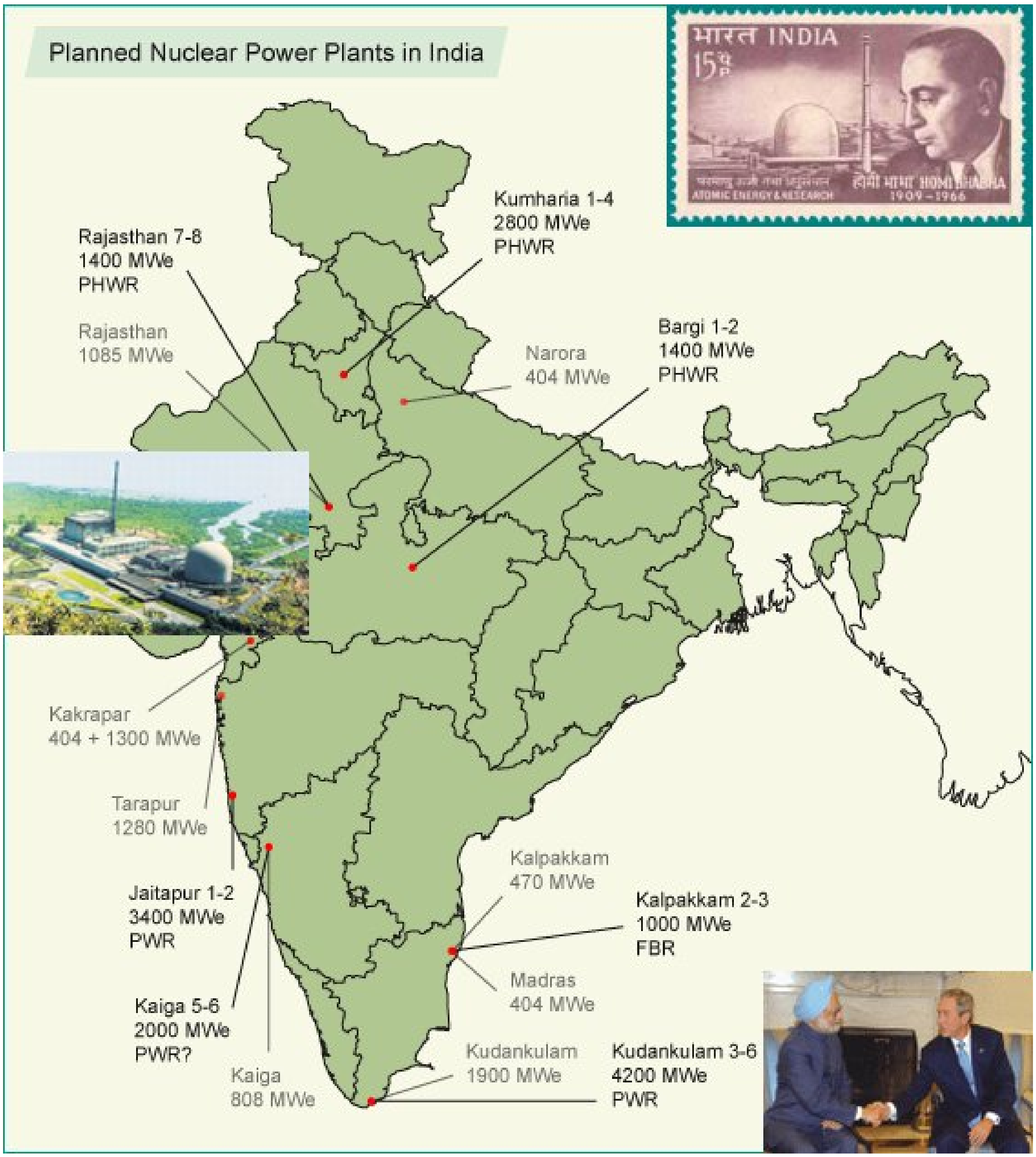
Nuclear Power Scenario in India:

Reality and Options Available



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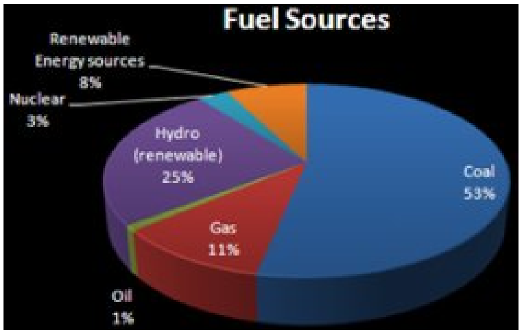
Energy Scenario in India

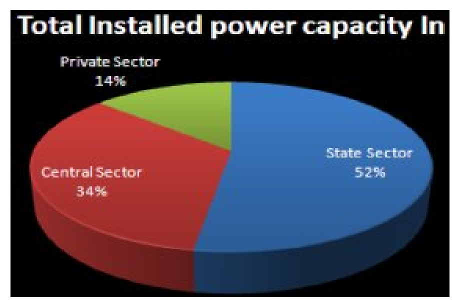


Electricity demand in India has grown an average 4% per annum over last 30 years. Given the current rapid economic expansion, the demand will grow much faster. For the Indian economy to grow at 9% annually, additional capacity of 60 GW must be added every five years. Government's promise of 100% electricity to domestic users will push up consumption.

Besides the increasing demand for power, gross inefficiencies and chaotic functioning of the power sector puts further pressure on power supply. For instance, the transmission and distribution networks are highly inefficient – experts say that there is 30 – 40% power loss. Financial health of the state electricity boards is poor. Capacity utilization is very poor:

- Most hydro and thermal power stations operate at 87% load factor.
- Thermal plants face shortage of coal
- Nuclear power plants operate at 50% loads, due to shortage of uranium
- In 2008, four gas based power projects were idle due to lack of fuel linkage

As of December 2010, the installed power generation capacity of India stood at 169 GW and is trying to add another 78 GW by 2012. The demand for electricity is expected to be about 1,000 GW by 2030. It has invested heavily in renewable energy, particularly in the wind energy – current installed capacity is about 13 GW. It also aims to produce 20 GW from solar power and 30 GW from nuclear energy in next 10-15 years. An investment of US $55 billion is expected by 2015 in the renewable energy sector, generating 35 GW power.



India is rich in coal and renewable energy sources (solar, wind, hydro and bio-energy sources) but it has very less hydrocarbon reserve (0.4% of world's reserve). Given the limited domestic fossil fuel reserves, India depends on fossil fuel imports to meet its energy demands. In 2009-10, the import of crude oil alone accounted for 31% of the country's total imports. So, it has ambitious plans to expand its renewable and nuclear power industries. It envisages increasing the contribution of nuclear power to overall electricity generation capacity from 3% to 9% within 25 years.

Impetus to current nuclear power initiatives has clearly come from the lifting of the 34 year old nuclear technology ban after India and US signed the nuclear cooperation treaty in 2008. Two things are clear from the above charts. One, there is tremendous scope for contribution from the private sector that produces less than 20% of the national requirement. Two, commitment to reduction in greenhouse gases to mitigate climate change demands that use of coal should be reduced for power generation. Nuclear energy along with renewable sources can achieve this goal.

However, India needs to move with caution because the recent Fukushima nuclear disaster has triggered anti-nuclear sentiments across the world and countries are reviewing their nuclear energy programs. Question people want to ask is: If Japan isn't capable of protecting its nuclear power plants from earthquakes/tsunamis, is India smarter?

Nuclear Energy

Nuclear Power Around the World

Nuclear power provides about 6% energy and 14% electricity requirement of the world. About 40% of electricity requirement is met by coal, followed by gas (21%) and hydro (16%). France, Japan and US account for about 50% of the nuclear generated electricity. Currently, there are 443 commercial nuclear reactors operating in 31 countries with about 378 GW total capacity. Over 60 power reactors are under construction in 15 countries, notably China, South Korea, India and Russia. The International Atomic Energy Agency (IAEA) anticipates addition of 73GW in new capacity by 2020 taking the total to 463GW, and then to 546 – 800 GW by 2030.

The world's first nuclear power station became operational in 1956 at Calder Hall in Sellafield, US with an initial capacity of 50 MW (later 200 MW). A year later in 1957, the United States got its first commercial nuclear generator, the Shippingport Reactor, in Pennsylvania. The worldwide capacity rose quickly to 100 GW by late 1970s and then to 300 GW by late 1980s. However, thereafter the growth slowed down – reached only to 366 GW in 2005. It was largely due to rising economic costs, coming from extended construction times and the lower oil prices.

Dominant Producers of Nuclear Power

Table 1: Top ten countries in 2010 with largest contribution from nuclear power

Table 2: Top ten countries by number of nuclear reactors in 2010 and nuclear energy as percentage of total energy:

Table 1

	Country	Percentage
1	France	76.2
2	Lithuania	72.9
3	Slovakia	56.4
4	Belgium	53.8
5	Ukraine	47.4
6	Sweden	42.0
7	Slovenia	41.7
8	Armenia	39.4
9	Switzerland	39.2
10	Hungary	37.2

Table 2

	Country	# Reactors	Percentage
1	US	104	19.7
2	France	58	76.2
3	Japan	54	24.9
4	Russia	31	16.9
5	S. Korea	20	35.6
6	UK	19	17.4
7	Canada	18	14.9
8	**India**	**18**	**2.9**
9	Germany	17	28.3
10	Ukraine	15	47.4

Table 3: The top ten countries planning for new nuclear reactors and MW planned

	Country	# New reactors planned	Number of MW planned
1	China	37	38,360
2	**India**	**23**	**21,500**
3	Japan	13	17,915
4	US	11	13,800
5	Russian Fed.	7	8,000
6	South Korea	6	8,190
7	UK	4	6,600
8	UAE	4	5,600
9	Canada	4	4,400
10	South Africa	3	3,565

It is clear from table 2 that India's share of power from the nuclear energy is considerably low compared with other economies and is now planning to expand it significantly.

Nuclear Power in India

Currently India produces about 4,780 MW power from its 20 operational nuclear power plants, which is only 3 percent of total power generated in the country. Indian stand on nuclear energy is clear: it sees it as an important clean source of energy along with other renewable sources that will reduce dependence on import of crude oil as well as help mitigate global warming.

One megawatt is the energy used by 200 urban homes in India.

India's energy requirement is growing at about 6 percent annually, fueled mostly by a growing population and a robust economy, the third largest in Asia. Besides, still nearly 40 percent of households have no access to electricity. Hence, it wants to expand the nuclear power program to cover its future energy need. It pans to add 20 GW of nuclear power capacity by 2020 and aims to meet 25% of its needs through nuclear power by 2050. This expansion became possible after the nuclear ban on India was lifted in 2008 after 34 years.

Since Pokharan nuclear test in 1974, India was excluded from any nuclear material trade because it had not (and still has not) signed the nuclear non-proliferation treaty (NPT). It changed when American congress ratified the Indo-US nuclear treaty (a waiver from the Nuclear Suppliers Group) in October 2008. The deal, which is a legacy of Manmohan Singh and George Bush, has set India on the path to energy independence. It is now free to import uranium as well as advanced nuclear power technology.

New reactors on the anvil

Reactor Type	Location	Capacity (MWe)
Indigenous PHWRs	Kumharia, Haryana	4x700
Indigenous PHWRs	Bargi, MP	2x700
LWR (Russian VVER)	Koodankulam, TN	4x1,000*
LWR (French EPR)	Jaitapur, Maharashtra	6x1,650
LWR (US, GE-Hitachi or Westinghouse)	Chhayamithi Virdi, Gujarat	6x1,000**
LWR (US, GE-Hitachi or Westinghouse)	Kovvada, AP	6x1,000**
LWR (Russian VVER)	Haripur, WB	6x1,000**

* Additional potential 2x1,000 MWe already under construction
** Final capacity will depend on the actual rating of reactors selected
(PHWR – pressurised heavy water reactors, LWR – light water reactors)

Understanding the Anatomy of Nuclear Power

The Fuel

All atoms are made up of three subatomic particles: Protons (positive electrical charge), Neutrons (neutral charge), and Electrons (negative charge). Protons and neutron are confined in the nucleus of the atom and the electrons revolve around it. In all normal chemical process, only electrons take part in the chemical reactions and the nuclei remain unaffected. In nuclear reactions, however, the nuclei are transformed.

Coal vs Nuclear Power

A 1 GW nuclear power reactor needs only about 30-35 tons of fuel per annum, as against 3.5-5.0 million tons of coal needed for a coal fired thermal power station of the same capacity

Only few elements (Uranium, Plutonium, and Thorium) have atoms suitable for use in a nuclear reactor. In fact, only certain isotopes of certain elements are fissile.

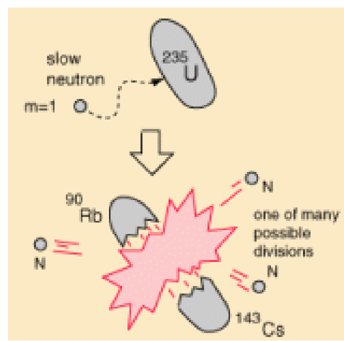
For example, two isotopes of Uranium-235 and Uranium-233 are fissile, while another isotope, U-238, is not. Other examples of fissile elements are Plutonium-239 and Uranium-233. Uranium-235, however, is the most common material of choice for a nuclear reactor.

All Uranium atoms contain 92 Protons; hence, it is located at the 92^{nd} position on the Periodic Table. Different Isotopes of Uranium have different numbers of Neutrons in the nucleus, thus they have a different mass. The two most common Uranium isotopes are Uranium-235 (92 protons + 143 neutrons = 235 AMU) and Uranium-238 (92 protons + 146 neutrons = 238 AMU). AMU is short for atomic mass unit.

Uranium Ore and "Yellow Cake"

Uranium is found in the ground as Uranium oxide which when purified has a rich yellow color and is called "**yellow cake**". The oxide is reduced to uranium that contains 99.3% Uranium-238 and only 0.7% Uranium-235. U-235 is known as fissile Uranium. Fissile Uranium is the type required for Nuclear Fission (the splitting of an atom). In order to make Uranium into useful fuel, it must be enriched in U-235 – increase its percentage from 0.7% to 2.5 – 3.5% before it can be used in light water reactors. While three-percent enrichment is sufficient for nuclear power plants, **weapon grade uranium requires at least 90 percent U-235**.

Fission: Neutrons Rule the Nuclear Reactor!



Neutrons (n) are the starting point for everything that happens in a nuclear reactor. When a U-235 atom captures a slow neutron, it becomes unstable and splits almost instantly releasing energy and further neutrons that sustain the reactor reaction.

U-235 + n ===> Ba-144 + Kr-90 + 2n + energy
U-235 + n ===> Ba-141 + Kr-92 + 3n + energy
U-235 + n ===> Zr-94 + Te-139 + 3n + energy
U-235 + n ===> Rb-90 + Cs-143 + 3n + energy

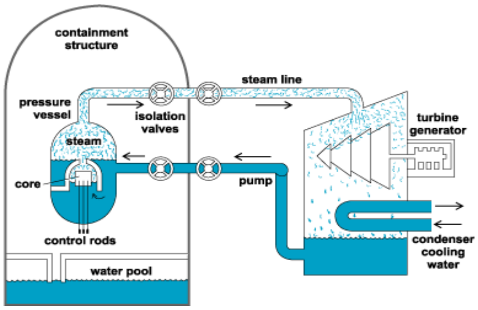
Neutrons produced in these reactions are fast neutrons – moving at 14,000 km/s or 31.3 million miles per hour.. A fast neutron will not be captured, so it must be slowed down by **moderation** to increase their capture probability in fission reactors. *A single fission event can yield over 200 million times the energy of the neutron which triggered it!*

[The opposite of fission is fusion where small atoms such as hydrogen fuse together. This type of nuclear reaction also gives out enormous amount of energy. Large scale exploitation of fusion energy is still a distant dream for the scientists. Sun is a natural fusion reactor constantly producing energy that sustains life on earth.]

Control Rods

Control rods are made of elements, such as boron or cadmium, capable of absorbing neutrons without undergoing fission. They are used in nuclear reactors to control the rate of fission that depends of density of neutrons. They are lowered in the reactor core and their position can be adjusted. They are designed to automatically get fully inserted in the core in case of emergency, so as to cease the fission reaction, and hence the reactor power. Their proper functioning is vital for reactor power control.

Moderation and Cooling



Moderation is the term used in nuclear science for slowing neutrons to a speed conducive to nuclear fission.

A Pressurized Water Reactors (PWR) uses water as both a moderator and a coolant. The coolant function removes the heat energy from the fuel. The moderator function causes the neutrons to collide with water molecules; thus slowing them down so that fission can take place. Without the moderator function, reactor will not function.

Light Water Reactors

While there are numerous reactor designs depending on the purposes, the most common type of nuclear power plants are Light Water Reactors (LWR). They require about 3% enriched uranium as reactor fuel and are available in two configurations: the boiling water type and the pressurized water reactors.

A Boiling Water Reactor (BWR) uses de-mineralized water as a coolant and neutron moderator. Heat produced by nuclear fission in the reactor core causes the cooling water to boil, producing steam. The steam is directly used to drive a turbine, after which it is cooled in a condenser and converted back to liquid water. This water is then returned to the reactor core, completing the loop. The reactor operates at about 285 degree Celsius.

In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the Pressurized Water Reactor (PWR). In a PWR the primary coolant water is pumped under high pressure to the reactor core. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator.

What is so Unique in a Nuclear Reactor?

Nuclear power plants produce electricity in the same way as any other thermal (say, coal) power plant. It also generates heat that boils off water and produces pressurized steam to drive a turbine generator. However, the **key difference** is that **in a nuclear reactor heat is generated by splitting nuclei of uranium**. In thermal power plants, the fuel like coal or oil is burned in the ordinary way to produce heat; here the normal chemical reactions are involved where atomic nucleus are not affected.

Energy is Produced from Nuclear Fission

In nuclear reactors, energy is produced by splitting (fission of) the nuclei of the nuclear fuel. A fissile material like uranium is used as fuel. Slow speed neutrons are used to induce **nuclear fission** of U-235 atoms. The U atom splits into two smaller atoms along with releases of energy and 2 – 3 more neutrons. These neutrons, after slowing down, cause further fission of other U-235 atoms with further release of energy and more neutrons. And thus the chain reaction can go on; this builds up both heat and neutrons inside the reactor core.

*As mentioned earlier, a single fission event can yield over **200 million times** the energy of the neutron which triggered it!* This is the unique feature of nuclear energy. In fact, about half kilogram of highly enriched uranium as used to power a nuclear submarine is equal to about a million gallons of gasoline.

The light (normal) water reactors require 2.5 to 3.0 percent U-235 in the fuel to sustained operation for power generation. The circulating water removes the heat and also slows the fission neutrons.

Some part of the remaining 97% Uranium-238 also converts into Plutonium-239 in the reactor. Pu-239 is also fissile and can be used as reactor fuel as well as in a nuclear bomb.

Difference between Nuclear Reactor and Nuclear Bomb

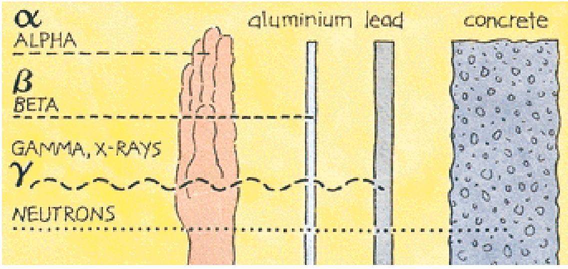
Both, U-235 and Pu-239 can be used as fuel in a nuclear reactor as well as nuclear bomb. However, in a reactor the fission process is controlled by adjusting the coolant pressure and control rods; only desired number of neutrons is allowed to cause fission so that there is no excess build up of heat or neutron. Under such condition the reactor is said to be “critical”. All efforts in the operation of a nuclear reactor are directed to **always** keep the fission process under control.

Since every fission event from one neutron generates 2 – 3 neutrons that can further cause more and more fission events, there is always the danger of reaction going out of control. In a bomb the same process starts, once initiated, and soon explosion takes place.

Nuclear Power Generation is a Dangerous Technology

Proponent of nuclear power talk about it without mentioning the terrible potential hazards it comes attached with. The typical advantages that are often sited are: Nuclear power generation does not emit CO2 so it is environmental friendly, technology is available, large amount of electricity can be generated from small amount of fuel from a single plant.

It is true that since energy comes from the atomic nucleus of uranium, it is enormous compared with other sources. But nuclear materials have their own peculiar problems that ordinary people generally don’t properly understand. Here are the risks typical to nuclear power generation.



1. **Hazards of Radioactivity**: As opposed to CO2 or other greenhouse gases, the nuclear reactions generate radioactive rays, typically alpha, beta and gamma ways. A fourth kind, neutron radiation, generally only occurs inside the reactor. While the first two can be easily blocked, the gamma rays are highly energetic and penetrating – they can even penetrate concrete walls so they need to be confined within thick lead shield. We can not smell or feel radioactive rays but they are devastating for cells of the body; they can cause irreversible changes to DNA as well as cancerous cell growth in unpredictable manner. No vaccine or medicine can counter the effects of radioactivity exposure. The effects can go on for generations, which is very inhuman. That’s why people fear nuclear weapons.
2. **Reactor Safety**: The extraordinary amount of energy released from nuclear transformations is also a great risk to the nuclear power plant. Not only the nuclear material must be contained within the core of the reactor, cooling water also has to be circulated continuously to prevent over-heating that can simply explode or melt down the reactor. Human errors and/or mechanical failures have been the reasons of most nuclear plant malfunctions and accidents. Now after Fukushima disaster, people are also worried about the possible impacts of earthquakes or tsunamis that can potentially cause nuclear accidents.
3. **Headache of Nuclear Waste**: It is not possible to destroy or dispose of the “spent fuel” or waste generated from the nuclear reactors like an ordinary factory waste because it contains elements that can continue to emit radioactivity for thousands of years. So the nuclear waste has to be contained and stored at safe locations away from human exposure for centuries. Besides, the nuclear waste contains plutonium that can also be used to make nuclear weapons. This further adds to the risks associated with it.

4. **Not Sustainable!**: The world supply of reactor fuel, uranium, is only enough for another 30 – 60 years depending upon its actual use. Therefore, nuclear power is not sustainable and is certainly not renewable.
5. **Potential Terrorist Targets:** Recent terrorist attack on a navel base in Pakistan has heightened global worries of their targeting or acquiring nuclear weapons. More nuclear power plants also means more targets for terrorists.

Therefore, the more nuclear power plants (and nuclear waste storage shelters) are built, the higher is the probability of nuclear disasters (man-made or natural).

Environmental Impact of Nuclear Energy

While suspended particulate matter (SPM), CO2, SOx, and NOx, emissions and waste disposal are dominant in the context of generating energy from fossil fuels, nuclear power is associated primarily with risks of radioactive release. Environmental impacts identifiable at various stages of the nuclear fuel cycle are: mining (accidents, release of radon gas and radioactive dust from Uranium mines and mills), radioactive seepage from waste and land degradation, processing (accidents), transport (accidents, risk of proliferation), and electricity generation (risk of catastrophic accidents, low and high level radioactive wastes).

Additionally, decommissioning of nuclear plants entails the disposal of radioactive wastes. While significant technological development has been made in the area of radioactive waste disposal and decommissioning, they are yet to be proven at large enough scale to satisfactorily resolve economic issues. However, despite these risks, global data suggests that of all the conventional energy options, nuclear energy has posed the least risks in terms of mortality per billion megawatt hours of generation.

Major Nuclear Disasters in the World

Comparison of Three Major Nuclear Power Plant Disasters in the World

	Fukushima (Japan)	Chernobyl (Former USSR)	Three Mile Island (USA)
Date of Incident	March 11, 2011	April 26, 1986	March 28, 1979
Rating on the Nuclear Events Scale (1 – 7)	Level 7	Level 7	Level 5
Type of reactor	Light water reactor (Boiling Water reactor)	RBMK-type reactor Graphite-moderated and Water Cooled	Light water reactor (Pressurized water Reactor)
Reactor(s) affected	Units 1–4 (Total of 6 reactors)	Unit 4 (Total of 4 reactors)	Unit 2 (Total of 3 reactors)
Output capacity at the time of accident	1,244 MW	1,000 MW	960 MW
Date of commissioning	1971 – 78	March 1984	December 1978
Cause and nature of accident	Loss of cooling due to damage caused by earthquake and tsunami	Power surge during testing causes fire and explosion. Release of large amount of radioactive material.	Equipment failure and human error causes leakage of reactor coolant. The reactor core undergoes 45% meltdown.

Amount of radiation leakage (Iodine-131 equivalent)	370,000–630,000 terabecquerels	5,200,000 terabecquerels	93,000 terabecquerels
Number of people evacuated	88,700	Approximately 116,000 from a 30 km area	Approximately 200,000 from a 24 km area
Fatalities	0	33	0

The Fukushima Nuclear Disaster

As opposed to the other two accidents mentioned below which are attributed to technical or human errors, the Fukushima disaster was triggered by earthquake and aggravated by the tsunami.

The plant comprises six separate boiling water reactors (BMRs). Experts consider this accident to be the second largest nuclear accident after the Chernobyl disaster, but more complex as multiple reactors were involved. At the time of the quake, Reactor 4 had been de-fueled while 5 and 6 were in cold shutdown for planned maintenance. The remaining reactors shut down automatically after the earthquake, the electricity grid was knocked out and generators started operating the cooling water supply. The plant was protected by a seawall designed to withstand a 5.7 m tsunami but not the 14 m maximum wave which arrived 40–60 minutes after the earthquake.

The entire plant was flooded and the diesel generators got damaged. All power for cooling was lost and reactors started to overheat, due to natural decay of the fission products. Three reactors experienced complete melt down and hydrogen explosions led to release of radioactivity into the environment.

The Chernobyl Disaster

The design of the Chernobyl was totally different from the Three Mile Island reactor in US. It was moderated by graphite and cooled by water. The accident occurred during a design test when safety interlocks were bypassed and the reactor was never actually shut down, thus the fission process continued uncontrollably, and the sudden surge in output shattered the reactor, opening up a gaping hole in the upper part of the building. The combustible graphite moderator then caught fire, sending out vast clouds of radioactive material over a huge area.

Despite several irregularities during tests on the reactor's power supply, including an unexpected drop in reactor output, operators continued the test, repeatedly violating operating procedures. Structural flaws in the reactor also exacerbated the situation.

In 2006, the World Health Organization estimated that as many as 9,000 people may have died as a result of the Chernobyl disaster.

The Three Mile Island Accident

This accident pertains to pressurized water reactor (PWR). A malfunction in the secondary water supply caused the pumps to stop working. Although the Emergency Core Cooling System started as it was designed to do, human error led to a mistaken decision to shut it down. Large amounts of coolant escaped leading to heat build up in the reactor. It resulted in severe core meltdown.

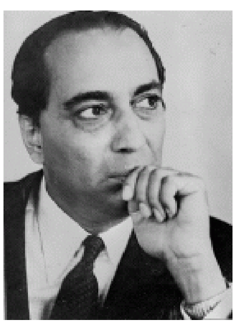
Some of the radioactive material from the fuel rods leaked into the primary coolant system, and was released into the atmosphere. However, since the reactor building and the structures remained intact, most of the radioactivity remained safely contained within the reactor building. The impact on the outside world was minimal.

Impact of the Fukushima Disaster

The recent Fukushima nuclear disaster (see left image) has rekindled the debate whether nuclear power can be considered a safer alternative to the fossil fuel (mainly coal and gas) power. This has also become a hot issue in India where a massive nuclear power projects are being planned. A significant fall out of the Japanese disaster is that The International Atomic Energy Agency (IAEA) has halved the nuclear power capacity addition by 2035. Most countries are now reviewing their nuclear power plans. Germany recently announced that it will **close down all of its 17 nuclear power plants by 2020**, despite the fact that nuclear power provides one-quarter of its electricity. German Chancellor Merkel said it plainly: "It's over. Fukushima has forever changed the way we define risk in Germany. We want to end the use of nuclear energy and reach the age of renewable energy as fast as possible." The European Union has ordered "stress test" on all its 143 reactors. Countries like China and Switzerland have adopted "pause and review" approach towards reactor construction.

Now the Fukushima disaster, which many consider the world's worst, has suddenly increased the number of skeptics worldwide. Just weeks later, the Japanese government called for the closedown of the Hamaoka nuclear plant, due to its vulnerability to earthquakes and tsunamis. This also brought into memory the damage to the Kashiwazaki-Kariwa Nuclear plant in Japan due to earthquake in 2007, when although the material damage was small but it caused a prolonged shut down. Not surprising, people are now seeing nuclear establishments as potential danger spots.

Genesis of Atomic Energy in India



After India attained independence the Atomic Energy Commission was set up in 1948 for framing policies in respect of development of atomic energy in the country. The Department of Atomic Energy (DAE) was established in 1954 with Dr. Bhabha as Secretary to implement the policies framed by the Atomic Energy Commission. Sir J.R.D Tata was one of the longest serving members in the Atomic Energy Commission and played a significant role in shaping the policies related to atomic energy program in the country. The Atomic Energy Establishment was set up at Trombay, near Mumbai in 1957 and was renamed Bhabha Atomic Research Centre (BARC) ten years later.

The atomic energy program, which was initiated in a modest manner initially, has now grown as a wide spectrum, multi dimensional multidisciplinary with 63 organizations under DAE. The spectrum of these significant activities include R&D in Nuclear Sciences and Engineering, Exploration & Mining of Radioisotopes Nuclear energy development and implementation, application of Nuclear Energy, Bio-Agricultural Research, Medical Sciences etc.

India's commercial Nuclear Power program started in 1969 with the commissioning of Tarapur Atomic Power Station (TAPS) in Maharashtra and currently has 20 operating reactors of various types. Country's progress could have been much better if the international ban (due to non-signing of NPT) was not placed in 1974.

Why India did not Sign NPT?

India could only join the NPT if it disarmed and joined as a Non Nuclear Weapons State, which is politically impossible.

As a result of the ban, India's nuclear power program has proceeded largely without fuel or technological assistance from other countries. Reflecting the technical difficulties of the country's isolation, the power reactors to the mid 1990s had some of the world's lowest capacity factors, but rose impressively from 60% in 1995 to 85% in 2001-02. Then in 2008-10 the load factors dropped due to shortage of uranium fuel.

Atomic energy activities in the country are governed by the Atomic Energy Act. The commercial nuclear power program of the first stage (comprising of PHWRs and imported LWRs) is being implemented by Nuclear Power Corporation of India Limited (NPCIL), and the second stage (comprising of Fast Breeder Reactors) by Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI). Both companies are fully owned by the union government.

India’s Three Stage Nuclear Power Program

The usual way to operate a nuclear reactor is to use uranium isotope 235 as fuel – generally about 3% U-235 can used in light water cooled reactors. However, India is poorly endowed with Uranium. Available Uranium supply can fuel only 10,000 MW of the Pressurized Heavy Water Reactors (PHWR). Further, India is extracting Uranium from extremely low grade ores (as low as 0.1% Uranium) compared to ores with up to 12-14% Uranium in certain resources abroad. This makes Indian nuclear fuel 2-3 times costlier than international supplies.

The substantial Thorium reserves can be used but that requires that the fertile Thorium-232 be converted to fissile material, U-233. In this context, a three-stage nuclear power program is envisaged. This program consists of setting up of Pressurized Heavy Water Reactors (PHWRs) in the first stage, Fast Breeder Reactors (FBRs) in the second stage and reactors based on the Uranium 233-Thorium 232 cycle in the third stage.

It is also envisaged that in the first stage of the program, capacity addition will be supplemented by electricity generation through Light Water Reactors (LWRs), initially through imports of technology but with the long-term objective of indigenization. PHWR technology was selected for the first stage as these reactors are efficient users of natural Uranium for yielding the plutonium fuel required for the second stage FBR program. The FBRs will be fuelled by plutonium and will also recycle spent Uranium from the PHWR to breed more plutonium fuel for electricity generation. Thorium as blanket material in FBRs will produce Uranium 233 to fire the third stage.

The first stage comprises of Pressurized Heavy Water Reactors (PHWRs) fuelled by natural uranium that contains only 0.7% of U-235, which undergoes fission to release energy. The remaining 99.3% comprises U-238 is not fissile; but a part of it gets converted in the nuclear reactor, to fissile element Pu-239. The Plutonium is extracted by reprocessing the spent fuel.

The second stage, comprising of Fast Breeder Reactors (FBRs) are fuelled by mixed oxide of U-238 and Pu-239, recovered by reprocessing of the first stage spent fuel. In FBRs, Pu-239 undergoes fission producing energy and U-238 converts into Plutonium239. Hence, the term Breeder; the FBRs produce more fuel than they consume. Over a period of time, Plutonium inventory can be built up by feeding U-238. Once sufficient inventory of P-239 is built up, Th-232 is introduced as a blanket material to be converted to U-233. Th-232 is not fissile but U-233 is.

The third stage essentially utilizes the fissile U-233 produced in the second stage, along with Th-232. India’s indigenous efforts rest on efficient functioning of this stage. Ideas are still being explored to come up with technology for large scale power generation from this stage. One such idea is Advanced Heavy water Reactor (AHWR), which will bypass the second stage. It uses light water as coolant and heavy water as moderator. It is fuelled by a mixture of P-239 and Th-232, with a sizeable amount of power coming from Th-232. This technology, however, is still in the pilot plant scale.

The pace of development of nuclear power is constrained by the rate at which plutonium can be bred and Thorium converted to fissile material. If India is able to import nuclear fuel, the process can be accelerated.

Impact of US-Indo Nuclear Treaty

> "India has to go for nuclear power generation in a big way using thorium-based reactors. Thorium, a non-fissile material, is available in abundance in our country."
>
> ***– A P J Abdul Kalam, 2007***

Now that uranium as well as latest technologies can be imported with the lifting of the nuclear ban, India is at a crossroad in terms of its nuclear energy policy – it can either continue pursuing its thorium based three stage indigenous program with added zeal to remove all snags and technological limitations. The other is to use imported uranium to build more current-generation reactors, and in the process, become vulnerable to foreign suppliers of uranium.

Considering long term independence in nuclear power, the best choice will be to import conventional uranium reactors for short term nuclear power generation and simultaneously accelerate development of the third stage large reactors exploiting advanced technologies from across the world.

India-US Nuclear Deal

The deal ended the 34 year old international ban on nuclear fuel and technology import. Thus, it ended India's global isolation on nuclear and high tech trade with rest of the world.

The framework for the agreement was agreed in 2005. It required India to separate its civil and military nuclear facilities and place all its civil nuclear facilities under the safeguard of International Atomic Energy Agency (IAEA). In exchange, the US agreed to work towards full civil nuclear cooperation with India. It took another three years to come into force when the IAEA approved the safeguards agreement with India. The US approached the 45 member Nuclear Suppliers Group (NSG) to grant waiver to India and allow it access to civilian nuclear technology and fuel and finally in Feb 2009 India signed a India-specific safeguards agreement with the IAEA. Soon the inspection of 35 civilian nuclear installations, which had been identified as "civil" in the separation plan, began in a phased manner. This made India the only country with nuclear weapons which is not a party to Non Proliferation Treaty (NPT) but allowed to nuclear commerce with the rest of the world.

The NSG was formed after India's first nuclear test in 1974 and was meant to isolate India on nuclear commerce. It forced India to develop its own technology based on the resources available in the country. Being rich in thorium (25% of world's thorium)and rather low in uranium (only 1% world share), Indian nuclear activities were guided by the three stage nuclear power program so as to use thorium as the main input rather than uranium, which is the conventional choice.

What made the Nuclear Deal Possible?

The Western powers, particularly the US, realized that India had already achieved independence as far as its nuclear weapon program was concerned. The limited supply of uranium in India is more than sufficient for military purposes (the five quick explosions in 1998 also proved the point) and the NSG's export restrictions mainly affected the civil power generation capacity. Therefore, looking at the growing size of Indian economy and its large domestic market, the deal opened up a way to exploit the huge Indian demand for nuclear reactors (of course, with uranium supplies). Politically, it provided the US a viable counterweight to the growing influence of China.

India, on its part had also realized that it needs Western cooperation and technology if it has to meet its long term energy needs by way of nuclear power. Besides, the deal also opened the possibilities of high-tech manufacturing industries in India, particularly the aerospace industry. So, in principle it was a win-win situation.

What is the Pact?

- The legislation amends Section 123 of the US Atomic Energy Act of 1954. It lets the US make a one-time exception for India to keep its nuclear weapons without signing the Nuclear Non-Proliferation Treaty (NPT).
- The amendment overturns a 30-year-old US ban on supplying India with nuclear fuel and technology, implemented after India's first nuclear test in 1974.
- Under the amendment, India must separate its civilian and military nuclear facilities, and submit civilian facilities to inspections by the International Atomic Energy Agency (IAEA).

Why is it Controversial?

- Critics say it undermines the NPT, which holds that only countries which renounce nuclear weapons qualify for civilian nuclear assistance.
- The accord sends the wrong message: it could undercut a US-led campaign to curtail Iran's nuclear program, and open the way for a potential arms race in South Asia.
- India says 14 of its 22 nuclear facilities are civilian. Critics say the pact could make bomb making at the other eight easier, as civilian nuclear fuel needs will be met by the US

What do the Deal's Supporters Say?

- US President George Bush called the deal necessary to reflect the countries' improved relations. It strengthens international security by tightening US ties to ally India, the world's biggest democracy. It also ensures at least a part of its nuclear program will undergo international inspection.
- New Delhi, which relies on imported oil for some 70 per cent of its energy needs, says nuclear power will help feed its rapidly expanding economy.
- France, which signed a similar deal with India in February 2006, says the move will help fight climate change and aid non-proliferation efforts.

International Rivalries

- China is said to have supported Pakistan's nuclear weapons program since the 1980s. Some analysts see the Indo-US deal as part of attempts by the US and Western powers to counter Chinese influence by promoting India.
- The IAEA said in 2004 that Libya and Iran's nuclear programs were based on Chinese technology provided by Pakistan.

India Lacks Independent Nuclear Regulatory Body

The Department of Atomic Energy (DAE) falls directly under the Prime Minister. The Atomic Energy Regulatory Board (AERB) was constituted on November 15, 1983 under the Atomic Energy Act, 1962. Currently, the AERB reports to the Atomic Energy Commission, a high-level policy-making body, chaired by the Secretary of the Department of Atomic Energy, who reports directly to the Prime Minister. Therefore, the AERB is a part of DAE and does not have an independent status desired for a truly regulatory body.

Union Minister of State for Environment and Forests Jairam Ramesh has agreed that for more than half a century there was no transparency in the nuclear energy program in the country. The government now intends to introduce a bill in the parliament to create an independent and autonomous Nuclear Regulatory Authority of India that will subsume the AERB. The government also plans to invite the

Operational Safety Review Team (OSART) of the International Atomic Energy Authority (IAEA) to assist its own safety reviews and audit.

All these actions seem to have been prompted by the public outcry after the Fukushima disaster. Rather than reviewing its nuclear power policy, government wants to stress on improving the safety of nuclear establishments as a way to assuage public concerns on nuclear safety.

History of Nuclear Accidents and Protests in India

Nuclear Accidents

Nuclear establishment in India is know for its secrecy and the public, by and large, knows little about how the functioning of nuclear activities. In the absence of an independent safety regulation body, people fear the safety standards are actually not very high in India. Following is a list of accidents that is known in the public domain.

April 2010 In a bizarre radiological accident in Delhi, the improper disposal of a derelict gamma-ray research device at the University of Delhi found its way to a scrap market in West Delhi and resulted in the death of a scrap-metal worker. It was owned by the University since 1968, but unused since 1985, and was sold to a scrap dealer in Feb 2010. Scrap workers dismantled and cut it into pieces unaware of the hazardous nature of the device. Eight were hospitalized where later, one died of exposure.

November 2009 Fifty-five employees consume radioactive material after tritiated water finds its way into the drinking water cooler in Kaiga Generating Station. The NPCIL attributes the incident to “an insider’s mischief”.

April 2003 Six tonnes leak of heavy water at reactor II of the Narora Atomic Power Station (NAPS) in Uttar Pradesh, indicating safety measures have not been improved from the leak at the same reactor three years previously.

January 2003 Failure of a valve in the Kalpakkam Atomic Reprocessing Plant in Tamil Nadu results in the release of high-level waste, exposing six workers to high doses of radiation. The leaking area of the plant had no radiation monitors or mechanisms to detect valve failure, which may have prevented the employees’ exposure. A safety committee had previously recommended that the plant be shut down. The management blames the “over enthusiasm” of the workers.

May 2002 Tritiated water leaks from a downgraded heavy water storage tank at the tank farm of Rajasthan Atomic Power Station (RAPS) 1&2 into a common dyke area. Substantial amount of radioactivity was released into the environment.

November 2001 A leak of 1.4 tonnes of heavy water at the NAPS I reactor, resulting in one worker receiving heavy dose of internal radiation.

April 2000 Leak of about seven tonnes of heavy water from the moderator system at NAPS Unit II. Various workers involved in the clean-up received ‘significant uptakes of tritium’, although only one had a radiation dose over the recommended annual limit.

March 1999 Somewhere between four and fourteen tonnes of heavy water leaks from the pipes at Madras Atomic Power Station (MAPS) at Kalpakkam, Tamil Nadu, during a test process. The pipes have a history of cracks and vibration problems. Forty-two people were reportedly involved in mopping up the radioactive liquid.

February 1994 Helium gas and heavy water leak in Unit 1 of RAPS. The plant was shut down until March 1997.

March 1993 Two blades of the turbine in NAPS Unit I break off, slicing through other blades and indirectly causing a raging fire, which catches onto leaked oil and spreads through the turbine building. The smoke sensors fail to detect the fire, which is only noticed once workers see the flames. It causes a blackout in the plant, including the shutdown of the secondary cooling systems, and power is not restored for seventeen hours. In the meantime, operators have to manually activate the primary shutdown system. They also climb onto the roof to open valves to slow the reactions in the core by hand. The incident was rated as a Level 3 on the International Nuclear Event Scale, INES.

May 1992 Tube leak causes a radioactive release of 12 Curies of radioactivity from Tarapur Atomic Power Station.

January 1992 Four tons of heavy water spilt at RAPS.

December 1991 A leak from pipelines in the vicinity of CIRUS and Dhruva research reactors at the Bhabha Atomic Research Centre (BARC) in Trombay, Maharashtra, results in severe Cs-137 soil contamination of thousands of times the acceptable limit. Local vegetation was also found to be contaminated, though contract workers digging to the leaking pipeline were reportedly not tested for radiation exposure, despite the evidence of their high dose.

July 1991 A contracted laborer mistakenly paints the walls of RAPS with heavy water before applying a coat of whitewash. He also washed his paintbrush, face and hands in the deuterated and tritiated water, and has not been traced since.

March 1991 Heavy water leak at MAPS takes four days to clean up.

Anti Nuclear Protests

Anti-nuclear activism in India had never been noticeable until 1998. The nuclear tests of may 1998 sparked off vociferous opposition from the civil society. First, in June 1998, an activist group hacked the network of Bhabha Atomic Research Center (BARC) to protest against India's recent nuclear tests. While no classified information was leaked, the incident attracted worldwide media attention. Then in August 1998, on the 53 anniversary of the Hiroshima atomic bomb explosion, over 2,50,000 people in Kolkata protested the recent nuclear tests ordered by Prime Minister Bajpai. Protests were also lodged in other cities.

A year later, in May 1999, anti nuclear activists lodged a three month march across northern India, starting from the underground test site at Pokharan to Sarnath near Banaras, to protest against last year's nuclear tests. After this event, anti nuclear groups were formed across the country.

The next big push the anti-nuclear lobby received when the Indo-Us deal was finalized. The deal was bitterly opposed by the Communists in the parliament in 2008. Since then the government's every announcement on inviting foreign technology to set up more nuclear power plants were opposed on the streets. The latest is the opposition to the 9900 MW Jaitapur Nuclear Power Project, the largest in the world and over twice as large as the current total nuclear power production in India!

Facts about Jaitapur Nuclear Power Plant

Jaitapur Nuclear Power Project (JNPP)

The government of India gave sanction to set up the Jaitapur Nuclear Power Project and three others in 2005. It was done after recommendation of the site selection committee, which considers prescribed criteria such as availability of land vs. population density, available source of cooling water, seismic background, flood analysis, environment aspects and proper access for transportation of heavy/over-dimensional equipment to plant site etc.

The 9900 MW Jaitapur Nuclear Power Project (JNPP) is proposed at the Madban village of Ratnagiri district in Maharashtra. It will be the largest nuclear power generating station in the world by net electrical power rating once completed. It will produce more than twice the current total nuclear power generated in the country! The project is so named because it is located at what was an important ancient port called Jaitapur.

As per seismic zoning map of Government of India, the Jaitapur site falls within zone III and there is no seismically active fault up to 30 km radius from the JNPP site (regulatory code require not to have any active fault within 5 km). Hence, the government does not consider is an earthquake prone area.

Earthquake-prone regions are categorized between Zones I and IX from least earthquake prone to most earthquake prone. Indian nuclear power plants are situated in Zone II and III except Narora plant in Uttar Pradesh, which is situated in Zone IV. Japan's nuclear plants are in Zones VII, VIII and IX.

Six reactor units of 1650 MW each, around 250 – 300 meters apart, are proposed. These are the third generation Pressurized Water Reactors (PWRs), also known as European/Evolutionary Pressurized Reactors (EPR). This type of reactor is not currently operational anywhere in the world. Finland has ordered one, which is under construction. China also has signed for three such reactors.

French state owned company, AREVA, will provide the reactors. While all six units will be set up over a period of 15 – 18 years, the first unit is planned to be completed by 2018. The guaranteed life of the proposed plant is 60 years.

Objections to the Project

Although government is committed to nuclear power, the democratically elected representatives have to be sensitive to public opinion. There is a fierce opposition to the project from die hard anti-nuclear activists who are allergic to the word "nuclear" to the poor local farmers and fishermen who have always lived in peace on this beautiful Konkan area, but are now worried about being displaced. There are also environmentalists who see irreversible damage to local eco-balance and biodiversity. Shiv Sena is opposing the project for political reasons. The recent Fukushima disaster in Japan has made them more vocal. Some points of their objections are listed here.

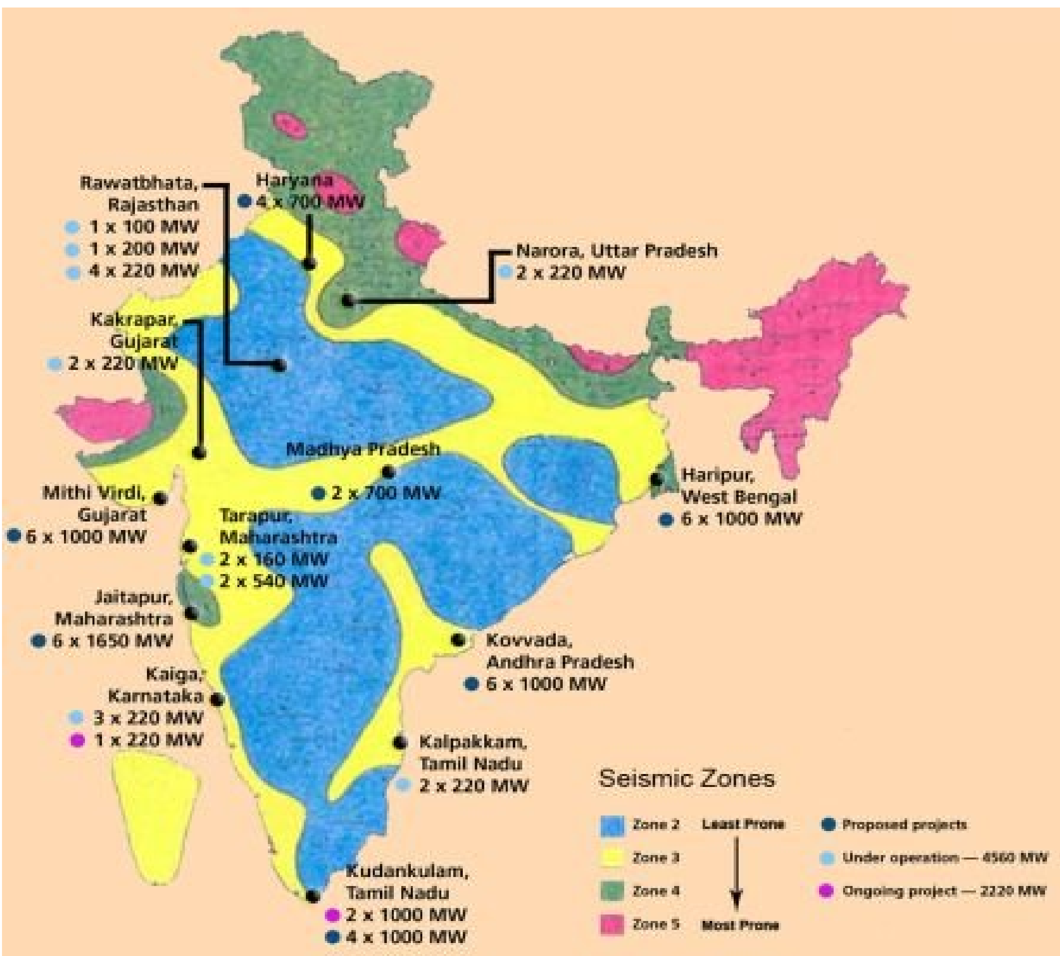
- **Nuclear Technology is Unfit:** Nuclear power is neither cheap, nor clean, nor safe. Radioactivity causes very long term damage to the environment. If Japan could not avoid damage by earthquake/tsunami, how India can prevent such disasters?
- **Untested Technology:** Critics say that AREVA's EPR technology is untested and expensive. No such EPR reactor is in operation anywhere in the world. However, four are under construction – one in France, two in China, and one in Finland.
- **Future of fisheries:** Since the plant will use the sea water for cooling and then release warm water in the Arabian Sea, fishermen in villages around are predicting destruction of fisheries in the nearby sea. Moreover, the tight security around the area will snatch livelihood of fishermen.
- **Compensation in case of Accident:** In Aug 2010, the parliament passed the Civil Liability for Nuclear Damage Bill 2010. This was one of the last steps needed to activate the 2008 Indo-U.S. civilian nuclear agreement as the United State's nuclear reactor manufacturing companies will require the liability bill to get insurance in their home state. In case of accident, it only allows the operator Nuclear Power Corporation of India Limited (NPCIL) to sue the manufacturers and suppliers – the victims will have no legal recourse. It also caps the maximum amount of liability to Rs 1500 crores only, to be paid by the operator. This is a sensitive issue considering the experience of Bhopal Gas victims.
- **Earthquakes/tsunamis:** Residents are worries about safety from earthquakes and claim that tremors have been observed on the Madban plateau. The probability of a tsunami, and the ensuing damage, has not been taken into account, although the probability of tsunami is quite low due to lack of seismic activity in the ocean.

- **Government Distorting Facts:** Critics also point to a report compiled by the disaster management centre of the Tata Institute of Social Sciences (TISS), which states that the government is not fully transparent about the huge negative social and environmental damage in the Konkan region. It accuses the government of deliberately manipulating notification of the area from “highly severity earthquake zone” to “moderate seismic severity zone”. It also said that a large part of the land to be acquired has been in use for agriculture, horticulture and grazing purposes, which the government had termed as barren land.
- **Radioactive Waste Disposal:** India does not have a long term waste disposal policy. It is not clear where the nuclear waste emanating from the site will be dumped. The plant is estimated to generate 300 tonnes of waste each year. EPR waste will have about four times as much radioactivity compared to ordinary pressurized water reactor.

Nuclear Plants and Seismic Zones in India

The massive earthquake in Japan and the subsequent nuclear crisis has triggered fears of nuclear security across the world, including India.

Most of India falls in the moderate risk to very high risk seismic zones and so do a majority of India's nuclear reactors. While there are no nuclear projects in Zone V (seismic intensity of 8 and above), the proposed Jaitapur Nuclear Power plant falls in Zone IV on the earthquake hazard zoning map. The map below plots India's nuclear power plants on a seismic map.



Renewable Energy Alternatives to Nuclear Energy

Renewable energy potential in India is of the order of 150 GW; however, the only renewable source that has been exploited is the hydropower, which forms about a quarter of the total power generation and other renewables add just 8%. India's energy need is still largely met by the highly polluting coal energy, which accounts for over half of electricity generation in the country. Thus, therefore is significant potential of expansion in the renewable sources such as solar, wind, biomass, etc.

Wind: India ranks as a "wind superpower" with estimated potential of 45,000 – 65,000 MW (only from 216 sites) compared with the installed capacity of about 13,000 MW. Development in wind power in India began in the 1990s and is perhaps the most mature technology among renewables.

Hydropower: Particularly the small hydro sector presents as excellent opportunity with an estimated potential of 15,000 MW. Only 10% has been exploited so far.

Energy from Wastes: Urban garbage throughout India represents another source of non-conventional energy. Good potential exists for generating approx. 15,000 MW of power from urban and municipal wastes. However, only 10% is currently explored.

Biomass: with over 540 million tons of crop and plantation residue, there is potential for about 20,000 MW power. A large fraction of it gets wasted. Installed capacity is only about 550 MW.

Solar: With about 300 clear sunny days in a year, solar energy should naturally become India's main source of energy. According to scientific data, the average intensity of solar radiation falling on India is 200 MW per square km. Even if 2% area is tapped about 1,600 GW per year will be available, which is enormous.

Currently, solar energy contributes less than 1% of total demand. High cost is the main factor: it ranges from Rs 15 – 30 compared with about Rs 3 – 5 per unit for the usual thermal energy. It is also ideal for electrification of remote rural areas where distribution infrastructure is weak or absent. Many experts consider solar as the ideal choice for the subcontinent and advise making solar power the backbone of economy.

Projected Power Generation from Renewable Energy Sources (in GW)

	2005	2010	2015	2020	2030	2040	2050
Wind	4	12	29	69	143	200	224
Solar – PV	0	0	2	10	118	486	1,093
Solar-Thermal	0	0	0.5	3	23	70	151
Biomass	0	1	4	8	19	41	70
Geothermal	0	0	0	2	6	18	30
Ocean Energy	0	0	0	1	3	5	11
Total	**4**	**13**	**35**	**92**	**310**	**819**	**1,579**

Source: Ministry of Non-Conventional Energy Sources

How to Achieve long Term Energy Security

With meager availability of Uranium in the country and vast resources of Thorium, any long-term nuclear strategy has to be based on Thorium. The three stage strategy of development of nuclear power from pressurized heavy water based reactors to fast breeder reactors to Thorium based reactors requires a sustained R&D effort. Success in these efforts could deliver some 250 GW of nuclear power by 2050 and much more thereafter.

Failure to economically develop India's Thorium based nuclear potential to the fullest will significantly increase India's dependence on domestic and imported coal. Nuclear power will not only enhance energy security but also yield rich dividends by reducing carbon emissions.

Looking at the limited resources of oil, gas and Uranium in the country solar energy and Thorium based nuclear option are the only two sizeable sources of energy for the country. Thus, R&D for the third stage of indigenous nuclear program as well as solar technology must be pursued with vigor.

The Way Forward – Options and Strategies

The best way for India to gain long term energy independence is utilize the post Indo-US civil nuclear cooperation situation to speed-up the development of the third stage of its indigenous nuclear program. India can now invite foreign technical collaboration and quickly develop the technology so that the vast thorium deposits can be used for commercial power generation. It will also avoid dependency on imported uranium to run its power plants.

Setting up an independent nuclear regulatory authority will be both helpful in enhancing the safety of its nuclear establishments as well as to assuage the public fear of nuclear accidents to at least some extent. Civil society can put pressure so that the bill is in-acted in the parliament without much delay.

Apart from the commitment to reduce greenhouse gas emission, it is in the best long term interest of India to invest in research and development of renewable energy technologies, particularly the solar energy. This is the only renewable energy that offers several advantages: it is clean, noise free unlike the wind power generation, and produces power without mechanical movement (important for efficiency reasons).

Modernization of power transmission and distribution system should be urgently taken up curtail losses, which are quite significant – more than one-third of generated power is currently lost. Moreover, there is tremendous scope for improvement in efficiencies both at power generation stage as well as at end use.

Finally, land acquisition system needs thorough overhaul through proper legislative measures. If the poor rural folks don't get just and quick compensation for loss of their property and lifestyle, the very purpose of development and progress loses meaning for them. Most agitations against power plants and large industries are rooted in the less-than-appropriate manner of land acquisition. Civil society has a big role to play here.

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