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# Effective Management of Nuclear Wastes

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**Abstract—***India is shaping up fast into a major hub for global trade and commerce along with the other developed nations, thereby providing a platform for greater development and a more prosperous future for us. With the rise in infrastructural and social standards complemented by the recent developmental boom has come a larger demand for energy to support such advances. However, like the other developing nations, the energy demand has been met through the use of non-renewable fossil fuels, thereby leaving significant trails in the long road to development. The large carbon footprint and the resultant environmental degradation has led to the search for alternative viable fuel sources and resulted in the exploitation of nuclear resources for energy security. Several such nuclear thermal power plants are operational in India. Here we discuss the issues of the effective management of the nuclear waste generated by these plants.*

**Keywords***: Nuclear, power plants, waste, management*

## 1. INTRODUCTION

In the recent years, India has emerged as a major hub for growth and development providing stability to the south-east Asian region in terms of trade and power balance. The large strides of progress had been made possible through large public-private investments in key sectors of agriculture, manufacturing, health-care, communications and energy security. This has the cumulative effect of even further progress and a large shift of population from the clutches of penury to a more secure and improved living standards. Keeping in pace with the development, electricity generation since independence until now, has gone up from 5. 1 billion Kwh to 480. 7 billion Kwh. With the per capita electricity consumption increasing 6. 3 % annually, it is set to grow two-fold by 2020, and reach 5000-6000 KWh by 2050, requiring about 8000 TWh per year [1]. In the past, the energy demand had been dealt with through use of conventional carbon based fuels. With the renewable energy sector yet to live up to its potential (currently providing upto 30% of India's energy requirement), there has been a vocal advocacy towards larger role of nuclear resources for power generation; former President of India, A. P. J. Abdul Kalam being one of the most visible proponent of this cause. The move to greater use of nuclear fuel for power generation is significant because of the zero or negligible carbon emission from these plants and the low cost of power generation. However, with the increase in the number of nuclear plants to provide energy for civilian purpose, the radioactive waste generated from this plant becomes an issue. The radioactive waste generated remains active for thousands of years and could be a source of major environmental hazard. In this article, we explore the issues of nuclear waste storage, disposal, and management in India.

## 2. NUCLEAR POWER SECTOR IN INDIA

India's nuclear energy endeavours came into being with the setting up of The Atomic Energy Establishment at Trombay, in 1957 and were renamed as Bhabha Atomic Research Centre (BARC) ten years later. Being excluded from the 1970 Nuclear Non-proliferation Treaty, India civil nuclear power programme was developed mostly indigenously and thus flagged her march towards peaceful civil nuclear capabilities. Boasting of a third of the total world's thorium reserve, but with low reserves of uranium, her nuclear programme is mainly based on thorium through a three-stage plan. According to the India Energy Book 2012 [2], the three stages of India's Nuclear .

Programme are:

I. Natural uranium based Pressurized Heavy Water Reactors (PHWRs).

II. Fast Breeder Reactors (FBR) fueled by plutonium.

III. Breeder Reactors for utilization of thorium.

The present uranium reserve (in India) would support the stage one of the plan of about 10, 000 MW (million watts) power generation through the heavy water ($D_2O$) moderated and cooled PHWRs. In the second stage, the power output can be increased to about 300, 000 MW through use of FBRs, which uses plutonium as the fuel. The plutonium could be generated from reprocessed spent fuel resourced from the first stage. In the third stage, the thorium can be utilized to obtain uranium 233, to be used as fuel, in which case the power generation can be increased many-folds.

**List of power stations in India § Nuclear power**

Currently, twenty-two nuclear power reactors have a total install capacity of 6,780 MW (3.5% of total installed base)

| Power station | Operator | State | Type | Units | Total capacity (MW) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Tarapur | NPCIL | Maharashtra | BWR PHWR | 160 x 2 540 x 2 | 1,400 |
| Rawatbhata | NPCIL | Rajasthan | PHWR | 100 x 1 200 x 1 220 x 4 | 1,180 |
| Kudankulam | NPCIL | Tamil Nadu | VVER-1000 | 1000 x 2 | 2,000 |
| Kaiga | NPCIL | Karnataka | PHWR | 220 x 4 | 880 |
| Kakrapar | NPCIL | Gujarat | PHWR | 220 x 2 | 440 |
| Kalpakkam | NPCIL | Tamil Nadu | PHWR | 220 x 2 | 440 |
| Narora | NPCIL | Uttar Pradesh | PHWR | 220 x 2 | 440 |
| **Total** | | **1000x2, 540x2, 220x14 200x1, 160x2, 100x1** | | | **6,780** |

The projects under construction are:

| Power station | Operator | State | Type | Units | Total capacity (MW) | Expected Commercial Operation |
|---|---|---|---|---|---|---|
| Rajasthan Unit 7 and 8 | NPCIL | Rajasthan | PHWR | 700 x 2 | 1,400 | Unit 7: June 2016 Unit 8: December 2016 |
| Kakrapar Unit 3 and 4 | NPCIL | Gujarat | PHWR | 700 x 2 | 1,400 | Unit 3: Late 2016/Early 2017, Unit 4: 2017 |
| Madras (Kalpakkam) | Bhavini | Tamil Nadu | PFBR | 500 x 1 | 500 | March 2017 |
| Kudankulam | NPCIL | Tamil Nadu | VVER-1000 | 1000 x 2 | 2,000 | 2022-2023 |
| **Total** | | | | **1000x2, 700x4, 500x1** | | **5,300** |

**The planned projects are:**

| Power station | Operator | State | Type | Units | Total capacity (MW) |
|---|---|---|---|---|---|
| Jaitapur | | Maharashtra | EPR | 1650 x 6 | 9,900 |
| Kovvada | | Andhra Pradesh | AP1000 | 1100 x 6 | 6,600 |
| MithiVirdi (Viradi) | | Gujarat | | 1000x6 | 6,000 |
| Haripur | | West Bengal | VVER-1000 | 1000 x 6 | 6,000 |
| Kudankulam | | Tamil Nadu | VVER-1000 | 1000 x 2 | 2,000 |
| Gorakhpur | NPCIL | Haryana | PHWR | 700 x 4 | 2,800 |
| Bhimpur | NPCIL | Madhya Pradesh | PHWR | 700 x 4 | 2,800 |
| Mahi Banswara | NPCIL | Rajasthan | PHWR | 700 x 4 | 2,800 |
| Kaiga | NPCIL | Karnataka | PHWR | 700 x 2 | 1,400 |
| Chutka | NPCIL | Madhya Pradesh | PHWR | 700 x 2 | 1,400 |
| Madras | BHAVINI | Tamil Nadu | FBR | 600 x 2 | 1,200 |
| Tarapur | | | AHWR | 300 x 1 | 300 |
| | **Total** | | | **1650x6, 1594x6, 1100x6 1000x10, 700x16, 600x2, 300x1** | **39,200** |

**Nuclear waste**

Nuclear waste is the material that nuclear fuel becomes after it is used in a nuclear reactor. After the nuclear reactions the contents are not the same. Before power production, the fuel was mostly Uranium (or Thorium), oxygen, and steel but after the reactions, many Uranium atoms have split into various isotopes of almost all of the transition metals. The waste also known as spent fuel, is dangerously radioactive, and remains so for thousands of years. They can be classified into three categories - low level, intermediate level and high-level waste according to the quantity and type of radioactivity contained in them. All radioactive waste, which is not high-level radioactive waste or intermediate-level waste or transuranic waste, is classified as low-level radioactive waste. Radioactive content in these low-level radioactive waste is much less and are made up of isotopes having much shorter half- lives than most of the isotopes contained in high-level radioactive waste or intermediate-level waste or transuranic waste. On storing these wastes for a span of 10 to 50 years will allow most of the contained radioactive isotopes in these wastes to decay, after which point the wastes can be disposed of as normal refuse. Investigations have shown that exposure of mammals to low levels of radiation may indeed be beneficial, causing ‘increased life span, greater reproductive capacity, better disease resistance, increased growth rate, greater resistance to higher radiation doses, better neurological function, better wound healing and lower tumour induction and growth [3]. Intermediate-level Waste contains higher amounts of radioactivity and may require special shielding. It typically comprises resins, chemical sludges and reactor components, as well as contaminated materials from reactor decommissioning. It may be solidified in concrete or bitumen for disposal.

Generally short-lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) is disposed off deep underground. High-level radioactive waste is the waste consisting of the spent fuel, the liquid effluents originating from the reprocessing of spent fuel and the solids intowhich the liquid waste is converted. It consists of core nuclear reactor materials including uranium, plutonium and other highly radioactive elements originating from fission, made up of fission fragments and transuranics. The radioactive fission fragments decay to different stable elements via different nuclear reaction chains in about 1000 years causing emissions to innocuous levels of radioactivity. On the other hand, transuranics take nearly 500, 000 years to reach such levels. Heat radiations lasts for over 200 years. Almost all of the radioactive isotopes in high-level waste emit large amounts of radiation and have extremely long half-lives (some longer than 100, 000 years), consequently long period of time are essential before they reach safe levels of radioactivity.

**Nuclear Waste Management**

Radioactive wastes occur at every stage of the nuclear fuel cycle which is the process of producing electricity from nuclear materials. The fuel cycle consists of mining and milling of the uranium ore, its processing and enrichment into nuclear fuel, its use in the reactor, the treatment of the used fuel taken from the reactor after use, and finally, disposal of the wastes. The fuel cycle is often considered as two parts - the "front end" which stretches from mining through to the use of uranium in the reactor - and the "back end" which covers the removal of used fuel from the reactor and its subsequent treatment and disposal. This is where radioactive wastes are a major issue. Waste from the front end of the nuclear fuel cycle is usually alpha-emitting waste emanating from the extraction of uranium. It also contains radium and its decay products. Uranium dioxide (UO2) concentrate from mining is not very radioactive. It is refined from yellowcake (U3O8), and then converted to uranium hexafluoride gas (UF6). As a gas, it undergoes enrichment to increase the U-235 content from 0. 7% to about 4. 4% (LEU). It is then turned into a hard ceramic oxide (UO2) for assembly as reactor fuel elements. [4]. The main by-product of enrichment is depleted uranium (DU), principally the U-238 isotope, with a U-235 content of ~0. 3%. It is stored, either as UF6 or as U3O8. Some is used in applications where its extremely high density makes it valuable, such as the keels of yachts, and anti-tank shells. [5]. It is also used with plutonium for making mixed oxide fuel (MOX) and to dilute, or downblend, highly enriched uranium from weapons stockpiles which is now being redirected to become reactor fuel. The back end of the nuclear fuel cycle, consisting mostly of spent fuel rods, contains fission products that emit beta and gamma radiation, and actinides that emit alpha particles, such asuranium-234, neptunium-237, plutonium-238 and americium-241, and even sometimes some neutron emitters such as californium (Cf). These isotopes are formed in nuclear reactors. Used fuel contains the highly radioactive products of fission. Many of these are neutron absorbers, called neutron poisons in this context. These eventually build up to a level where they absorb so many neutrons that the chain reaction stops, even with the control rods completely removed. At that point the fuel has to be replaced in the reactor with fresh fuel, even though there is still a substantial quantity of uranium-235 and plutonium present. In the United States, this used fuel is stored, while in countries such as Russia, the United Kingdom, France, Japan and India, the fuel is reprocessed to remove the fission products, and the fuel can then be re-used. If the used fuel is reprocessed then it is dissolved and separated chemically into uranium, plutonium and high-level waste solutions. About 97% of the used fuel can be reused and only 3% is discarded as high-level waste. The recyclable portion is mostly uranium depleted to less than 1% U-235, with some plutonium, which is most valuable. Another important method of waste management is solidification. Liquid high-level wastes are evaporated to solids, mixed with glass-forming materials, melted and poured into robust stainless steel canisters which are then sealed by welding. Another method of immobilizing high-level radioactive wastes is known as SYNROC' (synthetic rock), where the radioactive wastes are incorporated in the crystal lattices of the naturally-stable minerals in a synthetic rock. Final disposal of high-level waste is delayed for 40-50 years so that its radioactivity decays, after which less than one thousandth of its initial radioactivity remains, and it is much easier to handle. Next canisters of vitrified waste, or used fuel assemblies, are stored under water in special ponds, or in dry concrete structures or casks, for at least this length of time. The ultimate disposal of vitrified wastes, or of used fuel assemblies without reprocessing, requires their isolation from the environment for a long time. The common method is to bury them in stable geological formations of at least 500 meters depth. After being buried for about 1000 years most of the radioactivity will have decayed. The amount of radioactivity then remaining would be similar to that of the corresponding amount of naturally-occurring uranium ore from which it originated, though it would be more concentrated.

**Nuclear Waste Management**

To avoid any significant environmental releases over a long period of time after disposal, a 'multiple barrier' disposal concept is used. The radioactive elements in high-level (and some intermediate-level) wastes are immobilized and securely isolated from the biosphere.

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