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Nuclear Energy in India's Energy Security Matrix: An Appraisal

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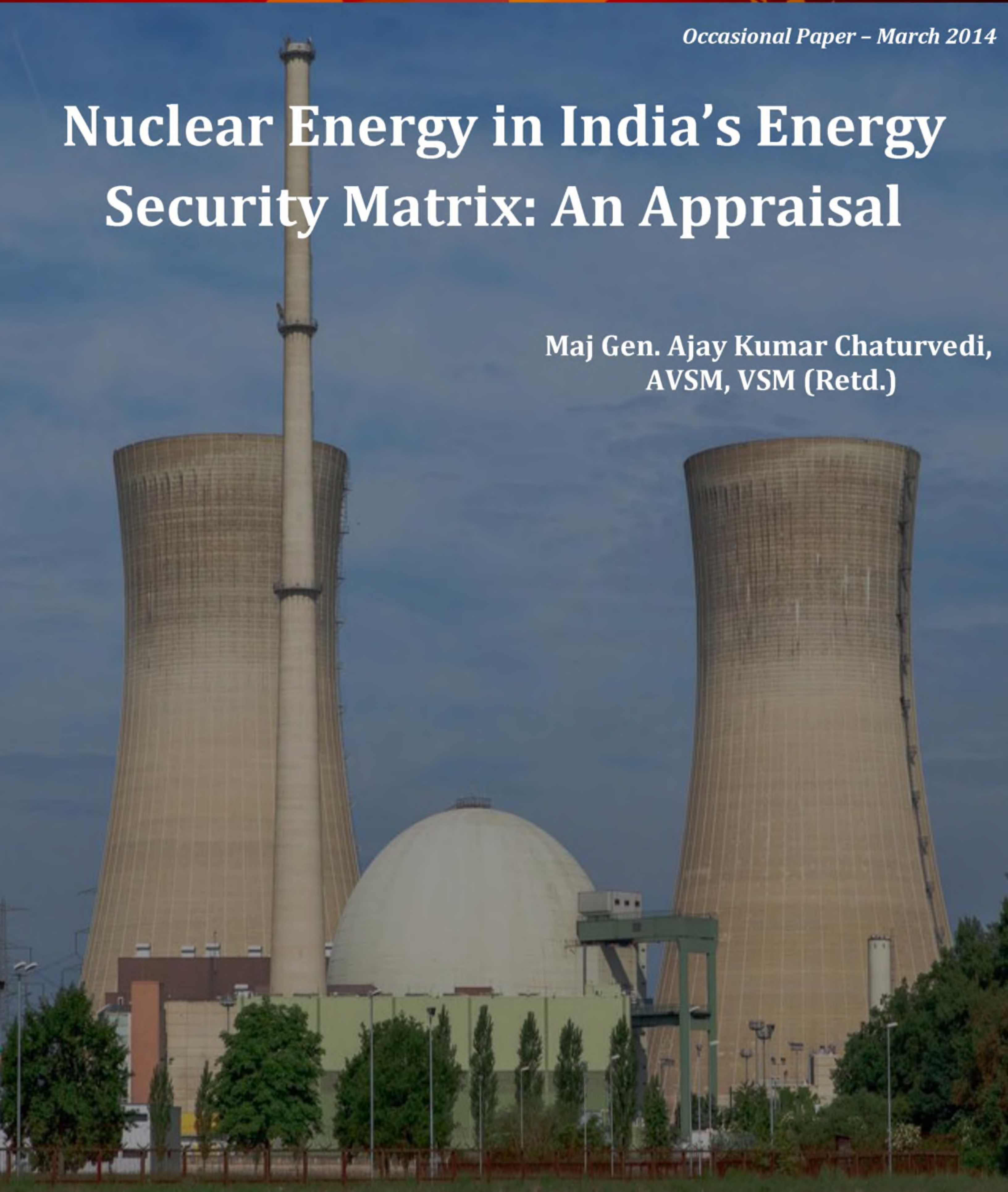
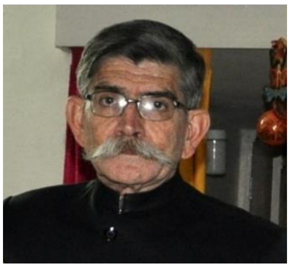


About the Author



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Abstract

Energy is essential for the economic growth of a nation. India, which is in the lower half of the countries as far as the energy consumption per capita is concerned, needs to leap frog from its present position to upper half, commensurate with its growing economic stature, by adopting an approach, where all available sources need to be optimally used in a coordinated manner, to bridge the demand supply gap. A new road map is needed to address the energy security issue in short, medium and long term. Solution should be sustainable, environment friendly and affordable. Nuclear energy, a relatively clean energy, has an advantage that the blueprint for its growth, which was made over half a century earlier, is still valid and though sputtering at times, but is moving steadily as envisaged. However in its journey to become the mainstay of the energy basket of the country, it is barely reaching to stage II. One of the issues with nuclear energy is that the country still does not have fully tested Fast Breeder Reactor (FBR) technology and thus the third stage which is contingent upon stage II becoming commercially viable, puts serious questions about its efficacy. Reaching Stage III of the development of Nuclear Energy Plan is critical because the country will have an advantage for speeding up its energy sufficiency based on the use of Thorium which the country has in plenty. Thus there is a need to examine the efficacy of the nuclear energy in India's energy security matrix, time frame in which it is possible and other enabling and limiting factors.

Abbreviations

AEC- Atomic Energy Commission

AERB- Atomic Energy Regulatory Board

AHWR- Advanced Heavy Water Reactor

AMD- Atomic Minerals Directorate for Exploration and Research

ASME- American Society of Mechanical Engineers

ASSOCHAM- Associated Chamber of Commerce and Industry of India

BHAVINI- Bharatiya Nabhikiya Vidyut Nigam Limited

BARC- Bhabha Atomic Research Centre

BHEL- Bharat Heavy Electrical Limited

BWR- Boiling Water Reactor

CAD- Current Account Deficit

CAT- Centre for Advanced Technology

CAGR- Compound Annual Growth Rate

CANDU- Canada Deuterium Uranium: This refers to the Canadian design of the pressurized heavy water reactor using deuterium as moderator.

CSO- Central Statistical Organization of Ministry of Programme Implementation

CTBT- Comprehensive Test Ban Treaty

DAE- Department of Atomic Energy

EBR- European Breeder Reactor/ Experimental breeder Reactor

EIA- US Energy Information Administration

ECIL- Electronics Corporation of India Limited

EPR- Evolutionary Power Reactor or European Power Reactor

EJ- Exa Joules= 10^{18} Joules

eV- Electron Volt- it is a unit of energy equal to approximately 1.6×10^{-19} joule.

FBR-	Fast Breeder Reactor
FBTR-	Fast Breeder Test Reactor
FICCI-	Federation of Indian Chamber of Commerce and Industry
GW-	Giga Watt
HWB-	Heavy Water Board
IAEA	International Atomic Energy Agency
IGCAR-	Indira Gandhi Centre for Atomic Research
INR-	Indian National Rupee
IREL-	Indian Rare Earth Limited
ITER-	International Thermonuclear Experimental Reactor
JV-	Joint Venture
kgOe-	Kilogram of Oil Equivalent
kWe-	Kilo Watt (electric)
kt-	Kilo Ton
KVA-	Kilo Volt Ampere
LENR-	Low Energy Nuclear Reactions
LEU-	Low Enriched Uranium
LWR-	Light Water Reactor
MeV-	Mega Electron Volt
MOX-	Mixed Oxide
mtoe-	Million Tons of Oil Equivalent
MW-	Mega Watts
MWe-	Mega Watt Electrical
NFC-	Nuclear Fuel Complex
NPP-	Nuclear Power Plant
NPT-	Nuclear Nonproliferation Treaty

NSG- Nuclear Suppliers Group

PFBR- Proto type Fast Breeder Reactor.

PHWR- Pressurized Heavy Water Reactor

PPP- Public Private Partnership

PSU- Public Sector Undertaking

PWR- Pressurized Water Reactor

PNE Peaceful Nuclear Explosion

USGS- US Geological Survey

UCIL- Uranium Corporation of India Limited

VVER- *Vodo-Vodyanoi Energetichesky Reactor (*Water-Water Power Reactor)

WNA- World Nuclear Association

Nuclear Energy in India's Energy Security Matrix: An Appraisal

Appendices

A: Nuclear Establishment in India
B: List of Nuclear Power Plants (NPP): Present/ Under Construction/ Planned

Annexes

I- Organization of Bhabha Atomic Research Centre (BARC)
II- Goals of BARC
III- Locations of NPP

Preview

Aim

"To examine the role of Nuclear energy in India's Energy Security Matrix in 2030 and beyond."

Scope

Following aspects are being covered in the development/ analysis of the subject:-

- Section- I: Introduction.
- Section-II: Growth of nuclear energy in India.
- Section-III: An appraisal of India's nuclear programme.
- Conclusion.

Section-I: Introduction

General

Relevance of Nuclear Energy: Nuclear power is one of the options for providing safe, environmentally clean, reliable and economically competitive energy services. Starting with a single nuclear power plant in 1950, the world has today 440 NPPs (SK Jain, 2004) with a total installed capacity of 372,000 MW (as of April 2012), producing about 13.5% of electricity of the entire world. In addition, 56 countries operate a total of 240 research reactors and further 180 nuclear reactors are powering some 150 ships/ submarines (World Nuclear Association Report, 2012). Today, 22 of last 31 nuclear power plants connected to the world energy grid have been built in Asia. (SK Jain, 2004) Major factors for this kind of growth are; economic growth, scarcity of other resources and increasing population. While it may be a new-found realization in these countries, in India it was envisaged long back and as such efforts to find ways and means to exploit nuclear energy commenced since early fifties.

Nuclear Fission: It can be defined as; either a nuclear reaction or a radioactive decay process in which the nucleus of an atom of a heavy metal splits into smaller parts (lighter nuclei). The fission process often produces free neutrons and protons (in the form of gamma rays). It is an exothermic reaction which can release large amounts of energy both as electromagnetic radiations and also as the kinetic energy of the fragments (heating the bulk material where fission takes place). The amount of free energy contained in a nuclear fuel is millions of times the amount of free energy contained in a similar mass of chemical fuel like gasoline. It should however be remembered that the products of nuclear fission are on an average far more radioactive than the heavy elements which normally are subjected to fission as fuel, and remain so for significant amount of time, giving rise to a nuclear waste problem with the associated need for its safe disposal.

Physics of Nuclear Fission: Natural uranium (U) existing in nature is mined to undergo fission. Natural Uranium has two isotopes of Uranium, namely; U^{235} which is only 0.7% of the quantity mined and U^{238}, which is 99.3%. Of these two isotopes only U^{235} is fissile. U^{238} on absorbing neutrons produces Plutonium (Pu^{239}). In case, instead of Uranium, another naturally occurring metal, Thorium (Th^{232}) is used for fission reaction (case of Fast Breeder reactors), it produces U^{233} on absorption of neutrons. Thus Pu^{239} and U^{233} are not naturally occurring isotopes and are produced in a nuclear reactor. The fission produces following:-

- Fission products, which are radioactive- Pu^{239}./ U^{233}
- Radiation.
- Fast neutrons at the rate of 2.5 neutrons per fission.
- Heat.

Closed versus Open Cycle: Fissile material (Pu^{239}/ U^{233}) is also recovered by reprocessing the spent fuel coming out of a reactor. This process is known as **closed nuclear fuel cycle**. In breeder reactors more fissile material can be produced than what is consumed.

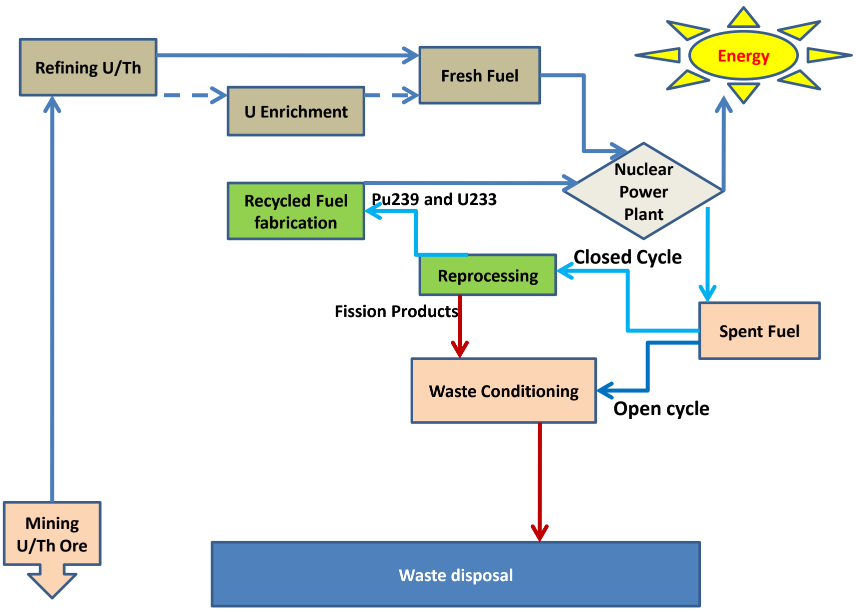


Figure-1.1: Open and Close Nuclear Cycle

Note: To make the nuclear power generation sustainable over a long time, especially if the availability of natural Uranium is limited, as is the case with India, **Closed Cycle** is the most viable option. ***It is a matter of interesting record that***

when the entire world was following the open cycle, India doggedly continued to work to develop a closed cycle and now it is a reality.

Type of Nuclear Reactors: There are two types of nuclear reactor systems namely **Thermal Reactors** and **Fast Reactors**. Their comparison is per Table- 1.1.

Table-1.1: Comparative study of Thermal versus Fast Reactors

Thermal Reactors	**Fast Reactors**
Fission is sustained primarily by thermal neutrons (E≈ 0.025 eV)	Fission is sustained by fast neutrons (E≈1MeV)
Moderator (ordinary water, heavy water, graphite, beryllium) is required to slow down the fission neutron, large core	No moderator, compact core, High core power density- liquid metal or helium gas as coolant.
Very high fission cross-section for thermal neutrons, less fuel inventory	Higher number of neutrons available for capture in fertile material. Breeding possible

Note: This is a broad classification. All known reactors are variants of one of these two types. As would be seen subsequently variants of PHWR are PWR/ LWR/ AHWRs due to fuel cycle, moderator used and technology improvement incorporated to enhance safety and better waste disposal.

Why Nuclear Energy?

International Atomic Energy Agency (IAEA) sponsored a study in 2008 on "The Role of the IAEA to 2020 and beyond". The study had the following view:

> "***Expanded use of nuclear technologies offers immense potential to meet developmental needs. In fact, to satisfy energy demands and to mitigate the threat of climate change- two of the 21st century's greatest challenges- there are major opportunities for expansion of nuclear energy in those countries that choose to have it".***

Only about 150 tons of uranium is needed for a capacity of 1000 MWe per year as against approximately 2.6 million tons of coal for similar capacity. In addition, nuclear energy conversion being clean has its own attended advantages in terms of pollution control and logistic convenience (Ratan K Sinha, 2005). In a study conducted by a research organization - Urban Emission, for Conservation Action Trust - it has been revealed that in 2011-2012, emissions from Indian coal plants (111 in number) have resulted into 80,000 to 115,000 premature deaths, more than 20 million asthma cases, hundreds of thousands of heart attacks, emergency room visits, hospital admissions, and lost workdays. The study estimates that the monetary cost associated with these health effects exceeds Rs.16,000 to 23,000 crores ($ 3.3 to 4.6 billion) per year (Conservation Action Trust). In terms of logistics, to meet the coal requirements of a 1000 MWe plant, five goods train are needed per year for transportation from mines to power plant (Ratan K Sinha, 2005).

Historical Perspective

Nuclear fission was first discovered in 1939, and the world's first chain reaction was achieved by the Manhattan Project on 02 December 1942 at the University of Chicago. On 20 December 1951, electricity was generated from nuclear power for the first time. The source was Experimental Breeder Reactor-I (EBR-I), a fast breeder reactor at the National Reactor Testing Station in Idaho, USA. Initially only about 100 KW (e), was produced.

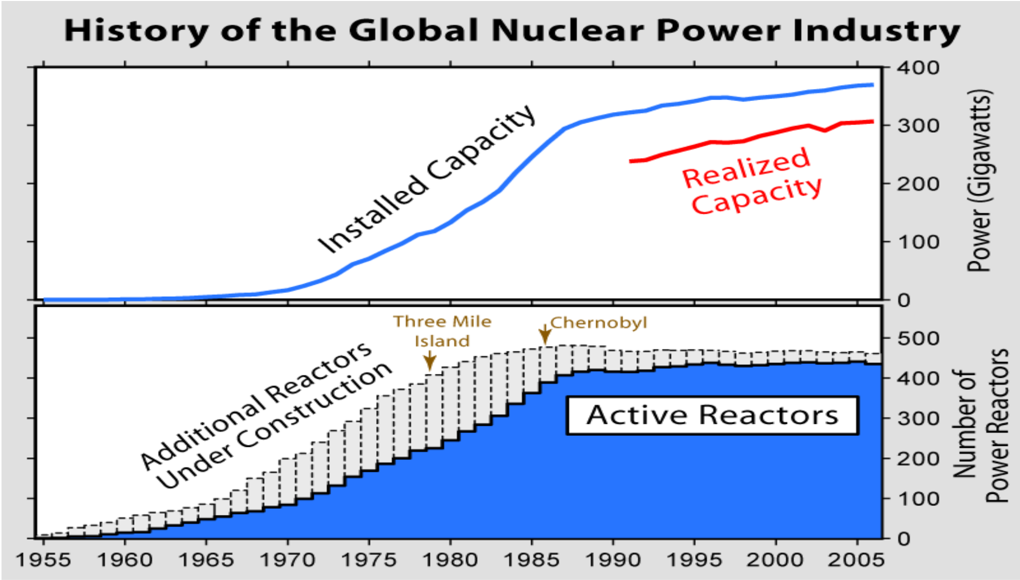


Figure-1.2: History of Nuclear Power

Source: Nuclear Power- Wikipedia uploaded on
http://en.wikipedia.org/wiki/Nuclear_power

Nuclear Power in the World Today

A group of 12 top economies was analyzed and it was found that there is a strong correlation between GDP and the electrical consumption of the country. Most of the countries in this group have nuclear energy generation programme with France being highest; 78 per cent and Italy presently having no nuclear programme (Ratan K Sinha, 2005).

Indian Resources at a Glance

Table-1.2: India: Energy Sources and their Potential

Resource	Amount	Potential (GWe- year)
Coal	38 billion Tons (extractable)	7614
Oil+ Oil Equivalent Gas	12 billion Tons	5833
Natural Uranium	61000 Tons Metal	328 in PHWRs
Thorium	225000 Tons Metal	• 42231 in FBRs • 225000 in Breeder Reactors

Hydro	150 GWe	69/year
Renewable	100 GWe	33/ year

Source: Department of Atomic Energy (DAE), "A Strategy for Growth of Electrical Energy in India", August 2004.

Comment: The indigenous resources (thorium) and resources ex import which has become possible, post Indo US Civilian Nuclear Accord-2008, can together help India to address its energy requirement substantially in next two decades' time.

Nuclear Energy as part of Long Term Energy Solution of India: Challenges

Some of the important challenges that are pertinent to further examination are; efficacy of nuclear energy to address energy needs with attended issues of technological development including waste management, management of funds to introduce it, tackling diplomatic and statutory hurdles to ensure time lines, capacity buildup and public perception management.

Section-II: Growth of Nuclear Energy in India

Evolution of India's Nuclear Programme

India decided to go for nuclear energy for power generation as early as 1948. Accordingly, it established an Atomic Energy Commission (AEC) in 1948 vide Government of India, Notification No F-402/DSR/48 dated 10 August 1948 under the clause 13 of the Atomic Energy Act No XXIX of 1948. The Commission had three members and the AEC was tasked to work under the guidance of the Prime Minister with following mandate:-

- To take such steps as may be necessary from time to time to protect the interests of the country in connection with the atomic energy by exercising the powers conferred on government of India by the provisions of Atomic Energy Act-1948.
- To survey the territories of the Indian Dominion for the location of useful minerals for their utilization for harnessing atomic energy.

- To promote research in their own laboratories and to subsidize such research in existing institutions and universities. Specific steps will be taken to increase teaching and research facilities in nuclear physics in the universities.

In August 1954, the Department of Atomic Energy (DAE) was established under the PMO for undertaking research and development in the field of nuclear energy. In March 1958, AEC was re-constituted by the Government of India to further strengthen it with full executive and financial powers. This resolution made the Chairman of the AEC; an ex officio Secretary to the DAE (Authority: New Resolution (No 13/7/58-Adm. Bombay dated 01 March 1958). The resolution laid down that the Commission will have full time and part time members totaling not below three and not exceeding seven according to the choice of the Chairman (Dhirendra Sharma, 1983). On 15 September 1962, Indian Parliament passed the Atomic Energy Act-1962 which replaced the earlier act. The new act is far more comprehensive and provides for constitution of Atomic Energy Regulatory Board (AERB) under the provision of Section 27 of the act, control of indigenous resources for power generation and through an amendment in 1987 (29 of 1987), the Central Government was empowered to produce electricity from nuclear energy. The Organization of Nuclear Establishment of the country which has grown over the years is as given in the Appendix A attached. In addition, the Bhabha Atomic Research Centre (BARC) which is a premier institution of the DAE and its activities are listed at Annexure I and Annexure II respectively.

By 1963, India had two research reactors and four nuclear power reactors. On May 18, 1974, India performed a 15 Kilo Ton (kt) Peaceful Nuclear Explosion (PNE). The Western powers termed it as a case of nuclear weapons' proliferation by India and cut off all financial and technical help. Though the nuclear programme had a setback, in hindsight it was a boon in disguise, because the Indian programme continued and, in fact, made substantial progress in mastering the entire nuclear cycle. Thus, India's nuclear programme has practically been indigenous. Between 11-13 May 1998, India carried out a second set of tests, testing both; fission and fusion devices. Promptly India was slapped with economic sanctions by USA and the UN Security Council adopted Resolution No 1172 unanimously on 6 June 1998, advising nations to stop trade on nuclear related items with India and Pakistan which had conducted its own tests (five in numbers), later on 28 May 1998.

India's Nuclear Energy programme has been a mission-oriented programme with a guiding principle of self-reliance through the utilization of domestic mineral resources. The events of the last 50 years have validated this approach. In this regard, a speech by Pandit Jawahar Lal Nehru on 26 June 1946 at a public gathering, is relevant,"*….* ***I have no doubt (that) India will develop her scientific researches and I hope Indian scientists will use the atomic force for constructive purposes….."***

Three Stage Nuclear Programme of India

In November 1954, Dr Homi Jehangir Bhabha, the then Chairman of AEC presented a three-stage plan for national development (Ramana MV, 2009) at a conference on "Development of Atomic Energy for Peaceful Purposes". Four years later in 1958, the Indian government formally adopted the three-stage plan (Woddi, Paul et al, 2009).

Stage I – In this stage, natural uranium (U) fuelled PHWR produce electricity while generating plutonium-239 (Pu^{239}) as a by-product. Heavy water is used as the moderator and the coolant (Ministry of External Affairs, Government of India, 2012). In order to ensure that existing plants get a lifetime supply of uranium, it becomes necessary to limit the number of PHWRs fueled exclusively by indigenous uranium reserves. This limit was set at 10 GW (Sethi, Manpreet, 2012).

Stage II – In this stage, fast breeder reactors (FBRs) would use a mixed oxide (MOX) fuel made from Pu^{239}, recovered by reprocessing spent fuel from the first stage, and U. In an FBR, Pu^{239} undergoes fission to produce energy, while the Uranium-238 (U^{238}) present in the mixed oxide fuel transmutes to additional Pu^{239}. Thus, the Stage II FBRs are designed to "breed" more fuel than they consume. Theoretically, the natural uranium in the first stage PHWR is likely to yield around 29 Exa Joules (EJ) of energy. However, the same uranium once having gone through multiple fuel cycles in fast breeder reactors can be made to yield between 65 and 128 times more energy (Bucher, RG, 2009). The surplus Pu bred in each of the FBRs would then be used to set up many more such reactors. Once the inventory of Pu^{239} gets built up, thorium (Th) would be introduced as a blanket material in the reactor and transmuted to uranium-233 (U^{233}) for use in the third stage (Jain, SK, 2012). This point (graduation from second to third stage) is expected to be reached when estimated power production is likely to reach approximately around 50 Giga Watt (GW) of nuclear power (Subramanyam TS, 2007).

Stage III – Stage III reactor or an Advanced nuclear power system involves a self-sustaining series of Th^{232}-U^{233} fuelled reactors. This would be a thermal breeder reactor, which in principle can be refueled – after its initial fuel charge – using only naturally occurring thorium. According to replies given in the Indian Parliament on two separate occasions, it was informed by the Government of India that large scale thorium deployment is likely at least "Three–four decades after the stabilization of the short doubling time based on the commercial operation of the fast breeder reactors**"** (Loksabha Q&A, 2010 and 2012). Therefore, full exploitation of India's domestic thorium reserves is not likely to occur until after the year 2050 (Stephenson, John; Tynan, 2007).

Fuel Reserves

Indian energy resource base was estimated to be capable of yielding a total electric power output of the order shown in the Table-1.2 (Tongia, Rahul and Arunachalam,1997). The Indian government recognized that thorium was a source that could provide power to the Indian people in long term (Woddi, Paul et al, 2009).

According to a report issued by the IAEA, India has limited uranium reserves, consisting of approximately 54,636 tons of "reasonably assured resources", 25,245 tons of "estimated additional resources", 15,488 tons of "undiscovered conventional resources, and 17,000 tons of "speculative resources". According to Nuclear Power Corporation of India Limited (NPCIL), these reserves are only sufficient to generate about 10 GWe for about 40 years (Iyengar PK et al, 2007). In July 2011, it was reported that at Tummalapalle mine in Kadapa district of Andhra Pradesh has a confirmed reserve figure of 49,000 tons with a possibility that it could rise to

150,000 tons (Bedi Rahul, 2011). These are promised to be one of the top 20 of the world's reserves though it could be of lower grade (Ibid).

Figure-2.1: Uranium Mines in India

Source: Nuclear Power Plants, published by World Nuclear Association, up dated up to 10 April 2013 uploaded on http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/India/#.Ud1o4fmmjdA

Note: Exploration is carried out by the Atomic Minerals Directorate for Exploration and Research (AMD). Mining and processing of uranium is carried out by Uranium Corporation of India Ltd (UCIL), in Jharkhand. Common mills are near Jaduguda (2500 t/day) and Turamdih (3000 t/day, expanding to 4500 t/day). Jaduguda ore is reported to be of grade 0.05-0.06% Uranium. All mines are underground except Banduhurang.

India has much bigger thorium reserves ; around 12–33% of the global reserves, (McHugh, Liam, 2012). As per official estimates shared in the country's Parliament in August 2011, the country can obtain 846,477 tons of thorium from 963,000 tons of Thorium Oxide, from Monazite sand of Kerala. This is a corroborated figure from IAEA. Mineable reserves are ~70% of identified exploitable resources. Therefore, about 225,000 tons of thorium metal is available for nuclear power programme (DAE, Government of India, 2013). India is generally considered as the leader of thorium based research in the world (Rehman Maseeh, 2011). According to Siegfried Hecker, a former director (1986–1997) of the Los Alamos National Laboratory in the U.S., "***India has the most technically ambitious and innovative nuclear energy program in the world. The extent and functionality of its nuclear experimental facilities are matched only by those in Russia and are far ahead of what is left in the US***" (Kademani, BS, 2006).

Indigenous Resources: An Analysis: Uranium used for the weapons programme, post Indo US Civil Nuclear Agreement, has been separated from the power programme. The domestic reserve of 80,000 to 112,000 tons of uranium is large enough to supply all of India's commercial and military reactors. Currently, India's nuclear power reactors consume, at most, 478 tons of uranium per year (Ashley J Tellis, 2006). Even if India were to enhance its nuclear power output by four times (and reactor base) to 20 GW by 2020, nuclear power generation would only consume 2000 tons of uranium per annum. Based on India's known commercially viable reserves of 80,000 to 112,000 tons of uranium, this represents a 40–50 years uranium supply for India's nuclear power reactors. This analysis highlights the need for a review of 10 GW ceiling on PHWR output. It may further be noted that with reprocessing and breeder reactor technology likely to become a reality in near future, this supply could be stretched out many times over. Furthermore, the uranium requirements of India's nuclear arsenal are only a small fraction of the indigenous production. Thus, India's indigenous uranium resources are more than enough to meet all strategic and power needs of the country in the foreseeable future (Ibid).

Present Status of Nuclear Power Generation in India

Growth of Nuclear Technology in India: Based on a contract for technical knowhow signed in 1956 with Canada, India's first research reactor, CIRUS went critical in 1960 and first nuclear power plant; 200 MWe Rajasthan Atomic Power Station (RAPS-1) began operation in 1972 (Canada Deuterium Uranium(CANDU) design). It had only 45 percent indigenous content. (David Martin,1986), (Fuhrmann, Mathew, 2012). The agreement for second nuclear power plant at Rajasthan, RAPS-

2, was signed in 1966. After PNE of 1974, USA and Canada terminated their assistance; RAPS-2 could be completed only later in 1981, with indigenous efforts.

Nuclear Power as a Source of Electricity: It is the fifth-largest source of electricity in India after coal, crude oil, natural gas and hydro electricity (12th Plan Document). As of 2012, India has 20 nuclear reactors in operation in six NPPs, generating 4,780 MW (2.9% of total installed base) (NPCIL, www.npcil.nic.in during January 2011). Another seven reactors are under construction with a total capacity of an additional 5,300 MW (Verma, Nidhi, 2008). The details of operational/ under construction/ planned nuclear reactors are as given in the Appendix B attached. The locations of NPPs are as shown vide Annexure III.

Future Plans. India is trying to increase the contribution of nuclear power to overall electricity generation capacity. By 2020, India's installed nuclear power generation capacity is planned to reach 20,000 MW (Business Standard, retrieved 26 August 2010) or in a worst case scenario (World Nuclear Association 2013) to 14,600 MW. Indigenous atomic reactors include 2X540 MW at Tarapur (NPCIL website August 20110). First FBR (PFBR) is expected to become operational by 2015 (original PDC: 2012-13 (The Hindu dated 16 June 2009)). In October 2010, India disclosed an ambitious plan to reach a nuclear power capacity of 63,000 MW by 2032 (The Economic Times, 11 October 2010).

Changing Reactor Profile: Almost the entire existing base of Indian nuclear power (4780 MW) is composed of first stage PHWRs, with the exception of the two Boiling Water Reactor (BWR) units at Tarapur (Banerjee Sri Kumar, 2010), (PTI Report) and now one *Vodo-Vodyanoi Energetichesky Reactor* (VVER), built with Russian collaboration. Capital costs of PHWRs is in the range of Rs. 6 to 7 Crore per MW (Jain, SK, 2012), coupled with a designed plant life of 40 years. Time required for construction has improved over a period of time and is now about five years. Tariffs of the operating plants are in the range of Rs. 1.75 to 2.80 per unit, depending on the life of the reactor (Deewan, Parag; Sarkar, A, 2009). The tariffs of new plants to be set up, both indigenous and imported, are expected to be about Rs. 2.50 in the year 2015 (at 2007 prices) (Jain, SK, 2012). India made a Fast Breeder Test Reactor (FBTR) with 40 MW of thermal and 13.2 MWe electrical power capacity, using mixed carbide fuel core (fabricated at BARC) as the driver for the first time anywhere in the world. The plant went critical in October 1985 (Atomic Energy I India). Although maximum power which this reactor has been able to generate is only 17.4 MWe, it has given a tremendous boost to the indigenous manufacturing capability of the critical components of a reactor. Over a period of time the foreign input has got reduced to a mere 20 per cent of the total cost which is mainly towards the knowhow and the cost of the raw materials (Dr. Baldev Raj, 2004). This capacity build up has given India tremendous confidence. As a logical follow-up of FBTR, it was decided to build a 500 MWe prototype fast breeder reactor (PFBR) which was designed by the Indira Gandhi Centre for Atomic Research (IGCAR) using a mixture of Uranium Oxide and Plutonium Oxide (MOX) as fuel. Project was sanctioned at a cost of Rs 3492 crores and work commenced in 2004 by Bharatiya Nabhikiya Vidyut Nigam Ltd (BHAVINI) at Kalpakkam. Original PDC was 2010 which has now been revised to produce power commercially by 2015. Physical progress as on date is 95.2 per cent. Cost of power from this plant, when completed, will be Rs 3.25 per unit. India has further plans to undertake the construction of four more FBRs as part of the 12^{th} Five Year Plan spanning 2012–17, thus targeting a total of 2500 MW from the five reactors (Jain, SK, 2012). Government has allocated Rs.250 crore for pre-project activities for two more 500 MW units, although the locations of these reactors are yet to be finalized (Zee News, 21 January 2012). In the interim with the support from Russia, India has gone for Light Water Reactors (LWRs) and is planning to go for Pressurized Water Reactor (PWR) with France. These reactors use natural uranium as fuel and natural water as moderator.

Capacity Utilization: The capacity factor of Indian reactors has improved from 71% in 2010-11 to 79% in 2011-12. Nine out of twenty Indian reactors recorded an unprecedented 97% during last year. With the imported uranium from France, the 2 X 220 MW PHWR reactors at Kakrapar have recorded a capacity utilization factor of 99%, during 2011-12. The overall availability factor for the year 2011-12 was at 89%.

Oxide versus Carbide Fuel versus Metallic Fuel: While considering fuel for subsequent reactors, it is found that the rate of breeding of plutonium using MOX is slow compared to metallic alloy of uranium, plutonium and zirconium. Therefore, one of the five planned FBRs is planned to be operated with metallic fuel instead of oxide fuel, as the design of the reactor has the flexibility to accept metallic fuel also (Bucher, RG, 2009). However, exclusive design of reactor is likely to firm up by 2020 (DAE report). Future FBRs using carbide fuel instead of oxide fuel will enhance power generation capacity to 15,500 MW instead of 11,500 MW by 2030, because of accretion in breeding capacity. (Anshu Bharadwaj et al, 2008).

Table-2.1: Breeder versus Thorium Based Technologies to Compress Time

Type	**U^{238}-Pu^{239} Cycle (Time in years)**	**Th-U^{233} Cycle (Time in years)**
Oxide	17.8	108
Carbide-Lee	10	50
Metal	8.5	75.1
Carbide	10.2	70

Analysis: It would take anywhere between a minimum of 10 and a maximum of 70 years for graduation from Stage-II to Stage-III. That gives the core issue for research to cut down this time. Some of the hedging issues will be; design of the reactor, response of the NSG, identification of location and finally funding. India will have to be ready for the contingency when such a scenario does not materialize due to geopolitical development/ excessive public protest by anti nuclear lobby. Discussion with conceptual level planners, including Dr R Chidambaram, Shri Shyam Saran and Shri BK Chaturvedi, brought out that ***they all look forward to Stage III getting materialized as planned but they were planning to find alternative solutions during short to medium term without materialization of Stage III.***

Parallel Approaches: In view of anticipated delay in materialization of Stage-III, the BARC has started working on reactor designs that allow more direct use of thorium (Jain, SK, page-4, 2004). The option so far accepted is Advanced Heavy Water Reactor (AHWR) (Bucher, RG, page-14-20, 2009).

AHWR: The design for AHWR-300-LEU is ready for deployment. AHWR is a 300 MWe vertical pressure tube type, boiling light water cooled and heavy water moderated reactor, using U^{233}–thorium MOX and Pu^{239}–thorium MOX (Krivit, Lehr & Kingery 2011). Low enriched Uranium (LEU) is to be used in AHWR (One India News 2011). It is readily available in international market (Nuclear Energy Institute 2012). It is expected to generate 65% of its power from thorium and can also be configured to accept other types of fuels like enriched uranium or MOX (Banerjee 2010, pp- 16). **However, it does not breed and therefore does not contribute to preparation for Stage-III** (Tongia & Arunachalam 1997). Therefore, dilemma will be whether to introduce AHWR or go for LWR/PWR ex import during the interim period. It is felt that while efforts should continue to get balance of the LWRs from Russia and PWRs from France (as per the current agreements with the respective countries), work on AHWR should not stop. It needs to be noted that presently preparatory work is in progress on AHWR and the completion of construction is not likely before 2022 (Rahman, 2011).

Safety Status of Indian Nuclear Plants

India has one of the best safety records in the world. IAEA in their review during 2013 had the following to say (Dr R Chidambaram, 18 April 2013):-

- Indian nuclear power reactors are safe against extreme natural events like earthquake, tsunami, floods etc and have margins and features in design to withstand them.
- The assessment of seismic margins indicates the plant (RAPS-3 and 4) can withstand several times the design peak ground acceleration values. It may be noted that RAPS reactors are considered as some of the safest in the world (Pallav Bagla, 2012).

Progress on the Other Technologies

The country has also recently re-initiated its involvement in international endeavours like the Low Energy Nuclear Reaction (LENR) aka cold Fusion research activities (B Sivakumar, 2011), and the International Thermonuclear Experimental Reactor (ITER) initiative (ITER-India uploaded on internet). The basic aim is to remain current with the cotemporary research and not get caught as part of group of "Have Nots" in future.

Indian Industry in Nuclear Power Generation Programme

Present Status: As per Atomic Energy Act 1962, construction of a NPP can be undertaken only by a government company wherein government share is not less than 51 per cent (Atomic Energy Act 1962, Section 22 (1) (b) amended vide Atomic Energy (Amendment) Act-1987, Secton-2 (bb)). Accordingly two PSUs, namely; NPCIL and BHAVINI were formed. The XII Plan proposals envisage construction to commence for 8X700 MW PHWRs, 2X500 MW FBRs, 1X300 MW AHWR and 8XLWRs of 1000 MW or higher capacity with foreign Collaboration. These nuclear power reactors are expected to be completed progressively in the XIII and XIV Plans with a cost of around $40 billion (Nuclear Power in India updated up to 10 April 2013) Therefore, it is essential that Indian industry be involved in support of the nuclear programme for the timely completion of all the projects.

Existing system of Private Participation: Due to forced isolation post PNE of 1974, Indian industry has been able to develop capabilities to manufacture certain equipment and take up construction. L&T and BHEL are to name two most important contributors. L&T has been producing heavy components for PHWRs and FBRs, heavy water plants, fuel re-processing plants and plasma reactors. L&T has graduated to offer onsite integration, installation of structure related to main reactor, Life extension services and now even certain fabrication for ITER project. They have now American Society of Mechanical Engineers (ASME) accreditation since 2007 for nuclear projects. In fact they are one of about ten major nuclear-qualified heavy engineering enterprises worldwide. BHEL as part of their energy & capacity addition programme have been manufacturing 81% of major equipment required for nuclear projects on primary side and on secondary side up to 540 MWe size. Their expertise is in TG Sets and steam generation sets (PK Agarwal, 2009). A number of infrastructure companies including Anil Ambani Group firm Reliance Energy, Tata Power, GMR, GVK, ALSTOM and aluminum manufacturer NALCO are keen to enter nuclear power business (A PTI Report, Published in Hindu dated 16 Apr 2010). In this regard, Government of India has clarified that no change is envisaged to existing policy of construction of the NPPs by the two PSUs of the DAE. However, private companies can provide equity as junior partners and also the policy of private players as well as other PSUs to undertake component/ equipment supply and work services to continue as hither to fore (In reply to questions in Parliament by Shri Pradeep Majhi on 24 February 2010 and Shri S Semmalai on 13 March 2013).

Need for Enhanced Private Participation: Notwithstanding the clarification and the precedence the world over (nuclear power sector is dominated by the government companies (Ed Crooks, Financial Times, 12 September 2010)) to raise the contribution of the nuclear energy in the energy basket of India from its present contribution of 4780 MWe to 20000 MWe by 2020, the participation of the private sector is inescapable. The Government can think of innovative ideas in this regard like PPP model/ extensive JVs with other PSUs. Even industrial organizations like Associated Chamber of Commerce and Industry of India (ASSCHAM) and Federation of Indian Chamber of Commerce and Industry (FICCI) are also of the same view. The efforts of two PSUs of DAE namely NPCIL and BHAVINI will have to be boosted by involvement of the private sector and the other PSUs. Such an approach will add a lot of strength to India and reduce her vulnerability while negotiating with foreign vendors and NSG members who, despite Indo US Nuclear deal and subsequent developments, are still not showing expected keenness for coming into Indian nuclear power sector.

JVs with other PSUs: In the meantime since the Atomic Energy Act-1962 allows NPCIL to form JVs with PSUs, "**Anushakti Vidhyut Nigam**", a JV between NPCIL and NTPC has already been incorporated for developing atomic power projects in the country. The preliminary work of first project of this company is in progress in Hisar district of Haryana (The Hindu Business Line, 22 Aug 2012). IOC is willing to invest

Rs. 8,000-10,000 crore over 6-7 years in NPCIL/ BHAVINI (A PTI Report, Published in The Hindu dated 16 Apr 2010). The Indian Railways has also approached NPCIL for setting up a 700 MW captive power plant. Discussions are in progress.

Economics of Nuclear Power

Trends in Indian Power Sector: Power requirement by 2030 is likely to reach 950,000 MW based on an assumption of 8-9% of GDP growth (The Economic Times 06 July 2006). On the supply side to meet the forecasted electrical consumption based on same projected growth rate of GDP, the Planning Commission projects a need of 306-337,000 MW of power by 2016-17 and 778-960,000 MW by 2031-32 (John Stepenson and Peter Tynan, pp-14 2009).

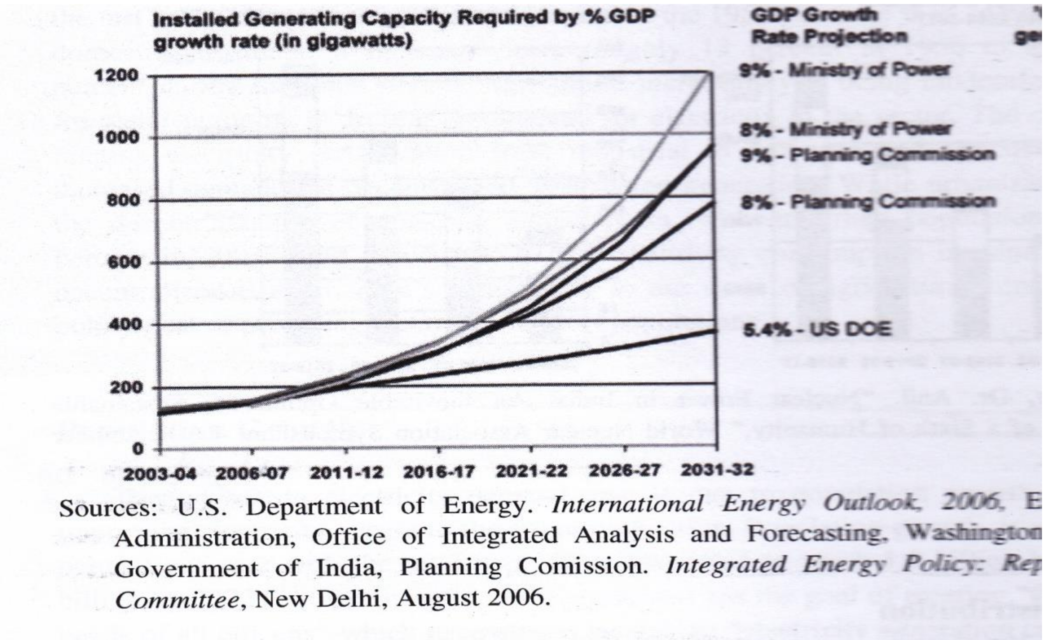


Figure-2.2: Installed Generating Capacity Required for GDP Growth

Table-2.2: Production of Power

Year	Power in MW
2010	187872@#
2020	241,000*

Source:

Energy Statistics-2012, Section-2.3, pp-10 uploaded on www.mospi.gov.in

@ Total installed capacity as on 31 March 2011- 206,526 MW (Energy Statistics-2012

* RNCOS Report, "Power Consumption to double up by 2020" dated 29 June 2010

Comment: As is evident from the above figures read in conjunction with Table 2.2, there is a gap between demand and supply of the power, which is yawning. India will require investments worth US $ 1250 billion up to 2030 in energy infrastructure, with 76% of the investment going to power generation, transmission and distribution (RNCOS Report dated 29 June 2010).

Cost of Nuclear Power: In principle, nuclear energy has the potential to be of relatively low cost. It ranges from 3.8 to 6.7 US cents per kWh. However, in India the cost is 2-3 times more than these figures. Some of the important reasons are as follows:-

- Limited availability of indigenous Natural Uranium ore and its low grade (having 0.1 per cent Uranium as compared to ore from other sources having in the range of 12-14 per cent) adds to the cost (Planning Commission, Integrated Energy Policy, 2006).
- Capital cost of building NPP with long gestation period (five to six years) with experience of delays adds to the cost.
- Cost of reprocessing each kilogram of spent fuel would be approximately Rs 26,000 with assumptions favourable to reprocessing and Rs 30,000 if assumptions are not favourable (MV Ramana, 2009).
- No law presently addresses insurance liability against accidents and thus it becomes the responsibility of the government and accordingly is added as part of subsidy.

India's nuclear programme would require overall investments of about Rs 35,000-40,000 crores per annum for about twenty years and cumulative sum would be in the range of about $160 billion. Not to forget that to build all the plants planned, a minimum of over a lakh of trained personnel would be needed for the construction, operations and maintenance of the plants and associated facilities, which will add to running cost (Anshu Bharadwaj et al, 2008),

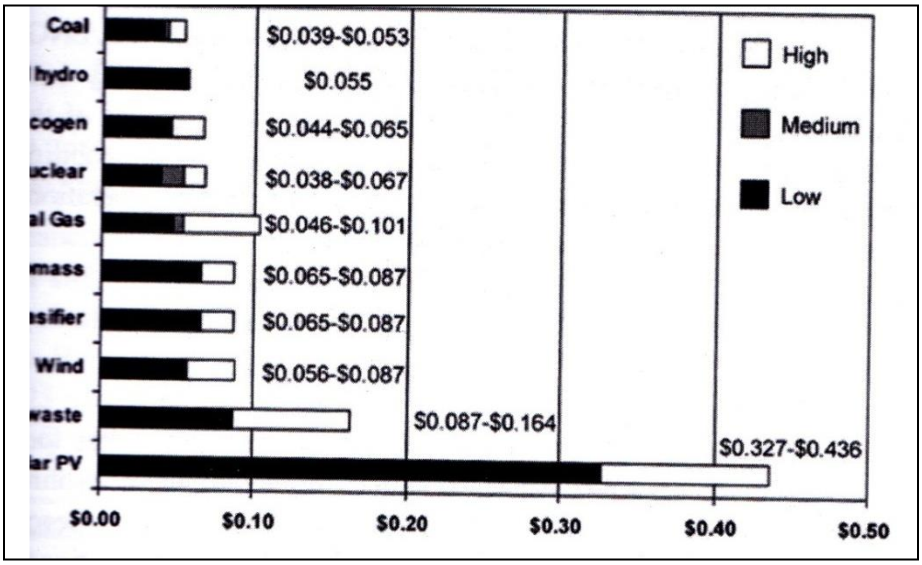


Figure-2.3: Cost Comparisons per kWh (US $)

Sources:

- EIA, February 2006.
- Government of India Planning Commission, Integrated Energy Policy,2006
- Victor, David G., 18 July 2006

Notes: An examination of the recently built PHWR,FBR and LWR shows that the capital cost of the NPP will range from Rs 9-13 Crores (least expensive will be PHWR and the most expensive will be FBR) per MW and with that the cost per unit of the electricity works out to be Rs 3.18 to 4.32.

Vulnerability to Strength through International Cooperation

Limited availability and poor grade of indigenous uranium with Stage-II realization still few years' away and ever growing demand due to growing economy call for boosting the power generation capacity. However, there was a decline of 12.83% from nuclear energy sources during 2006 to 2008 (data from Ministry of Power) besides not a very significant improvement from other sources. This kind of vulnerability has made India increasingly dependent on uranium imports to fuel its nuclear power industry but due to sanctions post 1998 nuclear tests imports were not easy. It was realized, that the only way out of the sticky situation was to go in for international cooperation. Opportunity came when President Bush offered a nuclear deal which was in the national interest of both the countries. For India, it meant to get sanctions on nuclear fuel and technology lifted and for US to get new jobs created besides reducing the carbon signature which use of dirty coal by India would have resulted. The historic Indo US Civil Nuclear Agreement was signed in 2008. New vistas of cooperation opened up, not only with the USA but with other members of the Nuclear Suppliers' Group (NSG) post agreement.

Impact of Indo US Civil Nuclear Pact: An Analysis

This agreement has been able to bring India from the list of nuclear pariah to mainstream as is evident from the agreements which India has signed with countries across the globe and with the passage of time, this phenomenon will gain further momentum and help India to upgrade the technological threshold and also able to procure Uranium which India is so short of. When all related issues are resolved and the agreement becomes fully operative, India is expected to generate an additional 25,000 MW of nuclear power by 2020, bringing total estimated nuclear power generation to 45,000 MW (Bibhudatta Pradhan and Archana Chaudhary, 2008). It may be noted that India has already been using imported enriched uranium for light-water reactors that are currently under IAEA safeguards and address other aspects of the nuclear fuel cycle.

Impact of NSG Waiver on Nuclear Trade: It was a historic moment for India when the 45-member NSG decided to resume civilian nuclear commerce with India without signing NPT or CTBT (Internet upload, "Indian companies likely to benefit from nuclear deal" http://www.stockinvest.in/posts/Indian_companies_likely_to_benefit_from_nuclear_deal). The waiver will not only give India access to fissile material and frontier technologies but will open avenues for investment**.** Some other relevant aspects are as follows:-

- As many as 400 Indian and foreign firms are seen as the beneficiaries of the far-reaching NSG verdict. India will/ can now attract over $40 billion in foreign investment over the next 10-15 years.

- Help domestic power sector infrastructure players to get technologically upgraded in collaboration with foreign vendors. This will help in long run the domestic nuclear power industry.

Following the waiver from the NSG in September 2008 which allowed India to commence international nuclear trade (uploaded on news.outlookindia.com retrieved 22 Aug 2010), India has signed bilateral deals on civilian nuclear energy technology cooperation with several other countries, including France (up loaded on www.rediff.com/news/2008/jan/25france.htm), the USA (Reuters Report published in livemint.com. 09 October 2008), the UK (Avril Ormsby, 2010) , Canada (Montreal Gazette. 29 November 2009) and South Korea (Srinivas Laxman, 2011). India also has uranium supply agreements with Russia (Anil Sasi, 2010). In fact, Russia has been an all weather friend and continued to support India in the field of nuclear fuel since 1988, when the first agreement on civil nuclear cooperation was signed between the two countries. Other agreements are with Mongolia (Financial Express, 15 September 2009), Kazakhstan (Sanjay Dutta, 2009), Argentina (The Hindu, 24 September 2010), and Namibia (*Republikein,* 02 September 2010). Besides government to government deals, an Indian private company (Dharni Sampada) has also won a uranium exploration contract in Niger (Internet upload: www.taurianresources.co.in). Finally with EU India is collaborating in the field of research on nuclear fusion (PTI 29September, 2008). Important agreements and the issues entailed are as follows:-

- India signed a Letter of Intent for purchasing plants with capacity of 10,000 MW from the USA. However the road ahead, post Indo US deal has not been exactly smooth. Liability concerns and a few other issues are preventing further progress on the issue. (Power Engineering Magazine. 27 February 2012) It has been stated that one of the points on the agenda during the visit of Vice President of the USA, Joe Biden from 23 July 2013 is to iron out stuck deals made as a consequence to Indo- US Civil Nuclear Agreement as it is in US interest that this deal is successful for geopolitical reason and also to nip in the bud itself which an economy like India will cause to global warming unless she goes for cleaner energy conversion technologies.

- Besides ongoing agreement of 1988 vintage to supply 2X 1000MW VVER reactors for Kudankulam (George Nirmala,1998), Russia signed an agreement in 2008 to supply four additional VVER-1200 reactors of 1170 MW capacity each (Sasi Anil,2010). Russia has assisted India in designing a nuclear plant for its nuclear submarine (Nuclear Threat initiative (NTI) Report-2009). In 2009, the Russians stated that they will not agree to curbs on export of sensitive technology to India. A new accord signed in Dec 2009 with Russia gives India freedom to proceed with the closed fuel cycle, which includes mining, preparation of the fuel for use in reactors, and also reprocessing of spent fuel (Bagchi Indrani, 2011).

- During the visit of the French President Nicholas Sarkozy to India in December 2010, framework agreements were signed for setting up of two third-generation EPR reactors of 1650 MW each at Jaitapur, Maharashtra by the French company AREVA. The deal caters for the first set of two of six planned reactors and the supply of nuclear fuel for 25 years (Yep, Eric & Jagota 2011). Construction is unlikely to start before 2014 because of regulatory issues and difficulty in sourcing major components from Japan due to India not being a signatory to the NPT (Makrand Gadgil, 2011).

- India signed an agreement with Mongolia on 15 June 2009 for supply of Uranium (Financial Express, 15 September 2009) and with Namibia for the same on 02 September 2009. The agreement also entails India assisting Namibia to set nuclear reactors in Namibia (Republikein online dated 02 September 2009*)*.

- Agreement with Canada when fully implemented will provide access for Canada's nuclear industry to India's expanding nuclear market and also fuel for India's reactors. (BBC Archives 06 November 2012).

- Agreement with Kazakhstan will pave the way for supply of fuel, construction and operation of atomic power plants, exploration and joint mining of uranium, exchange of scientific and research information, reactor safety mechanisms and use of radiation technologies for healthcare. Kazakhstan announced to supply India with 2100 tons of uranium and was ready to supply more, if India asks for it. (The Times of India 17 April 2011). Foreign Investment in India's Nuclear Sector.

- Indian Government is now encouraging foreign investment. It intends to set up 'Nuclear Parks' supplied by foreign companies and operated - for now - by the NPCIL. These 'parks' are planned to have installed generated capacity of 8,000-10,000 MW at a single site as against the maximum installed capacity at one location of 1,400 MW (Tarapur Atomic Power Station in Maharashtra, with four reactors), this will be a quantum leap.

- Russian company ATOMSTROYEXPORT, a government subsidiary, has reached a deal to build sixteen nuclear reactors in India. One of them has already attained criticality at Kudankulam, Tamil Nadu and second is also ready to go critical in the coming months.

- French company AREVA NP has agreed to construct 6X1650 MW reactors in Jaitapur, Maharashtra. The total capacity of the NPP Jaitapur will make it the largest in the world.

- Private US companies GE-Hitachi Nuclear Energy and Westinghouse Electric have been given sites at Kovada in Andhra Pradesh and Mithi Virdi in Gujarat, respectively.

Section-III: Appraisal of India's Nuclear Programme

Growth of nuclear energy programme of India is unique in more than one way. Firstly India was probably one of the first countries to have realized the importance of the nuclear energy and started to acquire capability to exploit it as early as early 1950s. Secondly in conception and so also in implementation it is by and large indigenous (India has been able to master the entire nuclear cycle including reprocessing of used fuel). Its 'Three Stage Plan' is highly imaginative and plans to exploit indigenous resources optimally. India's track record on safety issues is highly commendable. Over the years India has been able to build a good infrastructure for R&D and capacity to plan, design, construct and operate NPP of PHWR origin and has ventured into FBR and AWHR. Finally plant load factor (PLF) of Indian plants is comparable with the reactors of the advanced countries. USA now dominates the top 25 positions, followed by South Korea and Russia followed by Japan, Taiwan and India. The average PLF for the USA is 87 per cent and for India it is over 80 per cent (World Nuclear Association, April 2012). India so far is the only country which has a country specific Nuclear Accord despite not being a signatory to either NPT or CTBT and has a waiver from the NSG to do trade in nuclear related equipment/ technologies/ material.

This is where the good part ends. India is also unique in the sense that most of the projections have historically been slipping. Projections made in 1960s and their results are as tabulated below:-

Table-3.1: Slippages in Targets

Year	Power Projected	Power Produced
1987	20-25,000 MW	950 MW
2000	43,500 MW	2,700 MW

Source: MV Ramana, 2009.

Planning Commission estimates that due to its finite nature and with a mere five per cent annual growth in consumption, the coal is likely to run out in 45 years so far as economically extractable quantity is concerned (Anshu Bharadwaj et al, 2008). Therefore, nuclear and renewable energy assume greater importance for India's energy security in the long term context (beyond 2030 and more realistically beyond 2050).

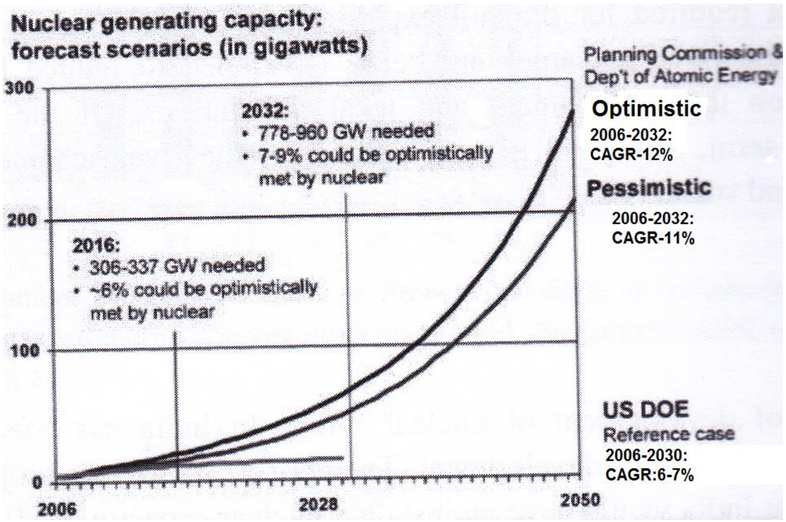


Figure-3.1: Forecast: Nuclear Generating Capacity (in GW)

Source:

- EIA, "Annual Energy Outlook, 2006, DOE/EIA-0383 (2006), Washington DC February 2006.
- Planning Commission of GOI, Integrated Energy Policy: Report of the Expert Committee, New Delhi, August 2006.

Note: Assumptions for the growth trajectory are based on following:-

- **GDP growth**- 8-9 percent.
- **Optimistic Scenario**-
  - FBR Technology gets successfully validated.

- Newly discovered uranium mines like Tummalapalle in Andhra Pradesh are exploited without any hitch so that PHWR planned to be erected are successfully erected without any time delay.
- India succeeds in acquiring LWRs of a total capacity of 8000 MW through import.
- India is able to assimilate the LWR technology through import.
- India successfully operationalizes AHWR by 2020 to exploit vast indigenous thorium resources.

• **Pessimistic Scenario**- All above less acquisition of LWRs ex import

Table 3.2 gives two scenarios which are based on assumptions by the Planning Commission as mentioned above.

Table-3.2: Nuclear Power Generation Projections

Year	Projection of Power Generation (in MW)	
	Optimistic	**Pessimistic**
2010	11,000	9,000
2020	29,000	21,000
2030	63,000	48,000
2040	131000	104,000
2050	275,000	208,000

Source: Anshu Bharadwaj et al, 2008

Analysis: An analysis based on the Figure-3.1 and the Table-3.2 centre stage few issues, which are as follows:-

- Current projections are based on assumptions of certain technological breakthroughs becoming a reality in the time frame envisaged. However, firstly the growth experience so far does not add credibility to these assumptions and also the increasing degree of difficulty in desired advanced technological breakthroughs is going to add to uncertainty. Cases in point, to name a few, are; breeder technology, indigenization of LWR, AHWR becoming operational and mixed carbide fuel becoming a reality.

- If fierceness of the public protest against Kudankulam is any indicator, the road to establishment of new NPPs is unlikely to be smooth.

- The rate of growth of accretion of the nuclear power from 1950 to 1980 was six per cent and from 1980 to 2000 it was eight percent, expecting it now suddenly to surge to 11-12 percent, as planned appears to be highly ambitious, more so because despite Indo-US accord and NSG waiver in place, nothing much is happening on the infusion of technology and other related developments (**It is indeed a reflection on the US policies post Bush Era and other geopolitical developments where India appears to be stranded on the wrong side of the flow. Recent visit of Vice President of USA Joe Biden is an effort to resolve issues related to recent stagnation**). In this regard, growth rate predicted by Department of Energy (DOE) of USA; six-seven per cent appears to be realistic. However, in all this gloom, there is a ray of hope in the form of a 540 MW, PHWR NPP at Tarapur (an indigenous endeavour) becoming critical eight months ahead of schedule. Similarly there appears to be a better understanding on the part of political decision makers and positive public awareness emerging, post Kudankulam attaining criticality. These developments may indicate that growth rate after all may not stagnate at six-seven percent.

- However, even if the highly optimistic targets which have been set, are realized the nuclear power will add to power inventory only about six percent by 2016, seven-nine percent by 2032 and only 20 per cent of the total power generation capacity of the country by 2052, by when hopefully cost effective thorium based power generation technology will get operationalized.

- To achieve the targets set, capabilities need to be built in a quicker time frame for; adding additional trained manpower with higher technical/ managerial threshold, an integrated forecasting/ planning/decision making/ monitoring mechanism preferably IT based so that operations can be real time. Aggressive diplomatic efforts to ensure, technical/ strategic collaborations with foreign players/ friendly countries based on mutual interdependence, organization of funds through policy review and review of Atomic Energy Act 1962. Specific areas which need immediate attention are as follows:-

    - Uranium Mining- hurdles need to be removed for land acquisition, public perception management, safety issues and related logistic problems.

    - Fuel Fabrication- especially development of mixed carbide fuel to replace MOX which presently is being used and has limitation in producing enough fissile material.

    - Reprocessing of spent fuel and waste management.

    - Careful site selection with a view to avoid situations like Haripur in West Bengal and Jaitapur in Maharashtra- a well planned awareness campaign is required to be launched.

    - Funds Management- funds required to achieve the set targets are substantial and from government funding in view of the prevailing geo-economic scenario and CAD of the country, a more imaginative policy will have to be thought off.

    - International cooperation- strategy to exploit geopolitical situation especially with USA, Japan, Russia and France to increase nuclear power generation capacity.

    - Capacity Building- A very large scientific manpower for research and development, technical manpower to build and run the plants/ infrastructure and managerial manpower to manage growth in an integrated manner within the nuclear establishment and with other forms of generation, transmission and end utilization needs.

Conclusion

In this paper, an effort has been made to appraise the growth of the nuclear energy in India and examine whether it has the potential to become an important element in the India's energy security design by 2030 and if not what measures need to be taken to compress the time frame. Besides identifying various problem areas in the utilization cycle of nuclear energy, all relevant actions that India needs to take have been incorporated at appropriate places in the paper. However, even at the cost of a bit of repetition, following issues are reiterated for immediate action:-

- Efforts to enhance mining of Uranium in existing prospected mines especially in newly identified mines of Tummalapalle, make an effort to identify new mines and finally through NSG try to acquire Uranium ex import with a view to exploit the success of PHWR technology where the feed stock is natural uranium.

- Enhance efforts to quickly master FBR technology to make it technologically feasible and commercially viable. Any slippages be considered serious and addressed on priority. This, in conjunction with increasing life and scope of PHWR programme, is essential for reaching thorium exploitation stage at the earliest. In this connection, international cooperation to use LWR/PWR reactors should be progressed, which will call for very nimble footed diplomatic engagements. Indian efforts for international programmes like ITER and LENR should be invested in adequately with an eye on future. Finally a concerted bid be made to build the capacity of human resources for research, execution and managing in academic institutions and the industry.

- Amendment to Atomic Energy Act -1962 should be on the immediate agenda of the new government to exploit the vast resources of the private sector to dovetail them into DAE's efforts. In the mean time, more and more

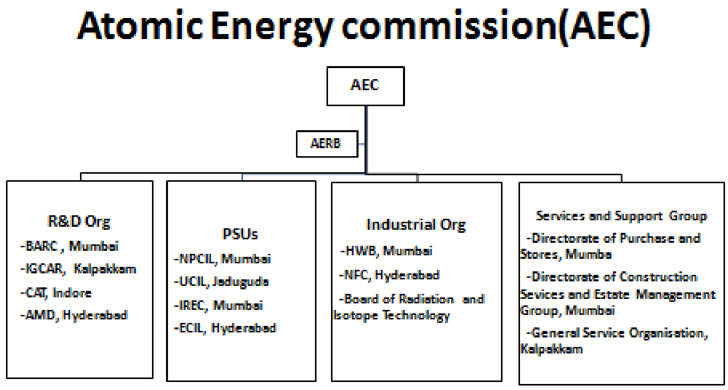
PSUs should be encouraged to support the endeavour of the NPCIL and BHAVINI to work within the existing law.

- The entire nuclear energy programme is in danger of getting derailed due to perception of people. Therefore, a concerted bid needs to be made to make people aware about the need for additional energy, nuclear energy being an option as it is clean and India as having one of the best safety records of NPPs.

Finally, it needs to be understood by all concerned that there is no choice but to continue developing the nuclear energy because while it may not be having the potential to be the panacea for India's all energy related problems in short to medium term, but in the long run (beyond 2032) it has a reasonably good probability to play an important role in the energy security matrix of India.

.Appendix A

Nuclear Establishment in India



Source: A talk by Ratan K Sinha, Distinguished Scientist and Director Reactor Design and Development Group, BARC (Presently Chairman, AEC), 'India's Energy Security-The Role of Nuclear Energy', at the Petroleum Federation of India, New Delhi on 27 May 2005.

Annexure I
To Appendix A

Bhabha Atomic Research Centre (BARC)

- **Groups-** BARC has been divided into a total of 19 groups. Details of these groups are as follows:-
    - Administrative.
    - Automation and Manufacturing.
    - Beam Technology Development.
    - Bio-Science.
    - Chemical Engineering and Technology.
    - Chemistry.
    - Electronics and Instrumentation.
    - Engineering Services.
    - Health Safety and Environment.
    - Knowledge management.
    - Material.
    - Medical.
    - Nuclear Fuel.
    - Nuclear Recycle.
    - Physics.
    - Radio Chemistry and Isotopes.
    - Reactor.
    - Reactor Design and Development.
    - Reactor Projects.
- These groups are further sub divided into 71 divisions.
- **Strength-**
    - Scientists and Engineers- 4130.
    - Staff- 14,900.

Source: A talk by Ratan K Sinha, Distinguished Scientist and Director Reactor Design and Development Group, BARC (Presently Chairman AEC), 'India's Energy Security- The Role of Nuclear Energy', at the Petroleum Federation of India, New Delhi on 27 May 2005.

Annexure II
To Appendix A

Goals of R&D Activities in Bhabha Atomic Research Centre (BARC)

- Indigenous development of Nuclear Technology for following purposes:-
  - For generating energy.
  - For non power applications.
- Research, Development, Demonstration and Deployment- **RD^3.**
- To share results of the research with the industrial undertakings of the DAE which are as follows:-
  - Nuclear Power Corporation of India Limited (NPCIL).
  - Nuclear Fuel Complex (NFC).
  - Heavy Water Board (HWB).
  - Indian Rare Earth Limited (IREL).
  - Uranium Corporation of India Limited (UCIL).
  - Electronics Corporation of India Limited (ECIL).
- Strive for excellence in all areas of nuclear science and technology. Some of the identified areas are as follows:-
  - Utilization of the research reactors.
  - Taking front and backend of the nuclear cycle to the logical conclusion.
  - Production of radio isotopes and development of the radiation technology.

Source: A talk by Ratan K Sinha, Distinguished Scientist and Director Reactor Design and Development Group, BARC (Presently Chairman AEC), 'India's Energy Security- The Role of Nuclear Energy', at the Petroleum Federation of India, New Delhi on 27 May 2005.

Appendix-B

Nuclear Power Reactors in India: Present and Future

Unit	Type	Capacity (MWe)	Since
Operational Reactors-			
Tarapur Power Plant			
TAPS-1 (Tarapur, Maharashtra)	BWR	160	28 October 1969
TAPS-2 (Tarapur, Maharashtra)	BWR	160	28 October 1969
TAPS-3 (Tarapur, Maharashtra)	PHWR	540	18 August 2006
TAPS-4 (Tarapur, Maharashtra)	PHWR	540	15 September 2005
Rajasthan Power Plant (Rawatbhata)			
RAPS-1 (Rawatbhata, Rajasthan)	PHWR	100	16 December 1973
RAPS-2 (Rawatbhata, Rajasthan)	PHWR	200	1 April 1981
RAPS-3 (Rawatbhata, Rajasthan)	PHWR	220	1 June 2000
RAPS-4 (Rawatbhata, Rajasthan)	PHWR	220	23 December 2000

Unit	Type	Capacity (MWe)	Since
RAPS-5 (Rawatbhata, Rajasthan)	PHWR	220	4 February 2010
RAPS-6 (Rawatbhata, Rajasthan)	PHWR	220	31 March 2010
Kalpakkam Power Plant Tamil Nadu-			
MAPS-1 (Kalpakkam, Tamil Nadu)	PHWR	220	27 January 1984
MAPS-2 (Kalpakkam, Tamil Nadu)	PHWR	220	21 March 1986
Narora Power Plant-			
NAPS-1 (Narora, Uttar Pradesh)	PHWR	220	1 January 1991
NAPS-2 (Narora, Uttar Pradesh)	PHWR	220	1 July 1992
Kakrapar Power Plant-			
KAPS-1 (Kakrapar, Gujarat)	PHWR	220	6 May 1993
KAPS-2 (Kakrapar, Gujarat)	PHWR	220	1 September 1995
Kaiga Power Plant-			
KGS-1 (Kaiga, Karnataka)	PHWR	220	6 November 2000

Unit	Type	Capacity (MWe)	Since
KGS-2 (Kaiga, Karnataka)	PHWR	220	6 May 2000
KGS-3 (Kaiga, Karnataka)	PHWR	220	6 May 2007
KGS-4 (Kaiga, Karnataka)	PHWR	220	27 November 2010
Kudankulam Power Plant-			
KNPP-1 (Kudankulam, Tamil Nadu)	VVER −1000	1000	10 August 2012@
Total Capacity		**5780@/ 4780**	
Under Construction-			
Units Under Construction	**Type**	**Capacity (MWe)**	**Expected Date**
KNPP-2 (Kudankulam, Tamil Nadu)	VVER −1000	1000	Mar-2014
KAPS-3 (Kakrapar, Gujarat)	PHWR	700	Jun-2015
KAPS-4 (Kakrapar, Gujarat)	PHWR	700	Dec-2015

Unit	Type	Capacity (MWe)	Since
RAPS-7 (Rawatbhata, Rajasthan)	PHWR	700	Jun-2016
RAPS-8 (Rawatbhata, Rajasthan)	PHWR	700	Dec-2016
PFBR (Kalpakkam, Tamil Nadu)$	PFBR	500	2004#
Total Capacity		**5300**	
Proposed*-			
Unit proposed	**Type**	**Capa-city (MWe)**	**Expected Date**
Jaitapur Nuclear Power Project	European Pressurized Reactor	9900	2017
Kudankulam, Tamil Nadu%	VVER	2X1200	2400
	AWHR	300 MWe&	
Total Capacity		**12300**	

Source: NPCIL website: www.npcil.nic.in

$-BHAVINI website: www.bhavini.nic.in

Note:

@ Attained criticality on 13 July 2013. Power production is likely to commence by end of August 2013. Delay has been on account of public protest against nuclear energy due to perceived safety issues.

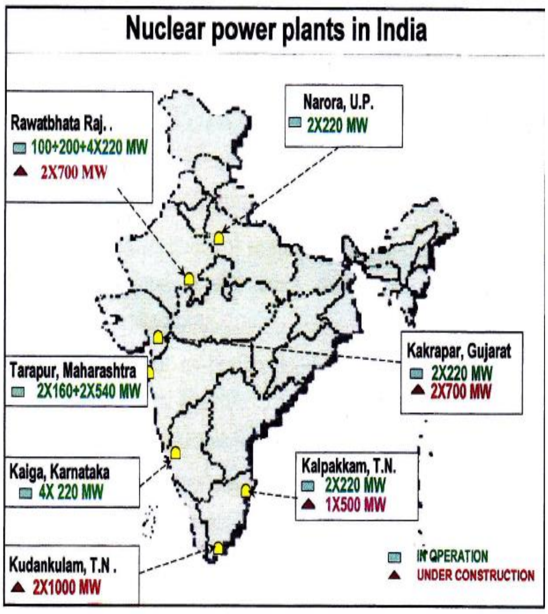
* Additional16X PHWRs of 700 MWe capacity are being taken up progressively for construction at five different inland sites already identified.

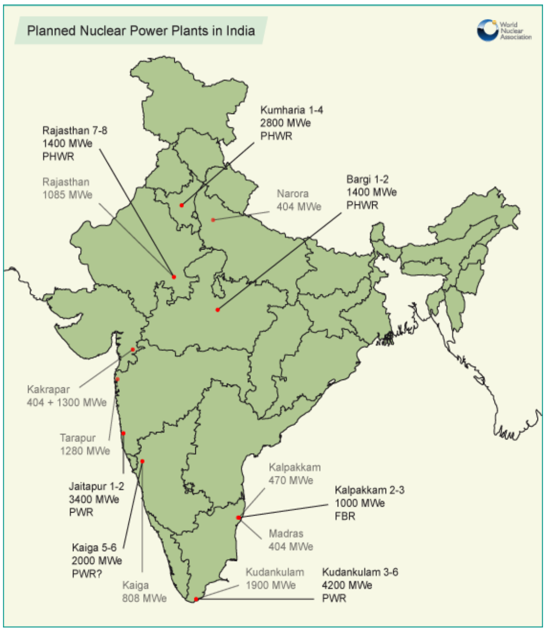
1. Progress as on May 2013- 95%.

Design finalized, site identification is in progress as a follow up of the Indo Russian Accord of 2008.

Annexure-III
To Appendix B

Location of Nuclear Plants in India





Nuclear Power Plants: Present/ Under Construction/ Planned

Source: Nuclear Power Plants, published by World Nuclear Association, up dated up to July 2013 uploaded on http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/India/#.Uenb_12mjdA

Note: Aim of the ongoing nuclear power programme of India is to have a capacity of 14600 MWe online by 2020 and by 2050 the total contribution from the nuclear energy will be 25% of total power generated in India (Ibid).

Image Source: http://commons.wikimedia.org

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