Nuclear energy development in India and Lessons Learnt from Fukushima

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Outline

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II. Brief description of events culminating in reactor meltdown in Fukushima Daiichi
III. Inferences from what is known from the Fukushima nuclear accident
IV. Concerns about India’s nuclear expansion post Fukushima: The Kudankulam agitation
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March 11, 2011 Earthquake

- The 2011 earthquake and tsunami was one of the worst crisis in Japan.
- 9.0-magnitude earthquake was Japan's largest and world's fourth largest earthquake since modern records started.
- The 9.0-magnitude earthquake at a depth of around 24 km in the Pacific Ocean floor at 70 km northeast of the Fukushima Daiichi nuclear complex housing six reactors, triggered tsunami waves as high as 14-15 metres.
- As of March 10, 2012: confirmed deaths and missing people estimated is around 19,000, most them tsunami related.
- Median estimate of direct economic loss due to the earthquake and tsunami is around US$275 billion besides US$65 billion damage as a result of the Fukushima nuclear accident.

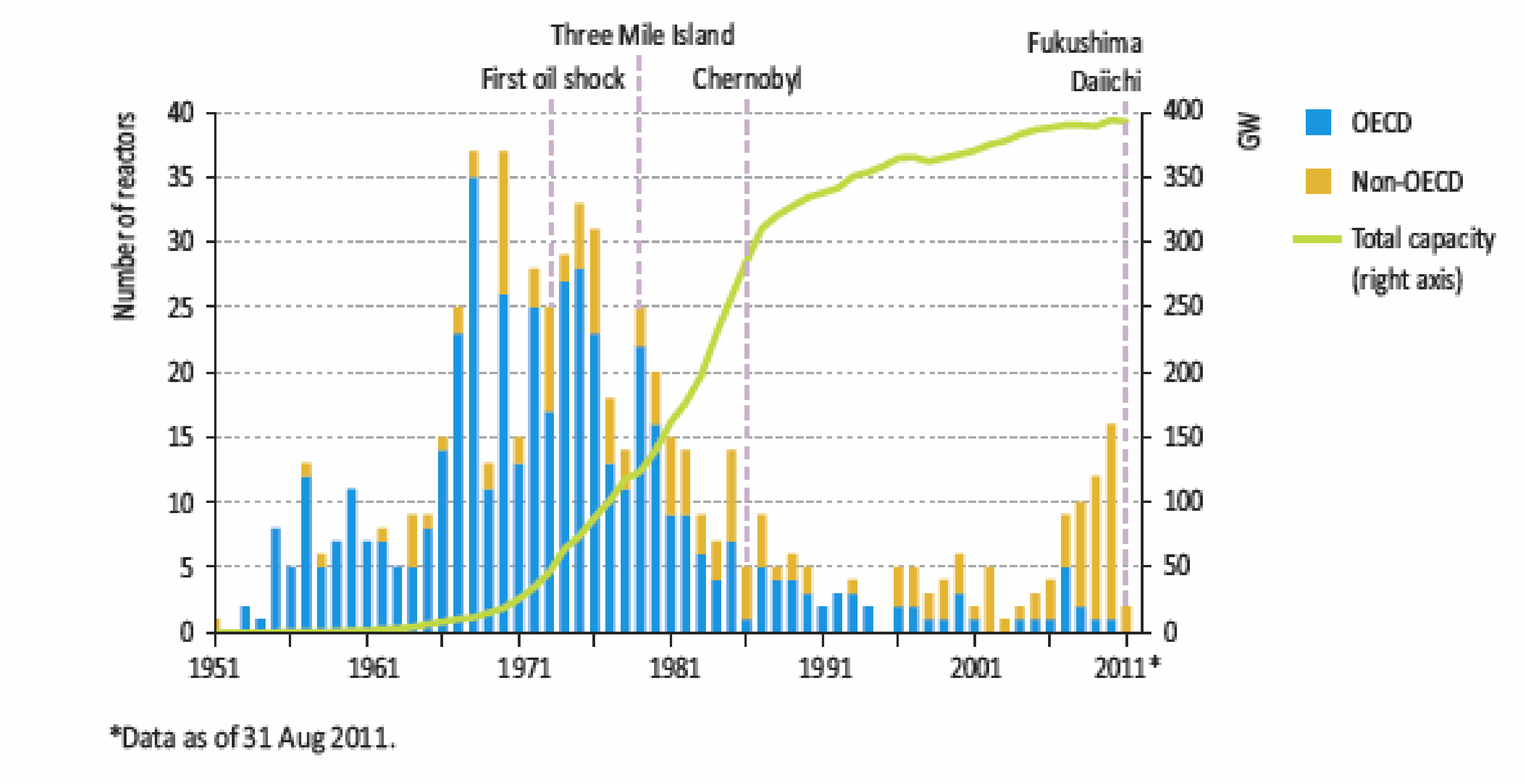
Fukushima Nuclear Accident: Sequence of Event

- At the time of quake, only three of the six Fukushima Daiichi reactors were in operation.
- Earthquake automatically triggered as designed a shutdown, halting fission chain reactions in the three operating reactors thereby shutting off the main source of heat production.
- Residual heat from the core still remains significant for a long time.
- Failure to remove this residual heat (which is enough to melt the fuel) leads to accidents.
- Heat removal is normally achieved by the reactor’s main cooling system, and if unavailable, by emergency core cooling systems—all of which require external power if plant is shut down for any reason.

Fukushima Accident Sequence

- After plant shutdown, Fukushima's only source of AC power supply was lost due to the natural disaster and resulted in total dependence on onsite emergency diesel generators to run cooling systems and other safety equipment.
- The complex had a 5.7 meter high seawall protection, but was inadequate to prevent the inundation from tsunami waves of far higher heights.
- Flooding rendered all of the onsite diesel power generators except one unusable.
- TEPCO operators tried to restore power to save the reactors, and eventually began injecting seawater. This proved inadequate to prevent meltdown generating high temperature steam and hydrogen, resulting in the subsequent explosions that tore off the secondary containment structure.

Impact of earlier nuclear accidents on nuclear programs



Source: IEA World Energy Outlook 2011, p.450

Fukushima Impact on Nuclear Power Policy

1 Countries with "**existing**" nuclear installations:	
Use of nuclear power in principle **not being contested**[1]	Argentina, Armenia, Belgium[2], Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Hungary, India[3], Iran, Mexico, Netherlands, Pakistan, Romania, Russia, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Taiwan, Ukraine, United Kingdom, United States
Use of existing nuclear power **being contested**	**Japan**[4]
Use of existing nuclear power **being phased-out**	**Germany**[5], **Switzerland**[6]
2 Countries "**currently constructing**" new nuclear installations:	
Construction projects **not being contested**[7]	Argentina, Brazil, Bulgaria, China, Finland, France, India, South Korea, Pakistan, Russia, Slovakia, Taiwan, Ukraine, United States
Construction projects **cancelled, scaled-back or delayed**	**Japan**
3-Countries with "**plans and/or proposals to construct**" new nuclear installations:	
Plans/proposals for new constructions **not being contested**	All 31 countries mentioned in Table-3 (see below) except Germany, Switzerland, Italy
Plans/proposals for new constructions **prohibited**	**Germany, Switzerland, Italy**[8]

Notes:
1) Assessing safety installations and incorporating lessons learned
2) Government is expressing concern about the feasibility of implementing a phase-out.
3) The public response and protests taking place at Kudankulam-1 (still under construction), suggest there may be further protests, and potentially a government response, especially given the democratic regime.
4) Clarifications to come in an update to the Japan's Strategic Energy Plan (expected 2012)
5) Immediate suspension of eight nuclear installations following Fukushima, and phased-out closure of remaining power plants as fast as possible
6) Expected closure of five nuclear power plant units between 2019 and 2034
7) Partial modification of safety standards or licensing procedures
8) Effective construction bans existed in Germany before Fukushima. These bans were being revisited as part of the "nuclear renaissance", but Fukushima halted or reversed these developments reversed this direction. In Italy, a referendum in June 2011 imposed a permanent ban on the reintroduction of a nuclear power programme.

Source: *World Energy Perspective: Nuclear Energy One Year After Fukushima* ,World Energy Council, 2012

Summary of Fukushima's global impact

- In USA, Fukushima has resulted in more stringent regulation and delays in licensing, but the pre-Fukushima challenges for nuclear expansion remain, such as those relating to storage of nuclear waste and problems with spent fuel pools.
- In France, history and institutional inertia leave intact its commitment saturated at current high levels of nuclear power.
- Germany had decided even before Fukushima to shut down all existing nuclear reactors.
- Britain seems unaffected by Fukushima and plans to replace old capacity plus some expansion are underway. Modest addition in Brazil and Argentina.
- In Middle East countries, nuclear projects are driven by prestige, building recessed deterrence, and use of gas for enhanced oil recovery.
- China has the most ambitious nuclear expansion plan (to add 86GWe by 2020). Fukushima resulted in temporary slowdown, but expansion plans are still intact.
- In ASEAN countries, Fukushima crisis has delayed the construction plans except Vietnam. In Indonesia anti-nuclear sentiments were strong even before Fukushima. Malaysia and Thailand have expressed interest to build after 2020.

Lessons from Fukushima: Underestimation of risks from Natural Disaster

- **Were risks to nuclear plant from large earthquakes and tsunamis underestimated?**
  - Strong tsunami-generating earthquakes have repeatedly occurred in most active parts of the Japanese subduction zone in the past since AD 869, including at least six destructive tsunamis that resulted in run-ups of 25 to 38 meters and thousands of fatalities.
  - However, when Fukushima Daiichi was designed and built, there were no records of large tsunamis in the coastal section near Fukushima.
  - The plant was initially designed to protect against a tsunami of height of 3.1 m and later increased to 5.7 m.
  - On the other hand, even at that time, many large tsunamis were known to have hit other areas including the 1896 Sanriku earthquake, with a tsunami height of 38 meters, and the 1933 Sanriku earthquake, with a tsunami of 27 meters.
  - It is not unreasonable to suggest that it was not prudent to have excluded the possibility of large tsunamis near Fukushima Daiichi.
  - Fukushima revealed an inadequate appreciation of the risks of the potential occurrence of the joint occurrence of very strong earthquakes and unusually high tsunamis and the need to strengthen measures to protect nuclear stations against them.
  - The analytical problem of estimating the likelihood of an event of which there is no record of occurrence as yet from the data on events that have occurred is complex. But there are studies which attempt to do such estimation.

Lessons from Fukushima: Inadequacy of Safety and Risk Management

- Since Japan is an earthquake prone zone and from the 1960s earthquake resistance has been a central feature of Japanese reactor designs, it’s surprising that defence against tsunamis were so weak at a nuclear power station located on Japan's coast.
- But it’s now coming to light that the human and institutional failures revealed in earlier accidents like Three Mile Island in 1979 and Chernobyl in 1986 had also played an important role in exacerbating the crisis.
- Inadequate power supply and lack of diversification of power sources (equipment that couldn’t withstand flooding) illustrates the need for having secure power supply for a long time to enable restoration of AC power from the plant or grid.
- Revisiting reactor’s safety systems to enable resilience in the face of adverse plant conditions similar to Fukushima natural disaster has also been identified as an important lesson from the accident.

Lessons from Fukushima: Confusion over measurement of earthquake magnitudes

- Surface wave and seismic moment for measuring earthquake intensity.
- The largest earthquakes recorded till1960s had surface-wave magnitudes of about 8.5. Magnitude 9 events (mega quakes) were not known.
- Since the mid-1960s, seismologists began quantifying the size of an earthquake by its seismic moment.
- They found that surface wave magnitude maxes out at about 8.5. For magnitudes of 8 or less, the new moment scale gives more or less the same results as surface-wave magnitude.
- The largest events go up to magnitude 9 and higher in the moment scale, reflecting their true size.
- Since 1977, there have been two mega-quakes: the 2004 Sumatra earthquake, a moment-magnitude of 9.3 and the 2011 Tohoku event of magnitude 9.0.
- Kanamori, a well known Japanese seismologist, recently determined that the values for these two events, calculated using the earlier surface-wave magnitude scale, were, respectively, 8.6 for Sumatra and 8.2 for Tohoku events.
- Although seismologists (and Japan has some of the best in the world) were familiar with the concept of seismic moment by the mid-1970s, engineers, government officials, and the general public were not.

Lessons from Fukushima: Available knowledge ignored

- The knowledge that magnitude 9 mega quakes existed as a class suggests that serious underestimation of some of Japan's earlier quakes and resulting complacency were likely to have occurred.
- It did not trigger a re-examination of the earthquake and tsunami countermeasures in Japan as it should have.
- In 2009, TEPCO and government regulators passed up another chance for reassessment and design improvement.
- The 2009 IAEA Safety Guide for Site Evaluations, and even the 2003 IAEA Safety Guide on Flood Hazard for Nuclear Power Plants on Coastal and River Sites published a year before the Sumatra earthquake and tsunami explicitly required a thorough consideration of historic tsunamis.
- TEPCO apparently overlooked these issues in the interest of saving cost for the company.

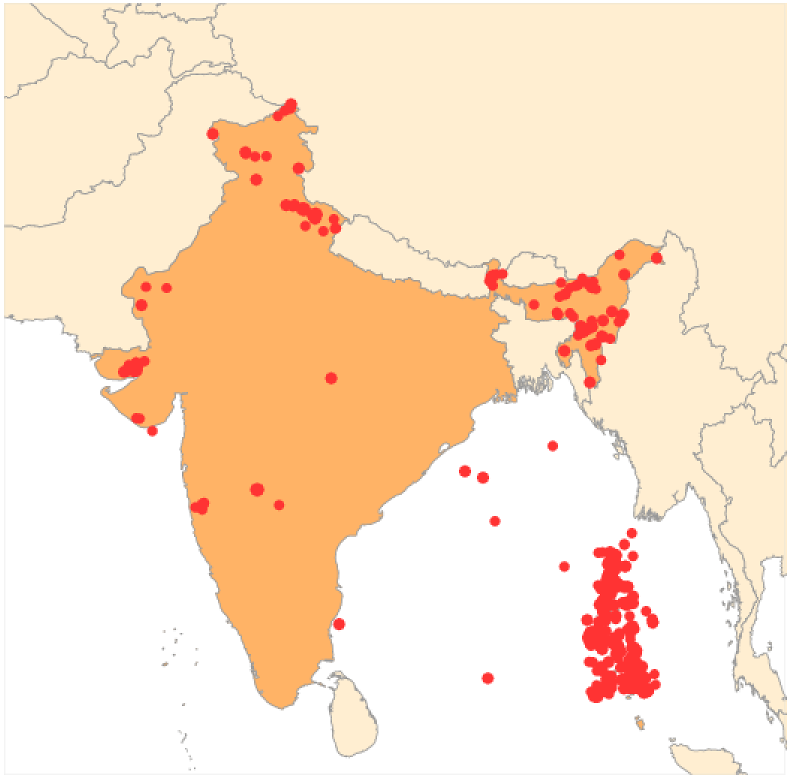
Lessons from Fukushima: Regulatory Independence

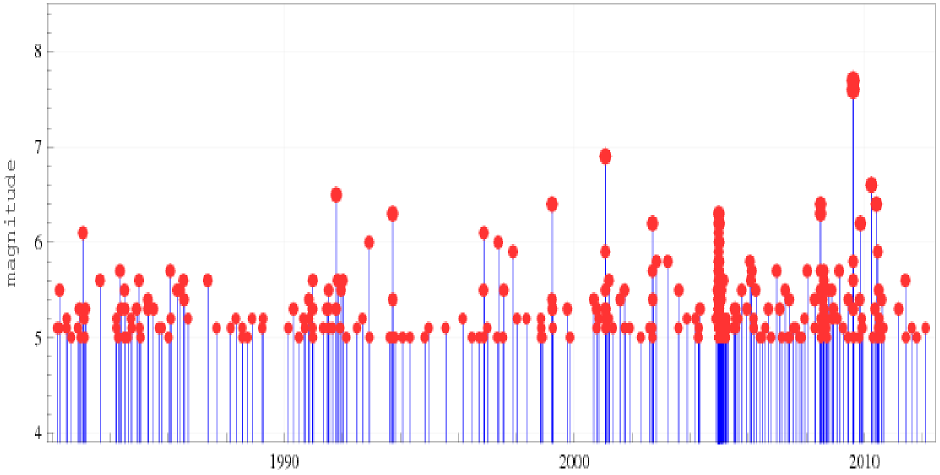
- The problems of regulatory capture, lack of transparency in nuclear safety and regulatory function, collusive ties between the regulators and the industry have surfaced after the Fukushima crisis.
- In Japan, three agencies (The Nuclear Safety Commission of Japan (NSC), Nuclear Industrial Safety Agency (NISA), and Nuclear Safety Division) share regulatory responsibilities.
- During the Fukushima crisis, coordination and consistency among them was more difficult to achieve. Fukushima highlighted several considerations necessary for a comprehensive and coherent regulatory framework.
- Creation of the new independent regulator (as promised by the government during the crisis) is delayed due to the political process, fuelling further public scepticism.
- These problems are not unique to Japan and can be traced to almost all nuclear programs in the world largely because of their earlier connection with military programs. For example, US NRC was created only in 1975 after the earlier arrangement (which has promotional and regulatory functions in the same organization) became untenable.

Lessons from Fukushima: Nuclear Siting

- The earliest reactors in the US and other countries were built in remote places and didn’t have containment.
- Expansion of civilian nuclear industry necessitated siting reactors closer to load/population centers. Hence later emphasis was on engineered safety features and containment structures to minimize environmental impact of accidents.
- Most countries avoid building (see the pic in next slide) reactors close to active faults and coasts that are vulnerable to flooding. Due to its land constraints, Japan built many of them in vulnerable sites and tried compensating with enhanced engineered safety features.
- Since a share of the operating and planned reactors are located along coast for cooling convenience, effective protection against flooding will be crucial.
- Although clustered siting of reactors has certain convenience, Fukushima has highlighted the risks of multiple reactor sites to common mode failures.

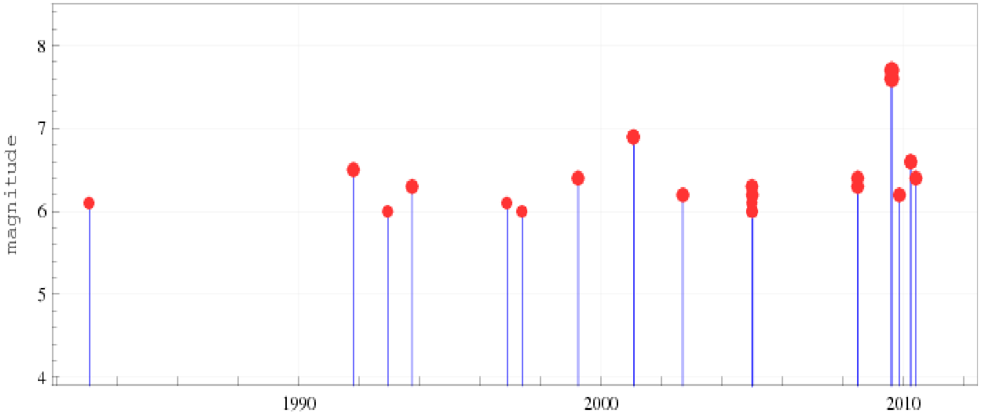
Earthquakes (>5R) in 30 years





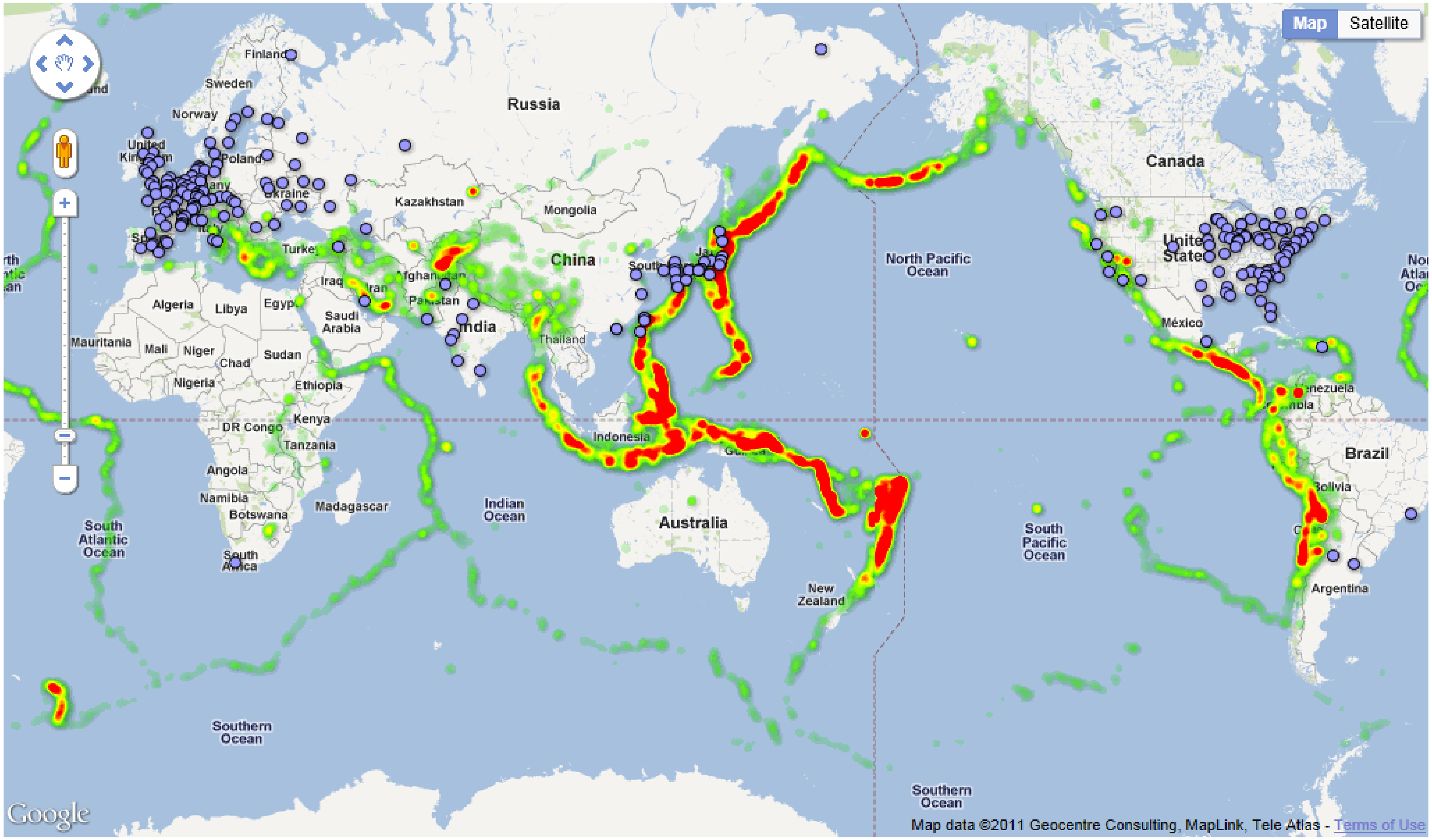
Graphical plots (generated by *Mathematica* 8) show magnitude 5 and above quakes in the last 30 years.

Earthquakes (>6R) in 30 years



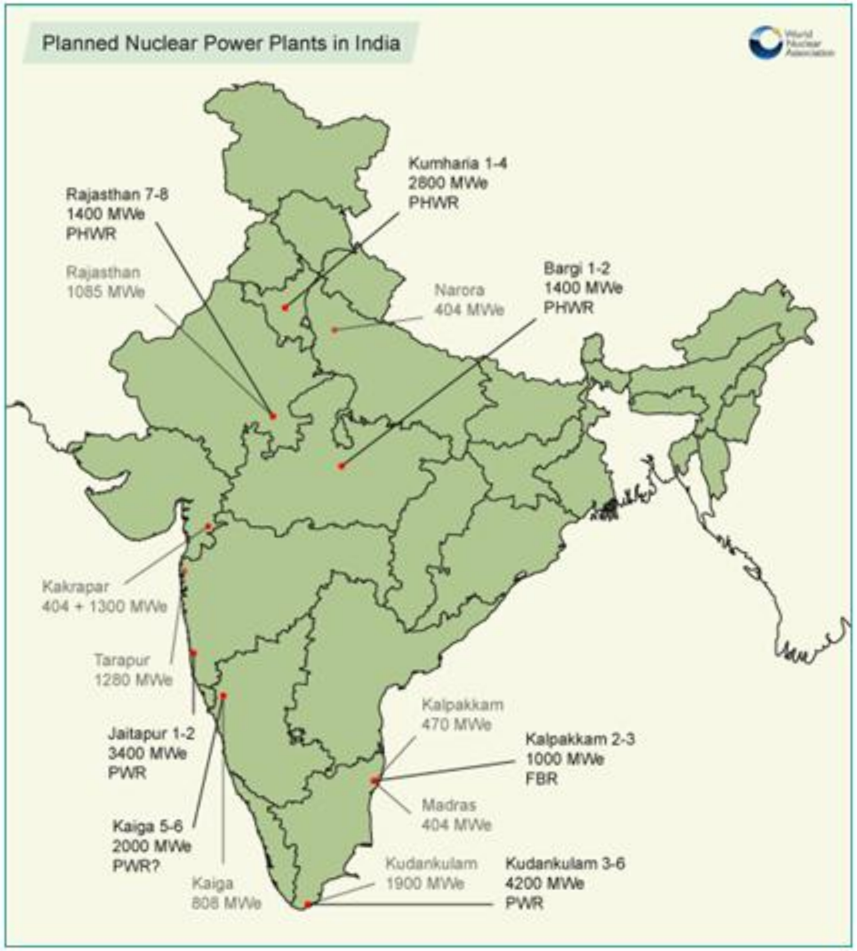
Graphical plots (generated by *Mathematica* 8) show magnitude 6 and above quakes in the last 30 years.

Nuclear Reactors in Seismic Zones

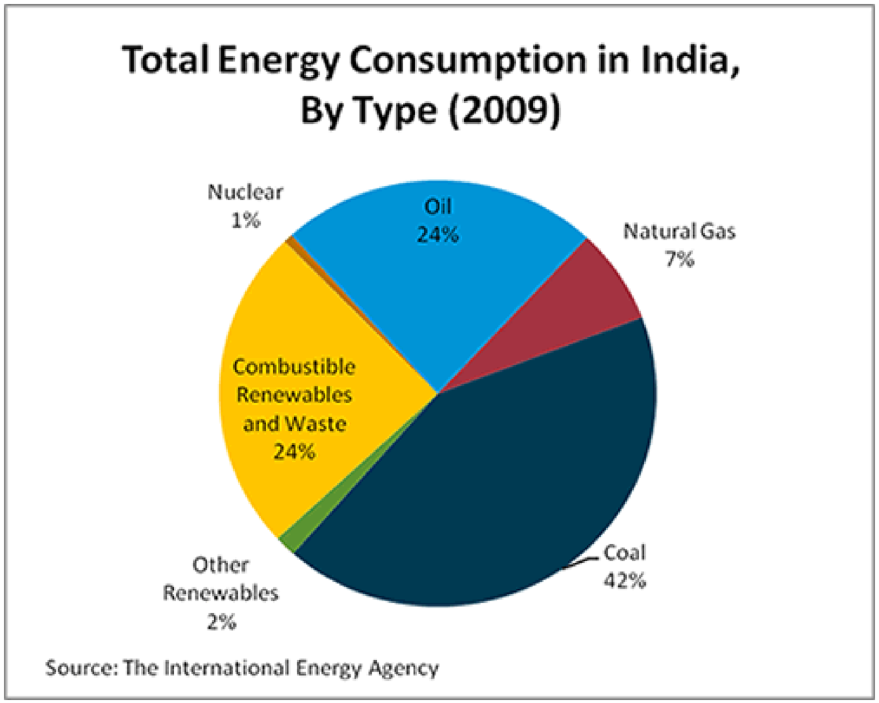


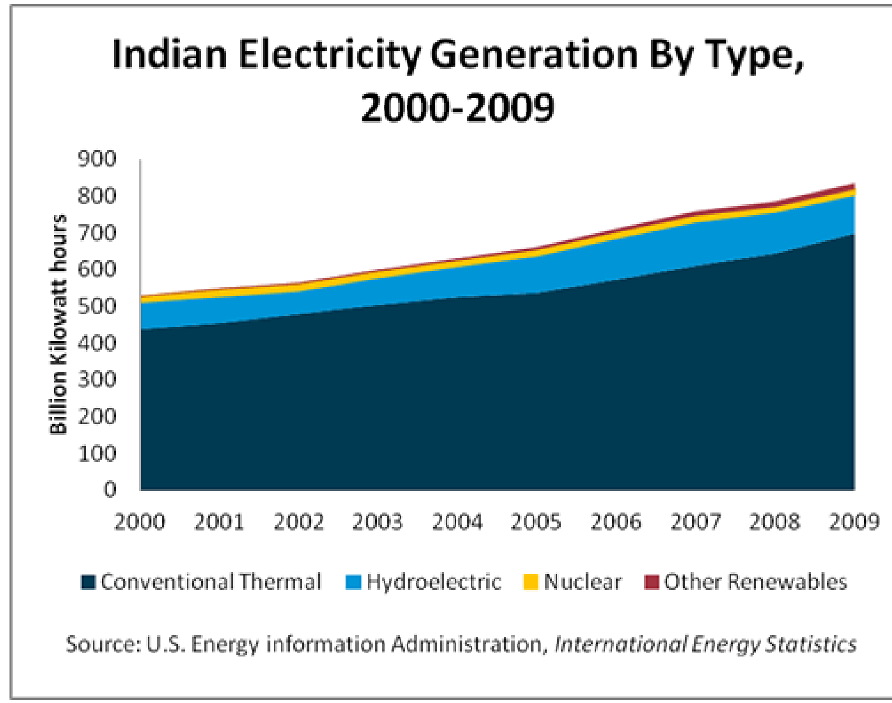
Source: http://maptd.com/map/earthquake_activity_vs_nuclear_power_plants/

Geography of planned nuclear expansion



India: Energy and Electricity Overview





Electricity production in 2009 tripled from 1990 level. But one third is lost in T&D and theft. Per capita consumption is 500 kWhr. The next five year plan (2012-2017) targets adding at least 100 GWe—mostly coal, and some gas. Nuclear will add 3.4 GWe.

Fukushima impact in India: Kudankulam Plant

- Official plan: add 20,000 MWe nuclear capacity by 2020 and 63,000 MWe by 2032, and supply 25% of electricity from nuclear sources by 2050.
- Fukushima’s immediate impact in India was the protests by thousands of people against the commissioning of the near-complete Russian built VVER reactors in Kudankulam by the central government. This became the focus of post Fukushima protests in India over nuclear safety concerns.
- The central government appointed a committee to review the safety aspects of the Kudankulam plant. A newly elected government of the state of Tamil Nadu (where Kudankulam is located) also appointed its own expert committee to review the safety of the plant.

Fukushima impact in India: Kudankulam Plant

- After more than seven months of letting the protesters take control of the situation, the central government with the help of the state government (which changed its mind) used repressive means to break the movement and threaten the people who led the protests. Although public protest has subsided, it can resurface there or in other places where projects are planned.
- Kudankulam is located in the rice and milk producing, heavily populated and fast growing southern state of Tamil Nadu near Sri Lanka. Within 50 km radius of the plant, 2-3 million people could be at risk in the case of a severe accident.
- The deleterious consequences of the Fukushima accident and the risks of their happening at Kudankulam are real. Potential risks and their costs have to be weighed against potential benefits from the plant in a scientific, social cost/benefit analysis in evaluating whether or not to bring Kudankulam on stream and institutionalising such analyses in the nuclear decision-making process.

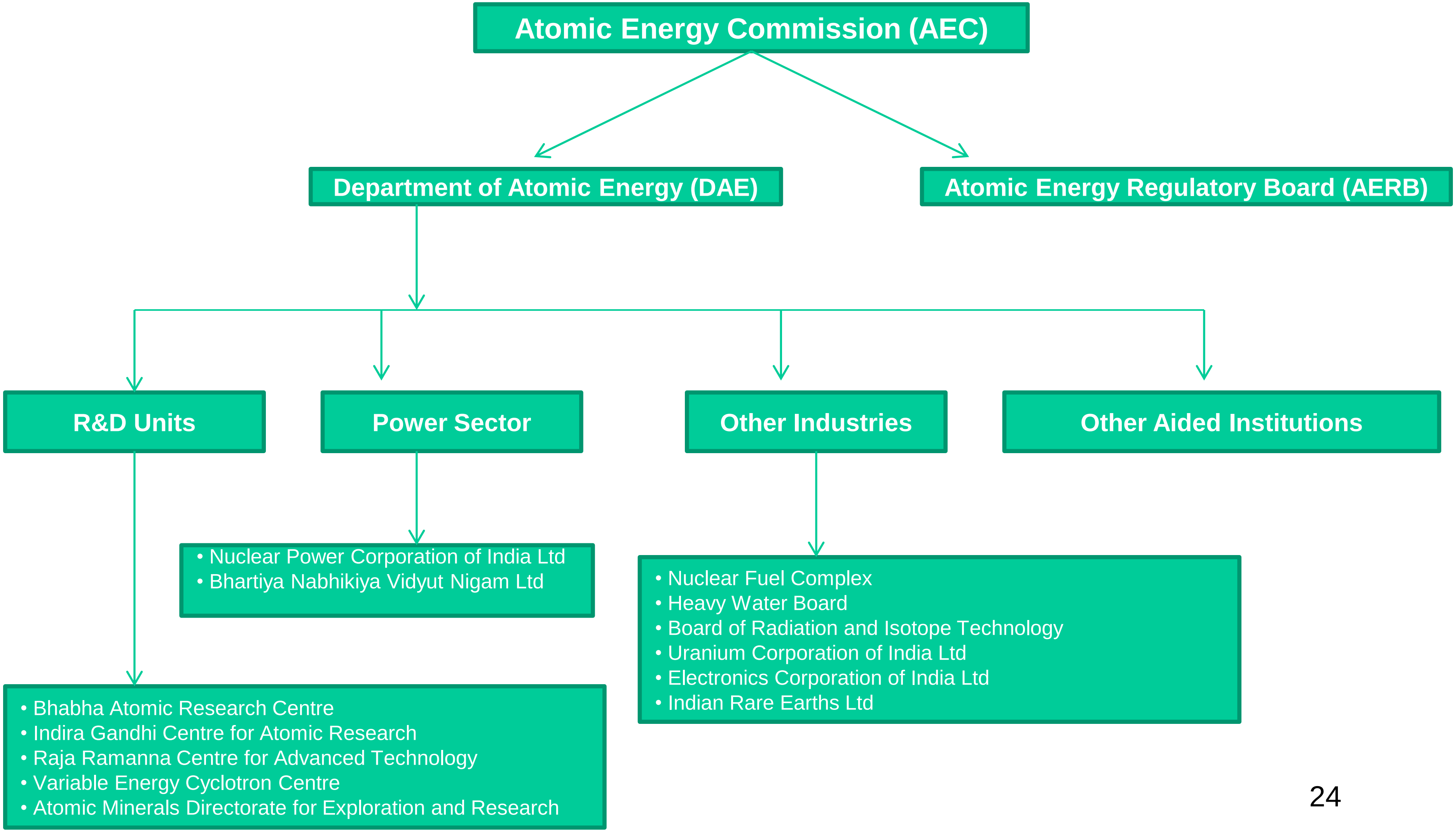
Fukushima impact in India: Kudankulam Plant

- A systematic analysis of estimates of the probabilities of earthquakes of magnitude greater than 6 and of tsunamis originating outside India that could threaten the Indian coast should be done.
- Social cost/benefit analysis of alternative responses to very low probability events but high consequence is a difficult analytical problem.
- However, to assure that the Kudankulam plant is “reasonably safe,” the government should attempt the difficult social cost/benefit analysis and make public its methodology and assumptions. The uncertainties in the data used and in estimation errors induce an “error band” around the average social cost/benefits and these should be made explicit.
- Superimposition of estimated probabilities of possible reactor accidents with site specific probabilities of earthquakes and tsunamis highlighted by Fukushima would enable the estimation of probabilities of a Fukushima-like event at Kudankulam.
- But, there is currently neither capacity nor interest in the concerned agencies to do such an analysis because the overriding objective seems to be development at any cost.

Fukushima Impact in India: Nuclear Regulation

- Failures and deficiencies in India's nuclear regulation was there even before Fukushima.
- The 1996 report by former regulatory chief (A. Gopalakrishnan) listed several safety lapses and vulnerabilities in DAE's facilities. Most of them were related to NPCIL, which operate India's commercial power reactors. This report has still not been made public, although media published selective contents.
- Following this controversy, a public interest litigation was filed in 1996 in the Bombay High Court by two civil society groups to make the Gopalakrishnan report public and create a more independent regulator. When the court summoned the DAE to respond, DAE invoked national security clause and avoided potential embarrassment the disclosure could have caused. But the DAE told the court that it will sincerely address the issues raised by the litigation. Since then, AEC has been very careful in its choice of candidates to head the AERB.
- Organizational restructuring for effective and transparent regulation has become even more urgent after the Fukushima crisis and the concern over the way Kudankulam protests were handled. The government announced setting up Nuclear Regulatory Authority (NRA) after Fukushima and have it separated from AEC. But questions about its capacity, dependence on DAE for resources remain.

India's Nuclear Regulatory Structure



In-built structural anomalies in India's nuclear regulation

- The DAE Secretary and AEC Chairman are the same person since Bhabha's time and enjoys direct access to the Prime Minister, who is also the minister of DAE.
- The AERB monitors the safety aspects of all DAE activities in the power and industrial sector.
- DAE is answerable to AERB on safety and regulatory matters, but the AERB Chairman reports to the AEC, the supreme nuclear policy making body of the government.
- The AERB has mostly depended on the DAE for technical expertise and other resources. Deputation of DAE staff to AERB is common, and DAE plays a major role in internal professional evaluation for promotion of AERB personnel.
- These structural deficiencies have long been a cause for concern as it calls into question the independence of the regulatory process.

Health Effects of Ionizing Radiation (Source: Clifford Singer, University of Illinois)

- Most exposures of people to radiation have been too low to produce prompt radiation sickness.
- Our understanding of the health effects of exposure to low-level ionizing radiation comes primarily from studies of Japanese atomic bomb survivors, and other studies (fetal exposure, Chernobyl; smokers; breast cancer diagnosis; mice studies, and background radiation studies).
- Doubling or tripling of background radiation levels has no statistically clear effect on public health overall.
- However, it cannot be precluded that extrapolation of atomic bomb survivor effects to low doses predicts increased mortality due to increased low-level radiation, with producing an overestimate by a factor of 3 or less for the general population, and an accurate estimate for exposure of children.