Available online at www.sciencedirect.com

SCIENCE DIRECT®

Nuclear Engineering and Design 236 (2006) 894–913

Nuclear Engineering and Design

www.elsevier.com/locate/nucengdes

Regulatory practices for nuclear power plants in India

Jaharlal Koley, S. Harikumar, S.A.H. Ashraf, S.K. Chande*, S.K. Sharma

Atomic Energy Regulatory Board, Mumbai, India

Received 11 March 2004; received in revised form 26 September 2005; accepted 28 September 2005

Abstract

Atomic Energy Regulatory Board (AERB) is the national authority to ensure that the use of ionizing radiation and nuclear energy in India does not cause undue risk to the health of workers and members of the public, and the environment. AERB fulfills its mission by stipulating and enforcing rules and regulations concerned with nuclear and radiological safety. This paper describes the regulatory authorization process of AERB as applicable to nuclear power plants (NPPs) during their construction as well as operating phases. The safety review process during construction is presented as case studies. Some current issues related to operating plants are also described. Two typical examples of safety upgradations made in old generation nuclear plants are given.

The regulatory process in India is continuously evolving to cater to the new developments. Some of the recent initiatives taken by AERB in that direction are briefly described. Today AERB faces new challenges like simultaneous review of a large number of new projects of diverse designs, a fast growing nuclear power program and functioning of operating plants in a competitive environment. This paper delineates how AERB is gearing up itself to meet these challenges in an effective manner.

1. Introduction

India is today on the threshold of a large expansion of its nuclear power programme. As on August 2005, there are 14 units with a total installed capacity of 2770 MW are in operation and 9 units of a total capacity of 4460 MW are in various stages of construction (Table 1). These new plants are scheduled to be commissioned in the years 2004–2010. Further expansion of nuclear power generation capacity to over 10,000 MW by 2010 and 20,000 MW by 2020 is planned. Assuring safety of nuclear power plants, both in operating units as well as those under design and construction is of utmost concern at this juncture.

The primary responsibility of ensuring safety of nuclear power plants (NPPs) rests with the organization responsible for their design, construction, commissioning and operation, i.e., the Nuclear Power Corporation of India (NPCIL). The task of laying down necessary rules and regulations and ensuring that all the safety criteria thus laid down are adequately met is entrusted to the regulatory body, i.e., the Atomic Energy Regulatory Board (AERB). This paper describes the regulatory practices followed by AERB in meeting these objectives.

2. Atomic Energy Regulatory Board and its regulatory structure

The Atomic Energy Regulatory Board was constituted on 15 November 1983 to carry out regulatory and safety functions envisaged under Sections 16, 17 and 23 of the Atomic Energy Act, 1962. The regulatory authority of AERB is also derived from the rules and notifications promulgated under the Act (AERB, 2000a). These include

- Radiation Protection Rules (1971),
- Working of Mines, Minerals and Handling of Prescribed Substances Rules (1984),
- Safe Disposal of Radioactive Wastes Rules (1987),
- Control of Irradiation of Food Rules (1996) and
- Factories Rules (1996).

Prior to the establishment of AERB, the regulatory functions were carried out by the Safety Review Committee of the Department of Atomic Energy (DAE) supported by Safety Committees for individual plants.

* Corresponding author.
E-mail address: skchande@aerb.gov.in (S.K. Chande).

0029-5493/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.nucengdes.2005.09.035

Table 1
Status of Nuclear Power Program in India

In operation			Year of commissioning
TAPS-1 & 2	2 × 160 MWe	BWR units	1969
RAPS-1	100 MWe	PHWR unit	1972
RAPS-2	200 MWe	PHWR unit	1980
MAPS-1	170 MWe	PHWR	1983
MAPS-2	220 MWe	PHWR	1985
NAPS-1 & 2	2 × 220 MWe	PHWR	1989 & 1991
KAPS-1 & 2	2 × 220 MWe	PHWR	1992 & 1994
KGS-1 & 2	2 × 220 MWe	PHWR	2000 & 1999
RAPS-3 & 4	2 × 220 MWe	PHWR	1999 & 2000
Under construction			
RAPP-5 & 6	2 × 220 MWe	PHWR	
KGS-3 & 4	2 × 220 MWe	PHWR	
TAPP-3 & 4	2 × 540 MWe	PHWR	
Kalpakkam	500 MWe	PFBR	
Kudankulam	2 × 1000 MWe	VVER	

2.1. The mission

The overall mission of AERB is to ensure that the use of ionizing radiation and nuclear energy in India does not cause undue risk to the health of workers and members of the public, and the environment. AERB fulfills its mission by stipulating and enforcing rules and regulations concerned with nuclear and radiological safety. In addition, AERB has also been given the mandate for overseeing industrial safety in all DAE units. This mandate is fulfilled by enforcing the Factories Rules.

2.2. Powers and functions

The Atomic Energy Regulatory Board has the powers to execute various functions to carry out its responsibilities. These include:

- Carrying out safety reviews of nuclear and radiation facilities under design, construction and operation.
- Issuing authorizations for siting, construction, commissioning, operation and decommissioning of nuclear and radiation installations.
- Ensuring compliance by radiation installations with the stipulated safety requirements.
- Organizing and conducting regulatory inspections of DAE units and radiation installations and enforcing corrective actions.
- Assessment of radiological safety status with regard to personnel exposures and environmental radioactive releases in nuclear and radiation facilities.
- Administering the provisions of the Factories Act, 1948 in the Units of the Department of Atomic Energy.
- Reviewing the emergency preparedness plans prepared by nuclear installations and participating in emergency preparedness drills as observers.
- Developing safety documents in the form of codes, standards, guides and other safety documents essential for carrying out regulatory and safety functions.
- Funding safety research and training activities related to regulatory functions.
- Keeping the general public informed on major issues concerning nuclear, radiological and industrial safety.

2.3. Organization

The Board of AERB consists of a Chairman, four members and a secretary appointed by the Government of India. While the Chairman, Secretary and one of the members (Chairman of Safety Review Committee for Operating Plants (SARCOP) is ex-officio member) are full time employees of AERB, the other three are persons of repute from major academic institutions and serve on the Board as part time members. The Board reports to the Atomic Energy Commission.

AERB carries out its functions with the help of a secretariat consisting of seven Scientific/Technical Divisions. The Secretariat is supported by an Administrative and an Accounts Division. The organization chart is shown in Fig. 1.

The AERB is supported in its work by an elaborate committee structure (Fig. 2). The apex committees are the Safety Review Committee for Operating Plants (SARCOP), Safety Review Committee for Applications of Radiation (SARCAR) and Advisory Committees for Project Safety Review (ACPSRs). SARCOP carries out safety surveillance and enforces safety stipulations in the operating units of DAE. SARCAR recommends measures to enforce radiation safety in medical, industrial and research institutions, which use radiation and radioactive sources. ACPSRs recommend to AERB issuance of authorization at different stages during construction and commissioning of nuclear facilities including NPPs of the DAE, after reviewing the submissions made by the plant authorities based on the recommendations of the associated Design Safety Committees.

The AERB also receives advice from another Advisory Committee, i.e., the Advisory Committee on Nuclear Safety (ACNS). The ACNS provides recommendations on the Safety Codes, standards, guides and manuals prepared for siting, design, commissioning, operation, quality assurance, regulation and decommissioning/life extension of nuclear facilities. These documents are prepared by the respective committees for each of these areas. The ACNS also advises the AERB on generic safety issues.

The administrative and regulatory mechanisms, which are in place, ensure multi-tier review by experts available nation wide. These experts come from within DAE, from reputed academic institutions and from other governmental agencies.

3. Development of safety documents

One of the mandates of the AERB is to develop safety documents that lay down requirements for meeting safety criteria for activities related to nuclear energy and provide guidance on methods for fulfilling the requirements. Soon after its formation in 1983, AERB initiated work in this direction with the help of experts with extensive experience in the relevant fields. Safety documents published by the International Atomic Energy Agency and regulatory bodies of other countries are appropri-

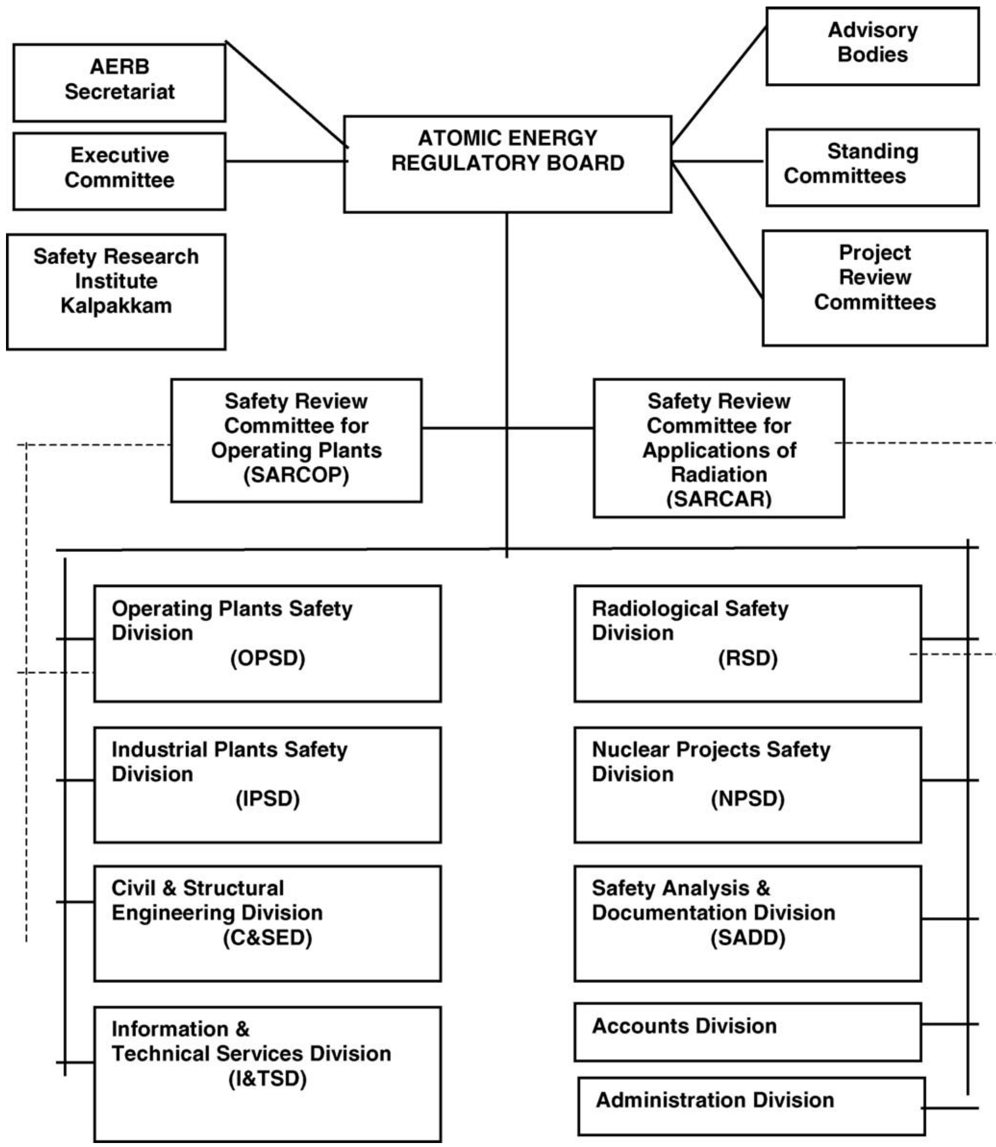


Fig. 1. Organization chart of AERB.

ately used as reference material for the purpose. Experience gained in designing and operating nuclear power plants and other nuclear facilities in India is also reflected in the material contained in the AERB documents (Fig. 3).

Safety Codes establish objectives and set minimum requirements that have to be fulfilled to provide adequate assurance for safety in nuclear and radiation facilities. Safety Guides provide guidelines and indicate methods for implementing specific requirements as prescribed in the codes, Safety Manuals elaborate specific aspects and contain detailed technical information and procedures.

By the year 1990, the apex documents called Safety Codes on siting, design, operation and quality assurance aspects of nuclear power plants were published by AERB. A large number of Safety Guides and other safety support documents were also developed progressively. As on date, AERB has published 5 Safety Codes and 45 Safety Guides concerning various aspects of NPPs and 51 other safety support documents. Several other documents are under various stages of preparation. A list of documents related to NPPs is given in Appendix A. All these safety documents are being extensively utilized in developing designs, operating procedures and in regulation activities including safety reviews by AERB.

4. Safety review of nuclear power projects

4.1. The review process during project stage

AERB has established an elaborate system for in-depth safety review of Nuclear Power Project (AERB, 2006). For this purpose, different stages of authorization have been identified. These stages are

- Siting
- Construction
- Commissioning

Fig. 2. Office of the AERB in Mumbai, India.

The safety review process for these stages of a project is briefly described below.

4.1.1. Siting

Evaluation of the proposed site is carried out as per the requirements laid down in AERB's code on siting of nuclear power plants. A detailed report on site selection is prepared by NPCIL that includes all important aspects of the proposed site. These are geological, seismological and meteorological characteristics of the site, population distribution around the site, land use and water use, distance of the site from nearest public roads, airports, chemical and explosive storage points, availability of a large water body nearby, etc. The report is then evaluated by an expert committee constituted by AERB wherein all site characteristics are checked against the norms specified in the code. In addition to review by AERB, the report has also to be cleared by Ministry of Environment and Forests and statutory bodies like Central and State Pollution Control Boards. The requirement to maintain an exclusion zone inside which no residence or any other public activity is permitted has also to be met. Besides, a low population zone around the exclusion zone is also identified where only natural growth of population is permitted in order to ensure that the number of people to be managed in the event of an emergency is limited.

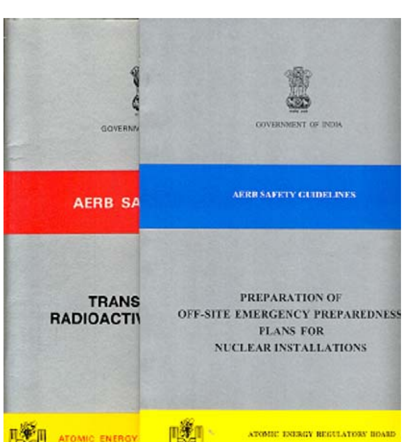
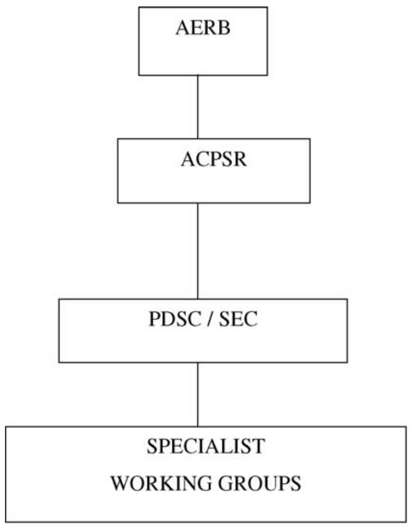


Fig. 3. Regulatory documents published by AERB.

Fig. 4. AERB members visiting the fuelling machine vault at RAPP-4.

4.1.2. Construction

4.1.2.1. Design review. Towards granting clearance for start of construction, a detailed review of the plant design is conducted. For this purpose, NPCIL submits a Preliminary Safety Analysis Report (PSAR) (Fig. 4). The PSAR provides general information on plant design and details of the Design Basis of the reactor and all its auxiliary systems as also safety analysis for Normal Operation, Anticipated Operational Occurrences, Design Basis Accidents and also Beyond Design Basis Accidents. These analyses are based on a set of Postulated Initiating Events, both internal and external to the plant, as prescribed by the AERB's Code on Design of NPPs and associated Safety Guides on the subject. Review of PSAR is carried out through a three-tier review process established by AERB. At the first level, the design details submitted by the utility are reviewed by the Project Design Safety Committee (PDSC) consisting of experts in different fields of design. The Advisory Committee for Project Safety Review (ACPSR) reviews the recommendations of this committee at the second level. On matters pertaining to regulatory consent of the nuclear power plant at various stages, the Board of AERB performs the third level of review based on recommendations of the PDSC and ACPSR. The PDSC and ACPSR are assisted by Expert Groups as necessary. The three-tier design review process for Nuclear Power Projects is schematically shown in Fig. 5.



AERB : Atomic Energy Regulatory Board
ACPSR : Advisory Committee for Project Safety Review
PDSC : Project Design Safety Committee
SEC : Site Evaluation Committee

Fig. 5. Safety review process for nuclear power projects.

4.1.2.2. Consent for construction. Consent for construction authorization of projects is given in three sub-stages, called clearance stages. They are

- Start of excavation
- First pour of concrete
- Start of erection of major equipment

Each of these sub-stages have their relevant review requirements. The regulatory review process of the project is staggered and clearance for a particular sub-stage is given based on the completion of design safety review relevant to that sub-stage. This scheme has been devised to permit parallel action for detailed review while site work for construction can also proceed simultaneously.

4.1.3. Commissioning

On completion of construction, the project construction group formally hands over the plant and its systems to the commissioning group. This can be done in a progressive manner such that commissioning of items like service systems can be taken up soon after their construction is completed and construction of other reactor systems can proceed in parallel.

Commissioning is the process by which constructed plant components and systems are brought into service and are tested to ensure that their performance is in conformance with the design intent. Commissioning is carried out by the plant's operations group and it provides them a good opportunity for getting thorough familiarization with the plant in addition to the knowledge acquired from class room training and study of the design and operations documents for the plant.

Reports of commissioning of various systems are reviewed by the Project Design Safety Committee and its expert groups. Recommendations of the Project Design Safety Committee are submitted to the Advisory Committee for Project Safety Review, which then makes recommendations to the Atomic Energy Regulatory Board for consideration of granting clearances for the major sub-stages of commissioning. These sub-stages for a pressurized heavy water reactor-based NPP are

- commissioning of the coolant and moderator system with light water,
- hot conditioning of primary heat transport system,
- initial fuel loading,
- charging heavy water to the system,
- first criticality of the reactor.

After first criticality and completion of reactor physics related tests, reactor power is raised in steps of 50%, 75%, 90% and 100% of full power with safety review at each stage. Thereafter the safety review responsibility is formally transferred from ACPSR to Safety Review Committee for Operating Plants (SARCOP) for continued operational safety review. Revisions, as necessary, based on commissioning results and details of as-constructed plant are incorporated in PSAR to produce the Final Safety Analysis Report.

4.1.4. Regulatory inspections during construction and commissioning

In addition to detailed design safety review, regulatory inspections of the projects is also carried out by AERB teams. This is to ensure that safety requirements in construction are appropriately followed and all pre-requisites are fulfilled before going to next stage in construction or commissioning. Typically three or four such inspections are conducted in a year depending on the stage of the project. Recommendations arising from the inspections are brought to the attention of project authorities and PDSC for implementation and follow-up.

4.2. Project safety reviews in progress

Although each new nuclear power plant in India is required to be licensed by AERB, the Design Safety Review process varies depending upon its design and licensing history. Safety Review process during licensing of the following Nuclear Power Projects is briefly given here to explain the difference in review process.

1. Indigenous and repeat designs
   (a) Kaiga Generating Station Units-3 & 4 (KGS-3 & 4)
   (b) Rajasthan Atomic Power Projects Units-5 & 6 (RAPP-5 & 6)
2. Indigenous and new designs
   (a) Tarapur Atomic Power Project Units-3 & 4 (TAPP-3 & 4)
   (b) Prototype Fast Breeder Reactor (PFBR) which has been renamed as Fast Breeder Reactor Project (FBRP)

3. Reactors of foreign design
   (a) Kudankulam Nuclear Power Project Units-1 & 2 (KK-NPP-1 & 2)

4.2.1. Kaiga-3 & 4 and Rajasthan-5 & 6 (220 MWe each)

These units are a repeat designs of the earlier standardised PHWR units constructed at these locations and which are operational viz. Kaiga-1 & 2 and Rajasthan-3 & 4. As such, the basic safety review for these projects had already been conducted. Present review is therefore limited to site-specific details and some changes in design and layout. Site clearance for these projects was issued earlier at the time of the commencement of first unit in the site. Clearance for First Pour of Concrete has been given after a quick review of present site conditions. Construction work for Kaiga units commenced in June 2001 and Rajasthan units in January 2002. The on-going detailed design review therefore lays emphasis on changes from earlier licensed design and the operational feedback from similar units in operation.

4.2.2. Tarapur-3 & 4 (540 MWe each)

Tarapur Atomic Power Project Units-3 & 4 are the first Indian PHWRs of 540 MWe capacity. The design of these units has been evolved by NPCIL from the standardised 220 MWe PHWR over the years. The design involves several new features compared to the design of the 220 MWe PHWR units. Considerable R&D efforts were also required to finalise the design of some new features. Consequently, a thorough design review is conducted for Tarapur-3 & 4. Though Project Design Safety Committee is conducting the overall safety review, several experts groups were constituted to review specific aspects of design and safety analyses.

The commissioning of the first of these units is scheduled for the year 2004. It may be mentioned that total construction time for this project has been brought down to about 5 years compared to 7 or 8 years for earlier nuclear power projects. Consequently, AERB also had to expedite its review process to match with the progress of the project.

4.2.3. FBRP (500 MWe)

The Fast Breeder Reactor Project (FBRP) is a uranium oxide–plutonium oxide fuelled fast neutron reactor, which employs liquid sodium as coolant. Design of the FBRP has been developed by the Indira Gandhi Centre for Atomic Research (IGCAR) at Kalpakkam in the state of Tamil Nadu. The plant will be located at the Kalpakkam Site. A Fast Breeder Test Reactor (FBTR) of 40 MW thermal capacity has been in operation at IGCAR since 1985. Experience gained in the FBTR has been appropriately used in the design of the FBR.

This being an entirely different design concept, AERB first developed "Safety Criteria for design of the PFBR" and the guidelines given in this document are used for review of FBR design. Earlier, the conceptual design of FBR was reviewed by Novatome of France and OKBM of Russia who have considerable experience with Fast Neutron Reactors. Comments from these organizations have been appropriately taken into account in the FBRP design. Based on preliminary review by AERB, the site was accepted and clearance for excavation was given in July 2002. Considering the fact that the FBR is the first power reactor of its kind, AERB has broadened the scope of its review work.

4.2.4. Kudamkulam (2 × 1000 MWe)

The Kudamkulam is a twin unit station of 1000 MWe each based on VVER type of light water reactors of Russian Design. One of the stipulations laid down by AERB was that the design of such a plant should be licensable by the Federal Nuclear and Radiation Safety Authority of Russia. Consequently, the design has been reviewed by the regulatory body of Russia and has its approval.

The PSAR of Kudamkulam units are under review in AERB. Review of the chapters necessary for giving clearance for 'Excavation' and 'First Pour of Concrete' was completed initially. Further review of PSAR Chapters is continued concurrently with the construction work of the project. To expedite the review process, 17 specialists groups are constituted. Recommendations of these specialists groups on specific chapters of PSAR are directly reviewed by the ACPSR. The review methodology for Kudamkulam-1 & 2 is based on the following documents:

- USNRC Regulatory Guide 1.70
- Technical Assignment for Kudamkulam-1 & 2 (Design documents, PSAR/FSAR)
- OPB-88/97 (Russian regulatory documents)
- Applicable IAEA Safety Codes and Guides
- Applicable AERB Safety Codes and Guides
- Applicable Russian Safety Codes and Guides

AERB and the Federal Nuclear and Radiation Safety Authority of Russia have signed an agreement for co-operation in the field of safety regulation in the peaceful uses of nuclear energy. In order to get clarifications and elaboration on certain points arising from the reviews, interaction of AERB expert review groups with Russian designers has also been arranged. This is found to be very useful in getting understanding of intricacies of the design. Also, in order to ensure that methodologies followed in Russian design are comparable with those followed by other countries, inter-comparison of certain areas of design was undertaken. Similarly, verification and validation of computer codes used for design and safety analysis was also checked.

5. Regulatory review of operating NPPs

5.1. The review process during operation

For the purpose of regulation of safety in nuclear power plants (NPPs) in operation, AERB has laid down requirements relating to the role of AERB, NPCIL headquarters and individual plant managements. In addition, specific requirements pertaining to educational qualifications, training requirements and licensing of operating personnel are also prescribed. Other requirements specified by AERB deal with operational limits and conditions; operating instructions and procedures; maintenance, inspection and periodic testing; radiation protection, radioactive effluents and waste management; security aspects;

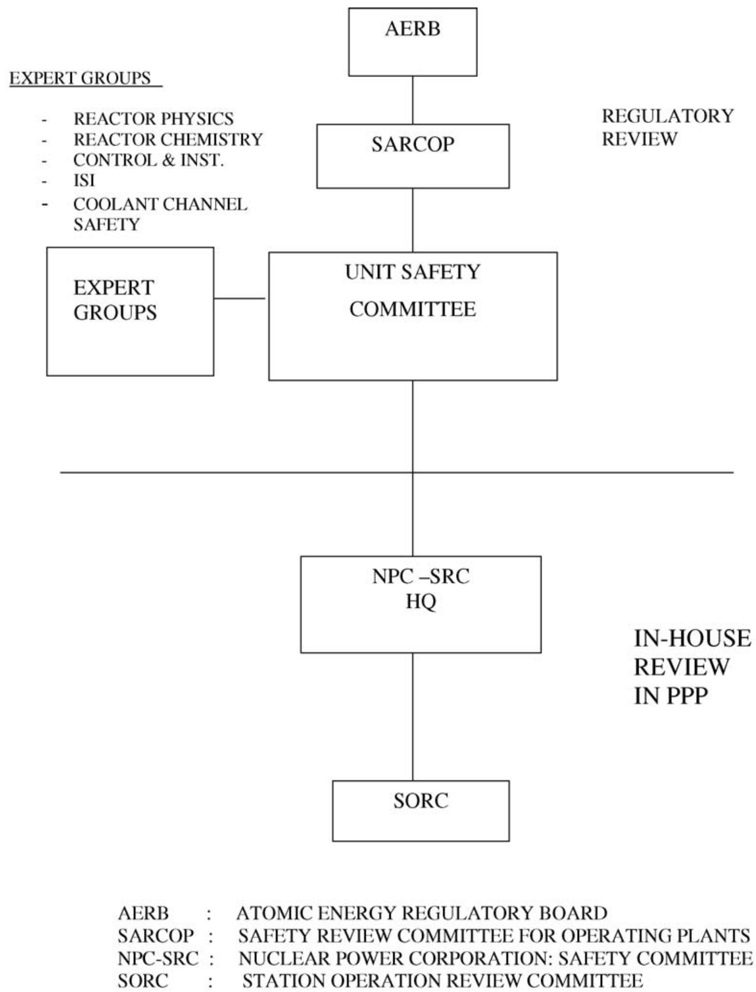


Fig. 6. Safety review process for operating nuclear power plants.

review and audit functions and emergency preparedness (Fig. 6). All these requirements are documented in AERB's "code of practice on safety in nuclear power plant operation". Elaboration and guidelines on methods for fulfilling the requirements of the code are given in a number of "Safety Guides" on individual topics, issued by AERB. Enforcement of the operating rules and regulations is accomplished through an elaborate safety review mechanism established by AERB.

As indicated earlier the authorization for regular power operation is granted after review of the NPP's performance at rated power within the commissioning authorization. The period for power operation within the commissioning authorization is normally 100 full power days. While applying for authorization for regular operation, the applicant has to submit the Safety Analysis Report (Final) reflecting the as built design cleared by the AERB, detailed performance reports, status of and measures to resolve the pending issues (if any). Subsequent to grant of this authorization, the responsibility of safety review is transferred from the Advisory Committee on Project Safety Review (ACPSR) to Safety Review Committee for Operating Plants (SARCOP)/Operating Plant Safety Division (OPSD). This signifies the end of the project stage and the NPP formally comes under the purview of safety review mechanism for operating facilities. As per present regulations, the authorization for operation is valid only for a limited period and required to be renewed as per prescribed requirements.

5.1.1. Normal review during authorization period

As indicated earlier, authorization for operation of a plant is issued by AERB for a specified period. During this period, the operational nuclear power plant is continuously under regulatory review.

For reviews within the authorization period, the following elements are covered:

1. Review of periodic reports submitted by the plant as per reporting criteria specified in the authorization for operation.
2. Review of off-normal occurrences of safety significance.
3. Radiological safety status.
4. Periodic regulatory inspections.
5. Review of proposals for modification in hardware, control logics, plant configuration and procedures related to safety and safety related system.
6. Reports of special Investigation Committees and/or special regulatory inspections following an event of major safety significance.

Table 2
Comparison between Application for Renewal of Authorization (ARA) and Periodic Safety Review (PSR)

	ARA	PSR
Periodicity	3 years	9 years
Scope	Limited	Exhaustive
Factors	Safety performance	Safety performance
	Operating experience feedback	Operating experience feedback
	Status of in-service inspection	Procedures
	Major jobs done	Equipment qualification
	Public concerns	Actual physical condition
		Life cycle management
		Safety analyses
		Organization/management
		Environmental Impact
		Emergency preparedness
		Environmental Impact
		Human factors and public concerns

In addition to the above, special reviews are also undertaken following an event or occurrence of major safety significance in India or abroad, to assess their impact on safety and need for any corrective measures.

5.1.2. Safety review for renewal of authorization

As per present regulations the authorization for operation has to be renewed as per prescribed guidelines for Periodic Safety Review. These safety reviews are of two types: a limited scope safety review called Application for Renewal of Authorization (ARA) every 3 years and a very comprehensive full scope review called Periodic Safety Review (PSR) every 9 years (Table 2).

The scope and depth of review required for PSR are detailed in AERB Safety Guide for renewal of authorization of NPP.

5.1.2.1. Application for Renewal of Authorization (ARA). Towards the end of authorization period, the utility has to submit an application as per the requirement of ARA to provide assurance to AERB that the NPP as a whole continues to be capable of safe operation.

This application requires a limited review (not as exhaustive as PSR described further) of certain important aspects of plant operation such as safety performance, operating experience feedback, in-service inspection and major modifications carried out during the period. The report of such a review provides an opportunity for systematic and integrated assessment of the status of the plant. Such a review monitors trends and detects early signs of degradations, if any.

Based on review of this ARA, AERB decides on renewal of authorization for a further period of 3 years.

5.1.2.2. Periodic Safety Review (PSR). For PSR, AERB has issued a Safety Guide AERB/SG/O-12 on "Renewal of Authorization for operation of NPPs" (AERB, 2000b). This document lays down the requirement for carrying out a comprehensive PSR, which should be carried out once in 9 years. The requirements of PSR are in line with the IAEA Safety Guide IAEA/SG/O-12 on Periodic Safety Review. PSR establishes requirements for safety assessment, which takes into account improvements in safety standards and operating practices, cumulative effects of plant ageing, modifications, feedback of operating experience and development in science and technology.

As per the requirement of PSR, the utility is required to carry out a comprehensive review covering the safety factors identified in the guide. The purpose of the review by the utility is to identify strengths and shortcomings of the NPPs against the requirements of current standards. Modifications or upgrades required to compensate for safety significant shortcomings are also proposed. The report on the PSR is subjected to regulatory review in the multi-tier review process for satisfactory resolution of the shortcomings.

5.1.2.3. License renewal. In addition to these periodic reviews during the lifetime of the plant, an even more elaborate exercise is carried out at the end of "design life" (typically 30 years) for which the plant was originally licensed. License renewal, thus, is required for much older plants and for which no PSR has been carried out. For such plants, it is necessary to re-examine the original licensing basis. In some cases it may be necessary to reconstruct the original licensing basis. The safety analysis also requires significant revision since in 30 years, the codes and methodology for analysis may change substantially.

Such a review has been carried out for Tarapur-1 & 2. Details of this review are described later.

All the above reviews are conducted through a multi-tier review mechanism. In the first place, two internal committees of NPCIL conduct the review. The first review is by the Station Operations Review Committee (SORC) followed by a review by a Safety Review Committee at the NPCIL's Headquarters (NPC-SRC) where design and quality assurance experts are also involved.

In AERB, the review is done first by a plant specific Unit Safety Committee (USC) and thereafter by the Apex Committee known as Safety Review Committee for Operating Plants (SARCOP). A quarterly report to the Board of AERB on safety status of the Department of Atomic Energy units is made by SARCOP and is discussed in board meetings. Items that are of major safety concern or which involve a significant change in the plant design or configuration are referred to the board for review and decisions. The board also reviews and approves major changes in policies and principles for regulation, matters concerning authorization/reauthorization or restrictions/suspensions on operation of NPPs. The Board and its Safety Committees also take assistance from Expert Groups constituted for specific purposes. The multi-tier safety review mechanism is schematically shown in Figs. 5 and 6.

5.1.3. Recommendations arising from safety reviews

A large number of recommendations get generated from this elaborate safety review process. These recommendations fall into the following categories:

(a) *Recommendations that need to be implemented immediately*

These are generally based on review of anomalies in operation, deviation from specified values of parameters and incidents having safety significance. Implementation of these recommendations, in most cases, is directly linked to permission for continuation of plant operation or restrictions on specific activities in the plant.

(b) *Recommendations which will bring about safety improvements*

These recommendations arise from review of operating experience of Indian as well as other plants in the world. Many of these recommendations can take considerable time for implementation as they involve activities like working out detailed designs, civil construction, procurement of components and integrating them with the existing plant. Also, some of these recommendations require carrying out theoretical analysis or design reviews towards obtaining better understanding. This can also take considerable time in certain cases due to need for developing necessary tools for analysis, their validation, etc.

(c) *Recommendations that require considerable research & development work*

These recommendations are generally based on acquisition of new knowledge from experience or research or both. These require extensive support by way of R&D from DAE and other national laboratories and academic institutions in addition to basic work by the stations and NPCIL Headquarter. These recommendations are also of a long-term nature.

The AERB staff keeps track of all recommendations for which necessary database management systems are available. These are periodically brought to the attention of stations, and NPCIL HQ. Unit Safety Committees and SARCOP periodically take stock of the progress and status of their implementation. This stocktaking and reviewing exercise is an on-going process.

5.1.4. *Regulatory inspection during operation*

During operation stage, regulatory inspections are carried out twice in a year to assess and verify compliance to the regulatory requirements. Besides the routine regulatory inspections, AERB also conducts special regulatory inspections with specific objectives as deemed necessary. Such inspections may be taken up after occurrence of major safety related incident or after major modifications to the plant (Fig. 7). Authorization for resumption of operation depend upon such inspections. During inspection, the compliance of the regulatory requirements are checked by review of records and other documents maintained by NPPs.

In particular following aspects are covered:

- Audit of operation, maintenance and quality assurance programmes.
- Adherence to the technical specifications and other licensing documents.
- Compliance to various regulatory recommendations.
- Adequacy of licensed staff at NPPs.
- Health of safety systems and safety related systems.
- Radiation safety and ALARA practices.
- Emergency preparedness.

Fig. 7. AERB members in control room of RAPS-1 & 2.

After inspection, a detailed inspection report is prepared and discussed with the plant authorities in an exit meeting. The utility is then required to submit an action taken report on the deficiencies pointed out during the inspection. These submissions are reviewed in AERB for disposition. Need for enforcement action, if any, is also determined.

5.1.5. *Licensing of operating personnel*

Licensing of plant personnel is another important aspect of the AERB's responsibilities. It is a mandatory requirement that personnel in operational positions at nuclear facilities should be formally licensed and qualified for various levels by the AERB. The entire process is exhaustively documented in two manuals, "Licensing Procedure for Operating Personnel" and 'QA Manual for Station Licensing Examination'. The competence requirement and the depth of knowledge and skills for each operational position are verified through a series of performance and knowledge checks prescribed in these manuals. Final verification is done through a written examination followed by certification by the AERB Committee. The licenses are valid for a period of 3 years and have to be renewed thereafter according to a prescribed procedure.

5.1.6. *Control of radiation exposures*

Protecting radiation workers in NPPs from undue radiation exposures is one of the prime objectives of the regulatory body. AERB is empowered to enforce provisions of Radiation Protection Rules, 1971. Under this rule, AERB specifies through safety directives, the dose limits for the radiation workers as well as for the members of public. The AERB has prescribed an annual dose limit of 30 mSv for radiation workers and a limit of 100 mSv over a period of five consecutive years. This limit is more conservative than ICRP-60 limits of 50 mSv/year and 20 mSv/year averaged over 5 years for radiation workers. AERB has also specified an investigation level at 20 mSv/year. A standing committee reviews the circumstances under which any radiation worker in the country has been exposed to more than 20 mSv in any particular year. This review is in addition to the review by the in-house committees. Finding the root cause for high exposures and suggesting remedial measures to reduce such exposures in future is the prime objective of such review. AERB ensures that all the radiation protection measures are in place through its continuous safety monitoring process as well as periodic regulatory inspections.

5.1.7. Controlling environmental releases

Environmental surveillance of all operating plants under Department of Atomic Energy is done by an Environmental Survey Laboratory at each site. These laboratories are established well before the plant goes into operation to enable collection of data on account of background radiation. The radiological impact due to operation of these plants is assessed on a continuous basis by collection and analysis of samples of items of diet, i.e., vegetables, cereals, milk, meat, fish, etc. Limits for radioactivity release to the environment through both gaseous route and liquid route is given in the technical specifications of each plant and approved by the regulatory body. The gaseous discharges are done through the stack. Liquid radioactive wastes are discharged after adequate dilution. Solid radioactive wastes are disposed in tile holes or in concrete trenches and buried. A separate authorization for solid waste disposal is issued by the regulatory body to each NPP.

5.2. Review of current issues of operating plants

During operational phase of NPPs, AERB carries out monitoring and review of safety as mentioned earlier. These reviews bring out several important issues where corrective actions and follow up are required. Following are some of the important issues, which were extensively reviewed by AERB.

5.2.1. Life management of Zircaloy-2 pressure tubes in PHWRs

All Indian PHWRs from Rajasthan-1 to Kakrapar-1 (seven units in all) are originally fitted with pressure tubes made of Zircaloy-2 material. As observed in the early reactors, both in Canada and India, Zircaloy-2 pressure tubes are prone to degradation due to embrittlement caused by hydrogen pick-up in the reactor environment. With increasing years in operation the high hydrogen content in the pressure tubes exceeds solid solubility limit. The precipitation of hydrides reduces the fracture toughness of the Zircaloy-2 tubes and they become susceptible to failure due to delayed hydrogen cracking (DHC). Depending upon the initial hydrogen content and the rate of hydrogen pick-up, the pressure tubes may typically have a lifetime of about 11 effective full power years (EFPY), if the pressure tube does not contact the associated calandria tube.

The pressure tubes and calandria tubes are separated from each other by garter spring spacers. Axial creep of the pressure tubes and/or displacement of the spacers can bring the tubes in contact with each other. If such contact occurs, the pressure tube could be at higher risk of failure much earlier. This is due to migration of hydrogen to the cold spot formed at the contact location leading to formation of hydride blisters. These blisters become potential locations for crack initiation.

A sudden failure of a pressure tube in 1983 in Pickering 2 NPP in Canada was the result of such a phenomenon. Following this incident, a program for assessment of service life of Zircaloy-2 pressure tubes was established in India for the old reactors. The major elements of this program include the following:

(a) Periodic in-service inspection of pressure tubes, to detect any pressure tube–calandria tube (CT–PT) contact.
(b) Sliver sampling of pressure tubes to assess hydrogen pick-up.
(c) Post irradiation examination of pressure tubes removed periodically from the reactors to assess the hydrogen pick-up rates and other material properties including fracture toughness.
(d) Theoretical estimation of creep contact time for the coolant channel assemblies, hydrogen pick-up rate and blister growth in the channels using specially developed computer codes.

After such assessments, if necessary, contact between calandria tube and pressure tube is broken by repositioning of spacers in contacting channels. Further operation of these reactors is permitted after ensuring that the acceptance criteria for fitness for service of the pressure tubes are satisfied.

With these measures, Madras-1 unit has been operated with Zircaloy-2 tubes up to 10.1 full power years. However for Rajasthan-2 and Madras-2 reactors, after about 8.5 effective full power years (EFPY) of operation, all the Zircaloy-2 pressure tubes were replaced with pressure tubes of zirconium niobium alloy which is also used in current Indian PHWRs. This material has superior mechanical properties and reduced hydrogen pick up during operation as compared to Zircaloy-2. The initial hydrogen content in these tubes is also controlled by adopting an improved manufacturing process. With these improvements, the projected life of pressure tubes in the current reactors is appreciably more.

For the remaining reactors using Zircaloy-2 pressure tubes, such en-masse replacement will be carried out at an appropriate stage based on the assessment of fitness for service.

5.2.2. Operation with steam generator tube leaks

Standardised PHWRs in India employ mushroom type steam generators having Incoloy-800 tubes. These steam generators are inspected periodically as per the established in-service inspection program. The steam generators (SG) in Narora and Kakrapar units have experienced tube failures in the recent past. Operation of the unit with SG tube leaks results in contamination of secondary side feed water. Due to presence of tritium activity in the primary coolant heavy water, a very small leak of the order of 1 kg/h can be detected. However, identification and isolation of the leaky tube is possible only after the leak rate has increased to about 5–6 kg/h. This warrants that the unit should be operated with tube leak to allow the leak to grow to detectable size. AERB permits operation of the unit in such condition, after the following concerns are addressed:

(a) Operation of unit with leaky SG tubes results in accumulation of large amount of tritium laden liquid waste due to leaks from secondary side. Due to steam leaks in the turbine building, certain amount of radioactivity gets discharged through this route, which is not permitted. AERB ensures that the station has sufficient storage capacity to hold the liquid waste getting generated during the proposed duration of operation and the discharges to the environment will not exceed the limits prescribed by AERB.

(b) The consequences of sudden opening up of the leak is properly analysed and emergency operating procedures to handle such an event are available in the control room.
(c) There is a possibility of spread of contamination in the clean environment of the turbine building during such an operation. Air activity in these areas is monitored by periodic sampling.

In addition, AERB has stipulated that the failed tube from the SG should be removed for metallurgical examination to determine the root cause of the failure.

5.2.3. Thinning of feeder elbows in PHWRs

The in-service inspection programme of the Indian PHWRs requires periodic inspection of feeder pipes of primary heat transport system. The selection of feeders for inspection and the frequency of inspection are specified on the basis of 'survey factor', which takes into account the maximum flow velocity and stress intensity.

In the year 1995, excessive wall thinning in primary heat transport (PHT) system outlet feeder elbows was reported in some Canadian reactors. Excessive wall thinning of PHT feeders can increase the risk of loss of coolant accident. Taking note of these observations, a thorough analysis of the inspection results of PHT feeders was taken up in the Indian reactors to ensure that the feeders have sufficient minimum wall thickness. In addition, full-scale inspection of 100% of the PHT feeders in Rajasthan Unit-2, which was under long shutdown at that time for en-masse replacement of coolant channels, was carried out. In this inspection, it was observed that in some feeder elbows the available wall thickness was lower than 87.5% of the originally specified nominal wall thickness (minimum acceptable wall thickness as per code requirement). A detailed analysis taking into account (a) the minimum thickness requirement as per ASME Section III NB and (b) the corrosion/erosion margin available was carried out to estimate the residual life of these feeders. Based on the residual life assessment, a few feeder elbows where the estimated residual life was less than 10 years were selected for repair. These elbows were repaired using weld overlay as per qualified repair procedure.

In addition, for assessment of corrosion/erosion rates and assessment of residual life, in-service inspection of all the feeders which had shown wall thickness of less than 87.5% of nominal thickness is being carried out at an increased frequency.

Similar large-scale inspection and residual life assessment of feeders was carried out during en-masse replacement of coolant channels in Madras Unit-2. Since residual life of all feeders was assessed to be more than 25 years, no repair/replacement was necessary.

Further, it is planned to carry out similar large-scale inspections/residual life assessment in other units during their long outages.

5.3. Safety upgradations in old plants

All NPPs are designed and operated to meet the prescribed level of safety required by the standards and practices that existed at the time of their design. However, safety standards get revised from time to time based on operating experience, new developments in technology and improved understanding. Hence, it is necessary that all the operating plants are periodically assessed to demonstrate that required level of safety is maintained. Towards this end, AERB has stipulated Periodic Safety Reviews (PSR) for old operating NPPs.

As mentioned before, PSR is a detailed safety review where all ageing related issues, shortfalls with respect to current standards and upgradation needs are addressed. Major plant retrofits are planned based on these assessments. Several such reviews have been conducted by the AERB, especially for older plants that include RAPS, TAPS and MAPS. Two typical examples of such reviews are described below.

5.3.1. Rajasthan Unit-2

Rajasthan Unit-2 is an old generation pressurized heavy water reactor (PHWR)-based NPP of 200 MWe capacity. It was commissioned in 1981 and was meeting the specified safety requirements applicable at that time. The design of PHWRs has changed substantially over a period of time and the present day Indian PHWRs are built after taking account of all current safety requirements. In accordance with AERB requirements, a detailed review of Rajasthan Unit-2 was conducted and a plan for required upgrades and modifications was finalised.

Rajasthan-2 was shut down in 1996 for en-masse replacement of all of its 306 coolant channels. The old coolant channels made of Zircaloy-2 pressure tubes were judged unsuitable for continued operation and were replaced by pressure tubes made of zirconium niobium alloy. This was done in a long shut down of the reactor when major upgradations to improve safety were also implemented. All proposals concerning modifications to safety related systems were reviewed and approved by AERB before execution of the jobs. Some of the major modifications to safety related systems carried out during this shutdown are described below.

(i) *Retrofitting of high pressure heavy water injection system into emergency core cooling system*

Pursuant to the recommendations of AERB, a high-pressure heavy water injection provision was retrofitted in the emergency core cooling system (ECCS). This would provide high-pressure heavy water injection during the initial short-term in case there is break in the reactor coolant piping. This is in addition to the already existing long-term core cooling from low-pressure moderator system.

(ii) *Supplementary control room*

A supplementary control room (SCR) was provided in a separate building to carry out important safety functions in case the main control room becomes uninhabitable due to a localized fire or damage caused by turbine missiles. Functions that can be carried out from SCR include (i) tripping of the reactor, (ii) opening of steam discharge valves for assured core cooling and (iii) monitoring of essential system parameters. Independent sensors with separate power supply have been provided for instrumentation in the SCR to ensure their operability under emergency conditions.

(iii) *Segregation of power and control cables*

For the purpose of minimising the impact of fire and other common mode failures to acceptable level, segregation of routes of safety related power and control cables was carried out. With this, control cables of triplicated channel instrumentation signals run through three separate cable tray routes from reactor building to control equipment room. In addition, a minimum physical separation has been maintained between the power cables and the high energy steam lines.

(iv) *Additional diesel generator of 600 kVA*

An additional diesel generator of 600 kVA capacity has been provided at a high elevation to ensure availability of essential power supply during a scenario of total loss of power due to flooding caused by failure of the Gandhi Sagar dam. The dam is located upstream of the Rana Pratap Sagar Lake that provides condenser cooling water to Rajasthan units.

After completion of the above and various other upgradation jobs, Rajasthan-2 was re-commissioned in 1998 as per the commissioning procedures approved by AERB.

Similar review and upgradation has been recently completed in Madras Unit-2 and is in progress in Rajasthan Unit-1 and Madras Unit-1.

5.3.2. Tarapur-1 & 2

Tarapur Units-1 & 2 were initially commissioned in 1969 and have been in operation since then. The Atomic Energy Regulatory Board had directed NPCIL in May 2000 to carry out comprehensive assessment of safety for long-term operation of the two boiling water reactors at Tarapur. The areas of review identified were

1. Design basis and safety analysis
2. Probabilistic safety analysis
3. Operational performance
4. Ageing management
5. Seismic re-evaluation

These reviews were carried out by an expert task groups specially appointed by NPCIL, between the year 2000 and 2003. The reviews were done based on the guidelines/approach as outlined in the AERB Safety Guide on Renewal of Authorization for operation of nuclear power plants AERB/SG/O-12, the USNRC standard review plan for review of safety analysis reports for NPPs (NUREG-800), the NPC Headquarter instruction on 'Ageing Management of NPP components, systems and structures important to safety' and the IAEA INSAG-8 on 'common basis for judging safety of NPPs built to earlier standards'. The reviews took into account the actual condition of the plant vis-a-vis the present day safety requirements.

(i) *Review of design basis and safety analysis*

During review of design basis, each system was reviewed against the applicable general design criteria. The review also covered aspects such as conformance with single failure criterion/redundancy, defense-in-depth, physical and functional separation of components and common cause failure vulnerabilities. The non-conformances identified from these reviews were evaluated for their significance on the lines of IAEA Safety Report Series No. 12 on "Evaluation of safety of operating nuclear power plants built to earlier standards—Common basis for judgement". These assessments considered the effect of non-conformances on safety function capability, frequency of initiating events and the associated potential consequences. Consideration was also given to the available/proposed compensating factors such as other engineered features and operational practices. Insights from the results of a Level-1 PSA were also used. Based on these assessments, extensive safety upgradation requirements were identified. The important ones among them are

(a) extensive modification in the emergency power supply system for the station inclusive of new diesel generators of higher capacity and unit-wise segregation of power supplies to obviate common cause failures;
(b) segregation of some other shared systems such as shutdown cooling system and fuel pool cooling system;
(c) addition of an independent set of CRD (Control Rod Drive) pumps to strengthen the emergency feed water supply to the reactor;
(d) addition of a supplementary control room; and
(e) extensive upgradation of fire protection system.

The existing safety analysis of TAPS was reviewed with respect to adequacy of original analytical techniques, list of events analysed and design/configuration changes that have taken place over the years. Based on this review, the safety analyses was redone using current analytical methods for the enveloping cases of the postulated initiating events (PIE). The safety report was updated to include these fresh analyses and the design modifications/backfits (earlier or as a result of the present review). The revised analysis showed that the safety criteria are met with good margin. It is worth mentioning here that these reactors were originally designed for 660 MWt, but are being operated at reduced power of 530 MWth since 1984, following tube failures in the secondary steam generators.

(ii) *Probabilistic safety assessment* (*PSA*)

A Level-1 PSA with internal events was done for TAPS for analyzing the existing design without considering the upgradations. The analysis indicated that the core damage frequency is around 7.0E-05/Reactor year (AERB, 2003).

(iii) *Seismic re-evaluation*

Seismic re-evaluation of structures, systems and components (SSC) of TAPS was carried out for the latest ground motion parameters derived for the site. Re-evaluation of safety systems and safety support system has been done using seismic margin assessment method considering the ductility and damping factors as given in IAEA Safety Reports Series No. 20 on ‘Seismic re-evaluation of existing nuclear power plants’. Other systems were qualified by seismic walk down by experts as per guidelines given in the same report. While most of the SSCs were found to meet the requirements, a few modifications involving strengthening of support structures were found necessary.

(iv) *Ageing management and operational performance*

An exhaustive ageing assessment and management programme has been worked out for the SSCs of the units. The programme took into account the present status of the SSCs, the in-service inspection done in the past and additional studies/inspections required in future in specific areas. Replacement of some of the equipment is also planned. Special attention has been given to the non-replaceable components such as reactor pressure vessels, containment and other civil structures.

The status of the reactor pressure vessel material is monitored with the surveillance specimen programme. Surveillance of specimens of reactor pressure vessel material indicated that it has adequate fracture toughness to assure safety of the pressure vessel. Fatigue analysis of the reactor pressure vessel has indicated that it has got sufficient residual life.

All these identified modifications and upgrades are scheduled to be carried out during 2005, when both units will be shutdown for about a 6-month period.

5.4. Safety review following major accidents

In addition to the routine and periodic reviews described above, special reviews are carried out following major events/accidents having significant impact on safety. Specially constituted teams review the existing safety provisions in all Indian NPPs in light of these incidents and recommend necessary upgradation in systems, procedures, and organizational aspects. Three such major reviews were carried out in the past.

5.4.1. Review following the TMI-2 accident

In March 1979, when the Three Mile Island accident took place, one 200 MWe PHWR (Rajasthan-1) was in operation and five units were under various stages of construction in India. Besides, two 200 MWe BWR units (Tarapur-1 & 2) were also in operation. A detailed review of safety of these NPPs was carried out in the light of this accident. The review focussed on the reliability and availability of the engineered safety features (ESFs), human engineering aspects and emergency preparedness in the public domain. Based on this review, several improvements were made in the operating units as well as in the design of new plants.

Some of these improvements are listed below:

- Enhancement in the reliability of emergency feed water supply to the steam generators in PHWR.
- Augmentation of feed capacity for inventory control of primary coolant system under loss of off-site power in TAPS.
- Remote operation of isolation valves of moderator heat exchangers to check spread of radioactivity to cooling water system in the event of leaks in heat exchanger tubes.
- Incorporation of high-pressure emergency core cooling system for PHWRs.
- Development of emergency operating procedures for a large number of postulated initiating events.

5.4.2. Review following the Chernobyl accident

AERB undertook detailed review of safety of Indian NPPs following the Chernobyl accident in 1986. The review focussed on (a) adequacy of safety systems and engineered safety features, (b) implications of propagating failures and (c) emergency preparedness aspects. Safety during operation of units at low power and under shutdown conditions was also reviewed in detail. The review re-emphasized the necessity for adhering to the already established principles of reactor safety design and operation. The feedback from the accident did point to the need for well-coordinated plans and organization for on-site and off-site emergencies that may arise from nuclear accidents. It also re-emphasized the need for maintaining ‘safety culture’ in the conduct of operations at the station, and having disciplined institutionalized procedures. Actions were taken to reinforce these aspects in operating principles and practices. Also organization and procedures for on-site and off-site emergencies were strengthened at all the power stations.

5.4.3. Review following the fire incident in Narora Atomic Power Station (NAPS)

A major fire incident occurred in the turbine building in Narora Unit-1 (220 MWe PHWR) in March 1993. The incident was initiated by failure of two turbine blades in the last stage of the low pressure turbine, which resulted in severe imbalance in the turbo-generator leading to rupturing of hydrogen seals and lube oil lines, leading to fire. The fire spread to several cable trays, relay panels, etc. in a short duration. The control room operators responded by tripping the reactor by manual actuation of primary shutdown system within 39 s from the start of the incident and also initiated fast cool down of the reactor.

The fire spread into the Control Equipment Room of the unit and resulted in damage to the power supply and control cables. Even though the power sources were available, power could not be supplied to the loads due to damage to the cables. A complete loss of power supply in the unit occurred at about 7 min into the incident and the resulting Station Blackout lasted for a period of 17 h. The smoke ingress into the main control room from Control Equipment Room rendered the control room uninhabitable. During the blackout, core cooling was maintained by thermo-siphoning on the primary side with the secondary side of steam generators fed by firewater to provide heat sink. The major fire was put out in about 1 h 30 min. There was no radiological impact of the incident either on the plant workers or in the public domain and no injury occurred to any individual. However, based on the degradation of defence-in-depth of the engineered safety features during the incident, the event was classified at Level-3 on the International Nuclear Event Scale (INES).

AERB carried out an in-depth investigation of the incident which resulted in several modifications and improvements covering design, operation and surveillance practices. The investigation also revealed the susceptibility of the existing design and layout of NAPS to common cause failure (CCF), mainly due to fire as the initiating event. The review, initially carried out for NAPS, was subsequently extended to cover all other operating stations. The design provisions of nuclear power plants under construction at that time (RAPP-3 & 4 and Kaiga-1 & 2) were also reviewed and remedial actions as required were taken.

Some of the resulting improvements are highlighted below:

- Rerouting of power and control cables of safety related loads to minimise the vulnerabilities to common cause failures.
- Provision of additional fire walls at identified areas in turbine building for limiting spread of fire.
- Strengthening of fire barriers at cable penetrations in floors and walls in the turbine building as well as at their entry points into the control equipment room.
- Enhancement of routine surveillance on fire barriers and fire dampers.
- Improvements in fire detection and mitigation systems.
- Relocation of some of the safety related equipment for physical separation to minimise vulnerability to common cause failures.
- Improvement in survival ventilation system for control room to ensure habitability in the event of a fire in the turbine hall.
- Design modification in the last stage blades of the low-pressure turbine and enhancement of surveillance requirements related to them.
- Improvements in Emergency Operating Procedure/ Guidelines for handling Station Black Out (SBO).

6. Safety review for decommissioning

The process of decommissioning begins after the final shutdown of the facility or after an abnormal event when the facility is no longer considered viable for operation and ends with the release of the site for use by a responsible organization as authorized by AERB or for unrestricted use by the public.

Though decommissioning of nuclear power plants is not of immediate concern in Indian context, AERB has issued a Safety Manual on Decommissioning of Nuclear Facilities. The manual provides the regulatory framework of safety within which decommissioning of an NPP can be carried out at the end of its service life. As per the present AERB requirement, the utility has to submit a preliminary decommissioning plan prior to grant of authorization for operation of NPP. For satisfactory and efficient decommissioning, some features have to be incorporated in the design.

The responsibility of decommissioning the nuclear power plant lies with NPCIL. For the purpose of meeting the cost of decommissioning, a decommissioning levy is collected from the consumers of electricity from nuclear power station and kept in a separate decommissioning fund. The decommissioning fund is invested in long term investment so as to earn optimum returns on the fund while maintaining adequate safety and liquidity of the fund. This gives assurance to AERB that lack of fund will not come in the way of safe decommissioning.

Before taking up the decommissioning of the facility, the utility will prepare a detailed decommissioning plan. Based on review of the plan, AERB will approve a set of technical specifications for the facility to be followed during decommissioning.

7. Recent initiatives

The regulatory process in India is continuously evolving to cater to the new developments in the nuclear power scenario and the experience of regulating the industry for over two decades. Some of the recent initiatives taken up by AERB are briefly described below (Chande and Koley, 2003).

7.1. Reporting and analysis of low-level events

Since the beginning, all Indian NPPs are required to report to AERB, all events that are of significance to safety of workers, public and environment and also the events having significance for nuclear safety. Technical specifications of each plant clearly define the criteria and procedure for reporting of these events. The lessons learnt from review and analysis of these events help to prevent recurrence of similar events. In fact, the lessons learnt from some minor events can really help in preventing events of major consequences. Having recognized this fact, AERB has now introduced a two level reporting system for events occurring in NPPs.

The higher-level events, called significant events are essentially the ones that were being reported as per the existing criteria. As brought out earlier, such events are now reducing, and some plants in fact have not reported any event during the previous year. This, though a welcome feature, deprives one of the benefit arising from their feedback. To overcome this, many plants have put in place a low-level event reporting system. However, it has been observed that in the absence of well-defined criteria, these plant specific systems are non-uniform and differ widely from plant to plant as regards the range of events reported and the depth of review they undergo. The feedback from these events also does not get spread to other plants. In order to overcome this problem, formal reporting of low-level events to AERB has been made obligatory from this year. Events covered in this category include

- Reactor trips due to external conditions.
- Non-availability of safety related systems (even within the technical specifications requirements).
- Radiological exposures beyond the investigation levels but below regulatory limits.
- Failure of safety systems discovered during surveillance (the system functions would be fully available because of redundancy).

Many of these events were not reportable under the earlier criteria of significant events. AERB will carry out a systematic review and analysis of these events and the experience feedback will be shared with all plants.

7.2. Optimization of in-service inspection and surveillance requirements

Indian NPPs have already achieved an annual capacity factor of about 85%. Further improvement in capacity factor can be achieved essentially by reduction in duration and frequency of planned outages. Requirements of in-service inspection, surveillance tests and preventive maintenance are the main contributors to these outages.

Provision of more redundant equipment to permit on-power maintenance and optimization based on experience and condition monitoring are some of the steps to reduce duration of maintenance outages.

As regards requirements of in-service inspection and surveillance tests, experience of several plants over several years is now available. The plant management has brought out that in the early years of operation, these requirements were rightly conservative, but now in the light of experience available they need to be reduced. From safety point of view, a sudden significant reduction in these requirements could be counter-productive as it increases the potential for unsafe failures. Considering both these views, AERB in collaboration with the utility has initiated a massive effort to review and optimise all ISI and surveillance requirements.

7.3. Probabilistic safety assessment (PSA) approach

The use of PSA in regulatory functions has been increasing all over the world. In the overall safety assessment of a facility, PSA is used as a complimentary tool for design basis events/accidents (DBAs) and a unique methodology beyond design basis events (BDBAs) to supplement to deterministic approach. The results of such risk assessment primarily give estimates of core damage frequency (CDF) and large early release frequency (LERF) to ensure that the operation of a nuclear plant does not pose undue risk to public health and safety.

Besides, AERB intends to use PSA for many specific purposes, some of which are outlined below:

- Estimations of importance (risk) measures of structures, systems (including computer-based systems) and components leading to identification of critical items important to safety. This is to ensure regulatory resources are used appropriately to focus attention on the most risk significant equipment, processes and activities.
- Identification of dominant accident sequences to ensure depth and level of regulatory review requirements.
- Review of design adequacy and plant modifications.
- Living PSA (LPSA)/risk monitoring (RM) of plant configuration in all the operational states (including shutdown state) so as to monitor, exercise regulatory control and ensure that the plant configuration is not at undue risk.
- Review of changes in technical specification relating to allowed outage time (AOT) and surveillance test interval (STI) of items important to safety with risk insights. This would ensure that the regulatory requirements are not laid on unnecessary conservatism but on optimization without compromising safety.
- Authorization/license of new plants and Periodic Safety Review (PSR) of operating plants with risk insights to ensure that reliability/availability of plant items important to safety are acceptable and do not pose undue risk for plant operation.
- Plant risks due to external events like seismic, fire and flood, and missile generations from high speed rotary components/external initiators, pipe whip, etc.
- Review of ISI programs, operating procedures for emergency conditions including off-site emergency preparedness plan with risk insights.
- Risk-based regulatory inspection to ensure adequate coverage of plant items important to safety, documentation and practices with optimum utilization of regulatory resources (propose to use).

8. Interaction with R&D institutions and international co-operation

In order to ensure that best technical inputs are available for its safety review functions, AERB maintains close interactions with R&D institutions like BARC and IGCAR and extensively utilizes the high level of expertise available in these premier institutions of the country. AERB also has strong participation in NPP related international co-operative activities like the Incident Reporting System, INES-Based Reporting and CANDU Senior Regulators' Meetings of the International Atomic Energy Agency. Co-operative agreements between AERB and the regulatory bodies of France and Russian Federation exist and in recent past, preliminary work has been done for developing co-operation with the US Nuclear Regulatory Commission.

9. Safety research

One of the functions of AERB is to promote and carry out research and developmental activities in safety areas that are relevant to the objectives of AERB. Towards this, AERB has established Safety Research Institute at Kalpakkam. Since its formal inauguration in February 1999, the Safety Research Institute has established the basic infrastructure required for organizing research activities and has initiated research work in the areas of nuclear, radiation and environmental safety.

Besides research, SRI activities also include organization of periodic training workshops and discussion meetings and building up a library of safety related computer codes.

AERB also awards research contracts to educational institutions to carry out investigations on topics related to (a) safety aspects of nuclear technology including industrial safety in nuclear and allied installations; and (b) safety aspects of radiation applications in agriculture, industry, medicine and research are considered.

10. Public awareness

Since its inception, AERB has adopted a pro-active programme to communicate with the public and to address concerns on safety. Public concern regarding the safety of nuclear power hinges mainly on three issues. First, the fear of accidents in nuclear power stations or facilities leading to releases of large amounts of radioactivity. Second, pollution of the environment from routine discharge of radioactivity from the facility. Third, the question of long-term storage and disposal of radioactive wastes generated from operation of nuclear reactors. Enlightened and discerning members of the public need assurance that nuclear facilities are sited, designed, constructed and operated by considering all safety aspects. They want to be assured that experienced and qualified staffs operate them. They would like to see an independent, effective regulatory mechanism to oversee all nuclear activities. The process of licensing of a nuclear facility should be transparent, objective and based on well-developed procedures. The public awareness programme of AERB goes a long way in satisfying the above needs. AERB issues several press releases and safety information notices every year in order to keep the public informed of its current activities.

Another medium for informing the public is the AERB web site http://www.aerb.gov.in, which disseminates information on the AERB. Apart from AERB Annual Reports, Newsletters and press releases, the web site carries information on the composition of the board, its important committees, a list of AERB publications and the format of various applications. The text of the Atomic Energy Act 1962 and those of safety related rules under the Act are also available on the web site.

In addition, talks/interviews are given occasionally in public and on radio and TV to inform the public about the role of the AERB and to discuss various safety related issues.

11. Looking ahead: future challenges

As mentioned before, India has undertaken a large expansion of its Nuclear Power programme. Presently, there are 14 operating nuclear power plants of a total capacity of 2760 MWe. Nine nuclear power plants (six pressurized heavy water reactors, two VVER type reactors and a Prototype Fast Breeder Reactor of indigenous design) of 4460 MWe are under construction. They are scheduled to be commissioned in the years 2004–2010. As per present projection, 20,000 MWe of generating capacity is to be achieved by the year 2020. This large expansion of nuclear programme is not only a major challenge to the utility but also to the regulatory body (Fig. 8). To cater this challenge effectively, the AERB needs large increase in regulatory resources and qualified and experienced manpower.

Some additional aspects of this challenge are discussed below.

11.1. Review of different designs

The nuclear power programme in India started with two BWR units at Tarapur. Subsequently 12 units of 220 MWe PHWR were constructed. At present, in addition to four PHWR units of 220 MWe and two PHWR units of 540 MWe, it is planned to construct a prototype fast breeder reactor of 500 MWe capacity and two units of VVER 1000 MWe. Besides this, indigenous Advanced Heavy Water Reactor (AHWR) has been planned. Design review, authorization/licensing and safety monitoring of reactors of various designs poses a major challenge to the regulatory body. There are no established guidelines. The review has to be based upon criteria developed from fundamental safety principles, and published information to the extent available and applicable. The regulatory body needs expertise in different design and safety requirements. AERB has developed regulatory documents only for PHWRs. Although these documents can be referred during licensing of other types of reactors to some extent, there is need for developing separate regulatory guidelines for each of these types of reactors.

Fig. 8. Meeting of the board is in progress.

In addition, the present legislative basis may need changes to address foreign designs. Also, to accommodate private participation in nuclear power industry.

11.2. Increased competition

Competitive pressures to increase production and reduce costs, could distract focus of the utility on safety. Stress on economic performance, the effect of downsizing and the use of contractors can, amongst other things, lead to overwork, uncertainty, deteriorating communication and unclear accountabilities. These can increase stress and hence challenge the effective maintenance of safety.

The major regulatory concerns are as follows:

(a) Shorter and deferred outages to improve capacity factors may lead to the following:
- Reduced in-service inspection and its scope
- Inadequate review of results of in-service inspection
- Reduction in surveillance tests frequencies
- Design changes to enable on-power testing
- Defer essential maintenance

(b) Departure from good/safe practices during operation as well as maintenance.

(c) Reduced investment in safety upgrades/back-fits.

To address these concerns, there is a need for new competencies in regulatory body. Today's nuclear regulator needs to have competence beyond those regarded as traditional, such as understanding the organizations, finance, and changed management. Variety of reactor type and modern state of the art technologies are equally challenging to the regulator.

11.3. Security aspects

The current security scenario around the world is of a major concern. A hostile action against nuclear facilities in the form of sabotage and/or theft or unauthorized removal of material can have adverse impact on the safety and health of workers, public and environment. The best defense against such potential threats is to have a comprehensive integrated design of security systems backed up by strong administrative and operational measures.

To address this issue, AERB intends to review and modify guidelines regarding design requirement on security systems of nuclear power plants, their operation, surveillance and QA requirements and training and qualification of personnel handling them.

12. Conclusions

Atomic Energy Regulatory Board of India is now in existence for nearly two decades and during this period it has grown into a mature and effective regulatory body. AERB has put in place a comprehensive system for design and operational safety review of nuclear power plants within the country. A large number of safety documents have been developed to aid in such reviews. Feedback from operational experience and lessons learned from major incidence both within and outside the country, have been appropriately utilized for modifying designs and procedures for enhanced safety.

Ageing management and safety upgradations of old NPPs to meet current safety standards have engaged the attention of AERB in recent past. Consequent actions have resulted in incorporation of major safety upgrades and design retrofits in some of the old plants. For the other old plants, required actions have been identified and are being implemented as per an agreed time schedule between AERB and NPCIL.

Modern analytical tools like PSA are being increasingly utilized by the AERB in safety reviews and assessments and significant in-house capabilities have been built in disciplines like PSA and thermal hydraulic analysis. AERB also maintains close liaison with premier R&D institutes like BARC and IGCAR and other academic institutions of the country to draw upon expertise available in support of its regulatory works. Similarly close interactions with international organizations like IAEA and regulatory bodies of other countries are also maintained to be abreast of latest developments in nuclear safety.

Today AERB faces new challenges like simultaneous review of a large number of NPP projects with diverse designs, a fast growing nuclear power program and functioning of operating plants in a competitive environment. AERB is gearing up itself to meet these challenges in an effective manner.

Acknowledgement

The authors are grateful to the Chairman of the AERB for his guidance and valuable suggestions made during the preparation of this paper.

Appendix A

A.1. List of regulatory documents related to NPPs

S. no.	Title	Document no.	Year of publication
A. Safety Codes			
1.	Code of practice on quality assurance for safety in nuclear power plants	AERB/SC/QA	1988
2.	Code of practice on design for safety in pressurized heavy water reactor-based nuclear power plants	AERB/SC/D	1989
3.	Code of practice on safety in nuclear power plant operation	AERB/SC/O	1989
4.	Code of practice on safety in nuclear power plant siting	AERB/SC/S	1990
5.	Code of regulation of nuclear and radiation facilities	AERB/SC/G	2000
B. Safety Guides			
1.	Safety classification and seismic categorisation of SSCs	AERB/SG/D-1	2003
2.	Fire protection in pressurized heavy water reactor-based NPPs	AERB/SG/D-4	1999
3.	Design basis events for pressurized heavy water reactors	AERB/SG/D-5	2000
4.	Fuel design	AERB/SG/D-6	2003
5.	Core reactivity control in pressurized heavy water reactor	AERB/SG/D-7	1998
6.	Primary heat transport system	AERB/SG/D-8	2003
7.	Emergency electric power supply system for pressurized heavy water reactors	AERB/SG/D-11	2001
8.	Liquid and solid radwaste management in pressurized heavy water reactor-based nuclear power plants	AERB/SG/D-13	2003
9.	Control of airborne radioactive materials in pressurized heavy water reactors	AERB/SG/D-14	2001
10.	Ultimate head sink and associated systems in pressurized heavy water reactors	AERB/SG/D-15	2000

Appendix A (*Continued*)

S. no.	Title	Document no.	Year of publication
11.	Loss of coolant accident analysis for pressurized heavy water reactors	AERB/SG/D-18	2001
12.	Safety related instrumentation and control	AERB/SG/D-20	2003
13.	Vapour suppression system (pool type) for pressurized heavy water reactors	AERB/SG/D-22	2000
14.	Design of fuel handling and storage systems for pressurized heavy water reactors	AERB/SG/D-24	2003
15.	Preparation of site emergency plans for nuclear facilities	AERB/SG/EP-1	1999
16.	Preparation of off-site emergency plans for nuclear facilities	AERB/SG/EP-2	1999
17.	Preparation of site emergency preparedness plans for non-nuclear installations	AERB/SG/EP-3	2000
18.	Preparation of off-site emergency preparedness plans for non-nuclear installations	AERB/SG/EP-4	2000
19.	Regulatory inspection and enforcement in nuclear and radiation facilities	AERB/SG/G-4	2002
20.	Role of the regulatory body with respect to emergency response and preparedness at nuclear and radiation facilities	AERB/SG/G-5	2000
21.	Codes, standards and guides to be prepared by the regulatory body for nuclear and radiation facilities	AERB/SG/G-6	2001
22.	Regulatory consents for nuclear and radiation facilities: contents and formats	AERB/SG/G-7	2001
23.	Criteria for regulation of health and safety of nuclear power plant personnel, the public and the environment	AERB/SG/G-8	2001
24.	Staffing, recruitment, training, qualification and certification of operating personnel of NPPs	AERB/SG/O-1	1999
25.	Operation limits and conditions for nuclear power plants	AERB/SG/O-3	1999
26.	Commissioning procedures for pressurized heavy water-based nuclear power plants	AERB/SG/O-4	1998
27.	Radiation protection during operation of nuclear power plants	AERB/SG/O-5	1998
28.	Preparedness of the operating organization for handling emergencies at nuclear power plants	AERB/SG/O-6	2000
29.	Maintenance of nuclear power plants	AERB/SG/O-7	1998
30.	Surveillance of items important to safety in nuclear power plants	AERB/SG/O-8	1999
31.	Management of nuclear power plants for safe operation	AERB/SG/O-9	1998
32.	Core management and fuel handling in operation of pressurized heavy water reactors	AERB/SG/O-10A	1998
33.	Core management and fuel handling in boiling water-based NPPs	AERB/SG/O-10B	1999
34.	Renewal of authorization for operation of nuclear power plants	AERB/SG/O-12	2000
35.	Safety guide for quality assurance in the design of nuclear power plants	AERB/SG/QA-1	2001
36.	Quality assurance in the procurement of items and services for nuclear power plants	AERB/SG/QA-2	1998
37.	Quality assurance in the manufacture of items for nuclear power plants	AERB/SG/QA-3	1998
38.	Safety Guide for quality assurance during site-construction of nuclear power plants	AERB/SG/QA-4	2001
39.	Quality assurance during commissioning and operation of nuclear power plants	AERB/SG/QA-5	1993
40.	Hydrological dispersion of radioactive materials in relation to nuclear power plant siting	AERB/SG/S-2	1998
41.	Hydrogeological aspects of siting of nuclear power plants	AERB/SG/S-4	2000
42.	Design basis flood for nuclear power plants on inland sites	AERB/SG/S-6A	1998
43.	Design basis flood for nuclear power plants at costal sites	AERB/SG/S-6B	2002
44.	Population distribution and analysis in relation to siting of nuclear power plants	AERB/SG/S-9	1998
45.	Safety Guide for seismic studies and design basis ground motion for nuclear power plant sites	AERB/SG/S-11	1990

A.2. Safety support documents developed by AERB

S. no.	Title	Document No.	Year of publication
1.	Safety Code for industrial radiography	AERB/SC/IR-1	2001
2.	Safety Code on operation and maintenance of land-based stationary gamma irradiators	AERB/SC/IRRAD	1993
3.	Safety Code for telegamma therapy equipment and installations	AERB/SC/MED-1	1986
4.	Safety Code for medical diagnostic X-ray equipment and installation	AERB/SC/MED-2 (Rev-1)	2001
5.	Safety Code for brachytherapy sources, equipment and installations	AERB/SC/MED-3	1987
6.	Safety Code for nuclear medicine facilities	AERB/SC/MED-4 (Rev-1)	2001
7.	Safety Code for the transport of radioactive materials	AERB/SC/TR-1	1986
8.	Safety Code on emergency response planning and preparedness for transport accidents involving radioactive material	AERB/SC/TR-3	1990
9.	Safety Guide for intervention levels and derived intervention levels for off-site radiation emergency	AERB/SG/HS-1	1993
10.	Safety Guide on radiological safety in enclosed radiography installations	AERB/SG/IN-1	1986
11.	Safety Guide on radiological safety in open field industrial radiography	AERB/SG/IN-2	1986
12.	Safety Guide for handling of radiation emergencies in industrial radiography	AERB/SG/IN-3	1989
13.	Safety Guide for works contract	AERB/SG/IS-1	1992
14.	Safety Guide for preparation of safety report of industrial plants other than nuclear power plants in the department of atomic energy	AERB/SG/IS-2	2001
15.	Safety Guide on medical management of persons exposed in radiation accidents	AERB/SG/MED-1	1990
16.	Safety Guide on compliance assurance programme for the safe transport of radioactive material	AERB/SG/TR-1	1991
17.	Safety Guide on standards of safety in transport of radioactive material	AERB/SG/TR-2	1991
18.	Safety Guide on procedure for forwarding, transport, handling and storage of radioactive consignments	AERB/SG/TR-3	1991
19.	Standard specifications for radiological safety for the design and construction of industrial gamma radiography exposure devices and the sources changers	AERB/SS-1	1992
20.	Safety standard for design, construction of ionizing radiation gauging devices	AERB/SS-2 (Rev-1)	2001
21.	Safety standard for testing and classification of sealed radioactive sources	AERB/SS-3 (Rev-1)	2001
22.	Standard specifications for radiological safety in the design and manufactures of consumer products containing radioactive substances	AERB/SS-4	1991
23.	Standard specifications for radiological safety in the design and manufacture of X-ray analysis equipment	AERB/SS-5	1992
24.	Standard specifications for radiological safety for the design and installation of land-based stationary gamma irradiators	AERB/SS-6	1993
25.	Civil engineering structures important to safety of nuclear facilities	AERB/SS/CSE	1998
26.	Design of concrete structures important to safety of nuclear facilities	AERB/SS/CSE-1	2002
27.	Design, fabrication and erection of steel structures important to safety of nuclear facilities	AERB/SS/CSE-2	2002
28.	Design, fabrication and erection of embedded parts and penetrations important to safety of nuclear facilities	AERB/NF/SS/CSE-4	2003
29.	Standard for fire protection systems of nuclear facilities	AERB/SS/IRSD-I	1996
30.	Radiation protection for nuclear facilities (Revision 3)	AERB/SM	1996
31.	Maintenance of civil engineering structures important to safety of nuclear power plants	AERB/SM/CSE-1	2002
32.	Safety Manual for decommissioning of nuclear facilities	AERB/SM/DECOM-1	1988
33.	Safety Manual on data base management for accidents/diseases happening due to occupation and implementation of the same in the Department of Atomic Energy	AERB/SM/IS-1	1991
34.	Safety Manual on atlas of reference plans for medical diagnostic X-ray installations	AERB/SM/MED-1	1988
35.	Safety Manual—handbook for medical management of persons exposed in radiation accidents	AERB/SM/MED-2	1989
36.	Safety Manual—site emergency plan for nuclear installations	AERB/SM/NISD-1	1986
37.	Safety Manual, off-site emergency plan for nuclear installations	AERB/SM/NISD-2	1988
38.	Safety Manual governing authorization procedure for nuclear power plant/project	AERB/SM/NSD-3	1989
39.	Safety Manual for civil engineering and building works for nuclear power plants	AERB/SM/S-1	1988
40.	Catalogue of earthquake ($\geq$M.3.0) in Peninsular India	AERB/TD/CSE-1	1983
41.	AERB Technical Manual on methods for the measurement of Radon Thoron and their Progeny in Dwellings	AERB/TM/RM-1	1992
42.	Personal protective equipment: helmets	AERB (PPE-1)	1992
43.	Personnel protective equipment: safety footwear	AERB (PPE-2)	1992
44.	Personal protective equipment: respiratory protective equipment	AERB (PPE-3)	1992
45.	Personal protective equipment: arm and hand protection	AERB (PPE-4)	1992
46.	Personal protective equipment: eye and face protection	AERB (PPE-5)	1992
47.	Personal protective equipment: protective clothing and coverall	AERB (PPE-6)	1992
48.	Personal protective equipment: ear protection	AERB (PPE-7)	1992
49.	Personal protective equipment: safety belts and harnesses	AERB (PPE-8)	1992
50.	Atomic Energy (Factories) Rules		1996
51.	Safety report format for industrial plants other than nuclear power plants	AERB/M/ISD-1	1990

References

AERB, August 2000a. "Regulation of Nuclear and Radiation Facilities" (AERB/SC/G).

AERB, 2000b. "Renewal of Authorization for operation of NPPs" (AERB/SG/O-12).

AERB, 7 April 2003. "Review Report on TAPS PSA by AERB Committee on PSA" (AERB/TH/61090/2345/2K3).

AERB, 2006. "Consenting Process for NPPs & Research Reactors: Documents Submission, Regulatory Review and Assessment of Consent Application" (AERB/SG/G-1).

Chande, S.K., Koley, J., 2003. Regulatory initiatives to sustain excellence in safety in operating NPPs. AERB News Lett. 16 (2).