety" with participation from Russia and India. Indian side was represented by Members of ACPSR-LWR and the Specialist Groups involved in the safety review of KKNPP consisting of experts from BARC, NPCIL and AERB. A second workshop of similar nature was organized by AERB in March 2008. In order to acquire adequate knowledge in VVER Design, Safety and Operation, a few AERB officials participated in the licensing and training process along with NPCIL engineers in Russian Federation.

Design Safety Review of KKNPP

NPCIL had prepared in 1989, the Technical Assignment (TA) document for KKNPP covering the scope, broad design specifications and safety requirements including those of AERB. The TA was reviewed by the Project Design Safety Committee (PDSC-KK) constituted by AERB with A.K. Anand as its Chairman and its comments were also taken into account in revision of TA. AERB constituted an Advisory Committee for Project Safety Review for LWRs (ACPSR-LWR) in October, 1994 with S.K. Mehta as Chairman. This Committee had various specialist/expert members from both DAE as well Non-DAE organizations.

The Preliminary Safety Analysis Reports (PSARs) of KKNPP, Topical Reports and QA documents were submitted to AERB in 1999, which formed the primary basis for review and assessment by AERB.

The Safety Review of Pressurized Water Reactor (PWR) was being carried out in AERB for the first time. In view of this, AERB decided to adopt a somewhat different review scheme from the one given in "Governing Authorisation Procedure for Nuclear Power

Project/Plant (AERB/SM/NISD-1)". In place of PDSC-KK which was earlier set up during 1989, a Co-ordination Group (KK-CG) was constituted in January, 2000 and many Specialist Groups were formed consisting of experts drawn from AERB, NPC and BARC for review of the PSAR Chapters and some specific topics. Since then the role of PDSC has been performed by KK-CG along with the Specialists Groups (SGs).

NPCIL forwarded various PSAR chapters to AERB between March, 2000 and March, 2001. The chapters have been written as per the Format of USNRC-RG 1.70. In the absence of applicable AERB Codes/ Guides for PWRs, relevant standards of IAEA and USNRC were used during the review process. The AERB Codes and Guides were also referred for the applicable issues. Compliance with the Russian Normative Technical Documents (NTDs) and TA was ensured. GAN review comments on PSAR chapters were also considered during review by AERB. Further, in order to gain confidence, limited in-house design check exercises were also conducted.

During the course of review of PSAR Packages, the specialist groups also had discussions with the concerned experts of Russian Federation towards resolving certain design issues. In order to acquire thorough knowledge of VVER-1000 design, safety and operation, some AERB officials were also trained in the Russian Federation during the period 2003-04.

Regulatory Clearances

Siting

AERB issued clearance for siting of KKNPP with two VVER-1000 MWe units, at Kudankulam in November, 1989. This was based on review of the report of the Site Evaluation Committee (SEC) chaired by S.K. Mehta followed by review by Advisory Committee for Site Evaluation (ACSE) chaired by S.M.Sundaram and finally by the Board of AERB.

Construction

A Workshop on "Consenting Process for NPPs" was organized in July, 2001 by AERB and various aspects related to consenting process were deliberated with experts in the field and representatives of Utility. One of the recommendations of this workshop was to carry out review concurrently with the progress of construction activities. Accordingly, the various submissions to AERB were staggered and the clearances were issued in three sub-stages viz. Excavation, First Pour of Concrete (FPC) and Erection of Major Equipment (EE).

Excavation

The clearance for excavation was given in October, 2001. The clearance was issued subject to compliance of stipulations like restriction on surface mining of limestone within Exclusion Zone and Sterilized Zone and design of embankment for water storage reservoir as ultimate heat sink.

First Pour of Concrete (FPC)

SGs, KK-CG and ACPSR-LWR had reviewed the required PSAR chapters prior to issue of recommendations for FPC in March, 2002. Also, sample civil engineering design verification checks for reactor building were taken up. Also, safety review of design of metallic liner for Inner Containment Wall (ICW), soil-structure interaction for raft under seismic event, seismic analysis models for reactor building, accidental torsion effects under seismic event, core catcher design etc was carried out.

Clearance for First Pour of Concrete was given in further sub-stages as follows:-

- FPC for Reactor Auxiliary Building (RAB) of Units-1&2- March 22, 2002
- FPC for Reactor Building (RB) of Units-1&2 was given on April 9, 2002, after establishing 28 days compressive strength of concrete blocks – i.e., the Clearance for the bottom Raft Portion of reactor building (non-hermetic portion) was given

- Clearance for Construction of +5.4 m El slab was granted on April 23, 2003.
- Permission for Installation of Core Catcher Vessel and Construction Beyond +5.4m up to 17.0m Elev. for RB was given on November 27, 2003 after satisfactory review of design safety aspect of Core Catcher and after satisfactory resolution of issues that emanated from sample civil engineering design checks at identified locations of ICW.
- After satisfactory review of liner details around major penetrations (equipment, emergency and personnel airlocks), permission for construction beyond 17.0 m Elev. of RB was given on June 15, 2004

The above can be seen as an example of concurrent regulation without compromise with safety or affecting the project schedule.

Erection of Major Equipment (EE)

Specialist Groups, KK-CG and the ACPSR made a number of important observations during review of design related PSAR Chapter (Rev-1). Subsequently, NPCIL submitted PSAR (Rev-2) progressively from January, 2002. Nuclear Project Safety Division (NPSD) carried out the detailed review of these packages (Rev.2) to ensure compliance with the comments/ recommendations made on Rev-1 and the important issues/observations were referred specifically for consideration of respective SGs. Also, based on this review, salient pending issues, those need to be resolved prior to authorization for EE, were identified and referred to NPCIL. NPCIL submitted the responses on these pending issues in February, 2005 and these were also considered during review of PSAR packages (Rev.2) by respective SGs and the ACPSR. On the basis of the responses provided and commitment to provide the details on certain specific issues, in a progressive manner, Clearance for EE was granted for Unit-1 in August, 2006 and for Unit-2 in June 2007.

For PWRs, erection of Reactor Pressure Vessel (RPV) is considered as start of EE stage as per the AERB Guide AERB/SG/G-1 on 'Consenting Process for Nuclear Power Plants and Research Reactors'.

Salient Observations from the Review

During the course of design safety review of KKNPP, a number of challenging issues emanated. Some examples of such issues are as follows.

Safety Classification of System, Structures and Components (SSCs)

The philosophy of safety classification, adopted in KKNPP was different from that of IAEA/AERB. The Russian philosophy is element based whereas the IAEA philosophy is system based. During the course of discussion, it was noted that the Russian classification system was more conservative and a direct correlation with IAEA classification could not yield any additional improvement in safety.

Containment Liner

The containment liner design, especially the areas around penetrations, was reviewed in detail to ascertain the integrity of the liner under normal operating conditions and accident conditions. The effect of failure of anchor, fatigue life and deformation of the liner surface after pre-stressing of primary containment were specifically seen.

First Of A Kind (FOAK) Systems

The design employs a number of systems and Engineered Safety Features (ESFs) of novel design. One of the salient features of the design is incorporation of 'Four Train Safety Systems', thus increasing reliability. Another important feature is provision of both active and passive systems to prevent accidents and/or to mitigate their consequences. Passive systems such as Passive Heat Removal System (PHRS), Second stage ECCS accumulators, System for retaining and cooling of molten core (Ex-vessel Core Catcher) etc. have been provided for catering to BDBA. Quick Boron Injection System (QBIS) has been incorporated in addition to the active Emergency Boron Injection System (EBIS) for catering to Anticipated Transients Without Scram (ATWS) situations. All such systems were asked to be adequately justified by submission of details of developmental tests/analysis and relevant reports. NPCIL obtained reports on these aspects from the designers and these were reviewed. It was further stipulated that such systems should be tested, and demonstrated to meet their design intents during commissioning. Some of the salient observations on FOAK systems are given in subsequent paragraphs:

Sharing of Safety System

A safety system designed for long term recirculation during LOCA and decay heat removal (JNA) is used for multiple functions namely (i) to remove core residual heat following reactor shut down, (ii) to provide cooling of spent fuel pool water and (iii) to perform low pressure ECCS function during LOCA. The JNA system has 4 trains each of 100% capacity and the trains are physically separated and independent with regard to supporting systems like power supply, cables etc. The JNA system performs safety as well as normal operation functions. Also, HX of each train of JNA system is shared by one train each of three other safety systems namely (i) Containment Spray system, (ii) High Pressure ECCS and (iii) EBIS system.

The aspect of use of a safety system for multiple purposes and sharing of its equipment with other safety systems were reviewed in detail under Anticipated Operational Occurrence (AOO), Design Basis Accident (DBA) and Beyond Design Basis Accident (BDBA) conditions. Based on the review, the design approach has been accepted by AERB subject to incorporation of suitable surveillance requirements for these systems during operation.

Passive Heat Removal System (PHRS)

This system has been provided to reject decay heat of reactor core to outside atmosphere, during Station Black Out (SBO) condition lasting upto 24 hours. The system can maintain hot shutdown condition of the reactor, thus, delaying need for boron injection. PHRS has four independent trains, each with three air-cooled heat exchangers located along the periphery on the outside of the secondary containment. Three trains are designed to provide 100% heat rejection capacity with reactor in shutdown condition i.e. 2% of reactor rated power. Specially designed air inlet/outlet dampers are provided across heat exchangers of PHRS for controlling air flow over these HXs. Experience with specially designed air inlet/outlet dampers is not available. Functional tests for damper opening/closing/modulation on steam pressure signal during commissioning as well as periodic tests will have to be done.

Second Stage ECCS Accumulators

Emergency Core Cooling System (ECCS) has four sub-systems, namely (i) high pressure emergency injection system, (ii) first stage hydro accumulators, (iii) long term recirculation and decay heat removal system (JNA) and (iv) second stage ECCS hydro accumulators. Second stage ECCS hydro accumulators have been designed to supply borated water for core cooling. The design envisages decay heat removal during BDBA condition of LOCA with SBO for 24 hours when the system operates together with PHRS. Performance of the system and especially of proper functioning of the special check valves would be ascertained during commissioning phase.

Quick Boron Injection System

Two systems, EBIS and QBIS are provided which can individually make the reactor sub critical by adding concentrated boric acid solution during an ATWS condition. This system would be tested during commissioning to establish its effectiveness and to ensure its performance is as per the design intent.

System for retaining and cooling of molten core

An Ex-Vessel core catcher filled with specially developed compound (oxides of Fe, Al & Gd) is provided for retention of solid and liquid fragments of the damaged core, parts of the RPV and reactor internals under severe accident condition resulting in melting of core and failure of RPV. The filling compound provides volumetric dispersal of the melt. It provides sub criticality of the melt and prevents it from spreading beyond the limits of containment. The filler compound has been developed to have minimum gas release during dispersal and retention of core melt. Cooling water can be supplied on top of core catcher from water storage inside the reactor building by opening of a remotely operated valve as per the accident management procedure. By design, accumulation of leaked out water from primary coolant system and ECCS provides cooling of core catcher vessel from outside without any need for operators' intervention. Appropriate surveillance requirements for this novel feature will have to be worked out and incorporated in Technical Specifications for Operation.

Departure from Nucleate Boiling Ratio (DNBR) Algorithm

An on-line measurement of DNBR and reactor trip on low DNBR has been implemented in KKNPP. Various aspects of this design are under review by experts in the field.

Un-bonded pre-stressing system for Primary Containment (PC)

Un-bonded pre-stressing system has been used in KKNPP for PC. This is the first time that such a system is being used in any NPP. In this system, a strand of seven ply wire is surrounded by HDPE sheath with grease packed between the strand and the sheath. A cable consists of 55 such HDPE sheathed strands placed inside a metallic conduit. The gap between the conduit and HDPE sheaths is filled by cement grout prior to tensioning of the cable. Grease and HDPE sheath reduce friction during tensioning. In this system cable tension can be monitored and re-adjusted if required and broken strands can be replaced during the life of the plant.

Based on review, many mockup tests were asked to be conducted to demonstrate effectiveness of various activities such as threading of HDPE sheathed strand, grouting of vertical and horizontal cables, re-threadability of strand etc. Full scale mock-ups were carried out and required changes were implemented during installation of the system. Considering the use of HDPE as sheath around metallic strands, life estimation for HDPE was carried out by accelerated ageing tests at Indian Rubber Manufacturers' Research Association as asked by safety committees. The test result has indicated 62 years of life at service temperature of 33°C.

Containment Isolation System

The containment isolation system contains two sets of valves in series, one pneumatically operated and another electrically operated with relatively large time for complete closure on ventilation ducts. Incorporation of electrically operated valves for isolation and higher closure time was accepted considering redundancy in power supply schemes, diversity of valve actuators and safety analysis.

C&I systems

Emergency Protection and Engineered Safety Features Actuation System, have common neutron sensors. Implication of this approach could be that emergency protection system and both systems to cater to Anticipated Transient Without Scram situations i.e. EBIS and QBIS can fail simultaneously. However, after a detailed review this approach has been accepted considering that there are separate sensors for two sets of 2 out of 3 coincidence logic.

Turbine Missile Impact

During the review and subsequently during the regulatory inspection, it was seen that certain safety related structures/ buildings [Main Control Room (MCR), part of secondary containment wall], are coming under Low Trajectory Turbine Missile (LTTM) strike Zone. Initially adequacy of safety for LTTM was demonstrated using probabilistic approach, which was not accepted by AERB. Subsequently based on deterministic assessment it was confirmed that there would not be any damage to MCR and Secondary Containment wall would not get penetrated.

Reactor Pressure Vessel (RPV)

The original design of RPV did not contemplate welds in the core region. However, the vessel now used has two welds in the core region. The effect of lifetime neutron fluence on these welds was evaluated and found to be acceptable.

The regulatory review of Kudankulam Nuclear Power Project gave AERB an immense opportunity to upgrade its expertise in variety of areas. Adopting a different scheme of review process, AERB could effectively carry out the multi-tier review process in a time bound manner. Clearly the experience gained in this project will be of great help in taking up review of future reactors, a number of which are likely to be of LWR type.

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