NUCLEAR WASTE: INDIA'S GORDIAN KNOT?

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The Nuclear Power Corporation of India Ltd. (NPCIL) has planned to launch 16 more reactors – eight 700 MW Pressurised Heavy Water Reactors (PHWRs) and eight Light Water Reactors (LWRs) – at an outlay of Rs 230,000 crore during the 12th Five Year Plan period (FYP) (1012-17).[1] This is in addition to NPCIL's four 700 MW PHWRs under construction at an outlay of Rs 22,000 crore. In the pursuit of ensuring energy security and harnessing nuclear source as a viable option in the national energy mix, around three dozen more nuclear plants have been proposed. In the process, the requirement of nuclear fuel will become significant, necessitating more domestic and external sources of uranium to tap. But, addition of single mw electricity from the nuclear source during the years ahead will add to the existing radioactive waste. Apprehensions have been raised about the safe disposal of radioactive waste generated in India.[2] Allegedly, there is no official disclosure about the volume of radioactive wastes generated so far. As is the case with other nuclear powers that have not been able to find a lasting solution, will the nuclear waste generated in India be India's Gordian Knot?

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1. "Nuclear Power Corporation of India to Launch 16 New Nuclear Reactors", *The Economic Times*, June 1, 2012.
2. Rashme Sehgal, "India Needs Proper N-Waste Disposal Tech", *The Asian Age*, May 13, 2008.

THE PROCESS AND THE BASICS

In India, radioactive materials are used in many sectors like medicine, industry, agriculture, energy, etc. During all these activities, some amount of 'waste' – "material left over for which no further use is foreseen" – is produced which need to be safely disposed off. "The underlying objective that governs the management of all such waste is protection of man and environment today and in future."[3] This study examines only the waste generated in the Indian nuclear energy sector during the various stages of nuclear fuel cycle which includes mining and milling of uranium ore, fuel fabrication, reactor operation, and spent fuel reprocessing. In India, waste out of reactor operation includes waste generated from PHWRs, BWRs and other activities, waste may arise out of accident condition and waste generated out of decommissioning of plants which may need safe disposal.

Safe disposal denotes: "Emplacement of waste in a repository without the intention of retrieval or approved direct discharge of waste into the environment with subsequent dispersion." The technical process, starting from origin of the waste till the final process of safe disposal, involves many coordinated steps. Most important is the 'conditioning' or 'treatment' that transforms the waste into a form suitable for transport and/or storage and/or disposal. The administrative and chain of operational activity involved in the handling, treatment, conditioning, transportation, storage and disposal of the waste is called 'waste management'. Broadly, radioactive waste is generated in three forms – liquid, solid and gaseous – which are further characterised on the basis of their degree of radioactivity and hazard involved: (a) High Level (HL), (b) Intermediate Level (IL), and (c) Low Level (LL). Each category requires separate process of handling. In India, "the safe and effective management of radioactive waste has been given utmost importance from the very inception of nuclear industry."[4]

3. K. Raj, K.K. Prasad, N.K. Bansal, "Radioactive Waste Management Practices in India", *Nuclear Engineering and Design*, March 11, 2004, p. 914.
4. Ibid.

VOLUME OF WASTE

Much concern has been in the air regarding the volume of radioactive waste that India would generate and can amicably dispose them when the major nuclear power countries have not been able to do so? In the Parliament, questions have been repeatedly raised "whether government has … assessed the quantity of nuclear waste likely to be generated by the nuclear power plants in the country".[5] And, the standard explanation furnished during all these debates is that "the quantity of this waste in our country is much smaller due to our adoption of the closed fuel cycle".[6] The interim storage facility is adequate and can store waste generated for 30-40 years by which time it will lose some radioactivity. Therefore, it is asserted that, "nuclear waste is not an immediate problem for India", and at the current level of nuclear power generation, India will not have any problem related to waste management which it may face by the year 2020-2030.[7]

Undoubtedly, considering the previous and current rate of nuclear energy production, the volume of waste already generated in India could be very small. The nuclear waste disposal issue in India at present, therefore, cannot be compared with the situation in the United States. Deliberate or otherwise, there is not available exact information in the public domain on the current inventory of radioactive waste in India and the amount that will be added in the decades ahead. Therefore, the issue has become a subject of intense speculation. Answering to the question by N.R. Govindarajar on handling of nuclear waste in the Rajya Sabha, Prithviraj Chavan, the Minister of States in the PMO and Ministry of Personnel, Public Grievances and Pensions, revealed on February 26, 2009 that:

5. During the last four years (2009-2012) four unstarred questions have been raised in the Lok Sabha and Rajya Sabha on February 26, 2009; July 28, 2010; August 17, 2011; and March 14, 2012, specifically regarding the quantity of nuclear waste generated in India.
6. *Lok Sabha Debate*, Unstarred Question no. 2747, "Nuclear Waste", asked by Nishikant Dubey, answered by V. Narayanasamy on August 17, 2011.
7. "Nuclear Waste not an Immediate Problem for India: Ramesh", *Times of India*, January 03, 2011.

> In India about 500-600 litres of high level waste is generated per tonne of spent fuel processed. Also about 1000 litres of intermediate level waste is generated per tonne of spent fuel. The quantities generated depend on the type of fuel, cooling period before reprocessing and the process adopted in the reprocessing plants. Low level nuclear waste is generated during normal operation and maintenance of nuclear plants. About 20,000-30,000 m3 of low level of nuclear waste is generated from a typical twin 220 Mwe PHWR nuclear plants per year.[8]

To estimate the approximate amount of waste produced, one needs to rely either on secondary sources based on individual predilections or to calculate the amount of fuel irradiated, taking into account the average figures revealed during the Parliament debate. Since the exact amount of fuel irradiated is again unknown, one need to calculate backward from the amount of nuclear energy produced over the years. Mostly, the media and the individual scholars have advanced their own estimation some times exaggerating and at other times overestimating leading to public outcry. For example, according to the study by MV Ramana a decade ago (2001), waste produced out of uranium mining and milling was 4.1 million tonnes; waste generated out of fuel fabrication was 2000 m3; low- and intermediate-level waste generated out of reactor operations is 22,000 m3 and 280 m3 respectively; from spent fuel storage (not to be reprocessed) 400 tonnes; from reprocessing 5000 m3 high-level waste, 35000 m3 intermediate-level waste, and 210,000 m3 low-level waste was generated.[9]

8. *Rajya Sabha Debate*, Unstarred Question no. 1012, "Handling of Nuclear Waste", by N.R. Govindarajar, answered by Prithviraj Chavan, on February 26, 2009.
9. MV Ramana, "Estimating Nuclear Waste Production in India", *Current Science*, vol 81, no 11, December 10, 2001, p. 1461.

Total Nuclear Waste Generation in India (Ramana, 2001)

Step in nuclear fuel cycle	Waste estimate (2 significant digits)
Uranium mining and milling	4.1 million tonnes
Fuel fabrication	2000 m^3
Reactor operations (low-level waste)	22000 m^3
Reactor operations (intermediate-level waste)	280 m^3
Spent fuel storage (not to be reprocessed)	400 tonnes
Reprocessing (high-level waste)	5000 m^3
Reprocessing (intermediate-level waste)	35000 m^3
Reprocessing (low-level waste)	210000 m^3

Source: *Current Science*, Vol. 81, No. 11, December 10, 2001, p. 1461.

Cumulative Low Level and Intermediate Level Waste Production (Ramana, 2001)

Name	Date of commencement	**Intermedate level waste (m^3)**	Low level waste (m^3)
RAPS 1	16 December 1973	35.1	2700
RAPS 2	1 April 1981	24.7	1900
MAPS 1	27 January 1984	20.7	1600
MAPS 2	21 March 1986	18.2	1400
NAPS 1	1 January 1991	13.0	1000
NAPS 2	1 July 1992	10.4	800
KAPS 1	6 May 1995	9.1	700
KAPS 2	1 September 1995	6.5	500
TAPS 1	28 October 1969	49.6	3875
TAPS 2	28 October 1969	49.6	3875
CIRUS	10 July 1980	32.0	2400
Dhruva	10 August 1985	12.0	900
Total		281.0	21650

Source: *Current Science*, Vol. 81, No. 11, December 10, 2001, p.

According to NS Sunder Rajan, the former Head of Waste Management Division, Bhabha Atomic Research Centre (BARC), with the aim to produce 10,000 MWe by the year 2000, India would generate 107,000 m3 of primary solid wastes, 771,00 m3 of low-level waste concentrates, 19900 m3 of intermediate-level wastes, and 8000 m3 of high-level wastes.[10] The production rate estimated by him for the year 2000 is in sharp contrast to the figures during 1985.

India's Estimated Waste Arisings (Rajan, 1986)

India's Estimated Waste Arisings

Primary solid wastes and low-level waste concentrates constitute the bulk of the estimated waste arisings in India up to the year 2000, at a projected electric power production of 10,000 megawatts. These consist of contaminated process equipment, protective clothing, used particulars filters, concentrated precipitates, and sludges from the low-level liquid waste treatment plants. The volume of the intermediate- and high-level waste generated in small, yet it constitutes the bulk of the radioactivity.

	1985	2000
Installed capacity (megawatts-electric)	1,350	10,000
Primary solid waste" (cubic metres)	1,850	107,000
Low-level waste concentrates (cubic metres)	3,000	77,100
Intermediate-level wastes (cubic metres)	450	8,000

* Up to 10^4 rontgen per hour

Source: *IAEA Bulletin*, (Spring) 1986, p. 40.

If the above trend is followed to estimate waste generation out of India's envisaged nuclear energy programme, by 2020 India would pile up double the volume of waste currently reserved in different facilities. If the government assurance on existing facilities' sufficient waste storage capacity is to be believed, India can comfortably manage additional nuclear wastes for the next three decades. But, as India has expedited domestic uranium exploration activities in recent days, the waste out of mining and milling would be manifold than the previous decades. The commercial uranium recovery plant at Jaduguda treats around 1000 tonnes of ore per day from the

10. N.S. Sunder Rajan, *IAEA Bulletin*, (Spring) 1986, at http://www.iaea.org/Publications/Magazines/Bulletin/Bull281/28104693740.pdf, p. 40.

Jaduguda mine, containing around 0.05% U_3O_8.[11] Taking into account the low quality of uranium ore reserved in India, the amount of tailings out of extensive mining would pose "reclamation" challenge of tailing ponds.[12] Negative perception of the public about mining as a polluting industry would complicate it further.

As India follows a closed fuel cycle, the second stage of its three stage programme will start soon where plutonium produced during the first stage as waste will be used as fuel.

As India follows a closed fuel cycle, the second stage of its three stage programme will start soon where plutonium produced during the first stage as waste will be used as fuel, the amount of high-level waste will reduce drastically. India has around 40 years of experience in the spent fuel reprocessing based on Plutonium Uranium Extraction (PUREX) process which has given the confidence that this technology can be successfully employed for the recovery of both uranium and plutonium with yield exceeding 99.5%.[13] Moreover, the high-level waste in India, essentially generated at reprocessing plants, is "much smaller due to the closed fuel cycle" it follows. These wastes are "vitrified into a glassy form, contained in multiple barrier containers and stored for an interim period of three to four decades in engineered vaults with necessary surveillance facilities".[14] Indian government is aware and has carefully assessed the quantity of nuclear waste generated, and accordingly a systematic management guideline and philosophy is adopted for integrated recycling, management, and geological repository in the long-run.

11. G.V. Rao and S. Prakash, "An Approach to Reduce Load on the Acid Leaching Circuit of the Commercial Uranium Recovery Plant at Jaduguda, India", *Magnetic and Electrical Separation*, vol 9, 1998, p. 27, at www.downloads.hindawi.com/archive/1998/032360.pdf
12. UCIL, "Uranium Mining and Milling Industry in India", at http://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%201/9_63_Gupta_India.pdf
13. At http://www.barc.ernet.in/publications/eb/golden/nfc/toc/Chapter%206/6.pdf, p. 51.
14. *Lok Sabha Debate*, Unstarred Question No 2747, "Nuclear Waste", asked by Nishikant Dubey, answered by V. Narayansamy on August 17, 2011.

GUIDELINE AND PHILOSOPHY

To keep the effective doses of radiation to individual and the environment As Low As Reasonably Achievable (ALRA), the Atomic Energy Regulatory Board (AERB) prescribes necessary codes and safety guidelines (2004) on safe handling, treatment, storage, transport and disposal of radioactive waste in conformity with the formulations by International Commission on Radiation Protection (ICRP). The guideline prescribes that a Waste Management Plant (WMP) along with a nuclear surface disposal facility shall be available prior to the commencement of nuclear power plant operation as a mandatory 'operational requirement'.[15] The plant management interact with the designer of WMP during design and construction phase to ensure plant capability to meet waste management objectives. So far, all seven Indian WMPs are co-located with waste generating facilities which help avoiding undue radiation exposure during transportation.[16]

The first philosophy followed in India is "waste minimisation" (clause 2.3.1 of Guidelines No. *AERB/NPP/SG/O-11*) at all stages of design, operation and maintenance through "volume reduction" and innovative treatment process. India's overall policy is based on universally adopted philosophy of (i) delay and decay of short lived radionuclides, (ii) concentration and containment of radioactivity as much as practicable, and (iii) dilution and dispersion of low-level activity to environment well below the nationally accepted levels.[17] As listed by the Nuclear Recycle Group of BARC, India's national policy for radioactive waste management broadly includes the following:

- Discharge through gaseous, liquid and terrestrial routes are as low as reasonably achievable.
- Low and intermediate level solid/solidified waste are emplaced in specially engineered near surface shallow land repository.
- High-level and alpha contaminated liquid waste from spent fuel

15. AERB, *AERB Safety Guide – Management of Radioactive Waste Arising from Operation of Pressurised Heavy Water Reactor Based Nuclear Power Plants*, "Operational Requirements", Clause 2.3.1, Guidelines No. AERB/NPP/SG/O-11, March 2004, p. 3.
16. Raj, Prasad, and Bansal, 2004, n. 4.
17. Ibid, p. 915.

processing and other radio metallurgical operations are immobilised in a suitable matrix and stored in an interim storage facility with appropriate cooling and surveillance for a period necessary. Thereafter, these waste products will be emplaced in a suitably engineered deep geological repository.

The waste generated out of uranium mining and milling requires separate set of management.

- Alpha contaminated waste not qualifying for nuclear surface disposal is provided suitable interim storage pending its disposal in a deep geological repository.
- Spent radiation sources are either returned to the original supplier or handed over to a radioactive waste management agency identified by the regulatory body.
- Co-location of near surface disposal facility with the nuclear installations.
- As spent fuel is a resource material in India and needs to be processed for recovery and recycle of fissile material, each reprocessing plant has a collocated vitrification plant.
- The regulatory body determines the period for which active control for the shallow land repository should be maintained by the waste management agency. Institutional control may span a period of 300 years comprising 100 years of active and 200 years of passive control so as to allow decay of most of the radionuclides.

The waste generated out of uranium mining and milling requires separate set of management. As Indian uranium ores are mined by the method of wet mining, proper ventilation is ensured to protect against undue radiation concentration. According to N.S. Sunder Rajan, the then Head, and Waste Management Division of BARC: “The ‘barren liquor’ produced from the uranium recovery process is treated with lime and barites for precipitation of radium and other uranium daughter products. Along with the mill tailings, it is disposed into a tailing pond, which is a natural depression to ensure settling”.[18]

18. Rajan, 1986, p. 38, n. 11.

PROCESS AND TECHNIQUE

In answer to an unstarred question by Vinay Kumar and Nishikant Dubey in Lok Sabha, the Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office V Narayanasamy on in March 9, 2011 and August 17, 2011 respectively informed that the government has, "an effective plan in place for the disposal of nuclear waste" and "latest technology" is used for safe management of the nuclear waste.[19] The entire process is claimed to be "a transparent" system and "efforts are continuously on to update and have a balanced Nuclear Waste Management System (NWMS)".[20] For example, extensive efforts are made in the field of research and development for new technologies to manage wastes generated in the future from the new reactor systems like advanced HWRs and Fast Breeders Reactors (FBRs).

The High Level radioactive wastes in India are stored temporarily within the plant boundary, and with regard to Low- and Intermediate-Level Waste (LILW), India's experience has been claimed to be fairly good.[21] This is mainly because of the comprehensive stages of waste management process that includes characterisation, treatment, conditioning, storage, disposal, surveillance/monitoring, etc., that is adopted. Characterisation is the first process to determine the physical, chemical and radiological properties for record keeping, segregation of materials for reuse, exemption and disposal or storage. Storage of wastes in designated facilities is mainly undertaken to ensure isolation and environmental protection. Some wastes require short storage period for decay of radionuclides and many other types are stored for interim period for subsequent treatment. In the process, waste is collected, segregated, decontaminated through chemical adjustments. Some waste requires conditioning to transform radioactive waste into solid form suitable for handling. It involves immobilisation of the waste and putting

19. *Lok Sabha Debate*, "Nuclear Waste", Unstarred Question No 2747, asked by Nishikant Dubey, answered by V Narayanasamy on August 17, 2011; *Lok Sbha Debates*, "Disposal of Nuclear Waste", Question No 2088, Question asked by Vinay Kumar, answered by V Narayanasamy on March 9, 2011.
20. *Rajya Sabha Debate*, "Nuclear Waste Management System", question raised by Ramachandra Khuntia, answered by the Minsiter of State for Parliamentary Affairs, Personnel, Public Grievances & Pensions and PMO V. Narayanasamy on March 10, 2011.
21. Rajan, 1986, n. 11, p. 37.

them in containers and additional packaging. The final step in the process is the emplacement of radioactive waste in a repository with reasonable assurance of safety. As per current practice, most types of wastes are disposed by concentration and containment but some effluents are discharged into the environment within authorised limits, specific to sites and vary from coastal to inland sites, with subsequent dispersion.[22]

India practices variety of "self reliant" management and treatment procedures for all types of radioactive wastes generated during operation of its nuclear facilities. For treatment of gaseous waste, it is ensured that all nuclear installations have an elaborate off-gas cleaning system. Indian scientists claim to have developed "very efficient gas cleaning techniques, employing different types of wet scrubbers like venturi, dust, packed bed, cyclone separators, high-efficiency low-pressure drop demisters, chillers and High-Efficiency Particulate Air (HEPA) filters to practically retain most of the particulate radionuclides".[23] All Indian nuclear facilities have emergency air clean-up systems, indigenously developed filter banks, ruthenium absorber, particulate respirator like the HEPA filters, charcoal impregnated sampling filter, and stack-sampling cartridges. The HEPA filters are provided in the exhaust systems which are standard filters of capacity m^3 /h with collection efficiency of more than 99.97% for submicron particles.[24] To contain effectively the environmental release of radioactive-iodine – the main radiological concern; proper ventilation and containment systems of combined particulate and iodine filters are deployed. To absorb and retain the radio-iodine, coconut shell-based activated charcoal impregnated with potassium iodide and potassium hydroxide is used.[25]

Large volume of low and intermediate level liquid waste are generated from reactor operations, off-gas scrubbers of nuclear facilities, fuel reprocessing facilities, active floor drains, decontamination centre, laboratories, drain from change room and showers as well as during

22. Ibid, p. 917.
23. Ibid.
24. S. Kumar, S.S. Ali, M. Chander, N.K. Bansal, K. Balu, "Integrated Radioactive Waste Management from NPP, Research Reactor and Back End of Nuclear Fuel Cycle – An Indian Experience", Waste Management Division, BARC, IAEA-SM-357/38, p. 8.
25. Ibid.

Depending upon the nature of the waste generated, different methods of treatment and disposal are adhered to.

management of high and intermediate level waste. For the treatment of this type of waste, chemical precipitation/coprecipitation process, ion exchange, evaporation, reverse osmosis, etc., are employed.[26] Some of the liquid waste management plants in India are:

- Effluent Treatment Plant in Trombay
- Solar Evaporation Pond in Rajasthan
- Ion Exchange Plant in Tarapur
- Waste Immobilisation Plants in Trombay, Kalkakkam
- Rasin Fixation Plants in Narora, Kakrapar and Tarapur
- Reverse Osmosis Plant in Trombay
- Vitrification Facility in Trombay

The high level liquid wastes generated during reprocessing of spent fuels are managed by a three-step strategy: (1) immobilisation of waste oxides in stable and inert solid matrices; (2) interim retrievable storage of the conditioned waste under continuous cooling; (3) disposal in deep geological repository.[27] First, these wastes are concentrated by evaporation, stored in stainless steel tanks and kept under constant cooling and surveillance. India is claimed to be "one of the seven countries in the world to have mastered the technology of High Level Waste Management".[28]

The management of solid waste has been in practice in India since the early sixties and six solid waste management sites are presently under operation.[29] Depending upon the nature of the waste generated, different methods of treatment and disposal are adhered to. All solid waste management plants are equipped with segregation, repacking, compaction, incineration and embedment process.[30] All spent radiation

26. Ibid.
27. K. Raj, et al, p. 920, n. 4.
28. *Rajya Sabha Debates*, Unstarred Question No. 1012, "Handling of Nuclear Waste", by Shri N.R. Govindarajar, answered by Shri Prithviraj Chavan, February 26, 2009.
29. M.P. Gupta, et al, "Indian Experience in Near Surface Disposal of Low Level Radioactive Solid Waste", Proceedings of the Symposium on Experience in the Planning and Operation of Low Level Waste Disposal Facilities, IAEA, Vienna (1996),
30. Kumar, et al, p. 4, n. 25.

sources from radiography units, hospitals, industry, agriculture, medicine, research centres, etc. are collected at Trombay or Kalpakkam and packed in standard steel drums. As some wastes, like contaminated equipments or components are not amenable to any treatment, they are packaged in appropriate containers. To reduce the volume of the waste, compaction and incineration method is followed. Presently, incinerators are in operation at Trombay, Kalpakkam and Narora.

The approach followed in the disposal of solid waste is multi-barrier: first, beta gamma emitting wastes are disposed in earth/stone lined trench, Reinforced Concrete (RC) trench and the tile hole (waste packages up to radiation field of 200-500 mGy/hr). Alpha contaminated waste is disposed of along with beta gamma waste. The trench is unlined shallow excavation in soil for disposal of low level waste and are covered by one metre of soil and backfill materials like vermiculite and bentonite to uptake the radionuclides and prevention of spread of radioactivity.[31]

The wastes with higher alpha activity are temporarily stored to be finally deposited in a permanent geological site in future. But before they are shifted to the permanent repository, they need to be cooled to a level where transportation and disposal become viable. One such storage and surveillance facility co-located with a vitrification plant is operational at Tarapur with a capacity for storing nearly 1700 over packs with an inventory of nearly 80,000,000 TBq of radioactivity.[32] Extra precautions are being taken for temporary storage sites at Narora and Rajasthan, considering seismic and less soil coverage respectively. The trenches are constructed totally or partially above the ground with sufficient arrangement for remote handling and preventing ingress of rainwater. For viewing the hot cells, either the direct viewing systems such as radiation shielding windows or radiation resistant CCTV systems are used. A radio controlled remote inspection device with remote traction and steering capability has been developed for in-service surveillance of storage tanks for high and intermediate level waste tank.

31. Ibid, p. 5.
32. Raj et al, p. 928, n. 4.

India has also begun experimenting on a new technological option, the accelerator-driven sub-critical reactor systems (ADS), which will incinerate nuclear waste.[33] Such a programme has been evolved for stage-wise development of systems and technologies in India. This is based on proton linear accelerator development in the first stage and cyclotron as a complementary one.[34] The ADS system "merges accelerator and fission reactor technologies into a single system that has the potential to efficiently generate electricity for nuclear fission and/or transmute the long lived waste material".[35]

WASTE OUT OF DECOMMISSIONING

India is known to have considerable experience in the field of decommissioning of nuclear facilities and major systems and successfully replaced several times the coolant channels after deconditioning.

Nuclear waste out of decommissioning of nuclear facilities needs special care; therefore, the AERB has made it mandatory for all nuclear installations to incorporate provisions for in situ decontamination and de-commissioning provisions from design stage until end of the operational phase. Keeping the future need for decommissioning of nuclear plants in India, a six-axis gantry servo robot has been developed especially for decommissioning of glove boxes or similar equipments.[36]

In the year 2000, it was decided to decommission the the thorium plant at Trombay, commissioned in 1955, due to ageing, structural weakness, extensive corrosion, and build up of radiation dose on the process equipment. The decommissioning was planned so as to minimise both the radiation exposure to working personnel and the generation of radioactive waste. The steps taken were decontamination of tanks and equipments, removal

33. G.S. Mudur, "Site Hunt for Nuclear Graveyard", *The Telegraph* (Kolkata), February 15, 2012.
34. S.S. Kapoor, "Accelerator-driven Sub-critical Reactor System (ADS) for Nuclear Energy Generation", *Panama Journal of Physics*, vol 59, no. 6, December 2002, p. 948.
35. A. Stanculescu, "Accelerator Driven System (ADS) and Transmutation of Nuclear Waste: Options and Trends", IAEA, http://users.ictp.it/~pub_off/lectures/lns005/Number_2/Stanculescu.pdf
36. "Waste Management: Remote Handling & Transportation", Nuclear Fuel Cycle, *BARC HIGHLIGHTS* at http://www.barc.gov.in/publications/eb/golden/nfc/toc/Chapter%2014/14.pdf, p. 95.

of the tanks and equipment from the plant and subsequent removal of civil structures, segregation of waste, and disposal of radioactive waste in dykes. The radioactive solid waste about 2,150 m3 consisting mainly of 70% concrete and 30% metallic waste was disposed in the dykes of size 25m x 25m x 3.5m and 33m x 37m x 3.5m.[37] During the decommissioning, about 300 m3 of contaminated soil excavated from three main drains was disposed in the dykes. A total of about 3,465 man-days were required for decommissioning with a radiation exposure of 122 person-mSv.[38]

ENMASSE COOLANT CHANNEL REPLACEMENT

Major portion of Indian nuclear power programme consists of PHWRs which require Enmasse Replacement of Coolant Channels (ECCR) of each unit with zirconium niobium tubes. The main components of this coolant channel that needed disposal were End Fittings (EF), Pressure Tubes (PT), and Garter Springs (GS). The disposal of waste materials out of this process requires meticulous planning and concerted efforts due to high radiation fields, and large quantities and odd dimensions of the components. This requires creation of additional facilities for their handling, transport, cutting, sizing, disposal and conditioning for which India has developed new technologies and existing technologies have also been improved upon.

Radioactive waste management during many ECCR campaigns has been carried out safely in India. Removal of coolant channels was carried out for MAPS-II during May–July 2002 and for MAPS-I during January-March 2005. ECCR of unit-2 of Rajasthan Atomic Power Station (RAPS-II) was carried out during April-September 1996.[39] During all these operations valuable experience has been gained. As a result, according to Nuclear Recycle Group of BARC, "Technology for the management of decommissioning

37. S. Kumar, P.M. Satya Sai, S. Manohar, R.R. Rakesh, "Studies for Onsite Disposal of Waste from Decommissioning/Revamping of Nuclear Facilities and NPPS in India", in IAEA, *Disposal Aspects of Low and Intermediate Level Decommissioning Waste Results of a coordinated research project 2002–2006*, December 2007, at http://www-pub.iaea.org/MTCD/publications/PDF/TE_1572_companion_CD_web.pdf, p. 54.
38. Ibid; P.B. Savant, et al, "Health Physics Experience on the Decommissioning of Thorium Plant of I.R.E. Ltd at Trombay", BARC/2004/I/011 (2004).
39. For more detail on India's capabilities on onsite disposal of waste from decommissioning see Kumar et. al., December 2007, ibid.

of reactors and other facilities is getting established in the Indian nuclear power programme."

INTEGRATED NUCLEAR RECYCLE PLANT AND GEOLOGICAL REPOSITORY

With a long-term perspective, India has a plan to set up three indigenous and state of the art Integrated Nuclear Recycle Plants with facilities for both reprocessing of spent fuel and waste management. Design of the first plant at Tarapur has been started and is expected to be functional by 2017. The remaining plants will be commissioned with a two to three years gap.[40]

With an aim to develop capacity for permanent disposal of radioactive waste that may arise in three-four decades ahead, research activities for the development of geological repository have been undertaken, though no substantial headway has been achieved. While answering the unstarred question "whether the government has any proposal to set up underground laboratories to study the effects and desirability of storing nuclear waste in deep underground sites", V. Narayanasamy informed the Lok Sabha that:

> Presently, work related to host rock characterisation with a view to develop comprehensive data bases are in progress. The DAE has a proposal to construct an Underground Research Laboratory during the XII Five Year Plan. The proposed laboratory will be of generic nature. Such laboratories are used for the development of methodology and technology related to emplacement of solidified waste in the repository. Experiments in such laboratories will form a basis for the development and construction of underground geological repository for storing high level nuclear waste in the future.[41]

40. *Lok Sabha Debate*, "Integrated Nuclear Recycle Fuel", Unstarred Question No 389 by PT Thomas, answered by Prithviraj Chavan on November 10, 2010.
41. *Lok Sabha Debate*, "Nuclear Waste", Unstarred Question no. 3419, answered on April 25, 2012.

Reportedly, India has begun scouting for deep underground sites to build a repository about one km below land surface and is also setting up a laboratory to develop the required technology.[42] The waste is planned to be disposed "at a depth of 800-1,000 metres to isolate radioactivity from the environment".[43] The then AEC Chairman Srikumar Banerjee told that the nuclear establishment is "looking for a rock formation that is geologically stable, totally impervious and without any fissures". In that case, the site should not have experienced any event in recorded history and should have a cooling mechanism using air draft. The DAE scientists have begun looking for options that vary from underground storage in rocky central India to plains where the storage may be housed inside layers of clay. Dr Banerjee is quoted saying "We will use an existing underground mine to study conductivity, heat management and percolation and rock stability. The site has to be totally impervious, geologically stable and without any fissure."[44] In their search for such a future repository, scientists have reportedly screened some 600,000 sqkm of India's landmass; mainly zones occupied by granites, and found a few zones between 5 sqkm to 25 sqkm for more detailed studies.[45]

According to K.K. Prasad, the former head Back End Technology Development Division of BARC, the geo-scientific studies for an Underground Research Laboratory (URL) have already been completed.[46] The work related to repository programme in India includes (1) heating experiments by multi heaters and single heater in an abandoned underground mine at Kolar Gold Fields (KGF); (2) site screening, selection and characterisation of host rock are ongoing programmes; (3) ongoing programmes include design and construction of a URL in a captive site. The main goals of the URL programme are:

42. "India to Get First Underground Repository for N-Waste", *Times of India*, May 06, 2012.
43. Lok Sabha Debate, Unstarred Question No.3419, "Nuclear Waste", answered On April 25, 2012. At http://www.dae.gov.in/parlqa/2012/budget2012/lsus3419.pdf, p. 2.
44. Kalyan Ray, "India keen on having nuclear waste repository", *Deccan Herald*, February 12, 2012.
45. G.S. Mudur, Site Hunt for Nuclear Graveyard, *The Telegraph* (Kolkata), February 15, 2012.
46. K.K. Prasad, "Underground Research Laboratory (URL) Programme In India", at http://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/URF/documents/Status/2004/MS/India.pdf

- To develop engineering technology for repository construction, operation and closure;
- To develop the disposal technology and validation of the disposal concept with modeling;
- To develop site characterisation techniques and methodology; and
- To demonstrate the geological disposal to the public and confidence building.

Geologically, India is endowed with a number of suitable rocks to serve as host rocks for geological repository. A few promising areas lying in the North west and Central India, occupied by good quality granites have been systematically investigated. According to BARC, for assessment of the rock mass response to thermal load from disposed waste over pack, an experiment of eight-year duration was carried out at a depth of 1000 m in an abandoned section of Kolar gold mine.[47] Some more in situ experiments pertaining to testing of full-scale engineered barriers i.e. simulated waste over pack, bentonite clay buffers and clays sand admixture, are planned to study the behavior of thermal, chemical, mechanical and hydraulic processes around over pack. Also for development of methodology and technology for charecterisation of field scale fractures as pathways for radionuclide and gas migration, experiments are planned in abandoned underground mines in future.[48]

However, no site for such a repository has been finalised. According to News reports, there were several unsuccessful attempts by authorities during the last few years in Madhya Pradesh's granite belt, in Karnataka's Kolar gold mines, and in Sanawada village in Pokhran district in Rajasthan.[49] To that extent, so far, no country in the world has succeeded in preparing a deep geological repository for nuclear waste. The United States has found no politically acceptable site yet. Work on the proposed site at Yucca Mountain has been controversial. However, if DAE succeeds in such an endeavour, "India will help boost people's

47. "Waste Management: Disposal of Radioactive Waste", Nuclear Fuel Cycle, *BARC HIGHLIGHTS*, at http://www.barc.ernet.in/publications/eb/golden/nfc/toc/Chapter%2017/17.2.pdf
48. Ibid.
49. Rashme Sehgal, "India Needs Proper N-Waste Disposal Tech", *The Asian Age*, May 13, 2008.

confidence in nuclear energy" says C. Ganguly, former head of Nuclear Fuel Cycle and Materials section at the International Atomic Energy Agency (IAEA) in Vienna.[50]

URANIUM MINING AND WASTE DISPOSAL

At present, India does not have sufficient domestic uranium supply that is capable of supporting its nuclear energy expansion programme. India's target to produce 10,000 MWe by 2020 would be entirely unachievable without a three-fold increase in uranium supply. In this pursuit, India is building up civil-nuclear cooperation networks with around twenty countries. Meanwhile, it is exploring new uranium reserves within the country. Indigenous output can only triple if the mines located in different states are approved and achieve full production, although presently they are only in the initial stages of exploration. However, there are many difficulties involved in exploring the new found reserves. Technologically, there are constraints in locating large tonnage high grade uranium deposits in the country; this may lead to dependence on exploiting more of low-grade, low-to-medium tonnage deposits. Socially, the negative perception about mining as a polluting industry, exaggerated safety concerns regarding tailing ponds, and spreading of misinformation by activists are major hurdles that require effective and urgent solutions.[51]

50. Ray, 2012, n. 45.
51. "Uranium Mining & Milling Industry in India", at http://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%201/9_63_Gupta_India.pdf

State-wise Uranium Reserve in India

Source: http://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%201/9_63_Gupta_India.pdf

As per the IAEA *Red Book*, the total Uranium reserve in India as on March 2007 is 1,07,268 te. In 2011, the DAE, after several years of survey, found that the Tumalapalli mine near Hyderabad (Andhra Pradesh) could be world's largest uranium reserve. It could provide up to 49,000 tons and there are indications that the total quantity could be as large as three times that amount (150,000 tons).[52] The Uranium Corporation of India (UCIL) in late 2011 has commissioned an underground mine and processing plant at Tummalapalle. But, anti-mining protests were triggered by the reported large-scale death of fish in the Ranikor River, allegedly from toxic waste caused by drilling and dumping into the river. The local government officials ruled out radiation poisoning as the cause, rather some officials claimed that miscreants had dumped poisonous materials into the river to

52. "Largest Uranium Reserves Found in India", *The Telegraph*, July 19, 2011.

create a scare and scuttle the mining project.[53]

Such incidents are no more sporadic in India these days. Since 1996, the Domiasat Uranium mining project has been stalled by large public protests, triggered by concerns over radiation. The National Alliance of Anti-Nuclear Movements (NAAM) organised a rally in Delhi in October 2009, supporting the Khasi Students Union's anti-uranium mining crusade. At Jantar Mantar, speakers from Meghalaya, Karnataka, Andhra Pradesh and Jharkhand highlighted the ill-effects of uranium mining and the dangers of setting up of nuclear power plants.[54] In Karnataka, the Gogi and surrounding village residents demanded relocation before start of uranium mine as they are worried about the consequences for future generations.[55]

There are also reported incidents of mining and waste management related incidents that have spread panic and resentment among local population. For example, an accident that occurred on December 24, 2006 near Jaduguda when one of the pipes carrying radioactive wastes from the uranium mill to a tailing pond burst, and thousands of litres of radioactive waste spilled into a nearby creek for nine hours before the flow of the radioactive waste was shut off.[56] While the DAE officials have called it a "small leak" and of no risk to anyone, the local population and the anti-nuclear lobby viewed it as a threat to the health of thousands of villagers who are "living in the deadly shadow of uranium".[57] There are many other reported issues like uranium mill tailings spillover during flash floods, concentration of uranium in local water sources, congenital deformities, sterility, cancer among people living within 2.5 km of the mines that have generated critical debate on uranium mining safety and waste management in India.

53. "Uranium Projects Show India's Nuclear Ambition Undiminished", at http://www.cleanbiz.asia/story/uranium-projects-show-india%E2%80%99s-nuclear-ambition-undiminished, May 02, 2012.
54. *The Telegraph*, October 02, 2009.
55. *Deccan Herald*, September 10, 2011.
56. U.A. Shimray, M.V. Ramana, "Uranium Mining in Meghalaya: Simmering Problem", *Economic & Political Weekly*, December 29, 2007, pp. 13-17.
57. Harsh Kapoor, "TS: Living in the Deadly Shadow of Uranium", *The Toronto Star*, October 10, 2010.

The nuclear establishment asserts that all uranium mines operations, including the Jaduguda, are safe.[58] Contrary to the allegations of no independent survey is conducted by UCIL or DAE, there were in fact two independent surveys commissioned: the first one was by the faculty from Radiotherapy and Radiology Department of the Patna Medical College and the second survey was undertaken by a medical team composed of civil surgeon, physician and nuclear medicine specialists from the Tata Main Hospital, Jamshedpur and Senior Medical Officer from the Mercy Hospital. Both the surveys found that all reported diseases are caused due to thalassaemia, chronic malaria, and malnutrition and alcohol drinking.[59]The Environment Survey Laboratory collects the environmental samples for analysis and found that concentration of uranium in Gara Nala, Subernarekha River, Gara River, etc. have been always less than the limits set by AERB and WHO. The Health Physics unit regularly monitors the concentration levels and discharges if any and ensures that the activity is not polluting the environment in any way.[60]

Advanced and systematic techniques are followed in the waste management at uranium mining areas: (1) waste rock of mines are used for back-filling of stopes; (2) coarser fraction tailings (deslimed) are used for back-filling; (3) slimes are stored in impoundment facility (Tailings Pond); and (4) plant effluent are treated before discharge to public domain. The tailing ponds are well engineered with natural barriers on three sides; channel ways and well-laid drainage system for discharge of effluents; and reclamation of Tailings pond after use with soil cover and plantation is strictly carried out.[61] Newer concepts like TTD System are under implementation to minimise the tailings pond area as the production and processing of large quantity of ore results in generation of large volume of tailings.

58. "Jaduguda Operations Safe", *The Hindu*, April 09, 2000.
59. Ibid.
60. Ibid.
61. "Uranium Mining & Milling Industry in India", at http://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%201/9_63_Gupta_India.pdf

INDIA'S GORDIAN KNOT?

There is no international consensus regarding the best technological solution for waste disposal.

Problems associated with radioactive waste management on a long-term are major ones that humanity has not been able to come to terms with so far. Although, there are undoubted technical solutions to finding various disposal routes for radioactive wastes, like shallow burial, deep mines, disposal under the sea-bed, and even shooting them to sun, amicable disposal options are comparatively limited. Even in the USA, shallow burial sites have been closed following the discovery of poor containment of wastes and sloppy management. In January 2012, the Blue Ribbon Commission concluded that there is no alternative to burying the waste underground. Sweden, France, UK, etc. are opting for the deep burial option as well. However, there is no international consensus regarding the best technological solution for waste disposal. The options available are also enmeshed in the dichotomy between scientific understanding and human values.

India, in this context, though does not feel the heat of nuclear waste at this stage as the volume piled up is comparatively small, it may become a Gordian Knot in the decades ahead for many unique issues. First, with the increasing institutionalisation of anti-nuclear movements in India, the trend in opposition from "Not In My Back Yard" (NIMBY) is likely to shift towards "Not In Anyone's Back Yard" (NIABY). Though India has variety of land and rock forms to build a geological repository, the issue of burying hazardous waste for future generations and guaranteeing an institution which can survive and be responsible for 1,000 years to safeguard the repository would pose serious hurdle for arriving at a national consensus. Second, the management of waste generated out of the reactor operations in India though perceptibly well planned and may not pose any problem for the next few decades, waste out of uranium mining projects and new exploration activities may experience strong social discontents. As quality of uranium reserve in India is poor and more quantity of ore to be processed to obtain a small quantity of Uranium, the amount of tailings produced in the process would be much more. This would pose bigger challenge for the industry to manage. Third, most of the uranium reserves in India are located in areas where tribal population lives who may not agree to vacate. As rehabilitation issues related to developmental projects in India in the past have become very contentious, uranium exploration induced displacement of local population in future would lead to further escalation of public resentment. Fourth, rampant corruption in every sector in India brings home the fear that, nuclear waste management undertaking may not be spared. Will India be able to set up an institution, for upkeep of deep buried radioactive waste, which has to survive for centuries without dilution of its integrity? Lastly, uranium is a strategic mineral and hence the property of the union government. But, state governments are poised to play greater role in future where conflict among states and union government over management of social acceptance of nuclear projects may arise. This would further delay the nuclear energy programme. Therefore, instead of slicing hurriedly the nuclear waste management spiral, India must untie the knot deftly and painstakingly before it becomes the Gordian. This can be managed by evolving a well-structured 'nuclear information management system' and a value-based 'Corporate Social Responsibility Culture' in the country.