NUCLEAR POWER IN INDIA

Himanshu Vishnoi
and
S Narayan

A Special Report by

CENTER FOR ASIA STUDIES

Institute of South Asian Studies

NUS National University of Singapore

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FOREWORD

Various facets of energy security would continue to engage the policy makers and other stake holders as energy continues to drive economies, policies and even geo-strategy. The country has come a long way since the Tarapore Nuclear Plant began commercial operation way back in 1969. The progress has been slow but steady. The keen debate that was generated during the run up to the Civil Nuclear Energy deal with US is a clear example of the interest displayed in India about this important source of energy.

Despite safety and environmental concern, with depleting natural sources, India has no choice but to augment its energy production by resorting to all available means; both conventional and renewable. India has acquired a credible capability in operating nuclear plants for power generation. At another level, it has also been successful in integrating a nuclear reactor for the indigenous nuclear submarine project (Advanced Technology Vessel). The capability has no meaning unless the issues of supply of nuclear fuel are sorted out with the Nuclear Suppliers Group (NSG).

The study report on Nuclear Power in India is a joint effort of the **Center for Asia Studies, Chennai** and the **Institute of South Asian Studies, NUS, Singapore**. The Center for Asia Studies has been engaged in educating and sensitizing the public in selected areas of specialisation through its website, publications and discussions.

Jointly authored by Mr. Himanshu Vishnoi and Dr S.Narayan it is an attempt to bring out various issues supported with facts and figures in the Indian context. It is hoped that the study report would provide invaluable data to researchers and other stake holders including the informed public.

Commodore RS Vasan, IN (Retd)
Head, Strategy and Security Studies
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Chennai.
16.04.2010

About the Authors

Himanshu Vishnoi

With over twelve years of experience in the Power Sector, Mr. Himanshu Vishnoi is currently Senior Vice-President (Finance), M/s. Athena Demwe Power Ltd. Having acquired his Bachelor of Engineering and Post-Graduate Diploma in Business Administration from Aligarh Muslim University and ICFAI Business School respectively, Mr. Vishnoi has worked with various leading consulting and advisory firms and corporate houses such as Ernst & Young, CRISIL and Reliance Energy among others.

Conversant in various aspects of Indian Power Sector viz. Generation, Distribution, Transmission, Trading, Business Planning, Mr. Vishnoi, has played an instrumental role in India's power sector and has worked on various prestigious assignments including the formulation of a Nuclear Road Map for NTPC.

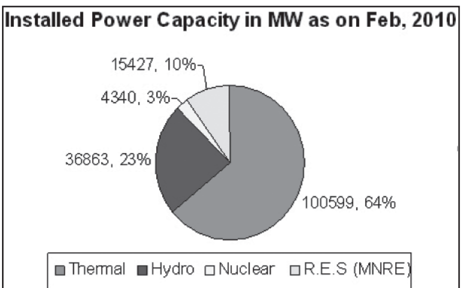
Dr. Narayan

Dr. S. Narayan, with nearly four decades (1965 to 2004) in Public Service in the State and Central Governments, was the Economic Adviser to the Prime Minister during 2003 - 04. Prior to this assignment, he served as Finance and Economic Affairs Secretary in the Government of India and earlier as Secretary in the Departments of Revenue, Petroleum and Industrial Development. As Secretary, Petroleum and Natural Gas, he was responsible for policy formulation and implementation in the hydrocarbon sector. Between 2000 and 2003, in the Ministry of Finance, his responsibilities included formulation of macroeconomic policy for the Government, tariff and taxation policies as well as initiatives for modernizing the capital markets. Earlier, as Secretary, Rural Development, in Tamil Nadu, between 1989 and 1995, he was responsible for launching micro credit group initiatives for the rural sector.

Narayan obtained his Ph.D from the Indian Institute of Technology in New Delhi. He has an M.Phil (Development Economics) from Cambridge University and Master of Business Management (Finance) from the University of Adelaide. He graduated with an M.Sc (Physics) from the University of Madras (Madras Christian College).

Nuclear Power in India

Current Scenario



(Source : http://www.cea.nic.in/)

Nuclear power supplied 4,340 MW (2.8%) out of 1,57,230 MW of India's electricity in 2009-10 as on 31 January 2010, and this will increase steadily as imported uranium becomes available and new plants come on line. Some 300 reactor-years of operation had been achieved by mid 2009. India's fuel situation, with shortage of fossil fuels, is driving the nuclear investment for electricity.

Since 2004, the target for nuclear power has been to provide 20 GW by 2020. In 2007, Prime Minister Manmohan Singh referred to this as "modest" and capable of being "doubled with the opening up of international cooperation." However, it is evident that even the 20 GW target will require substantial uranium imports. Late in 2008, the Nuclear Power Corporation of India Limited (NPCIL) projected 22 GW on line by 2015, and the government was talking about having 50 GW of nuclear power operating by 2050. In June 2009, the NPCIL said it aimed for 63 GW nuclear by 2032, including 40 GW of Pressurised Water Reactor (PWR) capacity and 7 GW of new Pressurised Heavy Water Reactor (PHWR) capacity, all fuelled by imported uranium.

Economics of Nuclear Power

Unit energy costs of nuclear power are comparable to power from coal at locations away from coal pits. The NPCIL which builds, owns and operates nuclear power stations is a triple A-rated company and has been highly commended for its excellent commercial performance, both in building power plants and in their operations.

High capacity factors, low discount rates and reduced capital costs are factors, which make nuclear power more attractive. Conditions in India have also become more favorable in terms of these parameters over the years. Further, with its low variable costs, nuclear power improves its relative economics with years of operation of the power plant.

Organisations and Structure

The nuclear establishment in India enjoys unique access to political authority and is protected from external oversight. Unlike most policy matters where the cabinet has the ultimate authority, the Atomic Energy Commission (AEC) is under the direct charge of the Prime Minister. This structure makes it difficult for most politicians or bureaucrats, let alone the public, to challenge nuclear policies or practices.

AEC

The AEC was first set up in August 1948, with the objective to promote peaceful use of atomic energy. In accordance with the Government Resolution dated 1 March 1958, the AEC was established in the Department of Atomic Energy (DAE). As per the resolution, the Secretary to the Government of India in the DAE is ex-officio Chairman of the Commission. Other members of the AEC are appointed for each calendar year on the recommendation of the Chairman, the AEC, upon approval from the Prime Minster. The role of the AEC is to formulate the development of the Indian atomic energy policies and programmes. Currently, Dr Srikumar Banerjee, Secretary to Government of India, is the Chairman of the Atomic Energy Commission.

DAE

The actual execution of the atomic energy policies is carried out by the DAE, which was set up in 1954. The DAE has formed a number of associated or subsidiary organisations. These include five research centres, five government-owned companies ("public sector enterprises"), three industrial organisations, and three service organisations. The roles and responsibilities of the DAE are as follows:

- Administration of the Atomic Energy Act, 1962 (33 of 1962), including the control of radioactive substances and regulation of their possession, use, disposal and transport;
- Research, including fundamental research in matters connected with atomic energy and the development of its uses in agriculture, biology, industry and medicine; and
- Atomic minerals-survey, prospecting, drilling, development, mining, acquisition and control;
- All activities connected with the development and use of atomic energy, including –
    - ❖ projects and industries concerned with substances and minerals prescribed under the Atomic Energy Act, 1962 (33 of 1962); their products and by-products;
    - ❖ generation of electricity through the use of atomic energy;
    - ❖ design, construction and operation of research and power reactors; and
    - ❖ establishment and operation of facilities and plants, including diversification -
        - ❑ for the production of materials and equipment required for research in the use of atomic energy and research in nuclear sciences; and
        - ❑ for the separation of isotopes, including plants adaptable to the separation of isotopes as by-product and the production of heavy water as a main or subsidiary product.
- Supervision of State undertakings concerned with prescribed or radioactive substances, including -
    - ❖ Indian Rare Earths Limited (IREL)
    - ❖ Electronics Corporation of India Limited (ECIL)

    - Uranium Corporation of India Limited (UCIL)
    - NPCIL
    - National Fertilizers Limited, in so far, as production of heavy water is concerned.
- Financial assistance for furtherance of studies in nuclear sciences and building up adequately
- International relations in matters connected with atomic energy and nuclear science including
    - All matters relating to the aided institutions under the administrative control of the DAE;
    - All matters relating to other grant-in-aid institutions concerning activities funded by the DAE.

For long, the DAE did not have a separate safety division. It was only in 1972 that the DAE constituted an internal Safety Review Committee. In 1983, the Atomic Energy Regulatory Board (AERB) was set up to oversee and enforce safety in all nuclear operations. This was modified in 2000 to exclude nuclear weapons facilities.

AERB

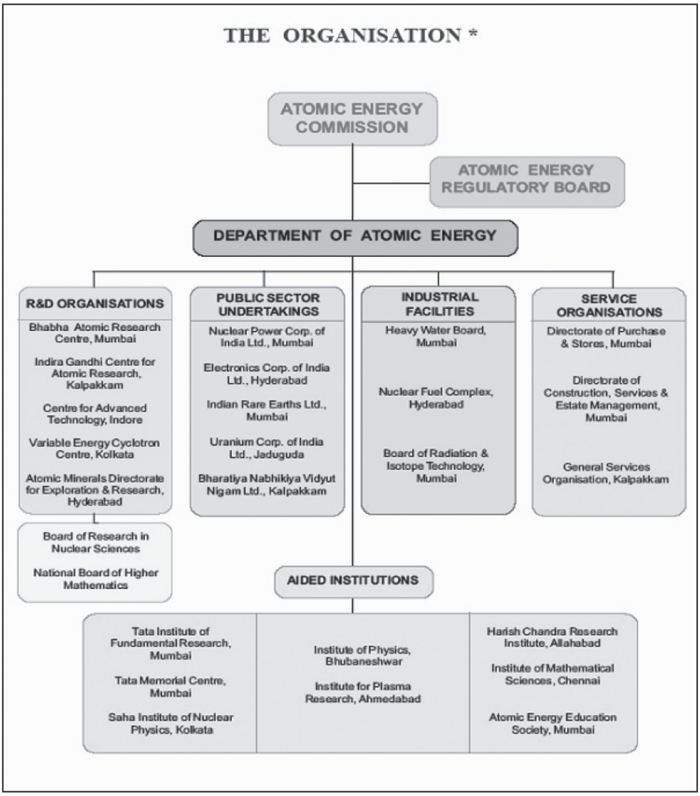
The AERB was constituted in India on 15 November 1983 by the President of India under Section 27 of the Atomic Energy Act, 1962. Currently, the Board consists of a full-time Chairman, an ex-officio Member, three part-time Members and a Secretary. Roles and responsibilities of the AERB are as follow:

- Ensure that the use of ionising radiation and nuclear energy in India does not cause undue risk to health and the environment;
- The AERB constitutes various types of committees for achieving its mission, which are constituted by the Chairman, AERB or Chairman, Safety Review Committee for Operating Plant (SARCOP) viz.
    - Advisory Committees
        - Advisory Committees include the Committees for Preparation of Regulatory Documents, Project

Safety Review, Nuclear Safety Review and other specific activities

- Project Design Safety Review Committees
- Safety Review Committees
  - Safety Review Committee for Application of Radiation (SARCAR): safety monitoring and enforcing committee that reviews safety aspects related to application of radiation in all the non-DAE units.
  - Safety Review Committee for Operating Plants (SARCOP): enforces safety stipulations in the operating units of the DAE.
- Licensing Committees
  - Authorise operators for the various licensed/ authorised positions of the station as specified in the Technical Specifications of the Operating Station.
- Standing Committees
  - Carry out assessments in very specific technical areas such as control and instrumentation including computer-based system used in NPPs, Occupational Health, Waste Disposal and Fatal Accidents.
- Technical Review and Assessment Committees and Task Force
  - Formed by either a Committee or Chairman/Vice-Chairman of the AERB with the membership of experts in a specific analytical area such as Thermal Hydraulic Analysis, Probabilistic Safety Analysis, Containment Structural Analysis, Seismic Qualification and Computer Codes Validation Assessment as and when required for carrying out a specific task within stipulated time.
- AERB's Internal Committees

Figure 1: Nuclear Power in India – Organizational Set-up



(Source: http://www.barc.ernet.in/rcaindia/images/4_5_clip_image002_0000.gif)

Nuclear Power Policy

All the Nuclear Power Plants are established as per the Atomic Energy Act, 1962 which has few special provisions as to electricity. The complete detail regarding these laws can be found at the official website of the DAE, Government of India (GOI) (http://www.dae.gov.in/). The Acts, Rules and Notifications regarding the nuclear power are as follow:

- Atomic Energy Act, 1962
- Atomic Energy (Arbitration Procedure) Rules, 1983
- Atomic Energy (Factories) Rules, 1996
- Atomic Energy (Control of Irradiation of Food) Rules, 1996.

- Atomic Energy (Working of the Mines, Minerals and Handling of Prescribed Substances) Rules, 1984
- Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987.
- Radiation Protection Rules, 2004

Special provisions as to electricity as per Atomic Energy Act, 1962 of India

1. Notwithstanding anything contained in the Electricity (Supply) Act, 1948, the Central Government shall have authority —

    i) to develop a sound and adequate national policy in regard to atomic power; to co-ordinate such policy with the Central Electricity Authority and the State Electricity Boards constituted under Sections 3 and 5 respectively of that Act; and other similar statutory corporations concerned with the control and utilisation of other power resources to implement schemes for the generation of electricity in pursuance of such policy; and to operate either by itself or through any authority or corporation established by it or a government company atomic power stations in the manner determined in consultation with the Boards or Corporations concerned with whom it shall enter into agreement regarding the supply of electricity produced;

    ii) to fix rates for and regulate the supply of electricity from atomic power stations either by itself or through any authority or corporation established by it or a government company in consultation with the Central Electricity Authority;

    iii) to enter into arrangements with the State Electricity Board in which an atomic power station is situated either by itself or through any authority or corporation established by it or a government company for the transmission of electricity to any other State. In the event there is a difference of opinion between the Central Government or such authority or corporation or government company as the case may be, and any State Electricity Board in regards to the construction of necessary transmission lines, the matter shall be referred to the Central Electricity Authority whose decision shall be binding on the parties concerned.

2. No provision of the Indian Electricity Act, 1910, or any rule made thereunder or of any instrument having effect by virtue of such law or rule, shall have any effect so far as it is inconsistent with any of the provisions of this Act.

3. Save as otherwise provided in this Act, the provisions of this Act shall be in addition to, and not in derogation of, the Indian Electricity Act, 1910, and the Electricity (Supply) Act, 1948.

Provision of Atomic Energy Act, 1962 of India

As per the Atomic Energy Act, 1962 of India, the National Thermal Power Corporation (NTPC) can enter into the nuclear power generation business, because the NTPC is a government-owned public sector enterprise with more than 51 per cent shareholding by the GOI. However, government clearance is required for entering into nuclear power generation business for setting up of nuclear power stations under Section 33.

Clause No 3.0 of the Atomic Energy Act. General Power of the Central Government, quote *"Subject to the provisions of the "Atomic Energy Act 1962", Central Government shall have the power:-*

a) to produce, develop, use and dispose of atomic energy either by itself or through any authority or Government company or corporation established by it;

b) to provide for the production and supply of electricity from atomic energy and for taking measures conducive to such production and supply and for all matter incidental thereto either by itself or through any authority or corporation established by it or a Government company."

Regulatory Requirements for Setting-Up a Nuclear Power Plant

At the stage of planning for a Nuclear Power Plant (NPP) at any given site, prior approvals are required from following statutory bodies:

- AERB
- Ministry of Environment And Forests (MoEF)
- State Pollution Control Board (SPCB)
- Centre Pollution Control Board (CPCB)

Regulatory Aspects during Construction, Commissioning and Operation

Periodic audits and regulatory inspection at site are carried out by AERB committees during construction, commissioning and operation to ascertain compliance of their codes and observations during review of design, construction procedures, commissioning procedures, operating practices and maintenance. AERB can stop construction, commissioning and operation of the plant, if it is not satisfied with the utilities compliance with its codes and standard's directives.

Site Selection Criteria

Criteria for assessment of siting of a NPP are specified in the siting code AERB/SC/S and related safety guides published by the AERB. The safety guides detail the acceptable procedures for meeting the requirements laid down by the siting code. Table 1 contains the list of related safety guides published by the AERB. Safety guides published by the International Atomic Energy Agency (IAEA) are also considered.

Table 1 List of AERB Safety Guides related to Siting of NPPs

S. No.	Safety Series No.	Title
1.	AERB/SG/S-1	Atmospheric Dispersion and Modelling
2.	AERB/SG/S-2	Hydrological Dispersion of Radioactive Materials in Relation to Nuclear Power Plant Siting
3.	AERB/SG/S-3	Extreme Values of Meteorological Parameters

4.	AERB/SG/S-4	Hydrogeological Aspects of Siting of Nuclear Power Plants
5.	AERB/SG/S-5	Models for Radioactive Dose Computation Methodologies from Radioactivity Concentrations in Environment
6.	AERB/SG/S-6A	Design Basis Floods for Nuclear Power Plants on Inland Sites
7.	AERB/SG/S-6B	Design Basis Floods for Nuclear Power Plants at Coastal Sites
8.	AERB/SG/S-7	Man-Induced Events and Establishment of Design Basis Events (Draft)
9.	AERB/SG/S-8	Influence of Site Parameters on Emergency Preparedness
10.	AERB/SG/S-9	Population Distribution and its Analysis in Relation to Siting of Nuclear Power Plants
11.	AERB/SG/S-10	Quality Assurance in Siting
12.	AERB/SG/S-11	Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites

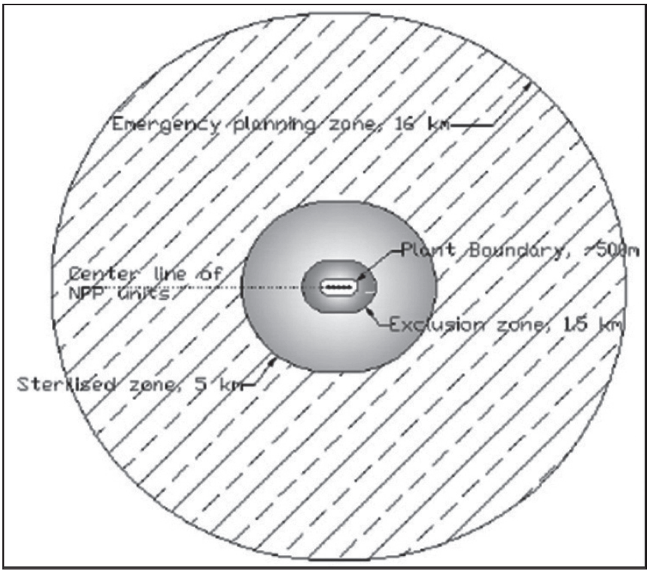
(Source: http://www.aerb.gov.in/t/sj/Siting.pdf)

Basic Requirements

For nuclear power plants, the 'site' includes the area surrounding the plant enclosed by a boundary, which is under effective control of the plant management. Current mandatory requirement of the AERB Siting Code is that an exclusion zone of at least 1.5km radius around the plant is to be established and this area should be under the exclusive control of the station wherein public habitation is prohibited. Though the exclusion zone distance could be greater than 1.5km, depending on the land acquisition and future expansion plans, the radiation dose limits for public are specified by the AERB at 1.5km distance from the plant.

In addition, a sterilised zone around the exclusion zone covering an area up to 5km radius around the plant is also established. Only the natural growth of population is permitted in the sterilised zone, but planned expansion of activities leading to enhanced population is regulated. Figure 2 depicts different zones that are defined in relation with the NPP site.

Figure 2: Distance of different zones as defined in AERB siting code, from the Reactor Centers of NPP.



(Source: http://www.aerb.gov.in/t/sj/Siting.pdf)

- **Rejection criteria:** For locating the plant, these stipulations need to be satisfied. Otherwise, the site is deemed rejected. No engineering measures can satisfactorily overcome the detrimental effects of not meeting these criteria - e.g., no possibility of ground failure, minimum distance from military installations, etc. Rejection criteria, generally given in terms of Screening Distance Values (SDV), are applied at site selection stage to shortlist the candidate sites. Safety of the plant against external events is ensured either by observing the SDV wherever applicable or by engineering the site and plant to mitigate the hazard caused by such events. If the hazard is located beyond the SDV, capability of that particular hazard to cause damage at site is considered to be negligible by engineering measures.
- **Mandatory Requirements:** These requirements are related to those phenomena whose effects shall be considered in the design of the NPP and evaluated during the siting process - e.g., wind, rainfall/flood, vibratory motion due to earthquake, etc. Usually, suitable measures can be adopted to take care of these phenomena in the engineering of the plant.

- **Desirable requirements:** Non-fulfillment of these requirements does not affect the plant attributes related to radiological safety - e.g., distance to facilities handling inflammable/toxic/explosive substances, population around site, etc. The design basis parameters of the plant are altered at the cost of economic penalty. Modifications of some activities/procedures of this class during plant operation may also have economic impact - e.g., evacuation of population surrounding the plant area in the event of an off-site emergency.

Table 2: Rejection Criteria with respect to various hazards for siting of NPPs

S. No.	Hazard	Rejection criteria and SDV, if applicable
1.	Earthquake	Site falling in seismic zone V as per BIS 1893
2.	Earthquake	Distance from capable fault < 5km
3.	Earthquake	Potential for soil liquefaction
4.	Earthquake/ Geological	Potential for slope instability which cannot be mitigated by engineering measures
5.	Earthquake/ Geological	Potential for ground collapse/subsidence/uplift which cannot be mitigated by engineering measures
6.	Geological	Possibility of formation of sand dunes
7.	Aircraft Imoact	Distance from small air fields < 5km
8.	Aircraft Imoact	Distance from major air ports < 8km
9.	Aircraft Imoact	Distance from military air fields < 15km
10.	Explosion	Distance from military installations storing ammunitions < 10km

(Source: http://www.aerb.gov.in/t/sj/Siting.pdf)

Indian Nuclear Power Industry Development

The Atomic Energy Establishment was set up at Trombay, near Mumbai, in 1957 and renamed as Bhabha Atomic Research Centre (BARC) ten years later. Plans for building the first Pressurised Heavy Water Reactor (PHWR) were finalised in 1964, and this prototype - Rajasthan-1, which had Canada's Douglas Point reactor as a reference unit, was built as a collaborative venture between Atomic Energy of Canada Ltd (AECL) and NPCIL. It started up in 1972 and was duplicated. Subsequent indigenous PHWR development has been based on these units.

The NPCIL is responsible for design, construction, commissioning and operation of thermal nuclear power plants. Mr S. K. Jain is the current Chairman and Managing Director. The NPCIL is a public sector enterprise under the administrative control of the DAE, GOI. The company was registered as a public limited company under the Companies Act, 1956 in September 1987, with the objective of operating atomic power stations and implementing atomic power projects for the generation of electricity in pursuance of the schemes and programmes of the GOI under the Atomic Energy Act, 1962.

Presently, the NPCIL is operating 17 nuclear power plants with a total installed-capacity of 4340 MW and has four reactors under construction, totalling 2720 MW capacity. The NPCIL has achieved more than 300 reactor years of safe nuclear power plant operating experience. The NPCIL operates plants with the motto, 'Safety First and Production Next'. The NPCIL generated about 90 billion units of electricity in the X plan (2002-2007), exceeding the set target by about 10 per cent, and added 1180 MW capacity against the target of 1300 MW capacity, thus realising 91 per cent of the target capacity addition.

Nuclear Power under Operation

At the start of 2010, the NPCIL said it had enough cash on hand for 10,000 MW of new plant. Its funding model is ***70 per cent equity, and 30 per cent debt financing.*** However, it is aiming to involve other public sector and private corporations in future nuclear power expansion, notably the NTPC. The NTPC is largely government-owned, and the 1962 Atomic Energy Act prohibits private control of nuclear power generation.

Table 3: India's Operating Nuclear Power Reactors

Reactor	State	Type	MW net, each	Commercial operation	Safeguards status
Tarapur 1 & 2	Maharashtra	BWR	150	1969	Item-Specific
Kaiga 1 & 2	Karnataka	PHWR	202	1999-2000	
Kaiga 3	Karnataka	PHWR	202	2007	
Kakrapar 1 & 2	Gujarat	PHWR	202	1993-95	In 2012 under new agreement
Kalpakkam 1 & 2 (MAPS)	Tamil Nadu	PHWR	202	1984-86	
Narora 1 & 2	Uttar Pradesh	PHWR	202	1991-92	In 2014 under new agreement

Rajasthan 1	Rajasthan	PHWR	90	1973	Item-Specific
Rajasthan 2	Rajasthan	PHWR	187	1981	Item-Specific
Rajasthan 3 & 4	Rajasthan	PHWR	202	1999-2000	Early 2010 under new agreement
Rajasthan 5 & 6	Rajasthan	PHWR	202	Feb-10, (Mid 2010)	Oct 2009 under new agreement
Tarapur 3 & 4	Maharashtra	PHWR	490	2006, 05	
Total (19)			**4183 MW**		

(Source: www.world-nuclear.org/info/inf53.html)

Note: *BWR = Boiling Water Reactor*
PHWR = Pressurized Heavy Water Reactor

The two Tarapur 150 MW Boiling Water Reactors (BWRs) built by General Electric (GE) on a turnkey contract before the advent of the Nuclear Non-Proliferation Treaty were originally 200 MW. They were down-rated due to recurrent problems but have run well since. They have been using imported enriched uranium and are under the IAEA safeguards. However, late in 2004, Russia deferred to the Nuclear Suppliers' Group and declined to supply further uranium to them. They underwent six months of refurbishment over 2005-06, and in March 2006, Russia agreed to resume fuel supply. In December 2008, a US$700 million contract with Russia's State Atomic Energy Corporation (Rosatom) was announced for continued uranium supply to them.

The two small Canadian (Candu) PHWRs at Rajasthan nuclear power plant started up in 1972 and 1980 respectively, and are also under safeguards. Rajasthan-1 was down-rated early in its life and has operated very little since 2002, due to ongoing problems and has been shut down since 2004 as the government considers its future. Rajasthan-2 was restarted in September 2009 after major refurbishment, and is running on imported uranium at full rated power. The 220 MW PHWRs (202 MW net) were indigenously designed and constructed by the NPCIL, based on the Canadian design.

The Kalpakkam (MAPS) reactors were refurbished in 2002-03 and 2004-05 and their capacity restored to 220 MW gross (from

170). Much of the core of each reactor was replaced, and the lifespan extended to 2033/36.

Kakrapar Unit 1 was repaired and upgraded in 2009, so was Narora-2.

Nuclear Power under Construction

The new Tarapur 3 & 4 reactors of 540 MW gross (490 MW net) are developed indigenously from the 220 MW (gross) model PHWR. They were built by the NPCIL. The first - Tarapur 4 - started up in March 2005, was connected to the grid in June 2005 and started commercial operation in September that year. Tarapur-4's criticality came five years after pouring first concrete; and seven months ahead of schedule. Its twin - Unit 3 - was about a year behind it and criticality was achieved in May 2006, with grid connection in June and commercial operation in August 2006, five months ahead of schedule.

Future indigenous PHWR reactors will be 700 MW gross (640 MW net). The first four will be built at Kakrapar and Rajasthan.

Russia is supplying the country's first large nuclear power plant, comprising two VVER-1000 (V-392) reactors, under a Russian-financed US$ 3 billion contract. VVER is the Soviet (and now, Russian Federation) designation for light water pressurised reactor. In Western countries, the PWR is used as the acronym. The AES-92 units at Kudankulam in Tamil Nadu state are being built by the NPCIL and will be commissioned and operated by the NPCIL under the IAEA safeguards. The turbines are made by Leningrad Metal Works. Unlike other AtomStroyExport projects such as in Iran, there has been only about 80 Russian supervisory staff on the job. Russia will supply all the enriched fuel and India will reprocess it and keep the plutonium. The first unit was due to start supplying power in March 2008 and go into commercial operation in late 2008. But, this schedule has slipped by about two years. The second unit is about 6-8 months behind it.

While the first core load of fuel was delivered in early 2008, there have been delays in supplies of some equipment and documentation. Control system documentation was delivered late, and when reviewed by the NPCIL, it showed up the need for significant refining and even reworking some aspects. Fuel loading of Unit 1 may take place only later in 2010, though in

October 2009, the NPCIL said the unit was 94 per cent complete and that 99 per cent of the equipment was on site.

Under plans for the India-specific safeguards to be administered by the IAEA in relation to the civil-military separation plan, eight further reactors will be safeguarded (beyond Tarapur 1 & 2, Rajasthan 1 & 2, and Kudankulam 1 & 2): Rajasthan 3 & 4 by 2010, Rajasthan 5 & 6 by 2008, Kakrapar 1 & 2 by 2012, and Narora 1 & 2 by 2014.

Table 4: India's Nuclear Power Reactors under Construction

Reactor	Type	MW net, each	Project control	Commercial operation due	Safeguards status
Kaiga 4	PHWR	202	NPCIL	Mar-10	
Kudankulam 1	PWR (VVER)	950	NPCIL	Sep-10	Item-specific
Kudankulam 2	PWR (VVER)	950	NPCIL	Mar-11	Item-specific
Kalpakkam PFBR	FBR	470	Bhavini	Sep-11	-
Total (4)		2572 MW			

(Source: www.world-nuclear.org/info/inf53.html)

Kaiga 3 started up in February 2007. It was connected to the grid in April and went into commercial operation in May 2007. Unit 4 was scheduled about six months behind it. But, it is about 18 months behind the original schedule due to a shortage of uranium. RAPP-5 was started up in November 2009 using imported Russian fuel and connected to the northern grid in December. RAPP-6 was started up in January 2010.

In mid 2008, the Indian nuclear power plants were running at about half of their capacity due to a chronic shortage of fuel. The situation was expected to persist for several years if the civil nuclear agreement faltered, though some easing in 2008 happened with the new Turamdih mill in Jharkhand state coming on line (the mine there is already operating). Political opposition has delayed new mines in Jharkhand, Meghalaya and Andhra Pradesh.

A 500 MW prototype Fast Breeder Reactor (FBR) is under construction at Kalpakkam by BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Ltd), a government enterprise set up under the DAE to focus on FBRs. It is expected to start up at the end of 2010 and produce power in 2011. Four further oxide-fuel fast reactors are envisaged but slightly redesigned by the Indira Gandhi Centre to reduce capital cost. One pair will be at Kalpakkam; and two more elsewhere.

In contrast to the situation in the 1990s, most reactors under construction are on schedule (apart from fuel shortages 2007-09), and the first two - Tarapur 3 & 4 – have slightly increased in capacity. These and future planned ones were 450 (now 490) MW versions of the 202 MW domestic products. Beyond them and the last three 202 MW units, future units will be a nominal 700 MW.

The government envisages setting up about ten PHWRs of 700 MW capacity by 2023, fuelled by indigenous uranium, as Stage 1 of its nuclear program. Stage 2 - four 500 MW FBRs - will be concurrently established.

Nuclear Power under Development

Following the Nuclear Suppliers' Group Agreement which was achieved in September 2008, the scope for supply of both reactors and fuel from suppliers in other countries opened up. Civil nuclear cooperation agreements have been signed with the US, Russia, France, UK and Canada (pending), as well as Argentina, Kazakhstan, Mongolia and Namibia.

The Russian PWR types were apart from India's three-stage plan for nuclear power and were simply to increase generating capacity more rapidly. Now, there are plans for eight 1000 MW units at the Kudankulam site. In January 2007, a Memorandum of Understanding (MOU) was signed for Russia to build four more there; and others elsewhere in India. The new units are expected to be the larger 1200 MW AES-2006 versions of the first two.

Between 2010 and 2020, further construction is expected to take the total gross capacity to 21180 MW. The nuclear capacity target is part of the national energy policy. This planned increment includes the initial 300 MW Advanced Heavy Water Reactor (AHWR).

In 2005, four sites were approved for eight new reactors. Two of the sites - Kakrapar and Rajasthan, would have 700 MW indigenous PHWR units, Kudankulam would have imported 1000 or 1200 MW Light Water Reactors (LWR) alongside the two being built there by Russia, and the fourth site was Greenfield for two 1000 MW LWR units - Jaitapur (Jaithalpur) in the Ratnagiri district of Maharashtra state, on the west coast. The plan has since expanded to six 1600 MW EPR units here.

The NPCIL has had meetings and technical discussions with three major reactor suppliers - Areva of France, GE-Hitachi and Westinghouse Electric Corporation of the USA for supply of reactors for these projects and for new units at Kaiga. These resulted in more formal agreements with each reactor supplier in early 2009, as mentioned below.

In April 2007, the government gave approval for the first four of these eight units: Kakrapar 3 & 4 and Rajasthan 7 & 8, using indigenous technology. In mid 2009, construction approval was confirmed; finance for them was approved in late 2009; and site works commenced in early 2010. In September 2009, India's largest engineering group, Larsen & Toubro (L&T) secured an order for four steam generators for Rajasthan 7 & 8, having supplied similar ones for Kakrapar 3 & 4. Construction is expected to take 66 months from first concrete (expected in 2010) to commercial operation.

In late 2008, the NPCIL announced that as part of the Eleventh Five Year Plan (2007-12), it would start site work for 12 reactors including the rest of the eight PHWRs of 700 MW each, three or four Fast Breeder Reactors (FBR) and one 300 MW AHWR in 2009.

The NPCIL said that, "India is now focusing on capacity addition through indigenisation" with progressively higher local content for imported designs, up to 80 per cent. Looking further ahead, its augmentation plan included the construction of 25-30 LWRs of at least 1000 MW by 2030. The AEC has said that India now has, "a significant technological capability in PWRs and the NPCIL has worked out an Indian PWR design", which will be unveiled soon, perhaps in 2010.

Table 5: Power Reactors Planned or Firmly Proposed

Reactor	State	Type	MW net, each	Project control	Start construct	Start operation
Kakrapar 3	Gujarat	PHWR	640	NPCIL	mid 2011	2017
Kakrapar 4	Gujarat	PHWR	640	NPCIL	2011	2017
Rajasthan 7	Rajasthan	PHWR	640	NPCIL	2011	2017
Rajasthan 8	Rajasthan	PHWR	640	NPCIL	2011	2017

Kudankulam 3	Tamil Nadu	PWR - AES 92 or AES-2006	1050-1200	NPCIL	late 2010	2017
Kudankulam 4	Tamil Nadu	PWR - AES 92 or AES-2006	1050-1200	NPCIL	2011	2017
Jaitapur 1 & 2	Maharashtra	PWR - EPR	1600	NPCIL	by 2012	2017-18
Kaiga 5 & 6	Karnataka	PWR	1000/1500	NPCIL	by 2012	
Kudankulam 5 & 6	Tamil Nadu	PWR - AES 92 or AES-2006	1050-1200	NPCIL	2012	2017
Kumharia 1-4	Haryana	PHWR x 4	640	NPCIL	by 2012	
Bargi 1 & 2	Madhya Pradesh	PHWR x 2	640	NPCIL	2012	
Kalpakkam 2 & 3	Tamil Nadu	FBR x 2	470	Bhavini	2012	2017
Subtotal planned	20 units	25,240 -26,240				
Kudankulam 7 & 8	Tamil Nadu	PWR - AES 92 or AES-2006	1050-1200	NPCIL	2012	2017
Proposed		PWR x 2	1000	NPCIL/ NTPC	by 2012	2014
Jaitapur 3 & 4	Maharashtra	PWR - EPR	1600	NPCIL	by 2016	
Proposed		FBR x 2	470	Bhavini		2017
Proposed		AHWR	300	NPCIL	by 2012	2020
Jaitapur 5 & 6	Maharashtra	PWR - EPR	1600	NPCIL		
Markandi (Pati Sonapur)	Orissa	PWR	6000			
Mithi Virdi 1-6, Saurashtra region	Gujarat	6 x AP1000	1250			
Pulivendula	Andhra Pradesh	PWR	2x1000	NPCIL 51%, AP Genco 49%		

Kovvada 1-6	Andhra Pradesh	6 x ESBWR	1350-1550			
Haripur 1-4	West Bengal	PWR x 4 VVER-1200	1200		2017	2022
SUBTOTAL PROPOSED	34 units approx	41,300 approx				

(Source: www.world-nuclear.org/info/inf53.html)

Way Ahead

AEC along with NPCIL made many efforts to make the targets come true i.e. to increase the nuclear power share to 25% by 2050. So many initiatives are taken including nuclear Energy Parks, MoU's with foreign as well as Indian major players in the sector. Some highlights of the above said initiatives are given below:

1. Nuclear Energy Parks

In line with past practice such as at the eight-unit Rajasthan nuclear plant, the NPCIL intends to set up five further "Nuclear Energy Parks", each with a capacity for up to eight new-generation reactors of 1000 MW, six reactors of 1600 MW or simply 10000 MW at a single location. By 2032, 40-45 GW would be provided from these five. The NPCIL says it is confident of being able to start work by 2012 on at least four new reactors at all four sites designated for imported plants.

The new energy parks will be built in:

- Kudankulam in Tamil Nadu: two more pairs of Russian VVER units, making 6800 MW.
- Jaitapur in Maharashtra: Preliminary work is likely to start soon with six of Areva's EPR reactors in view, making 9600 MW.
- Mithi Virdi (or Chayamithi Virdi) in Gujarat: to host US technology (Westinghouse AP1000).
- Kovvada in Andhra Pradesh: to host US technology (GE Hitachi ESBWR - possibly ABWR).
- Haripur in West Bengal: to host four further Russian VVER-1200 units, making 4800 MW.

At Markandi (Pati Sonapur) in Orissa, there are plans for up to 6000 MW of PWR capacity. Major industrial developments are planned in that area and Orissa was the first Indian state to privatise electricity generation and transmission. State demand is expected to reach 20 billion kWh/yr by 2010.

At Kumharia in Haryana, the AEC had approved the state's proposal for a 2800 MW nuclear power plant and the site is apparently earmarked for four indigenous 700 MW PHWR units. The northern state of Haryana is one of the country's most industrialised and has a demand of 8900 MW. It currently generates less than 2000 MW and imports 4000 MW. The village of Kumharia is in Fatehabad district and the plant may be paid for by the state government or the Haryana Power Generation Corp. Bargi in Madhya Pradesh is also designated for two indigenous 700 MW PHWR units. The AEC has also mentioned possible new nuclear power plants in Bihar and Jharkhand.

2. NTPC Plans

India's largest power company, **the NTPC, in 2007 proposed building a 2000 MW nuclear power plant to be in operation by 2017.** It would be the utility's first nuclear plant and also the first conventional nuclear plant not built by the government-owned NPCIL. This proposal has now become a joint venture with the NPCIL holding 51 per cent, and possibly extending to multiple projects utilising imported technology. The NTPC says it aims by 2014, to have demonstrated progress in, "setting up nuclear power generation capacity", and that the initial, "planned nuclear portfolio of 2000 MW by 2017", may be greater. The NTPC, now 89.5 per cent government-owned, is planning to increase its total installed capacity from 30 to 50 GW by 2012 (72 per cent of its coal) and 75 GW by 2017. It is also forming joint ventures in heavy engineering.

3. Overseas Reactor Vendors for Engineering, Procurement & Construction (EPC) Services

- In February 2009, **Areva signed a MOU with the NPCIL** to build two, and later four more EPR units at Jaitapur in the Maharashtra state of India. This followed **the government signing of a Nuclear Cooperation Agreement with France in September 2008.** In July 2009, Areva submitted a bid to the NPCIL to build the first two EPR units, with a view to commissioning them in 2017 and 2018. Areva is amongst the global leaders in nuclear power front-end and back-end activities, and manufacturing of heavy components. Areva offers reliable technological solution for CO2 free power generation. Areva already has presence in India in power transmission and distribution segment through the firm. Areva T&D Ltd employs 4200 persons at eight industrial sites.

- In March 2009, **GE Hitachi Nuclear Energy (GEH) signed agreements with the NPCIL and Bharat Heavy Electricals (BHEL)** to begin planning to build a multi-unit power plant using 1350 MW Advanced Boiling Water Reactors (ABWR). The 1350-MW ABWR technology is the world's only commercially-proven Generation III reactor design, with the first two of four units entering service in 1996 and 1997 and four additional units under construction today, with discussion continuing regarding the site. In May 2009, the L&T was brought into the picture.

- In May 2009, **Westinghouse signed a MOU with the NPCIL** regarding the deployment of six to eight of its AP1000 reactors, using local components (probably from the L&T). The Westinghouse believes the AP1000 is ideally suited for the worldwide nuclear power marketplace, as it is:

  - ❖ A passively safe design that employs natural forces - natural circulation, gravity, convection and compressed gas - to maintain safety in the highly unlikely event of an accident.

  - ❖ Modular in design, promoting standardisation and high construction quality.

  - ❖ Economical to construct and maintain (less concrete and steel, and fewer components and systems mean there is less to install, inspect and maintain).

  - ❖ Designed to promote ease of operation (features most advanced instrumentation and control system in the industry).

- After a break of three decades, the AECL is keen to resume technical cooperation, especially in relation to servicing India's PHWRs, and there have been preliminary discussions regarding the sale of an ACR-1000.

- In August 2009, the NPCIL signed agreements with Korea Electric Power Co (KEPCO) to study the prospects for building Korean APR-1400 reactors in India. This will depend on establishing a bilateral nuclear cooperation agreement.

- The LWRs to be set up by these foreign companies are reported to have a lifetime guarantee of fuel supply.

4. Other Arrangements:

1. The state-owned **National Aluminium Company (Nalco) has signed an agreement with the NPCIL** for the building of a 1000 MW nuclear power plant, in an attempt to diversify the source of electricity for its aluminum smelters.

2. India's national oil company, **Indian Oil Corporation Ltd (IOCL), in November 2009, joined with the NPCIL in a MOU**, "for partnership in setting up nuclear power plants in India." The initial plant envisaged is at least 1000 MW, and the NPCIL will be the operator with at least 51 per cent ownership. The IOC will take a 26 per cent stake in it. Investments have being made in the three major nuclear power projects at Kakrapur (1400 MW), Kudankulam (2000 MW) and Jaitapur (3300 MW). The outlay would be spread across the period of the project and would only be a part of the overall capital expenditure plan laid out for Indian Oil. The cost of a nuclear plant with an average capacity of 700-1000 MW would be in the range of Rs 7,000 -10,000 crore.

3. **The government has announced that it intends to amend the law to allow private companies to be involved in nuclear power generation and possibly other aspects of the fuel cycle, but without direct foreign investment.** In anticipation of this, Reliance Power Ltd, GVK Power & Infrastructure Ltd and GMR Energy Ltd are reported to be in discussion with overseas nuclear vendors including Areva, GE-Hitachi, Westinghouse and AtomStroyExport.

4. **The NTPC is reported to be establishing a joint venture with the NPCIL and BHEL** to sell India's largely indigenous 220 MW heavy water power reactor units abroad, possibly **in contra deals involving uranium supply from countries such as Namibia and Mongolia.** In September 2009, the AEC announced a version of its planned AHWR designed for export. In August and September 2009, the AEC reaffirmed its commitment to the thorium fuel cycle, particularly thorium-based FBRs, to make the country a technological leader.

Following these **will be a 1000 MW fast reactor using metallic fuel, and construction of the first is expected to start about 2020.** This design is intended to be the main part of the Indian nuclear fleet from the 2020s. A fuel fabrication plant and a reprocessing plant for metal fuels are planned for Kalpakkam, the former possibly ready for operation in 2014.

5. Heavy Engineering in Nuclear Power Plants

- The L&T announced in July 2008 that it was preparing to venture into international markets for supply of heavy engineering components for nuclear reactors. **It formed Rs 20 billion (US$ 463 million) venture with the NPCIL to build a new plant for domestic and export nuclear forgings at its Hazira, Surat coastal site in Gujarat state.** It is one of the world's biggest high-tech forging facilities in Public Private Partnership (PPP) mode. This is now under construction. It will produce 600-tonne ingots in its steel melt shop and has a very large forging press to supply finished forgings for nuclear reactors, pressurisers and steam generators, and also has heavy forgings for critical equipment in the hydrocarbon sector and thermal power plants.

- In the context of India's trade isolation over three decades, **the L&T has produced heavy components for 17 of India's PHWRs and also secured contracts for 80 per cent of the components for the FBR at Kalpakkam.** It is qualified by the American Society of Mechanical Engineers to fabricate nuclear-grade pressure vessels and core support structures, achieving internationally recognised quality standard in 2007. It is one of about ten major nuclear-qualified heavy engineering enterprises worldwide.

- Early in 2009, the **L&T signed four agreements with foreign nuclear power reactor vendors.** The first, with **Westinghouse**, enables the L&T to produce component modules for Westinghouse's AP1000 reactor. The second agreement was with the **AECL**, "to develop a competitive cost/scope model for the ACR-1000." In April 2009, it signed an agreement with **AtomStroyExport**, primarily focused on components for the next four VVER reactors at Kudankulam, but extending beyond that to other Russian VVER plants in

India and internationally. Then in May 2009, it signed an agreement with **GE Hitachi** to produce major components for ABWRs from its new Hazira plant. The two companies hope to utilise indigenous Indian capabilities for the complete construction of nuclear power plants including the supply of reactor equipment and systems, valves, electrical and instrumentation products for ABWR plants to be built in India. The L&T, "will collaborate with GEH to engineer, manufacture, construct and provide certain construction management services", for the ABWR project.

- Following the 2008 removal of trade restrictions, Indian companies led by **Reliance Power (RPower), NPCIL and BHEL** said that they **plan to invest over US$50 billion in the next five years** to expand their manufacturing base in the nuclear energy sector. The BHEL plans to spend US$7.5 billion in two years building plants to supply components for reactors of 1600 MW. It also plans to set up a 50-50 venture with the NPCIL to supply turbines for nuclear plants of 700 MW, 1000 MW and 1600 MW and seek overseas partners to provide technology for these enterprises. In July 2009, it announced that it was close to finalising a European partner to take 30-35 per cent of this joint venture. Another joint venture with the NPCIL and a foreign partner is to make steam generators for 1000-1600 MW plants.
- **HCC (Hindustan Construction Co.)** has built more than half of India's nuclear power capacity, notably all six phases of the Rajasthan Atomic Power Project and Kudankulam. It specialises in pre-stressed containment structures for reactor buildings. In September 2009, it formed a joint venture with UK-based engineering and project management firm AMEC PLC to undertake consulting services and nuclear power plant construction. The HCC has an order backlog worth Rs 10.5 billion (US$220 million) for nuclear projects from the NPCIL and expects six nuclear reactors to be tendered by the end of 2010.
- **Areva signed an agreement with Bharat Forge in January 2009** to set up a joint venture in casting and forging nuclear components for both export and the domestic market by 2012. BHEL expects to join this and the UK's Sheffield

Forgemasters will be a technical partner. The partners have shortlisted Dahej in Gujarat; and Krishnapatnam and Visakhapatnam in Andhra Pradesh as possible sites.

- Anticipating a big push into nuclear power, private utilities such as **Tata Power Co. Ltd and GMR Energy Ltd** have initiated talks separately with state-run miner UCIL to start a joint venture to mine the fuel that runs atomic power plants.
- With India's nuclear isolation likely to end soon, energy major **Tata Power is busy planning and studying a minimum US$3 billion (Rs 120 billion) foray into nuclear power.**

Status of Nuclear Fuels

The fuel most widely used in nuclear power generation is natural and enriched uranium. The natural uranium consists largely of three isotopes namely U235 (0.711%), U238 (99.284%), and U234 (0.0055%). Only U235 isotope is "fissile" (0.7% of natural uranium) i.e., capable of undergoing fission, the process by which energy is produced in nuclear reactors. U238 is fertile and gets converted into fissile material, i.e., plutonium. The plutonium (fissile) in the FBR can produce electricity and breed more plutonium and produce U233 fissile material if thorium is used as a blanket. It is possible to increase or "enrich" the percentage of U235 up to 3.0 per cent to 5.0 per cent from 0.7 per cent, done by three methods: i) gaseous diffusion, ii) centrifuge, and iii) laser. The most commonly used commercial proven enrichment processes are gaseous diffusion and centrifuge.

Uranium Resources in India

India's uranium resources are modest, with 54000 tonnes uranium as reasonably assured resources and 23500 tonnes as estimated additional resources in situ. Accordingly, from 2009, India is expecting to import an increasing proportion of its uranium fuel needs.

Mining and processing of uranium is carried out by UCIL, a subsidiary of the DAE at Jaduguda and Bhatin (since 1967); Narwapahar (since 1995); and Turamdih (since 2002), - all in Jharkhand near Calcutta. All are underground, the last two being modern. A common mill is located near Jaduguda, and processes 2090 tonnes of ore per day.

Table 6: India's Uranium Mines and Mills - Existing and Announced

State, district	Mine	Mill	Operating from	tU per year
Jharkhand	Jaduguda	Jaduguda	1967 (mine)	175 total from mill
			1968 (mill)	
	Bhatin	Jaduguda	1967	
	Narwapahar	Jaduguda	1995	
	Bagjata	Jaduguda	2009	
Jharkhand, East Singhbum dist.	Turamdih	Turamdih	2003 (mine)	190 total from mill
			2008 (mill)	
	Banduhurang	Turamdih	2007	
	Mohuldih	Turamdih	2011	
Meghalaya	Kylleng-Pyndeng-Shahiong	Mawthabah	2012, maybe 2010	340
	(Domiasiat)	Mawthabah, Wakhyn		
Andhra Pradesh, Nalgonda dist.	Lambapur-Peddagattu	Seripally /Mallapuram	2012	130
Andhra Pradesh, Kadapa dist.	Tummalapalle	Tummalapalle	2010	220

(Source: www.world-nuclear.org/info/inf53.html)

Uranium Imports

By December 2008, Russia's Rosatom and Areva from France had contracted to supply uranium for power generation, while Kazakhstan, Brazil and South Africa were preparing to do so. The Russian agreement was to provide fuel for PHWRs as well as the two small Tarapur reactors; the Areva agreement was to supply 300 tU. In February 2009, the actual Russian contract was signed with TVEL to supply 2000 tonnes of natural uranium fuel pellets for PHWRs over ten years, costing US$780 million, and 60 tonnes of low-enriched fuel pellets for the Tarapur reactors. The Areva shipment arrived in June 2009. RAPS-2 became the first PHWR to be fuelled with imported uranium, followed by units 5 & 6 there.

In January 2009, the NPCIL signed a MOU with Kazatomprom for the supply of uranium to India, and a feasibility study on building Indian PHWR reactors in Kazakhstan. The NPCIL said that it represented, "a mutual commitment to begin thorough discussions on long-term strategic relationship."

In September 2009, India signed uranium supply and nuclear cooperation agreements with Namibia and Mongolia.

Country-wise Uranium and Thorium reserves are indicated in Table given below.

Table 7: Countries Wise Uranium Reserves

Country	Uranium Reserves (Tons)	% age of World
Australia	1,143,000	24%
Kazakhstan	816,000	17%
Canada	444,000	9%
USA	342,000	7%
South Africa	341,000	7%
Namibia	282,000	6%
Brazil	279,000	6%
Niger	225,000	5%
Russian Fed.	172,000	4%
Uzbekistan	116,000	2%
Ukraine	90,000	2%
Jordan	79,000	2%
India	67,000	1%
China	60,000	1%
Others	287,000	6%
Total	4,743,000	100%

Table 8: Country Wise Thorium Reserves

Country	Thorium Reserves (Tons)	% age of World
Australia	1,143,000	31%
India	816,000	22%
Norway	444,000	12%
USA	342,000	9%
Canada	341,000	9%
South Africa	282,000	8%
Others	279,000	8%
TOTAL	3,647,000	100%

It can be seen from the above tables that India has very limited uranium, but abundant thorium reserves. Recognising the resource position, the DAE had drawn up plans even at the start of the atomic energy programme to exploit thorium through the fast breeder route, commencing with the first stage PHWRs, which uses natural uranium.

Uranium Fuel Cycle

The DAE's Nuclear Fuel Complex at Hyderabad undertakes refining and conversion of uranium, which is received as magnesium diuranate (yellowcake) and refined. The main 400 tonne/year (t/yr) plant fabricates PHWR fuel (which is un-enriched). A small (25 t/yr) fabrication plant makes fuel for the Tarapur BWRs from imported enriched (2.66 per cent U-235) uranium. Depleted uranium oxide fuel pellets (from reprocessed uranium) and thorium oxide pellets are also made for PHWR fuel bundles. Mixed carbide fuel for Fast Breeder Test Reactor (FBTR) was first fabricated by the BARC in 1979.

Heavy water is supplied by the DAE's Heavy Water Board, and the seven plants are working at capacity due to the current building program.

A very small enrichment plant - insufficient even for the Tarapur reactors - is operated by the DAE's Rare Materials Plant at Ratnahalli near Mysore. Some centrifuge R&D is undertaken by BARC.

Fuel fabrication is by the Nuclear Fuel Complex in Hyderabad, which is setting up a new 500 t/yr PHWR fuel plant at Rawatbhata in Rajasthan, to serve the larger new reactors. Each 700 MW reactor is said to need 125 t/yr of fuel. The company is proposing joint ventures with the US, French and Russian companies to produce fuel for those reactors.

Reprocessing: Used fuel from the civil PHWRs is reprocessed by the BARC at Trombay, Tarapur and Kalpakkam to extract reactor-grade plutonium for use in the FBRs. Small plants at each site were supplemented by a new Kalpakkam plant of some 100 t/yr commissioned in 1998, and this is being extended to reprocess FBTR carbide fuel. Apart from this, all reprocessing uses the Purex process. Further capacity is being built at Tarapur and Kalpakkam to come on line by about 2010. India will reprocess the used fuel from the Kudankulam reactors and keep the plutonium.

In 2003, a facility was commissioned at Kalpakkam to reprocess mixed carbide fuel using an advanced Purex process. Future FBRs will also have these facilities co-located.

The PFBR and the next four FBRs to be commissioned by 2020 will use oxide fuel. After that, it is expected that metal fuel with higher breeding capability will be introduced, and burn-up is intended to increase from 100 to 200 GWd/t.

To close the FBR fuel cycle, a fast reactor fuel cycle facility is planned, with construction to begin in 2008 and operation to coincide with the need to reprocess the first PFBR fuel.

Under plans for the India-specific safeguards to be administered by the IAEA in relation to the civil-military separation plan, several fuel fabrication facilities will come under safeguards.

Thorium fuel cycle development in India

The long-term goal of India's nuclear program has been to develop an advanced heavy-water cycle.

Stage 1 employs the PHWRs fuelled by natural uranium and LWRs to produce plutonium.

Stage 2 uses fast neutron reactors burning the plutonium to breed U-233 from thorium. The blanket around the core will have uranium as well as thorium so that further plutonium (ideally high-fissile Pu) is produced as well as the U-233.

In **Stage 3**, AHWRs burn the U-233 from Stage 2 and along with plutonium and thorium, getting about two thirds of their power from the thorium.

In 2002, the regulatory authority issued approval to start construction of a 500 MW prototype FBR at Kalpakkam and this is now under construction by BHAVINI. The unit is expected to be operating in 2011, fuelled with uranium-plutonium oxide (the reactor-grade Pu being from its existing PHWRs). It will have a blanket with thorium and uranium to breed fissile U-233 and plutonium respectively. This will take India's ambitious thorium program to Stage 2, and set the scene for eventual full utilisation of the country's abundant thorium to fuel reactors. Six more such 500 MW fast reactors have been announced for construction, four of them by 2020.

So far, about one tonne of thorium oxide fuel has been irradiated experimentally in PHWR reactors and some of this has been reprocessed, according to BARC. A reprocessing centre for thorium fuels is being set up at Kalpakkam.

Design is largely complete for the first 300 MW AHWR, intended to be built in the 11th plan period to 2012, though no site has yet been announced. It will have vertical pressure tubes in which the light water coolant under high pressure will boil, circulation being by convection. A large heat sink - "gravity-driven water pool" - with 7000 cubic metres of water is near the top of the reactor building. In April 2008, an AHWR critical facility was commissioned at BARC, "to conduct a wide range of experiments; to help validate the reactor physics of the AHWR through computer codes; and in generating nuclear data about materials such as thorium-uranium 233 based fuel, which have not been extensively used in the past." It has all the components of the AHWR's core including fuel and moderator, and can be operated in different modes with various kinds of fuel in different configurations.

In 2009, the AEC announced some features of the 300 MW AHWR. It is mainly a thorium-fuelled reactor with several advanced passive safety features to enable meeting the next generation safety requirements such as three days grace period for operator response; elimination of the need for exclusion zone beyond the plant boundary; 100-year design life; and high level of fault tolerance. The advanced safety characteristics have been verified in a series of experiments carried out in full-scale test facilities. Also, per unit of energy produced, the amount of long-lived minor actinides generated is nearly half of that produced in current generation LWRs. Importantly, a high level of radioactivity in the fissile and fertile materials recovered from the used fuel of AHWR, and their isotopic composition, preclude the use of these materials for nuclear weapons.

At the same time, **the AEC announced a Low Enriched Uranium (LEU) version of the AHWR.** This will use low-enriched uranium plus thorium as a fuel, dispensing with the plutonium input. About 39 per cent of the power will come from thorium (via in situ conversion to U-233), and burn-up will be 64 GWd/t. Uranium enrichment level will be 19.75 per cent, giving 4.21 per cent average fissile content of the U-Th fuel. While designed for closed fuel cycle, this is not required. Plutonium production will be less than in LWRs, and the fissile proportion will be less, and the Pu-238 portion three times as high, giving inherent proliferation resistance. The design is intended for overseas sales, and the **AEC says that, "the reactor is manageable with modest industrial infrastructure within the reach of developing countries."**

Other Important Aspects of Nuclear Power Generation

1. Radioactive Waste Management in India

Radioactive wastes from the nuclear reactors and reprocessing plants are treated and stored at each site. Waste immobilisation plants are in operation at Tarapur and Trombay; and another is being constructed at Kalpakkam. **Research on final disposal of high-level and long-lived wastes in a geological repository is in progress at BARC.**

2. Regulation and Safety

The AEC was established in 1948 under the Atomic Energy Act as a policy body. In 1954, the DAE was set up to encompass research, technology development and commercial reactor operation. The current Atomic Energy Act is 1962, and permits only government-owned enterprises to be involved in nuclear power.

The DAE includes the NPCIL, UCIL (mining and processing), ECIL (reactor control and instrumentation) and BHAVIN (for setting up fast reactors). The government also controls the Heavy Water Board for production of heavy water and the Nuclear Fuel Complex for fuel and component manufacture.

Non-Proliferation, US-India Agreement and Nuclear Suppliers' Group

India's nuclear industry has been largely without the IAEA safeguards, though four nuclear power plants have been under the facility-specific arrangements related to India's INFCIRC/66 safeguards agreement with the IAEA. In **October 2009, India's safeguards agreement with the IAEA became operational**, with the government confirming that 14 reactors will be put under the India Specific Safeguards Agreement by 2014.

India's situation as a nuclear-armed country excluded it from the Nuclear Non-Proliferation Treaty (NPT) and the related lack of full-scope IAEA safeguards meant that India was isolated from world trade by the Nuclear Suppliers' Group. A **clean waiver to the trade embargo was agreed in September 2008 in recognition of the country's impeccable non-proliferation credentials.** India has always been scrupulous in ensuring that its weapons material and technology are guarded against commercial or illicit export to other countries.

Following the 2005 agreement between the US and Indian heads of state on nuclear energy cooperation, the United Kingdom (UK), indicated its strong support for greater cooperation, and France and Canada moved in the same direction respectively. The US Department of Commerce, the UK and Canada relaxed controls on export of technology to India, while staying within the Nuclear Suppliers Group (NSG) guidelines. The French government said it would seek a nuclear cooperation agreement, and Canada agreed to, "pursue further opportunities for the development of the peaceful uses of atomic energy", with India.

In **December 2006, the US Congress passed legislation to enable nuclear trade with India**. Then in July 2007, a nuclear cooperation agreement with India was finalised, opening the way for India's participation in international commerce in nuclear fuel and equipment, and requiring India to put most of the country's nuclear power reactors under the IAEA safeguards and close down the CIRUS research reactor in 2010. This would allow India to reprocess the US-origin and other foreign-sourced nuclear fuel at a new national plant under the IAEA safeguards. This would be used for fuel arising from those 14 reactors designated as unambiguously civilian and under the full IAEA safeguards.

The IAEA greeted the deal as being "a creative break with the past" - where India was excluded from the NPT. After much delay in India's parliament, it then set up a new and comprehensive safeguards agreement with the IAEA, plus an Additional Protocol. The IAEA Board approved this in July 2008 after the agreement had threatened to bring down the Indian government. The agreement is similar to those between the IAEA and non-nuclear weapons states, notably Infcirc-66, the IAEA's information circular that lays out procedures for applying facility-specific safeguards, hence much more restrictive than many in India's parliament wanted.

The next step in bringing India into the fold was **the consensus resolution of the 45-member NSG in September 2008 to exempt India from its rule of prohibiting trade with non-members of the NPT.** A bilateral trade agreement then went to the US Congress for final approval. Similar agreements will apply with Russia and France. The ultimate objective is to put India on the same footing as China, in respect to responsibilities and trade opportunities, though it has had to accept much tighter international controls than other nuclear-armed countries.

The **introduction to India's safeguards agreement says that India's access to assured supplies of fresh fuel is an "essential basis"** for New Delhi's acceptance of the IAEA safeguards on some of its reactors, and that India has a right to take, "corrective measures to ensure uninterrupted operation of its civilian nuclear reactors in the event of disruption of foreign fuel supplies." But, the introduction also says that India will, "provide assurance against withdrawal of safeguarded nuclear material from civilian use at any time." In the course of the NSG deliberations, India also gave assurances regarding weapons testing.

In October 2008, the US Congress passed the bill allowing civil nuclear trade with India and a nuclear trade agreement was signed with France. The 2008 agreements ended 34 years of trade isolation in relation to nuclear materials and technology.

India's safeguards agreement was signed in early 2009, though the timeframe for bringing the eight extra reactors (beyond Tarapur, Rajasthan and Kudankulam) under the safeguards are yet to be finalised. The Additional Protocol to the safeguards agreement was agreed by the IAEA Board in March 2009, but it needs to be ratified by India.

The Nuclear Liability Bill

The Bill deals with the liabilities in case of a possible nuclear mishap. The Bill is necessary to activate the Indo-US Civilian Nuclear Agreement as **the US nuclear reactor manufacturing companies will require the Liability Bill to get insurance in their home state.** After this Bill becomes an Act, India will become a member of the international convention on liability in the civil nuclear arena.

Under the Bill, the foreign reactor builder - however culpable it is for a nuclear accident - will be completely immune from any victim-initiated civil suit or criminal proceedings in an Indian court or in a court at its home country. The Bill actually turns the legal liability of a foreign reactor supplier for an accident into mere financial compensation that too, pegged at a pittance and routed through the Indian state operator of the plant. **Foreign suppliers will have no direct accident-related liability.**

Debate over the Bill

The Bill is certainly debatable as it has certain clauses which indirectly let free the manufacturers and builders of nuclear reactors from any financial and legal liability. The Bill seeks to help out the US firms on these counts, going at times, even beyond what the American law provides.

Clause 6

According to the clause 6 of the Nuclear Liability Bill, the maximum financial liability in case a nuclear accident occurs at nuclear reactors has been set at the rupee equivalent of 300 million Special Drawing Rights (SDRs), which is equal to US$458 million (Rs 2,087 crore). The amount is considered meagre in comparison to the destruction caused by a nuclear accident. A same kind of law in the US has set the financial liability for such a accident at US$10.5 billion.

Clause 7

The clause 7 defines the share of financial liability for each of the culpable groups. It states that the operator will have to pay Rs 500 crore, and the remaining amount will be paid by the Indian government. This is considered a very minor point as the operator will be the NPCIL, which in itself is a government-owned facility.

The operator can claim the liabilities from the manufacturer and supplier if it is mentioned in the contract. But, the maximum amount payable by foreign companies will be a very little sum of Rs 500 crore. **Ultimately, it is the Indian taxpayer who will have to pay even when an accident has occurred due to mistakes committed by others.**

Clause 17

This clause deals with the legal binding of the culpable groups in case of a nuclear accident. **It does allow only the operator (NPCIL) to sue the manufacturers and suppliers. The victims will not be able to sue anyone.** Practically, no one is considered legally liable because the recourse taken by the operator will yield only Rs 500 crore, at maximum.

Clause 18

Clause 18 of the **Nuclear Liability Bill limits the maximum time to make a claim to 10 years.** This is very less as compared to the long-term damage that may be caused by a nuclear accident.

Clause 35

Clause 35 extends the legal binding that the responsible groups may have to face. The operator or the responsible persons in case of a nuclear accident will undergo the trial under the Nuclear Damage Claims Commissions and no civil court is given the authority. The country will be divided into zones, with each zone having a Claims Commissioner. In the US counterpart – the Price Anderson Act, the lawsuits and criminal proceedings goes under the US courts.

Bibliography

- http://www.world-nuclear.org/info/inf53.html
- http://www.igcar.ernet.in/nuclear/alagh.htm
- http://www.dae.gov.in/
- http://www.aec.gov.in/
- http://www.aerb.gov.in/
- http://www.barc.ernet.in/
- http://www.dae.gov.in/rules/aeact.htm
- http://www.aerb.gov.in/t/sj/Siting.pdf
- http://beta.thehindu.com/opinion/lead/article243734.ece?homepage=true
- http://www.npec-web.org/files/Ramana-NuclearPower InIndia.pdf
- http://www.cea.nic.in/
- http://www.npcil.co.in/pdf/press_09jan10.pdf
- http://www.npcil.nic.in/pdf/npcil_areva.pdf
- http://www.iaea.org/
- http://www.npcil.nic.in/
- http://www.projectsmonitor.com/TRANSPORT/worlds-largest-forging-facility-in-ppp-mode
- http://www.business-standard.com/india/news/westinghouse-npcil-ink-mounuke-co-operation/63098/on
- http://westinghousenuclear.mediaroom.com/index.php?s=43&item=188
- http://www.business-standard.com/india/news/ge-hitachi-inks-nuclear-dealnpcil-bhel/57138/on
- http://www.iocl.com/MediaCenter/News.aspx?NewsID=7981&News TypeID=8
- http://www.highbeam.com/doc/1G1-183284832.html
- http://www.accessmylibrary.com/coms2/summary_0286-36473528_ITM
- http://www.ucil.gov.in/
- http://www.bhavini.nic.in/
- http://www.business-standard.com/india/news/nalco-npcil-ink-pact-for-nuke-power-generation/377890/
- http://www.nfc.gov.in/default.htm
- http://www.npcil.nic.in/pdf/press_LNT_JV.pdf
- http://www.business-standard.com/india/news/hcc-amec-tie-up-for-services-to-n-power-plants/371829/
- http://www.bharatforge.com/press/PR-Bharat%20ForgeV4.pdf
- http://www.business-standard.com/india/news/lt-westinghouse-seal-deal-to-setn-power-plants/346373/
- http://www.livemint.com/2009/01/22135936/LampT-in-pact-with-Canadian.html
- http://machinist.in/index.php?option=com_content&task=view&id=2041&I temid=2
- http://internationalaffairs.suite101.com/article.cfm/nuclear-liability-bill-2010-india-part--ii

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