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PHWR BASED NUCLEAR POWER PROJECTS

AERB was still in its nascent stage, when construction of the fourth nuclear power station in the country was coming up, intended for installation at Narora. However, the safety review of the design of the PHWR units NAPP-1&2 was being carried out by the Narora Design Safety Committee (NDSC) constituted in 1974 by the Power Project Engineering Division (PPED), the precursor to NPCIL. It is important to note that this project marked not only the development of first Indian design of 220 MWe PHWR units but also the start of the safety review at design stage itself. The designs and equipment of TAPP-1&2, RAPP-1&2, and MAPP-1&2 were largely based on imported units from USA and Canada respectively. The NDSC evaluated the plant based on its design basis reports (DBRs), safety analysis report (SAR) and design manuals. Its mandate extended to the review of commissioning (from hot conditioning of primary heat transport system upto completion of phase-C commissioning tests). NDSC reported its findings and recommendations to DAE-SRC.

By the time AERB was sufficiently staffed for starting its review activity (mid 1984), it took upon itself the continuation of safety review of NAPP-1&2 projects, in addition to the ongoing safety reviews of operating plants (TAPS-1&2, RAPS-1&2, MAPS-1&2). Both NDSC and DAE-SRC were required to report their findings and recommendations to AERB for confirmation. AERB organized its activities expeditiously in order to fulfill its mandate consistent with the prevalent world practices.

Around 1988, IAEA had issued its safety standards for assuring safety in nuclear installations, in forms of safety codes and associated safety guides. The IAEA Safety Code on "Governmental Organization for Regulation of Nuclear Power Plants", Safety Series No. 50-C-G, issued in 1988 provided the requirements for any regulatory body to organize its review and monitoring activity. Based on the various international practices being adopted by USNRC, CNS, etc., AERB instituted a three-tier structure for safety review of nuclear power plant/projects (NPP) spanning major consenting stages.

Regulatory Documents for Consenting

M. R. Srinivasan, Chairman AEC called a meeting in January 1988 of senior officers of NPCIL and AERB on a request from A. K. De, Chairman AERB. The meeting highlighted the need for arriving at procedures in issuing authorizations at various stages of the project. Based on the inputs gathered at this meeting, the AERB Safety Manual on "Governing Authorization Procedure for Nuclear Power Projects/Plant (AERB/SM/NSD-3) was published in 1989. This seminal document provided a firm basis for defining regulatory requirements and the rationale for their application and enforcement. It clearly defined the stages requiring regulatory clearances as "Authorizations" and identified the required documentary submissions that were necessary for assessing the level of safety for the concerned authorization. This document also provided for interim clearances, within the overall activity of commissioning.

This was also the time when the impact of the Chernobyl accident was being felt by all the nations with respect to management of severe reactor accidents. After detailed review and extensive discussions with NPCIL, AERB issued two documents, namely, AERB Safety Manual on "Site Emergency Plan for Nuclear Installations (AERB/SM/NSD-1)", issued in 1986/87 and AERB Safety Manual on "Off-site Emergency Plan for Nuclear Installations (AERB/SM/NSD-2)", issued in 1988. For many years, the foregoing three manuals formed the basis of AERB's requirements with regard to regulatory review for projects and preparation of emergency preparedness plan.

In 2000, AERB issued the AERB Safety Code on "Regulation of Nuclear and Radiation Facilities (AERB/SC/G)", which defined the requirements of AERB's consenting process, its inspection provisions for verifying compliance with conditions of the consents, and enforcement actions for nuclear and radiation facilities. For nuclear power plants, the term “Consent” replaced the earlier term “Authorization”. A Safety Guide on “Consenting Process for Nuclear Power Plants and Research Reactors (AERB/SG/G-1)” was issued in 2007 in the light of experience of review and consents given earlier by AERB. This document besides specifying the consenting procedure, the assessment process, the documentary submission at each stage and the lead time for the submissions, also provided guidelines on preparation of various documents such as safety assessment report, safety evaluation report etc.

AERB has issued a series of safety codes and safety guides since its inception. These safety documents have been, by and large, non-prescriptive, and have been carefully drafted to be compatible with existing established professional codes of practice applicable to nuclear power plant systems like ASME, RCC series, etc. However, AERB also issued civil engineering standards for nuclear power projects, to bridge the gaps between Indian civil engineering codes of practice and requirements for nuclear structures with respect to design and inspection. For projects such as Kaiga-1&2 and TAPP-3&4, these standards appeared midway in the design and construction process. The ensuing review work compelled the designers to make mid course alterations to comply with prescriptive technical requirements of these standards.

Formation of Safety Review Committees

Once the required documents for getting the relevant Authorization/ Clearance are submitted by NPCIL, AERB constitutes a Site Evaluation Committee (SEC) for purpose of siting stage clearance and a Project Design Safety Committee (PDSC) for subsequent stages, drawing technical design experts from the respective fields. While Site Evaluation Report (SER) forms the basic input for site evaluation, documents like Design Basis Report and the Preliminary Safety

Analysis Report are the basic inputs to PDSC besides all the technical documents that are asked by the committee as and when needed. The PDSC so constituted would review the design from safety point of view and can recommend additional safety features, if required. The committee ensures compliance with the AERB codes and guides as applicable and also with the IAEA documents, as applicable. The committee liaises with the Civil and Structural Engineering Design Committee of AERB for review of Safety of Civil structures, in making its overall recommendation to AERB.

Three-tier Review Process for Consenting

In principle, the first level review is conducted by either the Site Evaluation Committee (SEC) and the PDSC. These committees are constituted from AERB and departmental organizations (NPCIL, IGCAR, BARC) with administrative and technical support by AERB. These committees, at times also constitute specialized working/ specialist groups, sub-committees and task-forces to examine any specific issue that could be referred to them. The group members are drawn from in-house and external organizations. These committees meet at frequent intervals to examine submissions, test results, etc. and present their recommendations for confirmation by the next level committee, viz., the Advisory Committee for Project Safety Review (ACPSR) as per the requirements. The ACPSR, includes experts from academic institutions viz. IITs etc, the Central Boiler Board, representatives from the Ministry of Environment & Forests and the representative from the Central Electricity Authority apart from experts from BARC, IGCAR, NPCIL and AERB.

There is a common ACPSR for all nuclear power projects of a given type. (i.e., one for PHWR & FBR and the other for LWR). The ACPSR conducts its review for confirmation only when the review by SEC and PDSC is complete and their recommendations are available. While ACPSR is free to examine any issue in its entirety, it generally provides assurance to AERB that the due process of safety review have been conducted, and that PDSC concerned has followed safety norms and standards in its deliberations. Additionally, ACPSR performs a vital regulatory assignment of involving external experts to assure objectivity in its deliberations.

Recommendations of SEC and PDSC confirmed by ACPSR are presented to AERB for further action. Generally, these recommendations are for grant of a requested consent/clearance. However, these review committees are empowered to recommend stoppage of any work on a project that they feel could jeopardize safety.

The major stages of AERB's consenting process for Nuclear Power Projects are Siting, Construction, Commissioning and Operation.

Siting Consent

Siting consent generally is a single step action, that is, a site is accepted at one go if AERB's requirement for siting are met. It requires a general review of design basis and the Site Evaluation Report (SER) incorporating site characteristics and basic design information submitted by the applicant. In addition, Design Basis Information document is also reviewed in so far as it is related to siting .

Construction Consent

At this stage, the overall design safety, including plant layout, plant buildings/structures, reactor systems, electrical systems, instrumentation and control systems, accident analysis, radiation protection, waste management system, reactor auxiliaries, etc are reviewed. AERB has a unique method with respect to Consent for Construction. Construction Clearance can be given in a single stage or in 3 sub-stages, if utility so desires. These sub-stages are: (i) Excavation for main plant area, (ii) First pour of concrete for structures important to safety and (iii) Erection of major equipment. This stage requires review of Preliminary Safety Analysis Report (PSAR), supplementary Design Basis Report (DBRs), QA during design and construction and construction schedule. The review process has been formulated accordingly. Experience with splitting of construction consent in this manner has been satisfactory as it facilitates early start of construction activities at site. Also, it facilitates site work concurrently with safety review.

Commissioning Consent

AERB grants regulatory clearance for several intermediate stages/ phases starting from hot conditioning up to raising reactor power to 100% rated power. Typically there are ten sub-stages for PHWR based NPPs. These intermediate stages are clearly identified and for certain important stages like first approach to criticality, full power operation etc, approval by ACPSR and the Board are mandatory. But for all stages, approval by PDSC and Chairman AERB are required.

Operation Consent

This stage involves routine power operations at rated power. Detailed test reports are reviewed to ensure that the unit is capable of sustained operation at rated power. The review of Final Safety Analysis Report (FSAR) which is the final version of PSAR incorporating as-built design and commissioning results had to be completed before the consent for operation is given. The objective of FSAR is to present the predicted response of the plant to postulated initiating event, to demonstrate with reasonable assurance that the Unit has capacity for preventing accidents and/or mitigating their effects sufficiently to preclude undue risk to public health and safety. AERB issues consent for continuous operation at rated power for a specified period like 5 years. Well before expiry of this period, NPCIL needs to submit the application for renewal of consent. The renewal of consent would be based on periodic safety review as specified by AERB in its Safety Guide AERB/SG/O-12.

It is recognized that the depth of review for each stage may be different depending upon the type/design of an NPP. This graded approach is aimed at more efficient and optimized utilization of available resources. Design features for the purpose of the review, are classified as follows:

- Standard/proven design being repeat (e.g. Kaiga-1&2/RAPP-3&4)
- Design evolved from standard design (improved design/proven design, e.g. TAPP-3&4)
- First of its kind engineering i.e. new design (e.g. use of PLC, software based design PFBR/AHWR)
- Imported reactor (VVER-KKNPP)

While basic philosophy and principles of regulatory review had been clearly established long before, the method of review and assessment however has been unique for each Committee depending upon the category of the reactor design. The formulation and publication of the regulatory documents strengthened the review process and facilitated conducting consenting process comprehensively and objectively. The experience gained, the expertise built and the knowledge acquired from these reviews have clearly enhanced the decision-making capability of AERB over the years.

Projects Review: Certain Highlights

Narora Atomic Power Station Unit-1&2 (NAPP-1&2)

The process of review of NAPP was most intensive in terms of man-hours invested. This was due to the evolving nature of Indian PHWR design, and also as a consequence the evolving nature of regulatory review. Narora Design Safety Committee (NDSC) chaired by S. K. Mehta, the then Director, Reactor Group, BARC held 208 meetings from 1986 till NAPS became operational in 1992. Its findings and recommendations were considered and confirmed in meetings of ACPSR.

In the course of NAPP review, several important questions cropped up, and these were addressed and resolved by joint discussions with NPCIL and BARC engineers. Some of the safety improvements made after the safety review include the following.

- Incorporation of Gravity Addition of Boron System (GRAB) for meeting requirement of sub-criticality margin during Station Black Out (SBO) condition. This feature was needed and used during the Fire Incident in 1993.
- Provision for reactor trip on "Low coolant flow in adjuster rods"
- Actuation of both shut-down systems on "More than one Secondary Shut-down System (SSS) bank not available"
- Provision of reactor trip on "More than one rod of Primary Shutdown System not in parked position"
- Provision of reactor trip on "No primary coolant pump/ shut-down cooling pump running"
- Provision of reactor Setback on "Emergency Core Cooling System (ECCS) in blocked condition with primary heat transport system temperature > 101°C"
- Delay in starting of closed-loop Primary Containment Filtration and Pump Back system (PCFPB) was incorporated based on results of thermal analysis of charcoal filters under accident conditions
- Provision for reducing compressed air ingress into boxed up containment
- Backup Nitrogen cylinders to compressed air storage tanks of air locks to maintain containment integrity under SBO condition.
- Incorporation of seismic monitors and seismic trip
- A thermo-siphon test was conducted on the reactor during commissioning phase to demonstrate adequacy of residual heat removal capability under SBO
- Programme for monitoring of position of garter springs around coolant channels and relocation of displaced garter springs to their designed locations

- Emergency Power Supply was found to be insufficient to meet all loads under certain Anticipated Operational Occurrences and Design Basis Events. Hence, a sequential loading scheme was evolved to meet these requirements
- Neutron shielding for the fuelling machine maintenance area was augmented by providing thermal neutron absorber materials on roll-on shields
- Design provision for purification of moderator under reactor shutdown, using boron saturated ion exchange columns.

Most of these modifications/improvements became an integral part of standard design that was repeated for future reactors.

Kakrapar Atomic Power Project Unit-1&2 (KAPP-1&2)

For Kakrapar Atomic Power Projects-1&2 (KAPP-1&2), DAE-SRC had constituted a Kakrapar Design Safety Committee (KDSC) in 1985. KDSC was initially chaired by S.K. Mehta then by S.C. Mahajan from 1992. It held 115 meetings from 1987 till KAPS became operational in 1996. Its findings and recommendations were considered and confirmed in meetings of ACPSR.

Testing of the high-pressure coolant injection as a part of the Emergency Core Cooling System (ECCS) showed deficiencies during commissioning. These deficiencies required modifications to procedures related to operation and surveillance of the ECCS. In view of similarities in their ECCS designs, these procedures were evolved, tested and applied to KAPP-1&2, NAPP-1&2 and also to RAPP-1&2 and MAPP-1&2 when high pressure ECCS was retrofitted as a part of safety upgradation during en-masse replacement of coolant channels.

In 1994, Kakrapar experienced unusually heavy rain for about 15 hours leading to flooding of KAPP site. At that time, KAPP-1 was operational but under shutdown state, and KAPP-2 was under commissioning. Water entered the turbine building basement, pump house and cable tunnels from turbine building and the switchyard.

This extensive flooding jeopardized the functioning of several systems important to safety. The incident was investigated by a committee constituted by NPCIL, and its report was reviewed by AERB. Procedures were drawn up for proper drainage of rain and flood waters at KAPP-1&2. The cause of this flooding event was due to clogging of discharge sluice gates of the nearby Moticher lake into Tapti river. As a result of this event, administrative measures were evolved for assuring adequacy of draining Moticher lake by the local authorities.

Following this the flooding potential at all operating power plants was re-assessed. Where such potential was determined, embankments were mandated around all structures of safety importance. In RAPP-1&2 a 'flood' DG was installed at higher elevation. For projects, adequate elevation of structures important to safety was mandated to avoid hazards of flooding.

The other important recommendations made during the safety review include the following.

- Requirement of continuous re-circulation flow instead of as-designed periodic purge flow of Annulus Gas Monitoring System was specified. Also, proper action-plan in case of development of leak in coolant tube or calandria tube was developed.
- Qualification and validation of software of Programmable Digital Comparator System (PDCS)

Kaiga Atomic Power Project Unit-1&2 (Kaiga-1&2) and Rajasthan Atomic Power Project Unit-3&4 (RAPP-3&4)

Project Design Safety Committee for Kaiga-1&2 (PDSC-Kaiga-1&2) was constituted in June, 1988. Rajesh Chandra, the then Head, RTD, BARC chaired this Committee for a very short duration. Later V. Venkat Raj, the then Director, HS&E Group, BARC and M.K. Ramamurthy, IGCAR chaired this Committee. The same committee carried out the safety review of RAPP-3&4 as the designs were identical for both the projects. However, separate meetings were held whenever site specific issues of RAPP-3&4 were discussed in the early stages of review. PDSC-Kaiga-1&2 held 395 meetings until Kaiga-1&2 and RAPP-3&4 became operational.

Authorization for Siting for Kaiga project was formally given by AERB in 1991, after the site data had been examined and accepted by AERB's Site Evaluation Committee (SEC), and was confirmed by AERB's Advisory Committee for Site Evaluation (ACSE). This was the first site for nuclear power projects that was formally assessed by AERB for acceptance of the site. The earlier sites had been selected and accepted before constitution of AERB.

After an in-depth review of operating experience of NPPs in 1995, AERB recommended automatic actuation of the GRAB system. Conseqently a dedicated, process-independent Liquid Poison Injection System (LPIS) was introduced at all power reactors wich came after KAPP.

In that review of 1995, AERB also concluded that all nuclear power plants should have full-scope training simulators for training and retraining operators for coping with off-normal and emergency conditions. This was necessary to comply with the prevalent international practices, in the aftermath of Chernobyl accident. A training simulator was installed at Kaiga, though it had some limitations.

Some of the safety improvements made after the safety review include the following.

- Improvements in plant layout towards housing of safety related equipments/components in Safe Shut-down Earthquake qualified buildings
- Design provision of seismically qualified water storage at site to facilitate reactor decay heat removal at least for seven days

- Provision of Meteorological towers, Micro-Meteorological Lab and SODAR facility at site for activity dispersal studies.
- Alternate road for evacuation under postulated emergency condition
- Separation of safety related and non-safety related portions of PDCS
- Requirement of on-line testing facility, channel-wise, all reactor trip parameters
- Preparedness of RAPP-3&4 against the release of H_2S from HWP, Kota

Delamination of Internal Containment Dome of Kaiga Atomic Power Project

During the construction of Kaiga Unit-1, a major safety issue cropped up in 1994, when a large portion of concrete from the undersurface of the inner containment dome in Kaiga Atomic Power Project (Kaiga APP) Unit-1 fell down unexpectedly. The delamination of concrete from the undersurface had occurred during tensioning of prestressing cables . Nearly 40% of the surface area and the material which had fallen was estimated to weigh about 130 tons. Fortunately there was no loss of life or damage to any equipment except some minor injuries to fourteen contractor workers.

AERB sent an inspection team led by V. N. Gupchup, Pro Vice-Chancellor, University of Bombay and Chairman of Civil Engineering Safety Committee (CESC), along with P.C.Basu, Head Civil Engineering Section, AERB. Based on the initial evaluation report from the inspection team, AERB directed NPCIL to immediately suspend all civil construction activities related to the Inner Containment Structures (wall and dome) of Kaiga Unit-2 and Rajasthan Atomic Power Project (RAPP) Units-3&4. In addition, NPCIL was instructed not to take up any civil construction activity in the entire Reactor Building of Kaiga Project, Unit-1 without AERB clearance.

To carry out an in-depth review of all the issues involved and to ascertain the root cause for the incident AERB appointed a senior level Experts Committee chaired by V.N.Gupchup. The Committee observed that prestressing cables were placed at close spacing in certain zones, particularly near the steam generator openings, causing excessive loading during the pre-stressing operation. This had resulted in delamination and collapse of a portion of the underside of the inner containment dome.

As a result of the investigation, a number of recommendations were made for re-engineering of the delaminated dome. Some of the major recommendations related to design improvements were

- to minimize the induced radial tension in the transition zones, the normal dome thickness to be increased gradually to the higher value of thickened portion around the SG openings
- to maintain stresses induced due to applied loads within allowable values specified in the codes
- to introduce radial reinforcement
- to avoid congestion and
- to take care of the constraints imposed in the design due to the construction practice adopted.

The Committee also recommended that for all design work including drawings and detailing, checking should be carried out by an independent peer consultants or by in-house experts. The Committee also advised implementation of appropriate quality assurance (QA) programme in design and construction.

The containment dome was successfully re-engineered and constructed. A number of changes were made in the original design based on the outcome of the investigation, safety evaluation of the re-engineered design and mock-up studies. The rehabilitated containment structure was accepted after successful proof test for structural integrity and integrated containment leakage rate test prior to commissioning.

Tarapur Atomic Power Project Unit-3&4 (TAPP-3&4)

A proposal to build a 500MWe PHWR was made in 1985. DAE-SRC constituted a Design Safety Committee (DSC-500) which had conducted 47 meetings from 1985 to 1990 to review the generic design of 500MWe PHWR for inland and coastal site. AERB constituted a Site Evaluation Committee in 1987 chaired by S.D. Soman to study the site evaluation reports of TAPP-3&4 for location of 2 x 500 MWe PHWR Plants. The site evaluation report of the Committee was reviewed by AERB Advisory Committee for Site Evaluation (ACSE). Based on the recommendations of the site evaluation committee and ACSE, AERB granted clearance in 1989. For the first tier review process, AERB constituted Project Design Safety Committee (PDSC) in 1990. PDSC had conducted a total of 387 meetings for this project. Anil Kakodkar, the then Director, RDDG, BARC and later L.G.K.Murthy, the then Director, H&SE, NPCIL chaired the Committee. Its findings and recommendations were considered in meetings of ACPSR.

Though AERB had granted construction consent for the TAPP-3&4 in 1993, NPCIL did not go ahead with construction immediately. After securing a revalidation of the construction consent in 1998, construction activities were started in 2000. TAPP-4 achieved first criticality within 5 years of start of construction i.e. in March 2005. TAPP-3 achieved first criticality in May 2006. TAPP-3&4 is an evolved design and has a number of new systems vis-à-vis earlier built 220MWe PHWRs; exhaustive safety review was performed at all stages of regulatory consents. Safety Committees and their specialist groups spent more than 8000 man-days in formal meetings during design safety review of this project.

During review of design and commissioning, a few issues of safety importance were identified. Some of the important recommendations made during the safety review include the following.

- Actuation of Moderator Liquid Poison Addition System (MLPAS) on failure (slow drop) of 2 or more shut-off rods

- Incorporation of logic to actuate both shut down systems on "low pressure in helium tank of shutdown systems # 2"
- Incorporation of third diesel engine driven fire water pump
- Provision for on-line testing of shut off rod clutch through partial drop of rod.
- Modifications to eliminate the problem of unwarranted actuation of Shut-down System No.2 due to single failure.
- Design changes to eliminate failure in Reactor Regulating System (RRS) due to halting of Output Processor Node (OPN) / Input Processor Node (IPN) resulting in reactor trips.
- Based on RRS stability analysis, cycle timings of IPNs & OPNs and control system gains were reduced appropriately to improve the system stability and avoid reactor trips on "High Bulk Neutron Power" due to occasional development of power oscillations in TAPP-4.
- Incorporation of backup Carbon Steel (CS) liner to SS liner of spent fuel storage bays (SFSB) to protect SS liner from corrosion due to chloride laden sub-soil seepage water rising along the rock-anchors.
- Review of design basis flood level at the site in view of experience at Kalpakkam during the event of Tsunami in December 2004.

Kaiga Generating Station-3&4 (KGS-3&4) and Rajasthan Atomic Power Project -5&6 (RAPP-5&6)

KGS-3&4 and RAPP-5&6 are "Repeat Design" of KGS-1&2 and RAPS-3&4 respectively with some differences in design and plant layout. PDSC was constituted for these projects in 2001 under the Chairmanship of S.M. Lee. The design safety review process for KGS-3&4 and RAPP-5&6 was focussed essentially on review of design differences in comparison to earlier built plants (viz. KGS-1&2 and RAPS-3&4), feedback from operating experience and observations made during regulatory inspections. KGS-3 achieved first criticality on February 26, 2007 and the unit was synchronized to the power grid in April 2008.

Kakrapar Atomic Power Project-3&4 (KAPP-3&4)

NPCIL is carrying out detailed design of 700MWe PHWR utilizing the experience of 540MWe PHWRs, TAPP-3&4. NPCIL has proposed to install two PHWR units at the Kakrapar site near the operating 220 MWe Units KAPS-1&2. Safety review towards granting siting consent for these Units is in progress. NPCIL has also submitted an application seeking clearance for site excavation, as the first sub-stage of construction consent. Accordingly, PDSC-KAPP-3&4 under the Chairmanship of A.K. Ghosh has started the design safety review.

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