Prospects & Challenges of Nuclear Energy Programme in India

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As my teacher and mentor, he has taught me more than I could ever give him credit for here. He has shown me, by his example, what a good scientist (and person) should be.
Total Installed Electric Power in India as on 31 May 2017: 3,77,460 MWe
at the time of independence in 1947: 1,500 MWe

Total Utility Power: 3,30,260 MWe
Captive Power: 47,200 MWe (31.3.2016)

India is the 3rd largest producer of electricity in the world but 240 million people in India have no access to electricity and annual per capita consumption of electricity is 1100 kWh which is less than half the world average.
The Ministry of Power, Govt. of India has set a target of 1,229.4 billion units (kWh) of electricity to be generated in the financial year 2017-18.

The government’s immediate goal is to double the current annual electricity generation and reach 2,000 billion units (kilowatt hours) in 2019-20 to provide 24x7 electricity for residential, industrial, commercial and agriculture use.
The energy gap is proposed to be filled in by carbon-free energy options, in particular, solar, wind, and nuclear.
Nuclear Power & Fuel Cycle Program in India Based on Limited Uranium but Vast Thorium Resources

**Stage I**: Indigenous PHWRs + Imported LWRs. Reprocess Spent Fuel & Stockpile Plutonium for FBRs.

**Stage II**: FBRs with U238-Pu239 core & Dep U/Th232 blanket. Recycle Pu & Stockpile U233 for Stage III

**Stage III**: Self-Sustaining Th232-U233 Thermal Breeders

Since 2009 India has been given approval by IAEA & NSG to import uranium. Hence, the Stage III is not likely to start in this century.
Status of Nuclear Power Reactors in India (August, 2017):

22 reactors in operation (6780 MWe): 2 x BWR 160 + 2 x VVER1000 + 16 x PHWR220 + 2 x PHWR

9 reactors are under construction (6700 MWe): 6 x PHWR 700 + 2 x VVER 1000 + 1 x PFBR 500

10 PHWR 700 approved in May 2017: Haryana (Gorakhpur - 2), Rajasthan (Mahi Banswara - 4), Madhya Pradesh (Chutka – 2) & Karnataka (Kaiga – 2)

Several large LWRs planned in collaboration with CEA, France (EPR 1650), Rosatom, Russia (VVER 1000) and Westinghouse (AP 1000) & General Electrics (ESBWR 1350), USA.
Map of India Showing Uranium Occurrences

(2,70,000 tons identified Uranium Resources < 260 US$/kgU as on August 2017)
Jharkhand:
- Operating U Mines: Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, Banduhurang & Mohuldih
- Operating U Mills: Jaduguda & Turamdih;

Meghalaya
- Mine & Mill planned: near Domiasiat

Andhra Pradesh
- U Mine and Mill in operation at Tummalapalle, Cuddapah
- Mine and Mill planned: Lambapur

Karnataka
- Mine and Mill planned: Gogi
Nuclear Fuel Fabrication in India for Operating PHWRs (CANDU) and 2 BWRs

- 10x PHWR 220 + 2x BWR 160 + 2x VVER 1000 under IAEA Safeguards using imported ‘U’ Fuel

Inputs to NFC:
- Uranium Concentrate from UCIL & imported Uranium
- Zircon Sand from IREL

Outputs from NFC:
- PHWR and BWR fuel bundles

For 10 Safeguarded PHWR 220, “U” for reload fuel for 10 yrs (~4000 tons) already contracted:
- Areva: 300 t (U concentrate)
- Russia: 2000 t UO2 pellets
- Kazak: 2000 t U concentrate

For 8 Unsafeguarded PHWRs (6x 220 + 2 x 540), “U” from UCIL is being used (needed: ~400t per year) for reload fuel
Uranium Fuel Cycle Activities in India

**PHWR Fuel Pin Bundle:** Zr alloy clad natural uranium (0.7% $^{235}$U) oxide fuel pellets

**LWR Fuel Rod Assembly:** Zr alloy clad enriched uranium (1.5-5% $^{235}$U) oxide pellets

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**Uranium Ore Concentrate**
(UOC: yellow cake)

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At NFC, starting from UOC & Zircon Sand, Zr Alloy Clad Natural UO2 Fuel Bundles are Manufactured Under One Roof – a Unique Nuclear Fuel Plant in the World

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The Nuclear Fuel Complex (NFC) at Hyderabad is the largest producer of PHWR Fuel in the world (1500 tons/year)
UO₂ imported
• Kazakhstan
• Russia
• Canada
In India, PHWR and Related Heavy Water, Uranium Oxide, Zirconium and Uranium Fuel Cycle Technology has Reached Industrial Maturity

Continuous operation for more than a year of different nuclear power reactors in India

Completion of Concreting of Inner Containment Dome of PHWR 700 MWe (Unit 3) at Kakrapar on July 16, 2017

Heavy Water Board (HWB), India is the largest producer (~ 425 tons/year) and supplier of nuclear grade heavy water in the world. The Manuguru plant is the largest heavy water plant in the world (~ 185 tons/year) and has produced ~ 5000 tons heavy water in the last 25 years.

The Nuclear Fuel Complex (NFC) at Hyderabad is the largest PHWR fuel fabrication facility in the world today and has produced annually more than 1500 tons Zircaloy 4 Clad Natural UO2 Fuel Bundles for the 16 PHWR 220 & the 2 PHWR 540 units in operation in India. NFC also produces the best quality Zirconium Sponge (< 50 ppm Hf) in the world and has crossed the 500 tons annual production mark in 2016-17.
Calandria Erection
Steam Generator Erection
Self – Reliance in Indian Industries

❖ Indian industries have successfully developed and adopted various technologies for manufacturing processes, inspection/quality surveillance etc., to meet the critical requirements of various International Nuclear Codes.

❖ They have been supplying components and equipment for our nuclear plants, in almost all areas.
Continuous Run (more than a year) recorded by Reactors (World)
VVER 1000 Reactor Assembly

VVER 1000 Fuel Assembly –
Zr -1. % Nb Clad Enriched UO2 ( ≤ 5 U235)

### World Commercial Spent Fuel Reprocessing Capacity

<table>
<thead>
<tr>
<th>LWR fuel</th>
<th>Capacity</th>
</tr>
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<tbody>
<tr>
<td>France, La Hague</td>
<td>1700</td>
</tr>
<tr>
<td>UK, Sellafield (THORP)</td>
<td>600</td>
</tr>
<tr>
<td>Russia, Ozersk (Mayak)</td>
<td>400</td>
</tr>
<tr>
<td>Japan (Rokkasho)</td>
<td>800*</td>
</tr>
<tr>
<td><strong>Total LWR (approx)</strong></td>
<td><strong>3500</strong></td>
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<table>
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<th>Other nuclear fuels</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK, Sellafield (Magnox)</td>
<td>1500</td>
</tr>
<tr>
<td>India (PHWR, 4 plants)</td>
<td>330</td>
</tr>
<tr>
<td>Japan, Tokai MOX</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total other (approx)</strong></td>
<td><strong>1870</strong></td>
</tr>
</tbody>
</table>

**Total civil capacity**: 5370

*now expected to start operation in 2016*

### World MOX Fuel Fabrication Capacity

<table>
<thead>
<tr>
<th>2009</th>
<th>2016</th>
</tr>
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<tbody>
<tr>
<td><strong>France, Melox</strong></td>
<td>195</td>
</tr>
<tr>
<td><strong>Japan, Tokai</strong></td>
<td>10</td>
</tr>
<tr>
<td><strong>Japan, Rokkasho</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Russia, Mayak, Ozersk</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Russia, Zheleznogorsk</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>UK, Sellafield</strong></td>
<td>40</td>
</tr>
<tr>
<td><strong>Total for LWR</strong></td>
<td><strong>250</strong></td>
</tr>
</tbody>
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The MOX Fuel Plant at AFFF, Tarapur, India has been responsible for Manufacturing the PFBR 500 Fuel Core (2 tons Pu)

The 3 spent PHWR fuel reprocessing plants in Tarapur (2 plants) and Kalpakkam (1 plant) have total capacity of 330 tons/year. These plants are not under IAEA safeguards.
Fast Breeder Reactor & Related Fuel Cycle Program in India

- India could leapfrog and develop a hitherto untried plutonium rich mixed plutonium uranium monocarbide fuel for the 40 MWt /13 MWe Fast Breeder Test Reactor (FBTR) at Kalpakkam, Tamil Nadu. The reactor is in operation since October 1985. The Carbide fuel has performed without any failure to high burn up of 160,000 MWD/T (HM). The mixed carbide fuel has been successfully reprocessed and the plutonium thus produced has been recycled in FBTR.

- A 500 MWe Prototype Fast Breeder Reactor (PFBR 500) at Kalpakkam is in the final stage of commissioning. Mixed uranium plutonium oxide (MOX) is the driver fuel. The PFBR fuel core and Reprocessed Depleted Uranium Oxide Blanket have been manufactured and awaiting loading.
Pilot Plant at BARC, Mumbai for Manufacturing Mixed Uranium Plutonium Monocarbide & Mononitride Fuel Pellets –

The hitherto untried (Pu 0.7, U0.3)C & (Pu 0.55, U 0.45)C Fuel Pellets for the Fast Breeder Test Reactor (FBTR) at IGCAR was and being manufactured in this plant.
Integrated Fast Reactor (IFR) Park [PFBR 500 + 2 x FBR 600 MWe + Fast Reactor Fuel Cycle Facility (FRFCC)] and Fast Breeder Test Reactor (FBTR) at Kalpakkam, Tamil Nadu.
A 18 lakh litres per day capacity sea water desalination plant operating on the Reverse Osmosis (RO) process and a Multi-Stage Flash (MSF) Sea Water Desalination Plant with a capacity of 45 lakh litres per day has been setup, as part of Nuclear Desalination Demonstration Project (NDDP) at Madras Atomic Power Station (MAPS), Kalpakkam, Tamil Nadu.

The hybrid MSF-RO plant is operated to produce distilled water for high end industrial applications and potable water for drinking and other applications.

Currently, the NDDP is the only one plant of its kind operating in the world.
Non-power Applications of Nuclear Energy in India
(Nuclear Agriculture Using $\gamma$-Radiation from Co $^{60}$/Cs $^{137}$ Radioisotopes)

Radiation Induced Mutant Varieties of Food Crops Seeds (oil seeds, pulses, cereals etc of high yield, shorter maturing time and resistant to biotic and abiotic stresses)

Cultivation of Different Mutant Varieties Groundnut Developed in BARC in Major Groundnut States in India – Gujarat, A.P., Rajasthan, Maharashtra, Karnataka & Orissa
A low gamma dose of less than 0.15 kGy is used for inhibiting sprouting, insect disinfection and destruction of parasites. A medium dose (1-10 kGy) is used for elimination of spoilage microbes in fresh fruits, meat and poultry and food pathogens in meat and poultry and hygienization of spices and herbs. Above 10 kGy is used for sterilization of food for special requirements and for shelf-stable foods without refrigeration.

Gamma irradiation (Co-60/Cs137) of food is carried out inside an irradiation chamber shielded by 1.5 to 1.8 m thick concrete walls. Food, either pre-packed or in-bulk, placed in suitable containers, is sent into the irradiation chamber with the help of automatic conveyor.
Summary and Concluding Remarks

- Nuclear power is a viable and carbon free option for generation of high base load electricity in India. Indigenous PHWRs, upcoming LWRs in collaboration with Rosatom, Russia, Areva, France, Westinghouse & General Electric, USA and FBRs will dominate nuclear power programme in India in this century. The process heat from these reactors could also be utilized for desalination of sea water.

- Non-power applications of Nuclear Energy include use of radiation & radioisotopes in food and agriculture, medicine and healthcare in industry and in research. Co-60 and Cs-137 are dominant gamma source and Tc-90 is the work horse radiopharmaceuticals.

- Natural UO2 and upto 5 % (U235) enriched UO2, clad in zirconium alloy are the reference fuels for all PHWR and LWR respectively in the world. LWRs will be the main reactor type in the world till the end of this century or till FBRs are commercialized.
FBRs and “closed” nuclear fuel cycle, involving reprocessing of spent nuclear fuel and recycling the actinides in FBRs, will ensure long term sustainability of nuclear power. The upcoming PFBR 500 MWe at Kalpakkam is the first step in that direction. A FBR park and an integrated fast reactor fuel cycle facility is being set up at Kalpakkam.

India has very limited uranium resources and that too of very low grade (0.03-0.06 % U3O8). Since 2009 India has access to international uranium market and has been importing natural uranium ore concentrate (yellow cake) from Areva and Kazatomprom and Cameco, Canada and natural and enriched UO2 fuel pellets from Russia. India might have to import plutonium to enhance the growth of FBR program.