Nuclear Power in India

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India is committed to growth of nuclear power

- On May 17, 2017, India's Union Cabinet gave its approval for the construction of 10 units of India's **indigenous** Pressurized Heavy Water Reactors (PHWR).
- Press release issued after the decision states,

  "The Cabinet's decision reflects the Government's commitment to prioritise the use of **clean power in India's energy mix, as part of low-carbon growth strategy** and to ensure long-term base load requirement for the nation's industrialization.

  It also supports India's commitment to sustainable development, energy self-sufficiency and bolsters global efforts to combat climate change."

India is committed to growth of nuclear power

Excerpts from “Saint-Petersburg Declaration By the Russian Federation And the Republic Of India: A Vision For The 21st Century” issued on June 1, 2017

- We welcome the conclusion of the General Framework Agreement and Credit Protocol for Units 5 and 6 of the Kudankulam Nuclear Power Plant.
- We will work towards the implementation of the Strategic Vision for Strengthening Cooperation in Peaceful Uses of Atomic Energy signed between the two countries on December 11, 2014.
- The future of Indian-Russian cooperation holds great promise across a wide spectrum covering nuclear power, nuclear fuel cycle and nuclear science and technology.
- India and Russia commit themselves to earnestly implement the "Programme of Action for Localization in India” signed on 24 December 2015, and to encourage their nuclear industries to engage closely and foster concrete collaborations.

India is committed to growth of nuclear power

- Budget speech, February 29, 2016. Indian Finance Minister announced the need to diversify the sources of power generation for long term stability. He also spoke about drawing a comprehensive plan, spanning next 15 to 20 years, to augment the investment in nuclear power generation and budgetary allocation up to INR 30 billion per annum. Considering that investments in power sector in India generally involve a debt to equity ratio of 70:30, this means an investment of INR 100 billion (1.54 billion US $) per year.
- In 2015, India communicated its Intended Nationally Determined Contribution (INDC, 2015) for the period 2021 to 2030 consisting of eight elements and the elements having direct relationship with nuclear energy are the following.
  - To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030.
  - To reduce the emissions intensity of its GDP by 33 to 35 percent from 2005 level.
- To achieve the target of enhanced generation from non-fossil sources, the communication also commits to make efforts to achieve 63 GW installed capacity based on nuclear generation by 2032 provided nuclear fuel supply is ensured.

Pursuit of closed fuel cycle is an integral part of nuclear power policy

- To get full benefit of energy potential of uranium and to exploit thorium. (Using thorium in a once through enriched U-Th cycle hardly gives any benefit.)
- It minimises nuclear waste per kWh of electricity generated. Partitioning of high level waste from reprocessing plants followed by transmutation of minor actinides is an effective solution to manage nuclear waste.
- It helps to recover valuable by-products. India has been recovering Cs-137 and making vitrified pencils for various applications.
- "Could spent nuclear fuel be considered as a non-conventional mine of critical raw materials?", Stephane Bourg, Christophe Poinssot, CEA, France, Progress in Nuclear Energy, 2016. They have made a case for recovering Rare Earth Elements and have opined that it would be economical only if Pu and U are also recycled. How about a future rogue state catching hold of a repository containing spent fuel and recovering Pu?

India has established legal regime governing nuclear power and non-power applications – 1

- The Atomic Energy Act, 1962
- Mines and Minerals (Development and Regulation) Act, 1957
- The Civil Liability for Nuclear Damage Act, 2010
  - The Civil Liability for Nuclear Damage Rules, 2011
  - INIP launched
- Regulated by Atomic Energy Regulatory Board (AERB).
  - Convention on Nuclear Safety, Regulatory review by IAEA, WANO peer review
- The Board has six members, and four are outside experts (AIIMS, IIT Bombay, NGRI, IIChT). It has expert manpower on its rolls and draws from the expert pool available in the country.
- The Government is responsible for disaster management through National Disaster Management Agency (NDMA).

India has established legal regime governing nuclear power and non-power applications – 2

- By including a reference to the "Nuclear Security Recommendations on Physical Protection of Nuclear Materials and Nuclear Facilities (INFCIRC/225/Rev.5)" in Nuclear Cooperation Agreements signed with other countries, India has committed to adhere to it.
- Unlawful Activities (Prevention) Act 1967 was amended in 2012 to include offences under the scope of and as defined in several treaties including CPPNM.
- The Weapons of Mass Destruction and Their Delivery Systems (Prohibition of Unlawful Activities) Act, 2005.
- India has a professional force to provide physical security to nuclear installations that is Central Industrial Security force (CISF).
- India has harmonised its export controls with the NSG framework.

Opening of international cooperation with India

- On July 18, 2005, India and USA issued a joint statement outlining a roadmap for opening international cooperation with India.
- Following the roadmap, India issued a separation plan in early 2006.
- The US Congress passed the Henry Hyde Act granting India exemption from certain requirements of the US laws and paved the way for signing a nuclear cooperation agreement (NCA) with India.
- India had dialogue with the USA, France and Russia to negotiate NCAs.
- India also had a dialogue with the IAEA secretariat to negotiate India-Specific Safeguards Agreement.
- Outreach with NSG countries; relaxation by NSG of its guidelines on 6th September 2008 to facilitate nuclear trade with India.
- Signing of NCAs with France (30.09.2008), USA (10.10.2008), and Russia (05.12.2008); end of nuclear isolation.

India's evolving electricity mix

- Until 1980, hydro installed capacity was 40% and generation was 43%. In 2012, hydro installed capacity came down to 20% and generation to 14.1%.
- Fuelled by GDP growth, electricity demand is rising (CAGR for the past decade = **5.9%**). Aspirational India demands reliable electricity supply. Reliance on coal is increasing. Electricity mix as on March 31, 2017 –

Technology	Thermal	Nuclear	Hydro	VRE	Total
Installed MW	218,330	6780	44,478	57,260	326,848
Generation TWh	994.230	37.674	122.378	81.869	1,242

Note: Total includes import of 5617 TWh from Bhutan. VRE comprises 32,280 wind, 12,289 solar, 4380 small hydro and the rest being bio power. Power generated by non-utilities was about 170 TWh and is additional.

Structure of nuclear industry in India

- Atomic Energy Act permits only Government or Government companies to own and operate nuclear power plants and fuel cycle facilities.
- Private companies can design and construct nuclear power plants, and manufacture equipment.
- Nuclear Power Corporation of India Limited has evolved from a government entity into a company. It is the designer for PHWR system and owns the technology. It owns and operates PHWRs. When India goes in for Indian Pressurised Water Reactors (IPWRs), NPCIL will be the system designer and the plant operator.
- BHAVINI, another government company, is the system designer and the operator for fast reactors.
- All front-end and back-end fuel cycle facilities are owned and operated by government entities. R&D related to fuel cycle is carried out in laboratories owned and operated by the government.

Situation today

- Several research reactors including a fast reactor and a reactor using uranium-233 derived from thorium are working.
- A very good R&D infrastructure in nuclear science and engineering.
- A sound knowledge base.
- Competent human resource and a strong human resource development programme.
- Wide ranging industrial infrastructure.
- Indian industry is known for frugal engineering.

- 18 PHWRs, 2 BWRs and 2 VVER are operating.
- 4 PHWRs and a PFBR are under construction.
- Plants already approved include 2x1000 MW at Kudankulam to be completed by 2022-23, 2x700 MW at Gorakhpur, Haryana to be completed by 2024-25 and 10x700 MW PHWR approved on 17 May 2017 (Gorakhpur 3&4: 2x700; Chutka:2x700; Mahi Banswara: 4x700; Kaiga: 2x700) to be completed in about 12 years.

Future plans

- KK-5&6, 1000 MW at Kudankulam (TN), likely to be completed in 66/72 months.
- 6x1200 MW, VVERs at a new site, which is under approval; first two units likely to be completed before 2026-27 and the remaining before 2031-32.
- 6x1100 MW at Kovvada (AP), all AP1000, by Westinghouse, USA, with first two units likely to be completed before 2026-27 and the remaining before 2031-32.
- 2x600 MW FBRs at Kalpakkam (TN) and 4x600 MW FBRs at a new site to be constructed by Bhavini.
- Reactors at additional sites already approved: 2x700 at Bargi (MP), 4x700 at Bhimpur (MP), and 6x1000 at Haripur (WB).
- 6X1594 MW ESBWRs, at Chhaya Mithi Virdi (Guj), GE-Hitachi; USA.
- 6x1650 MW at Jaitapur (Maha), all EPRs by EdF France.
- Haripur (WB) site is suitable for 6x1000 MW units, but no progress in land acquisition.
- **Additional units, likely to be Indian PWRs to be set up at sites, yet to be announced**.
- **All efforts must be made to reach a target of 63 GW by 2032.**

IPWR: Some details

- Reactor Power: 900 MW(e)/ 2700 MW(t)
- Design Pressure: 17.7 MPa
- Design Temperature: 350 ^{o}C
- Service Life: 60 years
- Fuel: UO_2 with average enrichment of 4.5% and maximum enrichment of 5%
- Fuel Burn-up at discharge: 46,200 MW-d/teU

- A joint venture by NPCIL and L&T has ben set up for forgings
- A 9000 tonne forging press has already been set up
- The plan is to increase it to 17,000 tonne

Summary of all sites

Blue: operating (6780); Red: Under construction (3300); Green: Approved (12400); Purple: Sites selected or advanced stage of planning (47064)

Existing sites

- Tarapur, Maha: 2x160+2x540
- Rawatbhata, Raj: 1x100+1x200+4x220+2x700
- Kalpakkam, TN: 2x220+1x500 (PFBR)+2x600 (FBR)
- Narora, UP: 2x220
- Kakrapar, Guj: 2x220+2x700
- Kaiga, Kar: 4x220+2x700
- Kudankulam, TN: 2x1000+4x1000

Greenfield sites

- Gorakhpur, Haryana: 4x700
- Mahi Banswara, Raj: 4x700
- Chutka, MP: 2x700
- Bargi, MP: 2x700
- Bhimpur, MP: 4x700
- Jaitapur, Maha: 6x1650 (EPR)
- Kovvada, AP: 6x1100 (AP-1000)
- Chhaya Mithi Virdi, Guj: 6x1594 (ESBWR)
- Haripur, WB: 6x1000 ??
- A site in AP (under Approval): 6x1200 (VVER)
- A site yet to be identified: 4x600MW FBR

Challenges

- While announcing sites for construction of reactors by foreign vendors, it was made clear that the offer is subject to arriving at technical terms and conditions that are mutually acceptable and enable a viable tariff regime for electricity generated. This continues to be a challenge in negotiations.
- Site selection for additional plants.
- Human resource
  - Meeting quantity and quality requirements,
  - Providing motivation to stay in India.
- Public perception
  - Radiophobia
  - Low frequency, but high consequence accidents

In conclusion

- India has developed a comprehensive capability on every stage of nuclear fuel cycle: Mining, fuel fabrication, uranium enrichment, reactor design, construction, manufacturing equipment and components, commissioning, operation, reprocessing and waste management.
- Research and development is continuing to develop new reactor systems. Research capability exists within the Department of Atomic Energy and also in the academic institutions.
- Indian industry is capable of manufacturing equipment in the country.
- Demand for electricity is growing and will continue to grow as India's per capita electricity consumption is very low.
- Government is committed to growth of nuclear power as it recognises it as a low-carbon option for generation of electricity.

Nuclear community has to continue R&D and develop reactor systems with the aim of zero radioactive release even in case of an accident.

Thank You for your attention