HALF LIFE

Radioactive Waste in India

Toxics Link
for a toxics-free world

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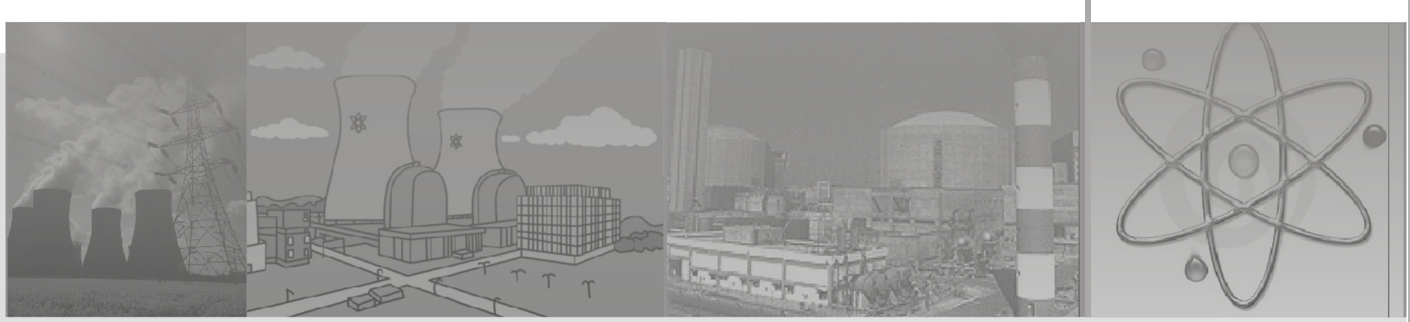

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Upasana Choudhry
Researcher

About the Organisations

Toxics Link is an information outreach and environmental advocacy organisation set up in 1996. It has a special emphasis on reaching out to grassroots groups and community-based organisations. The areas of its engagements include research, outreach and policy advocacy on issues of communities and urban waste, toxics free healthcare, hazardous waste and pesticides.

Toxics Link works closely with all stakeholders working on similar issues and has been conducive to the formation of several common platforms for them. It also networks internationally and is a part of international networks working on similar issues.

"We are a group of people working together for environmental justice and freedom from toxics. We have taken it upon ourselves to collect and share information about the sources and dangers of poisons in our environment and bodies, as well as about clean and sustainable alternatives for India and the rest of the world."

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Heinrich-Boell-Foundation (HBF) is a non-profit political foundation affiliated to the German political party of Alliance 90/The Greens. The Heinrich-Boell-Foundation has had an office in Delhi since 2002 and cooperates with Indian partners. Its focal areas of concern in India are Climate and Energy; Democracy and Conflicts as well as Gender and Trade.

The Foundation's primary objective is to support political education, thus promoting democratic involvement, socio-political activism, and cross-cultural understanding. The foundation also provides support for art and culture, science and research, and developmental co-operation. Its activities are guided by the fundamental political values of ecology, democracy, solidarity, and non-violence.

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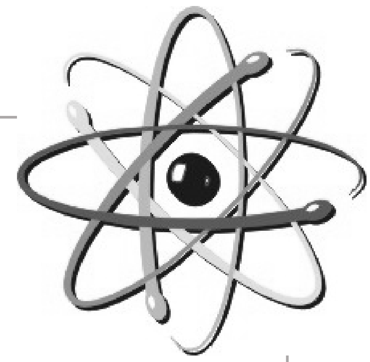


AEC	Atomic Energy Commission
AERB	Atomic Energy Regulatory Board
AHWR	Advanced Heavy Water Reactor
ALARA	As Low As Reasonably Achievable
AMD	Atomic Mineral Division
BARC	Bhabha Atomic Research Centre
BHAVINI	Bharatiya Nabhikiya Vidyut Nigam Limited
BWR	Boiling Water Reactor
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
DAE	Department of Atomic Energy
DNA	Doxyribonuclic Acid
DU	Depleted Uranium
EKRA	Expert Group on Disposal Concepts for Radioactive Waste
FBR	Fast Breeder Reactor
FBTR	Fast Breeder Test Reactor
GDP	Gross Domestic Product
HWB	Heavy Water Board
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiation Protection
IGCAR	Indira Gandhi Centre for Atomic Research
IRE	Indian Rare Earths Limited
KAPS	Kakrapar Atomic Power Station
KGS	Kaiga Generating Station
MAPS	Madras Atomic Power Station
MoEF	Ministry of Environment and Forest
NFC	Nuclear Fuel Complex
NRC	Nuclear Regulatory Commission
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plant
NPT	Non-Proliferation Treaty
PCB	Pollution Control Board
PGCIL	Power Grid Corporation of India Limited
PHWR	Pressurised Heavy Water Reactor
PTA	Partitioning and Transmutation
RAPS	Rajasthan Atomic Power Station
RWMC	Radioactive Waste Management Committee
TAPS	Tarapur Atomic Power Station
TIFR	Tata Institute of Fundamental Research
UCIL	Uranium Corporation of India Limited
USNRC	United States Nuclear Regulatory Commission
UNSCEAR	UN Scientific Committee on the Effects of Atomic Radiation
WANO	World Association of Nuclear Operators

Introduction

India's Nuclear Programme in not new and dates back to pre-independent India. It was in 1944 that Dr. Homi Jehangir Bhabha wrote to the Sir Dorabji Tata Trust for starting Nuclear Research in India. This resulted in the establishment of the Tata Institute of Fundamental Research (TIFR) in 1945, paving way for a full-fledged programme. However, in over six decades of its existence, the programme has failed to incite as much interest as it has done in the last few years in view of the '123 Agreement' recently signed between Indian and United States. India's policy of maintaining nuclear secrecy has been the main reason for this. India is not alone in doing so. Nuclear programmes the world over have symbolised power and hence have been loaded with secrecy.

Climate Change Concerns

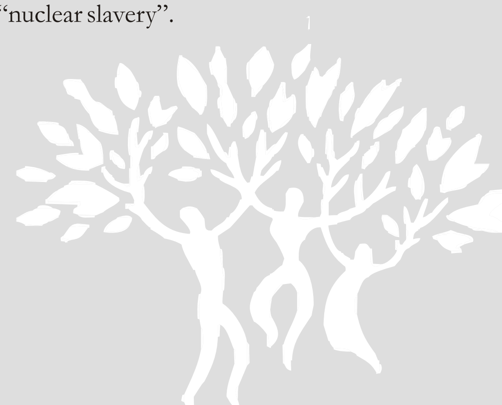
The dangers of uncontrolled global warming due to the burning of hydrocarbons too have shifted the world focus on nuclear energy as a solution. India, it is believed, will soon come under pressure to join the Kyoto Protocol, which would mean putting a cap on its emissions. At the same time, the country's energy needs are estimated to go up five to seven times if the country wishes to grow at 8 to 10% annually up to 2031. The result is a pro-nuclear energy policy. Nuclear power is seen to be critical to India's long-term energy security as well as the country's answer to climate change problem. However, it is no secret that in spite of spending extraordinary sums of money and effort, India's civilian nuclear programme is hampered by frequent breakdowns due to the use of inferior domestically-made parts, a poor safety record and a shortage of fuel.

Nuclear Boost

The recently-concluded 123 agreement that drew mass attention to the issue for the first time falls in line with the country's energy policy. The agreement and associated changes in the rules of the International Atomic Energy Agency (IAEA) and Nuclear Suppliers Group (NSG) have granted India *de facto* recognition as a nuclear-weapons state, gutting the four decades old international nuclear regulatory framework. Only the five permanent members of the UN Security Council, the United States, Russia, Britain, France and China have hitherto been internationally recognised nuclear-weapons states; and only they and other states that have signed the nuclear Non-Proliferation Treaty (pledging thereby not to develop nuclear weapons) have been allowed to engage in civilian nuclear trade. India had been barred from nuclear commerce under a US-led global embargo that was imposed in 1974 in response to the country's exploding a nuclear device. Now, under the Indo-US nuclear treaty, India will be able to import civilian nuclear technology and fuel from the US as the International Atomic Energy Agency (IAEA) and Nuclear Suppliers Group (NSG) removed their prohibitions on civilian nuclear trade with India in August and September 2008.

The nuclear agreement had lots of supporters in India, including India's ruling elite and corporate media. Indian big business, meanwhile, hopes the lifting of prohibitions on advanced technology trade will enable it to benefit from new partnerships with US firms and also that the involvement of foreign firms in India's civilian nuclear industry, including privately-owned US nuclear companies, will lead to further privatisation of India's energy sector.

Others, including some political parties, have opposed the nuclear deal on grounds that US intends to use it to chain India to its global strategy and that the agreement gives other countries a right to interfere in India's programme. The 123 agreement has been referred by them as a charter of “nuclear slavery”.



Interestingly, the agreement took the centre stage in almost all political debates. A lot of information has since become available in the public domain one of the positives of the agreement. But whilst different facets have come to light in course of the arguments and counter arguments that took place either in support of or to block the deal, a major aspect of the nuclear programme has been left out of all debates and discussionsthe issue of radioactive waste.

Like any other industry, the nuclear industry too generates waste. Nuclear waste has been a contentious aspect of nuclear power programmes around the world. The Nuclear Energy Agency, Organization for Economic Cooperation and Development (OECD), observes: "One of the key issues that has dominated the nuclear debate in recent years has been the safe management of radioactive wastes . . . radioactive wastes have caused more public concern than any other type of waste". In India too, apprehensions have been expressed about this segment of the nuclear programme.

It would not be wrong to say that there has never been a 'peaceful' nuclear programme anywhere in the world. If nuclear power is not used to make weapons, at the very least, such programmes cause immeasurable ecological damage. Almost half a century after Eisenhower's 'Atoms for Peace' speech, the planet is left with a legacy of nuclear waste that will be radioactive for tens or hundreds of thousands of years. As yet, no safe solution for its disposal exists anywhere in the world. India too is yet to come up with a safe disposal system. Considering India's growing cities and villages, it may only be a matter of time before people start living dangerously close to a nuclear dump.

About the Study

The prime objective of taking up this 'Study on Radioactive Waste in India' was to map the nuclear fuel cycle of the civilian nuclear programme (electricity generation) with the aim of tracking waste generation points. It seeks to examine the waste management practices in the country and assess its impacts on human health and environment, if any. It looks into the existing regulatory framework, government policies and initiatives. A comparison between countries has been made available at places to help place India in the global context. Critical issues have been flagged.

An inception workshop was convened in August 2008 with a small group of experts and based on their inputs, the scope and structure of the study were outlined. This is believed to be the first of its kind study on th issue in India. It attempts at providing an overview of radioactive waste without going deeper on any one aspect of the issue.

It is relevant to mention here that the scope of the study is limited to waste that is generated in due course of the civilian nuclear programme and the threats the same poses to the society. The study does not cover waste generated as part of the nuclear defence programme in the country. It also does not look into the issues of energy security and viability of nuclear energy as an energy option. Efficacy of nuclear energy in fighting climate change too falls outside the scope of the study. In addition, safety issues, both occupational and otherwise, with regard to the nuclear programme have been deliberately left out since given the wide nature of the issue, it can be a full-fledged study in itself. The study does not cover issues of displacement, land acquisition and compensation, especially in the context of mining and milling operations. Lastly, it does not map the nuclear waste as generated from all the various sources, namely industrial, agricultural, research and medical and the management practices followed. These have, however, been mentioned in passing at few places in the report and further work is advised to gain a better understanding on these other sources.

This study, taken up between September and November 2008, was exploratory in nature. Due to limited time availability and difficult access to first-hand information, the study draws heavily on available knowledge and information. Information has been collected from secondary sources, both online as well as offline. The information has been verified, wherever possible, through a process of formal and informal consultations with experts who have been closely following the issue over the years. Besides, journalists and filmmakers who have done work on the issue (or any part thereof) were also approached.

First-hand information has been collected from officials engaged with some of the nuclear establishments. Field visits were made to select points on the nuclear fuel cycle. Procedural delays and time lag in securing permissions from officials for site visits or seeking appointments has meant cutting down on the number of sites visited. Care has however been taken to ensure that critical waste generation points during the entire fuel cycle were visited. It is important to mention that no environmental samples were collected; health records checked; or other laboratory investigations made as part of this work.

Community views were gathered from mining and milling areas as also the views of community-based organisations such as Jharkhandi Organisation against Radiation (JOAR). However, at times, it was difficult to assess if those views were of an activist or a community member.

Information of several aspects of the nuclear programme is highly classified, which posed some challenges. The official responses, in a few cases, were found restrained. Additionally, the nature of activity in itself has meant limited access to processes during the field visits. The ground realities with regard to some of the current practices therefore have proved difficult to ascertain.

Photographs to support the collected information have not been possible due to strict prohibitions followed at the nuclear facilities. The photographs of nuclear establishments used in the report are largely from government documents, websites and other public documents.

Effort has been made through this study to present technical information in a simplified fashion to make the issue transparent, both to the intellect and to the vision, so that people can understand these issues better. It is hoped that this study will not only contribute to strengthening the ongoing discussions and debates, but also inspire more work in the future that will help bring out the issues around nuclear programme into the public domain.

1

Radioactive Waste: The Dilemma

For over 40 years, nuclear technology has spread into many areas of modern society, enabling advances in energy production, defence, medicine, agriculture, and industrial applications. But along with the use of nuclear technology comes an added burden Radioactive Waste or radwaste.

Wastes are generated at every stage of the nuclear fuel cycle. Proponents of nuclear energy however argue that the energy content of uranium is exceptionally high and so generating electricity from nuclear fuel results in only very small amounts of waste per unit of electricity produced. They also uphold nuclear power as the only energy industry that takes full responsibility for all its wastes, and costs this into the product. At the same time, one cannot refute the fact that the nuclear industry is responsible for generating wastes that are radioactive and thus could be damaging to human health and the environment if not properly managed.

Understanding Radioactivity

Some natural elements are unstable. Therefore, their nuclei disintegrate or decay, thus releasing energy in the form of radiation. This physical phenomenon is called 'radioactivity' and the radioactive atoms are called nuclei. The radioactive decay is expressed in units called Becquerels. One Becquerel equals one disintegration per second.

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Radionuclides decay at a characteristic rate that remains constant regardless of external influences, such as temperature or pressure. The time taken for half the radionuclides to disintegrate or decay is called **half-life**. This differs for each radioelement, ranging from fractions of a second to billions of years.

Types of Radiation

The term "radiation" is very broad, and includes such things as light and radio waves. In the context of this work, it refers to "ionising" radiation, which means that because such radiation passes through matter, it can cause it to become electrically charged or ionised. In living tissues, the electrical ions produced by radiation can affect normal biological processes. There are various types of radiation, each having different characteristics. The common ionising radiations generally talked about are:

- **Alpha radiation** consists of heavy, positively charged particles emitted by atoms of elements such as uranium and radium. Alpha radiation can be stopped completely by a sheet of paper or by the thin surface layer of our skin (epidermis).
- **Beta radiation** consists of electrons. They are more penetrating than alpha particles and can pass through 1-2 centimetres of water.
- **Gamma rays** are electromagnetic radiation similar to X-rays, light and radio waves. Gamma rays, depending on their energy, can pass right through the human body, but can be stopped by thick walls of concrete or lead.
- **Neutrons** are uncharged particles and do not produce ionisation directly. But their interaction with the atoms of matter can give rise to alpha, beta, gamma, or X-rays, which then produce ionisation.

Although we cannot see or feel the presence of radiation, it can be detected and measured in the minutest quantities with quite simple radiation measuring instruments.

Sources of Radiation

Radioactive wastes resulting from the nuclear fuel cycle are only one part of the radiation that is received from all sources. The world has evolved with radiation and radioactivity being natural occurrences. Natural background radiation too contributes to the total amount of radiation received by the average person in the course of a year.

Natural Radioactivity

It is somewhat surprising that nature has been a large producer of radioactive waste. Over the eons, the surface of the Earth and the terrestrial crust has been an enormous reservoir of primordial radioactivity. Small amounts of radioactive materials are contained in mineral springs, sand mounds and volcanic eruptions. Essentially, all substances contain radioactive elements of natural origin to some extent or the other. Monazite sand deposits in coastal areas may result in radiation exposure to humans around an order of magnitude in excess of the currently set international exposure limits to radioactive waste disposal (one millisievert (msv) per year) and volcanic deposits result in similar exposure. There is no place on Earth that is free from natural radioactive background; it may vary from place to place all the way from the low to the high.

The second source of radioactive waste is a part of industrial mining activity where, during mineral exploration and exploitation, one excavates the primordial material from the Earth that contains radioactivity, uses part of it and rejects the radioactive residues as waste. These are referred to as Naturally Occurring Radioactive Materials (NORMs) and are ubiquitous as residual wastes in processing industries that cover fertilizers, iron and steel, fossil fuel, cement, mineral sands, titanium, thorium and uranium mining as well as emanations and waste from coal and gas-fired power plants. The residual waste tailings from past mining and milling operations are estimated to be around several million tons at many places and the radioactivity contained may be nearly 0.001 exabecquerel (EBq) (1 EBq=1018 Bq). Thousands of such sites are scattered all around the world.

Artificial Radioactivity

Radioactivity was discovered about a hundred years ago. Following the Second World War and discovery of the fission process, human activity added radioactivity artificially to the natural one. Two main sources have been:

a) the civilian nuclear programmes, including nuclear power production, medical and industrial applications of radioactive nuclides for peaceful purposes, and

b) the military nuclear programme, including atmospheric and underground nuclear weapon testing and weapon production

The Table below presents the nature of artificial radioactive isotopes produced during nuclear reaction

Table 1.1: Common Radioactive Isotopes Produced during Nuclear Reactions

Isotope	Half-life	Isotope	Half-life	Isotope	Half-life
Relatively short half-life					
Strontium-89	54 days	Zirconium-95	65 days	Niobium-95	39 days
Ruthenium-103	40 days	Rhodium-103	57 minutes	Rhodium-106	30 seconds
Iodine-131	8 days	Xenon-133	8 days	Tellurium-134	42 minutes
Barium-140	13 days	Lanthanum-140	40 h	Cerium-141	32 days
Year to century-scale half-life*					
Hydrogen-3	12 years	Krypton-85	10 years	Strontium-90	29 years
Ruthenium-106	1 year	Cesium-137	30 years	Cerium-144	1.3 years
Promethium-147	2.3 years	Plutonium-238	85.3 years	Americium-241	440 years
Curium-224	17.4 years				
Longer half-life					
Technecium-99	$2X10^6$ years	Iodine-129	$1.7\ X10^7$ years	Plutonium-239	24000 years
Plutonium-240	6500 years	Americium-243	7300 years		

**Half-lives of the order of years to decades of isotopes of elements that can seek tissues or organs biologically (being akin to other elements chemically) are the most hazardous from point of view of radiation. For example, 90Sr, being chemically akin to Ca, can seek the bone and lodge itself there for years causing radioactive damage to surrounding tissues.*

When a reference is made to nuclear energy, the common thing that comes to mind is nuclear reactors (or perhaps nuclear weapons). Few realise the extent to which the use of radioisotopes has entered our lives over the last few decades. Using relatively small special-purpose nuclear reactors, it has become possible to make a wide range of radioactive materials (radioisotopes). For this reason, the use of artificially-produced radioisotopes has become widespread since the early 1950's, and there are now some 270 "research" reactors in 59 countries producing them.

In **medicine**, radioisotopes are widely used for diagnosis and research. Radioactive chemical tracers emit gamma radiation, which provides diagnostic information about a person's anatomy and the functioning of specific organs. Radiotherapy also employs radioisotopes in the treatment of some illnesses, such as cancer. More powerful gamma sources are used to sterilise syringes, bandages and other medical equipment.

In the **preservation of food**, radioisotopes are used to inhibit the sprouting of root crops after harvesting, to kill parasites and pests, and to control the ripening of stored fruit and vegetables. Irradiated foodstuffs are commonly accepted by world and national health authorities for human consumption in an increasing number of countries. Some pre-packed foods are also irradiated.

In growing **crops** and breeding **livestock**, radioisotopes are used. They are used to produce high yielding, disease and weather-resistant varieties of crops, to study how fertilisers and insecticides work and to improve the productivity and health of domestic animals.

Industrially, and in **minin**g, they are used to examine welds, to detect leaks, to study the rate of wear of metals, and for on-stream analysis of a wide range of minerals and fuels.

There are many other uses. A radioisotope derived from the plutonium formed in nuclear reactors is used in most household **smoke detectors**.

UNDERSTANDING WASTE

As in many other industrial processes, in the nuclear industry also, one gets unusable and unwanted *waste* products; the residues turn out to be hazardous. Although there is no internationally-accepted definition of radioactive waste, the one by the International Atomic Energy Agency (IAEA) best describes it as:

"*Any material that contains or is contaminated by radionuclides at concentrations or radioactivity levels greater than the exempted quantities established by the competent authorities and for which no use is foreseen*".

It should be recognised that different countries may have different interpretations. However, the important part of the definition is "*for which no use is foreseen*". This raises the question as to the status, for example, of spent nuclear fuel. Some countries, including India, deem spent fuel as a resource whereas Finland, USA, Sweden and many others regard it as a waste. The interpretation is therefore dependent as much on National Government Policy as on scientific or technical description.

Categories of Waste

In order to achieve the required standards of radioactive waste management, the nuclear industry throughout the world has grouped radioactive wastes into a number of categories. A large portion of radioactive waste produced from the nuclear fuel cycle has radiation levels similar to, or not much higher than, the natural background level. This waste is relatively easy to deal with. On the other hand, a small proportion is highly radioactive and requires particularly careful management.

- **Very low level waste (VLLW)** or **Exempt waste (EW)** is radioactive waste which contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping etc) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel, etc also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes. The waste is therefore disposed of with domestic refuse, although countries such as France are developing facilities to store VLLW in specifically-designed VLLW disposal facilities.

- **Low-level waste (LLW)** is generated from hospitals, laboratories and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters, etc., which contain small amounts of mostly short-lived radioactivity. It is not dangerous to handle, but must be disposed of more carefully than normal garbage. It is usually buried in shallow landfill sites. To reduce its volume, it is often compacted or incinerated (in a closed container) before disposal. Worldwide, it comprises 90% of the volume but only 1% of the radioactivity of all radwaste.

- **Intermediate level waste (ILW)** contains higher amounts of radioactivity and may require special shielding. It typically comprises resins, chemical sludge and reactor components, as well as contaminated materials from reactor decommissioning. Treatment and disposal of ILW varies depending on the waste form and whether it is **short**- or **long- lived**. In general, short-lived ILW can be disposed of in shallow land burial, but long-lived ILW must be disposed of in a manner similarly to that which is used for high-level waste.

High-level waste (HLW) is highly radioactive and contains long-lived radioactivity. It generates a considerable amount of heat and requires cooling for many years before disposal. It can be considered as the "ash" from "burning" uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW: used fuel itself in fuel rods, or separated waste from reprocessing the used fuel. HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered no longer hazardous for people and the surrounding environment.

Some countries choose to categorise alpha-bearing waste separately. For example in the USA, "Transuranic Waste" (TRU), is defined as "*waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half lives greater than twenty years, per gram of waste*". Such waste arises from research laboratories, fuel fabrication plants and reprocessing plants. Some alpha waste is classed as LLW, but hulls, caps and fins from reprocessing plants would be classed as ILW.

RADIATION DOSE

The biological effects of ionising radiation vary with the type and energy. The amount of radiation, or 'dose', received by a person is measured in terms of the energy absorbed in the body tissue, and is expressed in 'gray'. One gray (Gy) is one joule deposited per kilogram of mass. Equal exposure to different types of radiation expressed as gray does not however necessarily produce equal biological effects. One gray of alpha radiation, for example, will have a greater effect than one gray of beta radiation. When we talk about radiation effects, we express the radiation as effective dose, in a unit called the 'sievert' (Sv).

Regardless of the type of radiation, one sievert (Sv) of radiation produces the same biological effect. Since one sievert is a large quantity, radiation doses normally encountered are expressed in millisievert (mSv) or microsievert (μSv) which is one-thousandth or one millionth of a sievert. For example, one chest X-ray will give about 0.2 mSv of radiation dose. In the US, the most commonly used unit is rem or mrem (millirem) (Conversion of rem to Sieverts: 1 rem = 0.01 Sv = 10 mSv). On average, our radiation exposure due to all natural sources amounts to about 2.4 mSv a year though this figure can vary, depending on the geographical location by several hundred percent.

The individual dose limit for radiation workers averaged over 5 years is 100 mSv, and for members of the general public, is 1 mSv per year. These dose limits have been established based on a prudent approach by assuming that there is no threshold dose below which there would be no effect. This means that any additional dose will cause a proportional increase in the chance of a health effect.

CAUSE FOR CONCERN

Radioactive waste, whether natural or artificial, is a potential harbinger of radioactive exposure to humans through many channels. The routes are direct exposure to materials that are radioactive, inhalation and ingestion of such materials through the air that one breathes or food that one consumes. The degree of damage caused by radiation depends on many factors dose, dose rate, type of radiation, the part of the body exposed, age and health, for example. Exposure may occur to particular organs locally or to the whole body. Embryos including the human foetus are particularly sensitive to radiation damage.

The effects of radiation at high doses and dose rates are reasonably well documented. A very large dose delivered to the whole body over a short time will result in the death of the exposed person within days. Much has been learned by studying the health records of the survivors of the bombing of Hiroshima and Nagasaki. We know from these that some of the health effects of exposure to radiation do not appear unless quite a large dose is absorbed. However, many other effects, especially cancers are readily detectable and occur more often in those with moderate doses. At lower doses and dose rates, a degree of recovery in cells and in tissues is believed.

However, at low doses of radiation, there is still considerable uncertainty about the overall effects. It is presumed that exposure to radiation, even at the levels of natural background, may involve some additional risk of cancer. However, this has yet to be established.

There is experimental evidence from animal studies that exposure to radiation can cause genetic effects. However, the studies of the survivors of Hiroshima and Nagasaki give no indication of this for humans. With all the knowledge so far collected on effects of radiation, there is still no definite conclusion as to whether exposure due to natural background carries a health risk, even though it has been demonstrated for exposure at a level a few times higher.

The radio toxicity of a particular radionuclide is quantified in terms of what is referred to as 'potential hazard index' that is defined in terms of the nuclide availability, its activity, maximum permissible intake annually and its half-life. This depends on a variety of factors like physical half-life, biological half-life, sensitivity of the organ or tissue where the nuclide is likely to concentrate, ionising power of the radiation from the nuclide that depends on the energy of the radiation emitted from the radionuclide, etc. Table 1.1 gives an indication of the likely effects of a range of whole body radiation doses and dose rates to individuals:

Table 1.2: Likely Effects of a Range of Whole Body Radiation doses and Dose Rates to Individuals

10,000 mSv (10 sieverts) as a short-term and whole-body dose would cause immediate illness, such as nausea and decreased white blood cell count, and subsequent death within a few weeks. Between 2 and 10 sieverts in a short-term dose would cause severe radiation sickness with increasing likelihood that this would be fatal.
1,000 mSv (1 sievert) in a short-term dose is about the threshold for causing immediate radiation sickness in a person of average physical attributes, but would be unlikely to cause death. Above 1000 mSv, severity of illness increases with dose. If doses greater than 1000 mSv occur over a long period, they are less likely to have early health effects but they create a definite risk that cancer will develop many years later.
Above about **100 mSv**, the probability of cancer (rather than the severity of illness) increases with dose. The estimated risk of fatal cancer is 5 for every 100 persons exposed to a dose of 1000 mSv (i.e. if the normal incidence of fatal cancer were 25%, this dose would increase it to 30%).
50 mSv is, conservatively, the lowest dose at which there is any evidence of cancer being caused in adults. It is also the highest dose, which is allowed by regulation in any one year of occupational exposure. Dose rates greater than 50 mSv/yr arise from natural background levels in several parts of the world but do not cause any discernible harm to local populations.
20 mSv/yr averaged over 5 years is the limit for radiological personnel such as employees in the nuclear industry, uranium or mineral sands miners and hospital workers (who are all closely monitored).
10 mSv/yr is the maximum actual dose rate received by any Australian uranium miner.
3-5 mSv/yr is the typical dose rate (above background) received by uranium miners in Australia and Canada.
3 mSv/yr (approx) is the typical background radiation from natural sources in North America, including an average of almost 2 mSv/yr from radon in air.
2 mSv/yr (approx) is the typical background radiation from natural sources, including an average of 0.7 mSv/yr from radon in air. This is close to the minimum dose received by all humans anywhere on Earth.
0.3-0.6 mSv/yr is a typical range of dose rates from artificial sources of radiation, mostly medical.
0.05 mSv/yr, a very small fraction of natural background radiation, is the design target for maximum radiation at the perimeter fence of a nuclear electricity generating station. In practise, the actual dose is less.

Children are More Susceptible

Children and the unborn are especially susceptible to radiation because of rapid cell division during physical growth. DNA is most vulnerable to radiation impact while cells divide. In addition to cancer and birth defects, evidence exists that radiation is permanently mutating the gene pool and contributing to its gradual weakening, resulting in developmental deficiencies in the foetus, hereditary disease, accelerated aging, and such non-specific effects as loss of immune competence. The work of Dr. Alice Stewart, a British epidemiologist, established in the 1950's that children born to women who received even one abdominal x-ray during pregnancy were four times more likely to suffer childhood cancer as a "post birth defect".

Childhood disease clusters have been found in many communities with nuclear facilities. This list includes increase in childhood leukaemia near reprocessing facilities in La Hague, France and at Sellafield in the British Isles and the Krummel nuclear reactor in Germany. Childhood leukaemia cases near Sellafield are associated with occupational exposure to the father before *conception* of the child. Increases in childhood leukaemia also occurred Europe-wide after the passage of the Chernobyl radiation cloud. Increases in other childhood cancers have been found near nuclear operations in the Navaho Nation (uranium mining), Brookhaven, New York (nuclear weapons), and nuclear power stations in Oyster Creek, NJ and Clinton, Illinois. Increase in Down 's syndrome are found near Yankee Rowe power station in Massachusetts. Heart defects of various types have been associated with ionising radiation exposure as well.

Radiation Effects

Every inhabitant on this planet is constantly exposed to naturally occurring ionising radiation called background radiation. Sources of background radiation include cosmic rays from the Sun and stars, naturally occurring radioactive materials in rocks and soil, radionuclides normally incorporated into our body's tissues, and radon and its products, which we inhale. We are also exposed to ionising radiation from man-made sources, mostly through medical procedures like X-ray diagnostics. Radiation therapy is usually targeted only to the affected tissues.

Much of our data on the effects of large doses of radiation comes from survivors of the atomic bombs dropped on Hiroshima and Nagasaki in 1945 and from other people who received large doses of radiation, usually for treatment. About 12% of all the cancers that have developed among those survivors are estimated to be related to radiation.

Ionising radiation can cause important changes in our cells by breaking the electron bonds that hold molecules together. For example, radiation can damage our genetic material (DNA). But the cells also have several mechanisms to repair the damage done to DNA by radiation.

Potential biological effects depend on how much and how fast a radiation dose is received. An acute radiation dose (a large dose delivered during a short period of time) may result in effects, which are observable within a period of hours to weeks. A chronic dose is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose as the cells need time to repair themselves.

Radiation effects are also classified in two other ways, namely somatic and genetic effects. Somatic effects appear in the exposed person. The delayed somatic effects have a potential for the development of cancer and cataracts. Acute somatic effects of radiation include skin burns, vomiting, hair loss, temporary sterility or sub fertility in men, and blood changes. Chronic somatic effects include the development of eye cataracts and cancers.

The second class of effects, namely genetic or heritable effects appears in the future generations of the exposed person as a result of radiation damage to the reproductive cells, but risks from genetic effects in humans are seen to be considerably smaller than the risks for somatic effects.

Protection Mechanisms Against Radiation

There are four ways in which people can be protected from identified radiation sources:

- **Limiting Time:** For people who are exposed to radiation in addition to natural background radiation through their work, the dose is reduced and the risk of illness essentially eliminated by limiting exposure time.

- **Distance:** In the same way that heat from a fire is less the further away you are, the intensity of radiation decreases with distance from its source.

Shielding: Barriers of lead, concrete or water give good protection from penetrating radiation such as gamma rays. Radioactive materials are therefore often stored or handled under water, or by remote control in rooms constructed of thick concrete or lined with lead.

Containment: Radioactive materials are confined and kept out of the environment. Radioactive isotopes for medical use are dispensed in closed handling facilities, while nuclear reactors operate within closed systems with multiple barriers, which keep the radioactive materials contained. Rooms have a reduced air pressure so that any leaks occur into the room and not out from the room.

Over the years, as more was learned, scientists became increasingly concerned about the potentially damaging effects of exposure to large doses of radiation. The need to regulate exposure to radiation prompted the formation of a number of expert bodies to consider what needed to be done. In 1928, an independent non-governmental body of experts in the field, the International X-ray and Radium Protection Committee was established. It was later renamed the International Commission on Radiological Protection (ICRP). Its purpose is to establish basic principles for, and issue recommendations on, radiation protection.

The three key points of the ICRP's recommendations are:

- **Justification**: No practice should be adopted unless its introduction produces a positive net benefit.
- **Optimisation**: All exposures should be kept as low as reasonably achievable, economic and social factors being taken into account.
- **Limitation**: The exposure of individuals should not exceed the limits recommended for the appropriate circumstances.

These principles and recommendations form the basis for national regulations governing the exposure of radiation workers and members of the public. They have also been incorporated by the International Atomic Energy Agency (IAEA) into its Basic Safety Standards for Radiation Protection published jointly with the World Health Organization (WHO), International Labour Organization (ILO), and the OECD Nuclear Energy Agency (NEA).

An intergovernmental body was formed in 1955 by the General Assembly of the United Nations as the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR is directed to assemble, study and disseminate information on observed levels of ionising radiation and radioactivity (natural and man-made) in the environment, and on the effects of such radiation on man and the environment. Basic approaches to radiation protection are consistent all over the world. The ICRP recommends that any exposure above the natural background radiation should be kept 'as low as reasonably achievable' (ALARA), but below the individual dose limits.

The ICRP and the IAEA recommend that the individual dose must be kept as low as reasonably achievable, and consideration must be given to the presence of other sources which may cause simultaneous radiation exposure to the same group of the public. Also, allowance for future sources or practices must be kept in mind so that the total dose received by an individual member of the public does not exceed the dose limit.

The ICRP recommends that the maximum permissible dose for **occupational exposure** should be 20 millisievert per year averaged over five years (i.e. 100 millisievert in 5 years) with a maximum of 50 millisievert in any one-year. For **public exposure**, 1 millisievert per year averaged over five years is the limit. In both categories, the figures are over and above background levels and exclude medical exposure.

Risks Versus Benefits

Radiation protection is said to set examples for other safety disciplines in two unique respects. First, there is the assumption that any increased level of radiation above natural background will carry some risk of harm to health; and second, it aims to protect future generations from activities conducted today. The use of radiation and nuclear techniques in medicine, industry, agriculture, energy and other scientific and technological fields has undoubtedly brought tremendous benefits to society. It is often argued that no human activity or practice is totally devoid of associated risks and that radiation should be viewed from the perspective that the benefit from it to mankind is less harmful than from many other agents. This argument should not simply make radiation exposure to people acceptable. Benefits to society should not always come at a cost of huge risks. There is a need for maintaining the right balance.

Uranium And Radioactivity

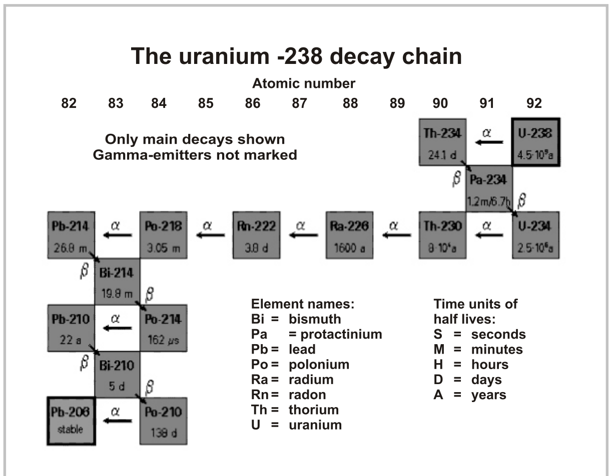
Uranium (chemical symbol U) is a naturally-occurring radioactive element. Uranium is very dense, about 19 grams per cubic centimetre, 70% more dense than lead. The International Atomic Energy Agency (IAEA) defines uranium as a Low Specific Activity material. In its natural state, it consists of three isotopes (U-234, U-235 and U-238). Other isotopes that cannot be found in natural uranium are U-232, U-233, U-236 and U-237.

Table 1.3: Isotopes Their Abundance, Half Lives and Activity

Isotope	Relative abundance by weight	Half life (years)	Specific activity (Bq mg^{-1})
U-238	99.28%	4510000000	12.4
U-235	0.72%	710000000	80
U-234	0.0057%	247000	231000

Decay products of U-238 include thorium-234 (Th-234), protactinium-234 (Pa-234), U-234, Th-230, radium-226 (Ra-226), radon-222 (Rn-222), polonium-218 (Po-218), lead-214 (Pb-214), bismuth-214 (Bi-214), Po-214 Pb-210 and Po-210. Decay products of U-235 include Th-231, Pa-231, actinium-227 (Ac-227), Th-227,Ra-223,Rn-219, Po-215, Pb-211, Bi-211 and thallium-207 (Tl-207).

Figure 1.1: The Uranium-238 Decay Chain



Isotopes of natural uranium decay by emitting mainly alpha particles. The emission of beta particles and gamma radiations are low.

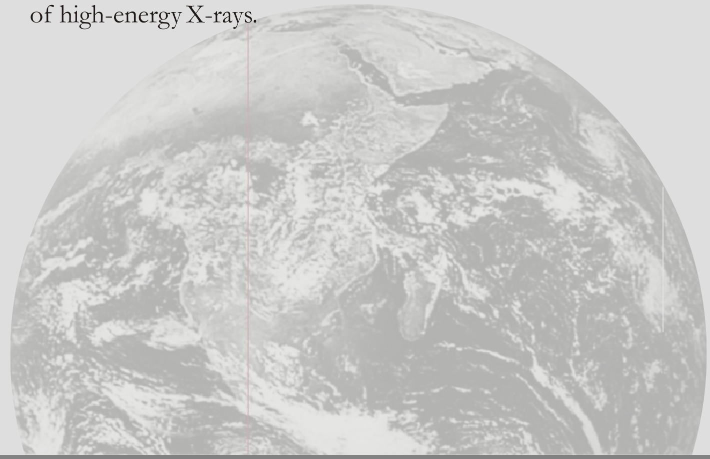
Applications of Uranium

Uranium has both military and civilian applications.

The major application of uranium in the military sector is in high-density penetrators. This ammunition consists of depleted uranium (DU) alloyed with 12% other elements. Depleted uranium is also used as a shielding material in some containers used to store and transport radioactive materials. Other uses of DU include counterweights for aircraft control surfaces, as ballast for missile re-entry vehicles and as a shielding material. Due to its high density, this material is found in inertial guidance devices and in gyroscopic compasses. DU is preferred over similarly dense metals due to its ability to be easily machined and cast as well as its relatively low cost.

The main use of uranium in the **civilian** sector is to fuel commercial nuclear power plants; by the time it is completely fissioned, one kilogram of uranium-235 can theoretically produce about 20 trillion joules of energy (2×10^{13} joules); as much energy as 1,500 tonnes of coal. Prior to the discovery of radiation, uranium was primarily used in small amounts for yellow glass and pottery glazes (such as uranium glass and in Fiestaware).

The discovery of the radioactivity of uranium ushered in additional scientific and practical uses of the element. The long half-life of the isotope uranium-238 (4.51×10^{9} years) makes it well suited for use in estimating the age of the earliest igneous rocks and for other types of radiometric dating (including uranium-thorium dating and uranium-lead dating). Uranium metal is used for X-ray targets in the making of high-energy X-rays.



Uranium can combine with other elements in the environment to form uranium compounds. The chemical form of the uranium compounds determines how easily the compound can move through the environment, as well as how toxic it might be. Some forms of uranium oxides are very inert and may stay in the soil for thousands of years without moving downward into groundwater. The average concentration of natural uranium in soil is about 2 parts per million (in India, it is much less), which is equivalent to 2 grams of uranium in 1000 kg of soil. Uranium in higher concentrations (50 - 1000 mg per kg of soil) can be found in soil associated with phosphate deposits.

In air, uranium exists as dust. Very small dust-like particles of uranium in the air are deposited onto surface water, plant surfaces and soil. These particles of uranium eventually end up back in the soil or in the bottom of lakes, rivers and ponds, where they mix with the natural uranium that is already there. Typical activity concentrations of uranium in air are around 2 μBq per cubic metre.[1]

Most of the uranium in water comes from dissolved uranium from rocks and soil; only a very small part is from the settling of uranium dust out of the air. Activity concentrations of U-238 and U-234 in drinking water are between a few tenths of mBq per litre to a few hundred mBq per litre, although activity concentrations as high as 150 Bq per litre have been measured in Finland.[2] Activity concentrations of U-235 are generally more than twenty times lower.

Uranium in plants is the result of its absorption from the soil into roots and other plant parts. Typical activity concentrations of uranium isotopes in vegetables are slightly higher than those found in drinking water. Activity concentrations in root vegetables are generally lower.[3]

Small amounts of natural uranium are ingested and inhaled by everyone every day. Due to of the differences in diet, there is a wide variation in consumption levels of uranium around the world, but primarily intake depends on the amount of uranium in the water people drink. Most of the uranium ingested is excreted in faeces within a few days and never reaches the blood stream. The remaining fraction will be transferred into the blood stream. Most of the uranium in the blood stream is excreted through urine in a few days, but a small fraction remains in the kidneys and bones and other soft tissue.

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Harmful Effects of Uranium

Since the advent of the nuclear age, there has been widespread use of uranium involving the mining of uranium ore, enrichment and nuclear fuel fabrication. These industries have employed large numbers of people, and studies of the health of working populations have been carried out. The main risk to miners, and not just those involved in uranium mining, comes from exposures to radon (mainly Rn-222) gas and its decay products. A study of miners who worked in poorly ventilated mines at a time when the hazards of radon were not known and thus had been exposed to high levels of radon, demonstrated that this group had an excess of lung cancers and that the risk of cancer increased with increasing exposure to radon gas. Studies of workers exposed to uranium in the nuclear fuel cycle have also been carried out. There are some reported excesses of cancers but, unlike the miners, no correlation with exposure can be seen.

In sufficient amounts, uranium that is ingested or inhaled can be harmful because of its chemical toxicity. Like mercury, cadmium, and other heavy-metal ions, excess uranyl ions depress renal function (i.e., affect the kidneys). High concentrations in the kidney can cause damage and, in extreme cases, renal failure. The general medical and scientific consensus is that in cases of high intake, uranium is likely to become a chemical toxicology problem before it is a radiological problem. Since uranium is mildly radioactive, once inside the body, it also irradiates the organs, but the primary health effect is associated with its chemical action on body functions.

Like any radioactive material, there is a risk of developing cancer from exposure to radiation emitted by natural and depleted uranium. This risk is assumed to be proportional to the dose received. Limits for radiation exposure are recommended by the International Commission on Radiological Protection (ICRP) and have been adopted in the IAEA's Basic Safety Standards. The annual dose limit for a member of the public is 1 mSv, while the corresponding limit for a radiation worker is 20 mSv. The additional risk of fatal cancer associated with a dose of 1 mSv is assumed to be about 1 in 20,000. Defenders of the industry argue that this 'small' increase in lifetime risk should be considered in light of the risk of 1 in 5 that everyone has of developing a fatal cancer. It must also be noted that cancer may not become apparent until many years after exposure to a radioactive material.

[1] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 'Sources and effects of Ionizing Radiation', Report to the General Assembly, (New York: UN, 2000).

[2] Ibid.

[3] Ibid.

It is possible to estimate how much DU an individual could be exposed to before the above chemical and radiological limits are exceeded. The table below shows how much depleted uranium would have to be inhaled or ingested to lead to a kidney concentration of 3µg per gram of kidney (chemical toxicity limit) or to a dose of 1 mSv (radiation dose limit). These values have been calculated with the bio-kinetic models currently recommended by the International Commission on Radiological Protection (ICRP). The values have been calculated for two types of uranium compounds: 'moderately soluble' compounds, such as UO_3 and U_3O_8 and 'insoluble' compounds, such as Uo_2.

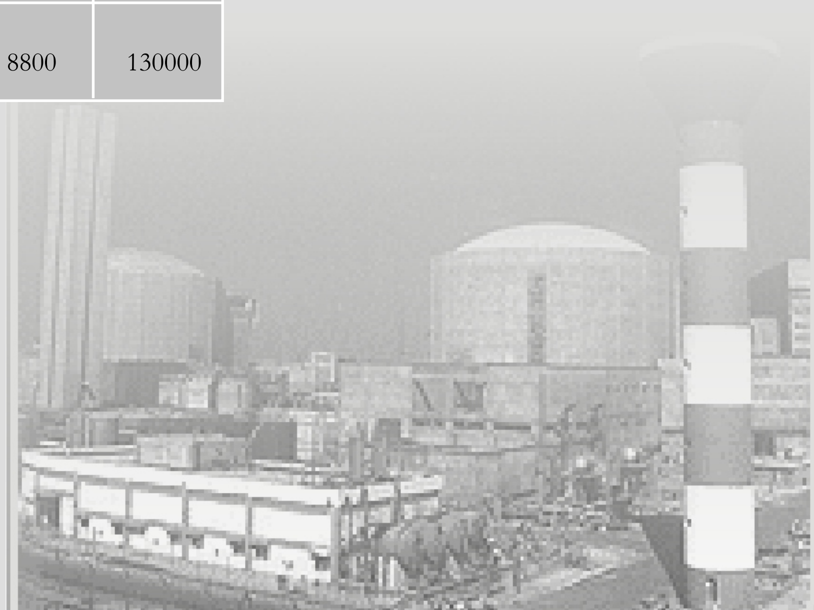
Table 1.4: Inhalation of Depleted Uranium and Concentration in Kidneys

Route of intake	Intake leading to a kidney concentration of 3 µg per gram		Intake leading to a dose of 1 mSv	
	Mass (mg)	**Activity (Bq)**	**Mass (mg)**	**Activity (Bq)**
Inhalation of reference 'moderately soluble' DU aerosol	230	3400	32	480
Inhalation of a reference 'insoluble' DU aerosol	7400	110000	11	160
Ingestion of a reference 'moderately soluble' DU compound	400	5900	1500	22000
Ingestion of a reference 'insoluble' DU compound	4000	59000	8800	130000

It should be borne in mind that the amounts required to give a kidney concentration of 3 µm per gram would be larger if the intake was given over a longer period of time, since it would give the kidneys more time to excrete the DU. In addition to the radiological hazard from uranium isotopes, there is also a potential risk associated with other radionuclides that are formed from the radioactive decay of uranium isotopes and that can be found in the food ingested or in the air inhaled. The values in the table above were calculated taking into account the build up of these radionuclides inside the body, but do not include the contribution of these radionuclides in the food ingested or in the air inhaled.

Another potential harmful effect is due to external exposure to the radiation emitted by uranium isotopes. The main radiation emitted by isotopes of uranium is alpha particles (helium nuclei). This is not the case however with natural uranium, where people are also exposed to the more penetrating beta and gamma radiation emitted by the decay products of uranium that are normally found in equilibrium with the uranium isotopes. In the case of DU, the only beta emitting decay products present are Th-234, Pa-234m and Th-231, all of which emit low intensity gamma-radiation, and, thus the risk from external exposure to DU is considerably lower than for exposure to natural uranium.

There have been a number of studies of workers exposed to uranium and, despite some workers being exposed to large amounts of uranium, there is no evidence that either natural uranium or DU is carcinogenic. This lack of evidence is seen even for lung cancer following inhalation of uranium. As a precaution for risk assessment and to set dose limits, DU is assumed to be potentially carcinogenic, but the lack of evidence for a definite cancer risk in studies over many decades is significant and should put the results of assessments in perspective.

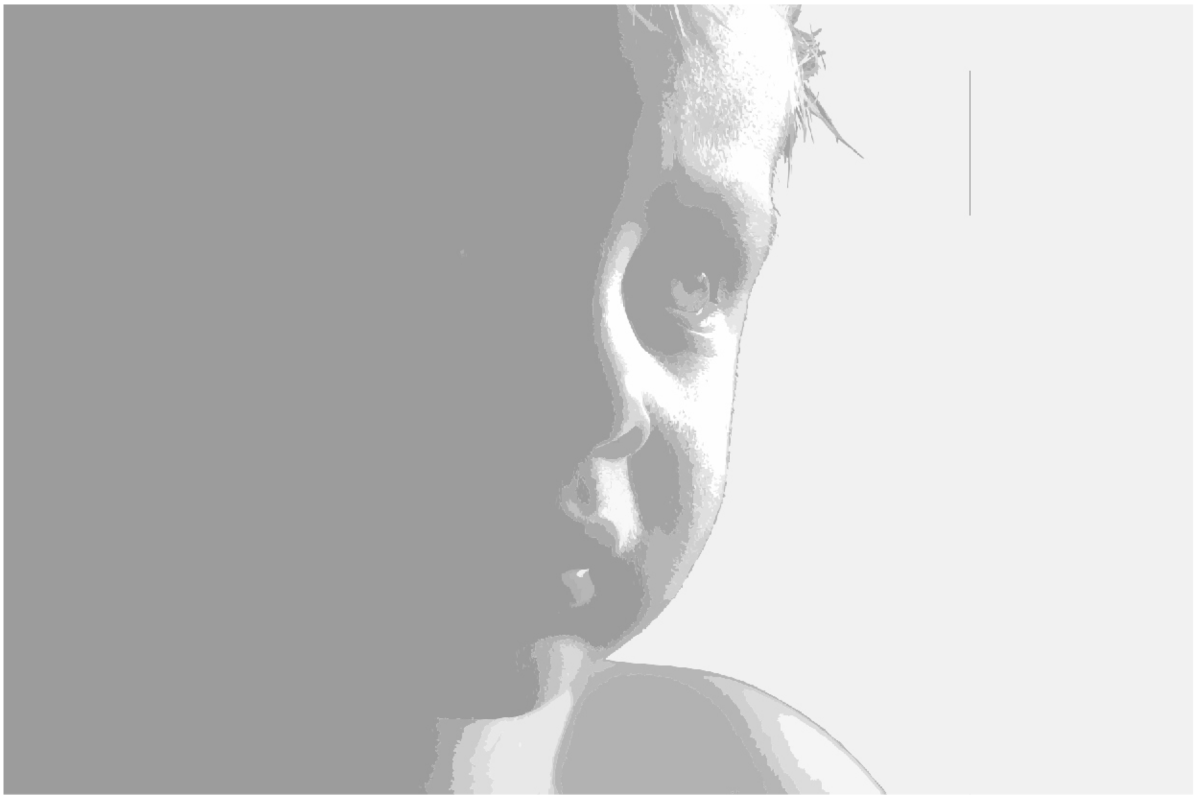


Effects of Uranium on Children

Like adults, children are exposed to small amounts of uranium in air, food, and drinking water. However, no cases have been reported where exposure to uranium is known to have caused health effects in children. It is not known whether children differ from adults in their susceptibility to health effects from uranium exposure. In experiments, very young animals have been found to absorb more uranium into their blood than adult animals when they are fed uranium.

It is not known if exposure to uranium has effects on the development of the human foetus. There have been reports of birth defects and an increase in foetal deaths in animals fed with very high doses of uranium in drinking water. In an experiment with pregnant animals, only a very small amount (0.03%) of the injected uranium reached the foetus. Even less uranium is likely to reach the foetus in mothers exposed to uranium through inhalation and ingestion. There are no available data of measurements of uranium in breast milk. Because of its chemical properties, it is unlikely that uranium would concentrate in breast milk.

The effect of exposure to uranium on the reproductive system is not known. Very high doses of uranium have caused a reduction in sperm counts in some experiments with laboratory animals, but the majority of studies have shown no effects.



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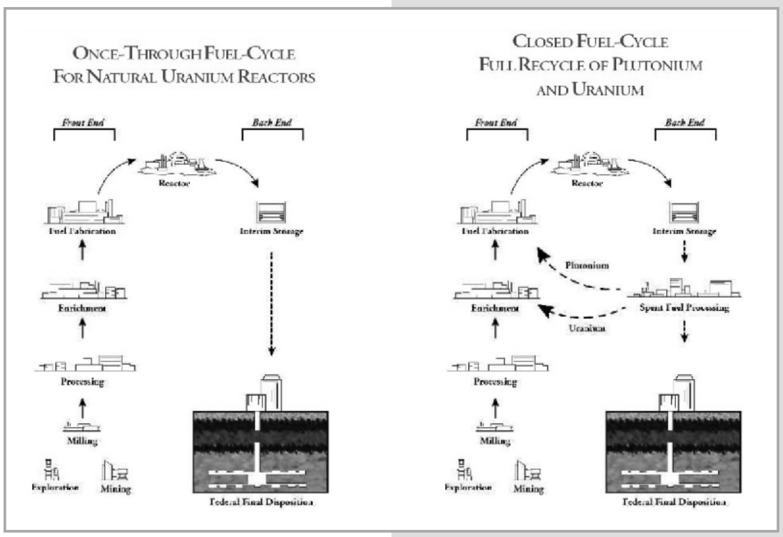
The Nuclear Fuel Cycle

The term 'nuclear fuel cycle' is used to describe the progression of nuclear fuel through a series of differing stagesstarting with the mining of uranium and ending with the disposal of nuclear waste. These various steps can be categorised into 'front end' and 'back end' of the fuel cycle. The **front end** of the fuel cycle involves steps required to prepare uranium for use in a nuclear reactor and broadly include steps of mining and milling, conversion, enrichment and fuel fabrication. Once the uranium has been used in a reactor to produce electricity, it is known as 'spent fuel' and undergoes a further series of steps including temporary storage, reprocessing, and recycling before eventual disposal as waste. Collectively, these steps are known as the **back end** of the fuel cycle.

If spent fuel is not reprocessed, the fuel cycle is referred to as an **open fuel cycle** (or a once-through fuel cycle); if the spent fuel is reprocessed, it is referred to as a **closed fuel cycle**. India has adopted a closed fuel cycle for its nuclear programme.

Figure 2.1: Closed and Open Fuel Cycles



The various steps generally involved in the nuclear fuel cycle have been elaborated below.

Uranium Mining

The earth's crust contains an average of about 3 ppm (or 3 g/t) uranium, and seawater approximately 3 ppb (= 3 mg/t). Naturally occurring uranium consists of three isotopes, all of which are radioactive: U-238, U-235, and U-234. U-238 and U-235 are the parent nuclides of two independent decay series, while U-234 is a decay product of the U-238 series.

Table 2.1: Properties of the Natural Uranium Isotopes

	U-234	**U-235**	**U-238**
Half-life	244,500 years	703.8 * 10^6 years	4.468 *10^9 years
Specific activity	231.3 MBq/g	80,011 Bq/g	12,445 Bq/g

Table 2.2: Isotopic Composition of Natural Uranium

	U-234	U-235	U-238	Total
Atom %	0.0054%	0.72%	99.275%	100%
weight %	0.0053%	0.711%	99.284%	100%
activity %	48.9%	2.2%	48.9%	100%
activity in 1 g U (Nat)	12,356 Bq	568 Bq	12,356 Bq	25,280 Bq

The uranium content of the ore is often between only 0.1% and 0.2%. Therefore, large amounts of ore have to be mined to get at the uranium. Uranium is usually mined by either surface (open cut) or underground mining techniques, depending on the depth at which the ore body is found. Quite clearly, open pit mining is used where deposits are close to the surface and underground mining is used for deep deposits, typically greater than 120 m deep. Canada produces the largest share of uranium from mines (23% of world supply from mines), followed by Australia (21%) and Kazakhstan (16%).

Mining methods have been changing over the years. In-situ leach mining has been steadily increasing its share of the total as against excavation. In in-situ leaching method, oxygenated groundwater is circulated through a very porous ore body to dissolve the uranium and bring it to the surface. The uranium is then recovered from the solution as in a conventional mill.

Milling
From these, the mined uranium ore is sent to a mill, which is usually located close to the mine. At the mill, the ore is crushed and ground to a fine slurry, which is leached in sulphuric acid to allow the separation of uranium from the waste rock. It is then recovered from solution and precipitated as uranium oxide (U_30_8) concentrates also known as "yellowcake", though it is finally khaki in colour. This generally contains more than 80% uranium. Packed in 200 litre drums, the yellowcake is transported for conversion into fuel.

Conversion
The product of a uranium mill is not directly usable as a fuel for a nuclear reactor. Additional processing, generally referred to as enrichment, is required for most kinds of reactors. This process requires uranium to be in gaseous form and this is done by converting it to uranium hexafluoride (UF_6), which is a gas at relatively low temperatures.

At a conversion facility, uranium is first refined to uranium dioxide, which can be used as the fuel for those types of reactors that do not require enriched uranium. Most is then converted into uranium hexafluoride, ready for the enrichment plant.

Enrichment
Only 0.7% of natural uranium is "fissile" or capable of undergoing fission, the process by which energy is produced in a nuclear reactor. The vast majority of all nuclear power reactors in operation and under construction require enriched uranium fuel in which the proportion of the U-235 isotope has been raised from the natural level of 0.7% to about 3.5% or slightly more. The enrichment process removes about 85% of the U-238 by separating gaseous uranium hexafluoride into two streams: One stream is enriched to the required level and then passes to the next stage of the fuel cycle. The other stream is depleted in U-235 and is called 'tails'. This is mostly U-238.

So little U-235 remains in the tails (usually less than 0.25%) that it is of no further use for energy, though such 'depleted uranium' is used in metal form in yacht keels, as counterweights, and as radiation shielding, since it is 1.7 times denser than lead.

Fuel Fabrication
Enriched UF_6 is then transported to a fuel fabrication plant where it is converted to uranium dioxide (UO_2) powder and pressed into small pellets. These pellets are inserted into thin tubes, usually of a zirconium alloy (zircalloy) or stainless steel, to form fuel rods. The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor.

Nuclear Reactor
Several hundred fuel assemblies make up the core of a reactor. In the reactor core, the U-235 isotope fissions or splits producing heat in a continuous process called a chain reaction. The process depends on the presence of a moderator such as water or graphite and is fully controlled.

Some of the U-238 in the fuel is turned into plutonium in the reactor core. The main plutonium isotope is also fissile and it yields about one third of the energy in a typical nuclear reactor. As in fossil-fuel burning electricity generating plants, the heat is used to produce steam to drive a turbine and an electric generator.

Spent Fuel

With time, the concentration of fission fragments and heavy elements formed in the same way as plutonium in a fuel bundle will increase to the point where it is no longer practical to continue to use the fuel. So after 1224 months, the 'spent fuel' is removed from the reactor. The amount of energy that is produced from a fuel bundle varies with the type of reactor and the policy of the reactor operator. When removed from a reactor, a fuel bundle will emit both radiation (principally from the fission fragments) and heat. Used fuel is unloaded into a storage pond immediately adjacent to the reactor to allow the radiation levels to decrease and absorb the heat. Used fuel is held in such pools for several months to several years. Depending on policies in particular countries, some used fuel may be transferred to central storage facilities. Ultimately, used fuel must either be reprocessed or prepared for permanent disposal.

Reprocessing

Used fuel is about 95% U-238, but also contains about 1% U-235 that has not fissioned, about 1% plutonium and 3% fission products, which are highly radioactive, with other transuranic elements formed in the reactor. In a reprocessing facility, the used fuel is separated into its three components: **uranium**, **plutonium** and **waste**- containing fission products. Reprocessing enables recycling of the uranium and plutonium into fresh fuel, and produces a significantly reduced amount of waste (compared with treating all used fuel as waste).

The uranium from reprocessing, which typically contains a slightly higher concentration of U-235 than occurs in nature, can be reused as fuel after conversion and enrichment, if necessary. The plutonium can be directly made into mixed oxide (MOX) fuel, in which uranium and plutonium oxides are combined. In reactors that use MOX fuel, plutonium substitutes for the U-235 in normal uranium oxide fuel.

Vitrification

After reprocessing the liquid, high-level waste can be calcined (heated strongly) to produce a dry powder, which is incorporated into borosilicate (Pyrex) glass to immobilise the waste. The glass is then poured into stainless steel canisters, transported and stored with appropriate shielding. This is as far as the nuclear fuel cycle goes at present. The final disposal of vitrified high-level wastes, or the final disposal of spent fuel, which has not been reprocessed spent fuel, has not yet taken place.

Wastes

Wastes from the nuclear fuel cycle are categorised as **high-, medium- or low-level wastes** by the amount of radiation that they emit. These wastes come from a number of sources.

- low-level waste produced at all stages of the fuel cycle;
- intermediate-level waste produced during reactor operation and by reprocessing;
- high-level waste, which is waste containing fission products from reprocessing, and in many countries, the used fuel itself.

When we talk about nuclear fuel cycle, we can now well understand that it is not actually a 'cycle' by any means, but rather, it is a cycle with a great number of open ends if one might call it a cycle at all. So, one cannot speak of "recycling" in any sense as suggested by the term.

Final Disposal

The waste forms envisaged for disposal are vitrified high-level wastes sealed into stainless steel canisters, or spent fuel rods encapsulated in corrosion-resistant metals such as copper or stainless steel. The most widely-accepted plans are for these to be buried in stable rock structures deep underground. Many geological formations such as granite, volcanic tuff, salt or shale will be suitable. The first permanent disposal is expected to occur about 2010.

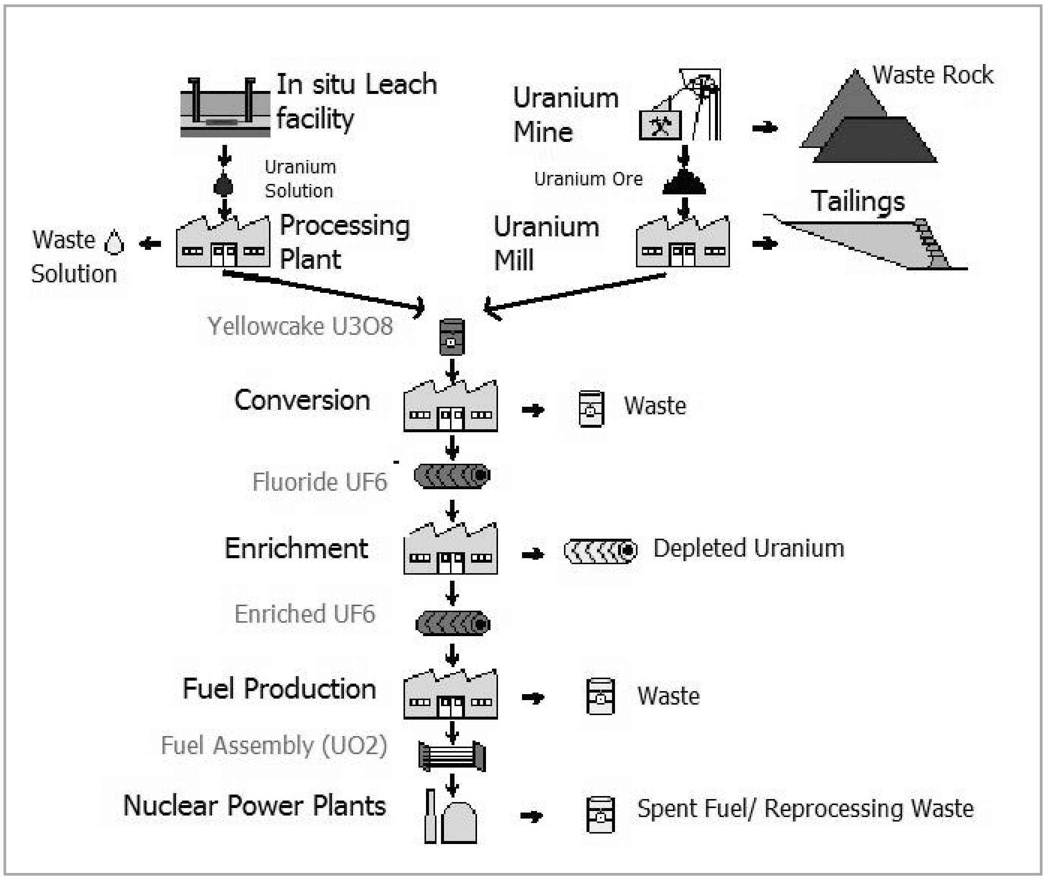
Most countries intend to introduce final disposal sometime after about 2010, when the quantities to be disposed of will be sufficient to make it economically justifiable. A number of countries are carrying out studies to determine the optimum approach to the disposal of spent fuel and wastes from reprocessing. The general consensus favours its placement into deep geological repositories, initially recoverable.

Nuclear Fuel Cycle And The Radioactive Waste

Radioactive wastes produced from the nuclear fuel cycle need to be managed and disposed safely. For low- and intermediate-level wastes, these are mostly being implemented. For high-level wastes, some countries await the accumulation of enough of it to warrant building geological repositories. Eventually all radioactive wastes decay into non-radioactive elements. The more radioactive an isotope is, the faster it decays.

The main objective in managing and disposing of radioactive (or other) waste is to protect people and the environment. This means isolating or diluting the waste so that the rate or concentration of any radionuclides returned to the biosphere is harmless. To achieve this, practically all wastes are contained and managed. Below is a rough representation of the nature of waste generated during the various stages of nuclear fuel cycle. This is further elaborated in the following stages.

Figure 2.2: Wastes Generated in a Nuclear Fuel Cycle



Mining and Milling

Mining uranium ore generates a huge amount of waste rock. The processing of the ore also generates fine sandy tailings, which contain virtually all the naturally-occurring radioactive elements found in uranium ore. These tailings need to be collected in engineered tailings dams and finally covered with a layer of clay and rock to inhibit the leakage of radon gas and ensure long-term stability. In the short term, the tailings material is often covered with water. After a few months, the tailings material contains about 75% of the radioactivity of the original ore.

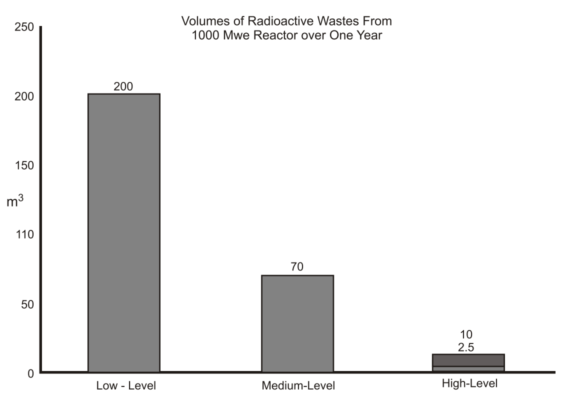
Conversion, Enrichment, Fuel Fabrication

Uranium oxide concentrate from mining, essentially "yellow cake" (U_3O_8), is not significantly radioactive slightly more so than the granite used in buildings. The process involves refinement and conversion to uranium hexafluoride gas (UF_6). As a gas, it undergoes enrichment to increase the U-235 content from 0.7% to about 3.5%. Every tonne of uranium hexafluoride becomes separated into about 130 kg of enriched UF_6 and 870 kg of 'depleted' UF_6 (mostly U-238). It is then turned into a hard ceramic oxide (UO_2) for assembly as reactor fuel elements.The main by-product of enrichment is depleted uranium (DU), principally the U-238 isotope, which is stored either as UF_6 or U_3O_8.

Electricity Generation
In terms of radioactivity, High-level Waste (HLW) is the major issue arising from the use of nuclear reactors to generate electricity. Highly radioactive fission products and also transuranic elements are produced from uranium and plutonium during reactor operations and are contained within the used fuel. Where countries have adopted a closed cycle and utilised reprocessing to recycle material from used fuel, the fission products and transuranic elements are separated from uranium and plutonium and treated as HLW (uranium and plutonium is then re-used as fuel in reactors). In countries where used fuel is not reprocessed, the used fuel itself is considered a waste and therefore classified as HLW.

Low and intermediate level waste is produced as a result of operations, such as the cleaning of reactor cooling systems and fuel storage ponds, the decontamination of equipment, filters and metal components that have become radioactive as a result of their use in or near the reactor.

Each year, nuclear power generation facilities world-wide produce about 200,000 m^3 of low and intermediate level waste and 10,000 m^3 of high level waste (including spent fuel designated as waste). The amount of HLW however varies with reactor technology. The newer technology is said to reduce amounts of HLW.



INTERNATIONAL INSTRUMENTS

There are well-established safety standards for the management of radioactive waste. International and regional organisations such as the IAEA, OECD/ NEA, EC and ICRP are responsible for developing standards, guidelines and recommendations under a framework of co-operation to assist countries in establishing and maintaining national standards. National policies, legislation and regulations are all developed from these internationally agreed standards, guidelines and recommendations. Amongst others, these standards aim to ensure the protection of the public and the environment, both now and in the future.

The International Atomic Energy Agency (IAEA)
The IAEA was established by the United Nations in 1957 to ensure world co-operation for the peaceful use of nuclear energy. It has some 145 member countries, including India, and the main role of the organisation is to establish guiding principles and standards for radiation protection and safety as well as that of having a controlling role in relation to the non-proliferation treaty (NPT) on nuclear weapons. The IAEA has since 1988 prepared a series of safety documents regarding the handling of radioactive waste. In the context of their 'Radioactive Waste Safety Standards', it has formulated recommendations as to the necessary standards and criteria for the handling and final disposal of spent nuclear fuel and radioactive waste. One of the main documents in this regard is 'The Principles of Radioactive Waste Management' of 1995 which forms a basis for the 1997 convention regarding safety with the handling of spent nuclear fuel and on safety with regard to the handling of radioactive waste. Whilst IAEA guidelines and regulations have no legal jurisdiction, in practise, member countries usually comply with their recommendations.

Principles and Objective of Radioactive Waste Management

It should be remembered that radioactivity does not implicitly recognise national boundaries, nor on the timescales do national borders themselves remain a constant. It is therefore important that to ensure we follow the main objective of radioactive waste management, common principles and practices are applied around the world.

A general principle of radioactive waste management is that waste should not be created unnecessarily and that they are created safely and appropriately managed and treated. They should then be disposed of at appropriate times and in appropriate ways. As well as ensuring environmental protection, these principles recognise also the protection of people both workers and members of the public. The main objective is described in IAEA documentation as follows:

"The main objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations."

The fundamental principles of radioactive waste management as laid down by IAEA are:

1. Protection of Human Health

Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

2. Protection of the Environment

Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.

3. Protection beyond National Borders

Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

4. Protection of Future Generations

Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

5. Burdens on Future Generations

Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

6. National Legal Framework

Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

7. Control of Radioactive Waste Generation

Generation of radioactive waste shall be kept to the minimum practicable.

8. Radioactive Waste Generation and Management Interdependencies

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

9. Safety of Facilities

The safety of facilities for radioactive waste management shall be appropriately assured during their life time.

International Commission on Radiological Protection (ICRP)

Radiological protection dates back to the early years of medical uses of radiation and radioactive materials, with various countries introducing protection rules during the first few decades of this century. Since 1928, the International Commission on Radiological Protection (ICRP) has published universal recommendations, regularly updated in the light of recent information, on the effects of radiation exposure on health. The ICRP is an independent experts association. Many of its recommendations have been adopted by organs such as the IAEA and the EC as well as by individual countries.

OECD Nuclear Energy Agency (OECD NEA)

Within the framework of the OECD (Organisation for Economic Co-operation and Development), a nuclear section operates known as the NEA (Nuclear Energy Agency). Membership currently consists of all European Union member countries as well as Australia, Canada, Japan, Republic of Korea, Mexico and the US. The NEA provides both an advisory and a support role for its member states with regard to questions concerning the handling of radioactive waste in general, and the development of strategies for the handling of radioactive waste in particular with regard to the handling of spent fuel, and long-lived waste. Furthermore, the NEA is involved in the assembling of information on the influence of nuclear waste on health and the environment, and on developing methodologies and strategies for safety analysis.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source. This is achieved by:

- Encouraging harmonisation of national regulatory polices and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation, preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;

- Assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;
- Developing exchanges of scientific and technical information, particularly through participation in common services;
- Ensuring that appropriate technical and economic studies on nuclear energy development and the fuel cycle are carried out; and
- Setting up international research and development programmes and joint undertakings.

In recent years, the organisation has expanded its activities towards addressing the societal aspects of the disposal of spent nuclear fuel and has subsequently established a *Forum for Stakeholders Confidence*, in addition to organising conferences, etc. Furthermore, the NEA has issued a report "The environmental and ethical basis of geological disposal", which presents a consensus position in the form of a Collective Opinion of the Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency. The report addresses the strategy for the final disposal of long-lived radioactive wastes seen from an environmental and ethical perspective, including considerations of equity and fairness within and between generations. In these and related tasks, NEA works closely in collaboration with the IAEA, with which it has concluded a co-operation agreement, as well as with other international organisations in the nuclear field.

The European Commission

Within the European Commission, there are a number of services concerned with aspects of radioactive waste management, both as regards member and non-member countries.

The **Nuclear Safety Unit of DG-Energy and Transport Unit** has responsibilities in the fields of nuclear installation safety, radioactive waste management and decommissioning of nuclear facilities. Setting up and encouraging co-operation, coordination and information exchange between the various bodies and organizations involved in radioactive waste management is an integral part of the Unit's activities within the Community. Furthermore, the Unit's activities are also increasingly oriented towards the major problem areas of radioactive waste management, namely; stimulating and raising the level of the debate on such topics as siting, safety cases, environmental impact assessment, and public involvement, information and acceptance.

Extensive research in the field of nuclear waste has been carried out under the auspices of **DG Research**.

INTERNATIONAL CONVENTIONS

International cooperation in the field of nuclear energy has been conducted within the framework of established organisations since the 1950s when the EUROTOM Treaty was drawn up and the first states ratified the Statue of the IAEA. Following the Chernobyl incident however, the shortcomings of such 'ad hoc' international cooperation became clearer thus demonstrating the need to strengthen international environmental law regarding such nuclear activities. There is, however, no international legislative authority in the field and the tools of international law continue to be applied through the medium of international conventions pertinent to this area, both in the field of nuclear activities and in that of environmental conventions. However, such conventions are binding only on those countries that have signed and ratified them.

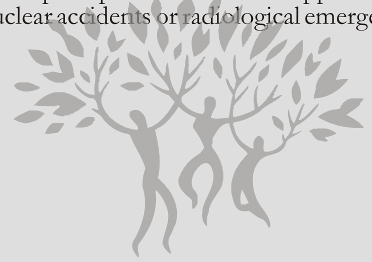
Within the framework of IAEA, four conventions in the area of Radiation and Waste Safety currently have legal force. They are:

The **Convention on Nuclear Safety** (1994, in force since 1996) establishes an international co-operation mechanism to maintain safety in nuclear installations. The convention enjoins the partners to introduce precautionary measures and to develop legislation for nuclear technological developments.

Two conventions were introduced in the wake of the nuclear accident at Chernobyl:

The **Convention on Early Notification of a Nuclear Accident** (1986) establishes a notification system for nuclear accidents that have the potential for an international transboundary release of radiological material that could have safety considerations for other States.

The **Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency** (1986) sets out an international framework for co-operation among concerned Parties and the IAEA to facilitate prompt assistance and support in the event of nuclear accidents or radiological emergencies



The **Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management** was adopted and opened for signature at a Diplomatic Conference in September 1997 and entered into force on the 18 June 2001. The Joint Convention is the first legal instrument to directly address these issues on a global scale. The Joint Convention applies to spent nuclear fuel and radioactive waste resulting from civilian nuclear reactors and applications, and to spent fuel and radioactive waste from military or defence programmes, if and when such materials are transferred permanently to and managed within exclusively civilian programmes, or when declared as 'spent fuel' or as 'radioactive waste' for the purposes of the Convention, by the Contracting Party. The Convention also applies to planned and controlled releases of liquid or gaseous radioactive materials from regulated nuclear facilities into the environment. The obligations of the Contracting Parties with respect to the safety of spent fuel and radioactive waste management are based, to a large extent, on the principles contained within the IAEA Safety Fundamentals document entitled "The Principles of Radioactive Waste Management", published in 1995. Currently, 46 countries have signed or ratified the Joint Convention. India has neither signed nor ratified the Convention.

Other conventions include the **Non-proliferation treaty on nuclear weapons**, **the convention on compensation in the nuclear energy field, the convention on compensation regarding sea transport of nuclear substances** as well as conventions that apply in geographically specific areas, such as the OSPAR Convention (1992) that applies to the North-East Atlantic, the Treaty on the Antarctic, and the global dumping convention or the 'London convention' that prohibits the dumping of radioactive substances into the sea.

The Rio Convention, **United Nations Sustainable Development, Agenda 21**

Section II contains the programme area: *Promoting the safe and environmentally sound management of radioactive wastes.* The objective of the programme area is to ensure that radioactive wastes are safely managed, transported, stored and disposed of, with a view to protecting human health and the environment, within the wider framework of an interactive and integrated approach to radioactive waste management and safety.

Measures introduced in the convention include the promotion of policies and practical measures to provide for the safe processing, conditioning, transportation and disposal of spent nuclear fuel and radioactive wastes and the promotion of planning, including the environmental impact assessment where appropriate, of safe and environmentally sound management of radioactive waste.

OTHER RELEVANT LEGISLATIONS

Other relevant legislation with respect to the decision-making processes and the management of spent nuclear fuel include:

EU Directive on Environmental Impact Assessment (EIA), [85/337/EEC amended 97/11/EC]

According to this directive, an environmental impact assessment must be carried out for all major development projects prior to their implementation. The directive contains a list (Annex 1) of types of projects that always require an Environmental Impact Assessment in accordance with Article 4(1) of the directive. Included in this list is the mandatory requirement of an EIA for installations designed:

- for the processing of irradiated nuclear fuel or high-level radioactive waste,
- for the final disposal of irradiated nuclear fuel,
- solely for the final disposal of radioactive waste,
- solely for the storage (planned for more than 10 years) of irradiated nuclear fuels or radioactive waste in a different site than the production site (Annex 1, 97/11/EC).

The directive identifies several steps in the EIA procedure that must be followed by the member states, including screening, scoping, review, consultation and public participation. Furthermore, minimal requirements are introduced for the contents of an Environmental Impact Statement (EIS). All the Nordic countries must comply with this directive, Denmark, Finland and Sweden through their membership of the European Union, and Iceland and Norway through their membership of the European Economic Area (EEA). EIA was introduced into national legislation in the Nordic countries during the period 198 1994, either through separate legislation and regulations, or by inclusion in other acts.

EU Directive on Strategic Environmental Assessment of Certain Plans and Programmes

A new EC directive has been adopted on the Environmental Assessment for certain plans and programmes. The directive was adopted by the European Parliament on 31 May 2001 and by the European Council on 5 June 2001. The purpose of the SEA-Directive is to ensure that the environmental consequences of certain plans and programmes are identified and assessed during their preparation, and thus before their adoption. The public and environmental authorities can lodge opinions, with all results being integrated and taken into account in the course of the planning procedure. After the adoption of the plan or programme, the general public is then informed of the decision and of the way in which it was made. In cases where there are likely to be transboundary effects of significance, the affected Member State is publicly informed, and thus also has the possibility to make comments which are also integrated into the national decision making process.

The Directive will enter into force after its publication in the Official Journal. Afterwards, Member States will have three years to integrate the new instrument into their national systems. Programmes initiated after the Directive enters into force, and prior to the requirements of the directive being enacted into national legislation, may, it should be noted, be subject to the requirements.

The ESPOO Convention

Furthermore, an international convention exists on this topic; namely, the Espoo convention, formulated by the United Nation's Economic Commission for Europe in 1991, which entered into force in 1997. The general objective of the directive is to prevent or reduce the adverse transboundary impacts of proposed activities. The convention lists projects where an Environmental Impact Assessment shall be carried out, where such projects are considered likely to have considerable cross boundary effects. Among such cases are those activities that involve nuclear technology. The convention also lays down a set of minimum requirements that the Environmental Impact Statement shall contain. The Convention requires extensive levels of cooperation between the countries involved. An important principle of the convention is that the authorities and the general public in countries neighbouring the country where the development takes place are given the opportunity to participate in the EIA process, in addition to the authorities and the general public in the countries in which the development actually takes place.

The Aarhus Convention

The Aarhus Convention concerns access to information, public participation in decision making and the right to trial regarding environmental issues. The goal of the convention is to enable the public to gain access to information and to participate in the decision-making process on issues regarding environmental issues. The convention contains a list of activities to which such provisions apply. Different types of nuclear activities are included in these lists, including spent nuclear fuel disposal.

The Nuclear Programme in India

3

Growth in the economy is made possible by several inputs, energy being one of them. For a large country like India with over one billion population and rapid economic growth rate, no single energy resource or technology constitutes a panacea to address all issues related to the availability of fuel supplies, environmental impact, climate change and health externalities. Therefore, it has been found necessary that all resources become an integral part of an energy mix as diversified as possibleto ensure energy security.

An adequate and uninterrupted power generation is an intrinsic essentiality for the overall development of any nation. In quantitative terms, the per capita consumption of electric energy is regarded as an indicative parameter of the socio economic growth rate of a nation. Per capita power consumption in India is around 400 Kwh/yr, which is well below the world average consumption of 2400 Kwh/yr. A massive increase in the power generation to match the world average consumption is propagated in the coming years to enhance the overall national growth rate. Electricity demand in India has been increasing rapidly, and the 534 billion kilowatt hours produced in 2002 was almost double the 1990 output, though it still represented only 505 kWh per capita for the year.

Table 3.1: Source wise Energy Demand (All in mtoe)

	1960-61	1970-71	1980-81	1990-91	2000-01	2006-07	2011-12#
Coal	35.64	36.48	56.96	94.15	131.52	200.02	270
Lignite	0.01	0.81	1.23	3.58	6.43	8.72	13
Oil	8.29	19.14	32.26	57.75	106.97	132.75	186
Natural Gas	-	0.60	1.41	11.49	25.07	34.60	48
Hydro Power	0.67	2.17	4.00	6.16	6.40	9.75	12
Nuclear Power	-	0.63	0.78	1.60	4.41	4.86	17
Wind Power	-	-	-	-	0.13	0.83	<1
Total	44.61	59.83	96.73	174.73	280.93	391.53	546

Note: # Projected Requirement at the end of the Eleventh Plan as per the IEPC report.
Source: Planning Commission

Table 3.2: Generating Capacity Anticipated at the End of the 11th Plan (MW)

	Hydro	Thermal	Nuclear	Wind and Renewables	Total
Installed Capacity as on 31 march 2007	34653.77	86014.84	3900.00	7760.60	132329.21
Addition During 11th Plan	16553.00	56844.00	3380.00	14000.00	92577.00
Total Capacity Anticipated As on 31 March 2012	51206.77	144658.84	7280.00	21760.60	224906.21

Source: Planning Commission

NUCLEAR ENERGY POLICY

India has consciously proceeded to explore the possibility of tapping nuclear energy for the purpose of power generation. The set objective has been to use the two naturally occurring elements Uranium and Thorium, which have good potential to be utilised as nuclear fuel in Indian Nuclear Power Reactors. The estimated natural deposits of natural Uranium are under 70,000 tonnes and Thorium, under 3, 60,000 tonnes.

India's civil nuclear strategy has been directed at complete independence in the nuclear fuel cycle. This is necessary as it was excluded from the 1970 Nuclear Non-Proliferation Treaty (NPT) due to acquiring the nuclear weapons capability after 1970. India's nuclear energy self-sufficiency extends from uranium exploration and mining through fuel fabrication, heavy water production, and reactor design and construction, to reprocessing and waste management. The current nuclear energy installed capacity is 3900 MWe, which is 3.1% of the total installed power generation capacity. This will increase steadily as new plants come on line. The Eleventh Five Year Plan (2007-2012) power programme includes 3380 MWe of nuclear power plants. The total outlay for power projects of Nuclear Energy during the Plan period is Rs 22,723 crore.[4]

[4] Planning Commission, Government of India, *Eleventh Five Year Plan 2007-2012*; Vol III, Chapter 10 on 'Energy', (New Delhi: Oxford University Press, 2008).

India's fuel situation is said to be driving the nuclear investment for electricity, and 25% nuclear contribution is foreseen by 2050, one hundred times the 2002 capacity. The target for nuclear power, since about 2004, has been to provide 20,000 MWe by 2020. But in 2007 the Prime Minister referred to this as "modest" and capable of being "doubled with the opening up of international cooperation."

The Government of India is making efforts to import nuclear fuel from abroad, which is expected to improve the supply of nuclear fuel for nuclear power plants. It is also expected that the execution of nuclear projects too will be opened up to enable participation by other PSUs and the private sector. The effect of this is likely to become visible in the Twelfth Plan period. A capacity addition of about 11000 MW during the Twelfth Plan has been indicated by NPCIL. The long-term nuclear power programme is based on utilising the vast indigenous resources of thorium for electricity generation.

Three-Stage Programme

India has a three-stage nucear power programme.

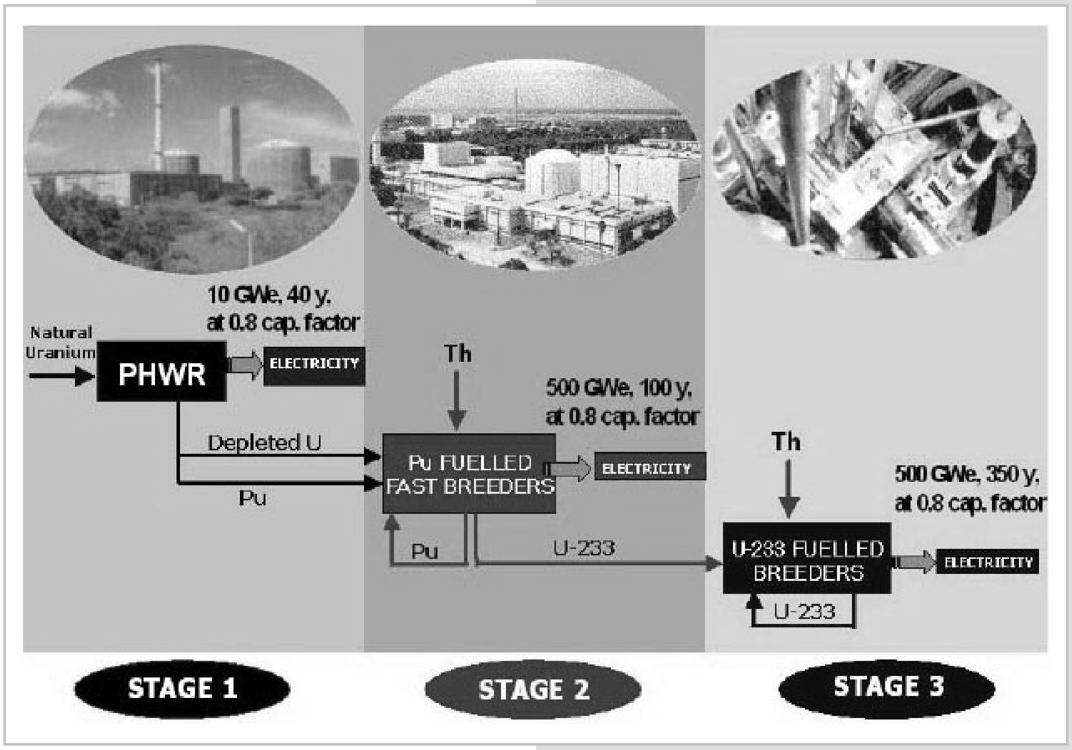
Stage One

The first stage **of India's nuclear programme** is based on Pressurised Heavy Water Reactors (PHWR), which are fuelled by natural uranium. The requirement of natural uranium for these reactors is met from indigenous resources. The first stage of the programme was based on the PHWR Technology for the following advantages: optimum utilisation of the limited uranium resources; higher Plutonium yield, for the second stage fuel; and availability of indigenous technology.

India preferred a closed cycle mode in view of its phased expansion of nuclear power generation extending through the second and third stages. "**Closed cycle**" refers to chemical separation of U-238 and Pu-239 and further recycling.

Nuclear power projects have been set up and operated directly under the Government of India since the late 1960s. When the construction of the first nuclear power station commenced in September 1987 when the Nuclear Power Corporation of India Limited (NPCIL), a wholly-owned company of Government of India was formed. The formation of NPCIL was to give the required degree of operational freedom and to mobilise funds from the Indian capital market to finance new nuclear power projects. NPCIL is responsible for designing, constructing commissioning and operating the nuclear power plants of the first stage nuclear power programme.

3 Stages of India's Nuclear Power Programme



Stage Two

The second stage envisages the utilisation of plutonium produced and re-processed from the first stage in a fast breeder reactors (FBR) and producing electricity and more plutonium and uranium-233 from thorium. The target is to produce a sustained energy output of 420 GWe from FBR.

The work on the second stage of the nuclear power programme is in progress at the Indira Gandhi Centre for Atomic Research (IGCAR). The 40MWt Fast Breeder Test Reactor (FBTR) at Kalpakkam has been in operation since 1985. India is the sixth nation to have the technology to build and operate a FBTR besides USA, UK, France, Japan and the then what used to be USSR. The setting up of a plutonium-fuelled Prototype Fast Breeder Reactor (PFBR) capable of generating 500 MWe of power is in progress at Kalpakkam in Tamilnadu.

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), a wholly-owned enterprise of GoI, was set up in 2003 under the administrative control of the DAE with the objective of constructing and commissioning PFBR and to pursue construction, commissioning, operation and maintenance of subsequent Fast Breeder Reactors for generation of electricity in pursuance of the Stage two of the programme. Concurrently, it is proposed that thorium-based fuel be used along with a small feed of plutonium-based fuel in Advanced Heavy Water Reactors (AHWRs). The AHWRs are expected to shorten the period of reaching the stage of large-scale thorium utilisation.

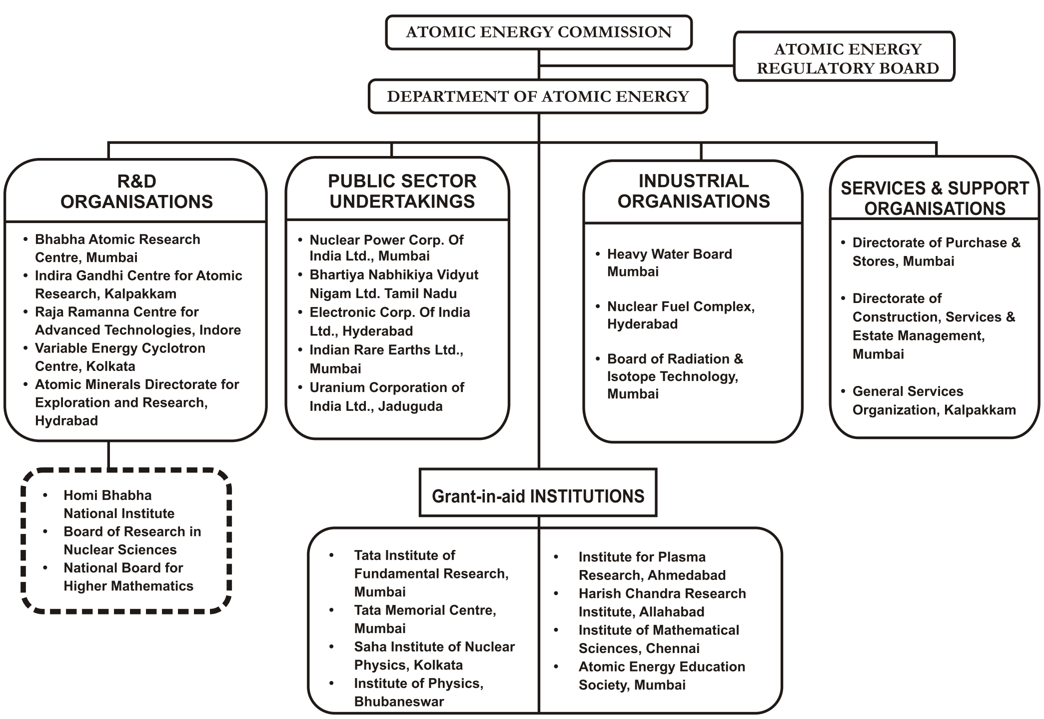
Stage Three

The third stage of reactors will be based on thorium cycle producing power and more uranium-233 for which R&D efforts are in progress and some breakthroughs have already been achieved. The requirements of thorium would be met from vast resources of the mineralmonazite. Towards building thorium-based reactors, the DAE has been taking great strides including setting of a 30kW (th) neutron source reactor KAMINI at Kalpakkam, Tamil Nadu. This reactor has been in operation since 1997. KAMINI uses uranium-233 based fuel derived from irradiated thorium.

NUCLEAR ESTABLISHMENTS

The Indian Atomic Energy Organisational Structure is shown below:

India's Atomic Energy Organisational Structure



The nuclear power programme and nuclear research and development activities are under the control of the Prime Minister. He operates through Atomic Energy Commission (AEC) and Department of Atomic Energy (DAE). The chairman of the AEC also holds the post of secretary of the DAE. Development of nuclear power and related nuclear fuel cycle and research and development activities are carried out in various units under the AEC/ DAE. The organisation is broadly divided into various sectors such as research and development, industrial, public, and the services and support . It provides for the close interaction needed between the production and R&D units.

The Atomic Energy Commission (AEC), set up under the Atomic Energy Act in 1948, has the ultimate control of all activities relating to commercial usage of nuclear energy. The AEC formulates policies for the DAE, prepares its budget, and ensures that the policies are implemented. It is responsibile for safety through the Atomic Energy Regulatory Board (AERB).

The Atomic Energy Regulatory Board (AERB), which is answerable to the AEC, formulates safety standards and regulations. It approves the commissioning of nuclear stations on the basis of its own safety assessments and upon information provided by the Safety Review Committee of the DAE.

The functional responsibilities of AERB are:

1. Preparation of safety codes, guides, standards and technical regulations relating to nuclear and radiation safety.

2. Supervision of the authorisation process, including the approval of specifications for nuclear facilities and granting of authorisation at different stages like site evaluation, construction, operation, final shut down and decommissioning.

3. Surveillance of facilities both under construction and in operation.

The Department of Atomic Energy (DAE) was set up in 1954 and has full executive powers to implement the policies of the AEC. All centers such as the two main research centres, other research institutions receiving support; the Nuclear Power Corporation; the heavy water projects; and fuel-chain undertakings, report to the DAE.

The **Research and Development sector** includes Bhabha Atomic Research Centre (BARC), Indira Gandhi Centre for Atomic Research (IGCAR), Atomic Minerals Directorate for Exploration and Research (AMD), Centre for Advanced Research (CAT), Variable Energy Cyclotron Centre (VECC), and fully aided research institutions like Tata Institute of Fundamental Research (TIFR), Institute for Plasma Research (IPR) and others. It also includes BRNS and NBHM for providing extra-mural funding to universities and other national laboratories.

The **Industrial sector** includes Government owned units, Heavy Water Board (HWB) manufacturing heavy water, Nuclear Fuel Complex (NFC) manufacturing nuclear fuel, zircaloy components and stainless steel tubes, and Board of Radiation & Isotope Technology (BRIT) for radioisotopes.

The **Public Sector Enterprises** under the control of DAE include:

- Nuclear Power Corporation of India Limited (NPCIL) is responsible for design, construction, commissioning and operation of stage one nuclear power plants (PHWR);
- BHAVINI is responsible for design, construction, commissioning and operation of stage two nuclear power plants (Fast Breeder Reactors);
- Uranium Corporation of India Limited (UCIL) is responsible for mining, milling and processing of uranium ore;
- Indian Rare Earths Limited (IRE) is responsible for mining and processing mineral sands containing thorium and rare earth minerals, and producing minerals such as ilmenite, rutile, monazite, zircon and garnet;
- Electronics Corporation of India Limited (ECIL) supplies commercial electronics, reactor ontrol and instrumentation equipment related to atomic energy.

The **Directorate of Construction Services and Estate Management** is responsible for construction and maintenance of residential housing/office buildings and other related facilities; and the **Directorate of Purchase and Stores** is responsible for centralised purchases and stores.

There is no public participation at any stage of the process. The public, in fact, comes to know of a project only when people start receiving eviction notices and their land gets acquired for a project of "national importance". It is almost impossible to get any relevant information regarding nuclear activity from the authorities.[5]

Anumukti, 'An overview of the Indian Nuclear Programme', Report to the No Nukes Asia Forum, 1997.

NUCLEAR POWER PROJECTS DEVELOPMENT

India's nuclear power programme has proceeded largely without fuel or technological assistance from other countries. Its power reactors which, till the mid-1990s, had some of the world's lowest capacity factors, reflecting the technical difficulties of the country's isolation, rose impressively from 60% in 1995 to 85% in 2001-02 but has since decreased to 57% in 2006-07. Constraint in nuclear fuel availability is the main reason for lower PLF (plant load factor).

Plans for building the first Pressurised Heavy Water Reactor (PHWR) were finalised in 1964. The prototype 'Rawatbhata-1', which had Canada's Douglas Point reactor as a reference unit, was built as a collaborative venture between Atomic Energy of Canada Ltd and NPCIL. It started in 1972 and was duplicated. Subsequent indigenous PHWR development has been based on these units. India has 15 small and two mid-sized nuclear power reactors in commercial operation, six under construction including two large ones and a fast breeder reactor, and more are in the planning stages.

Table 3.2: India's Operating Nuclear Power Reactors

Reactor	Type	MWe net, Each	Commercial Operation	Safeguards status
Tarapur 1 & 2	BWR	150	1969	item-specific
Kaiga 1 & 2	PHWR	202	1999-2000	
Kaiga 3	PHWR	202	2007	
Kakrapar 1 & 2	PHWR	202	1993-95	by 2012 under new agreement
Kalpakkam 1 & 2	PHWR	202	1984-86	
Narora 1 & 2	PHWR	202	1991-92	by 2014 under new agreement
Rawatbhata 1	PHWR	90	1973	item-specific
Rawatbhata 2	PHWR	187	1981	item-specific
Rawatbhata 3 & 4	PHWR	202	1999-2000	by 2010 under new agreement
Tarapur 3 & 4	PHWR	490	2006, 05	
Total (17)		**3779 Mwe**		

Kalpakkam also known as Madras/MAPS; Rawatbhata also known as Rajasthan/RAPS; Kakrapar = KAPS, Narora = NAPS; Dates are for start of commercial operation.

The two Tarapur 150 MWe Boiling Water Reactors (BWRs), built by GE on a turnkey contract before the advent of the Nuclear Non-Proliferation Treaty, were originally 200 MWe. These were using imported enriched uranium and were under the International Atomic Energy Agency (IAEA) safeguards. These were derated due to recurrent problems. In late 2004, Russia deferred to the Nuclear Suppliers' Group and declined to supply further uranium to them. These reactors underwent six months refurbishment over 2005-06 and in March 2006, Russia agreed to resume the fuel supply.

The two small Canadian (CANDU) PHWRs at Rawatbhata started in 1972 & 1980, and are also under safeguards. Rawatbhata-1 was down-rated early in its life and has operated very little since 2002 due to ongoing problems. It was shut down in 2004 and the government is considering over its future. The 220 MWe PHWRs (202 MWe net) were indigenously designed and constructed by NPCIL on the basis of a Canadian design. The Kalpakkam (MAPS) reactors were refurbished in 2002-03 and 2004-05 and their capacity was restored to 220 MWe gross (from 170). Much of the core of each reactor was replaced and the life spans were extended to 2033/36.

Recent Reactor Developments

The new series of 540 MWe (gross, 490 MWe net) nuclear reactors are developed indigenously from the 220 MWe (gross) model PHWR. The Tarapur 3&4 units were built by NPCIL. The first, Tarapur 4, started in March 2005 was connected to the grid in June and started commercial operation in September 2005. Its twin, unit 3, was about a year behind and criticality was achieved in May 2006, with grid connection in June and commercial operation in August 2006.

Russia's Atomstroyexport (ASE)) is supplying the country's first large nuclear power plant that comprises of two VVER-1000 (V-392) reactors, under a Russian-financed US$ 3 billion contract. The AES-92 units at Kudankulam are being built by NPCIL and will be commissioned and operated by NPCIL under the IAEA safeguards. Russia will supply all the enriched fuel, though India will reprocess it and keep the plutonium. The first unit is due to start supplying power in March 2008 and will go into commercial operation late in 2008, after some delay. The second unit is about nine months behind it.

Under the plans for India-specific safeguards to be administered by the IAEA in relation with the civil-military separation plan, eight further reactors will be safeguarded (beyond Tarapur 1&2, Rawatbhata 1&2, and Kudankulam 1&2): Rawatbhata 3&4 by 2010, Rawatbhata 5&6 by 2008, Kakrapar 1&2 by 2012 and Narora 1&2 by 2014.

A 500 MW prototype fast breeder reactor (FBR) is under construction at Kalpakkam by BHAVINI, a government enterprise that was set up to focus on FBRs.

Tarapur 3 & 4 were increased in capacity. These and the future planned ones were the 450 (now 490) MWe versions of the 202 MWe domestic products. Beyond these, the future units will be a nominal 700 MWe.

The Russian PWR types are separate from India's three-stage plan for nuclear power and are simply to increase the generating capacity more rapidly. There are plans for eight (8) 1000 MWe units at the Kudankulam site, and in January 2007, a memorandum of understanding was signed for Russia to build four (4) more there, as well as others elsewhere in India.

Between 2010 and 2020, further construction is expected to take total the gross capacity to 21,180 MWe. The nuclear capacity target is a part of the national energy policy. This planned increment includes those set out below including the initial 300 MWe Advanced Heavy Water Reactor (AHWR).

Table 3.3: India's Nuclear Power Reactors under Construction

Reactor	Type	MWe net, each	Project control	Commercial Operation status	Safeguards
Kaiga 4	PHWR	202 Mwe	NPCIL	end of 2008	
Rawatbhata 5 & 6	PHWR	202 Mwe	NPCIL	end of 2008, 3/09	by 2008 under new agreement
Kudankulam 1 & 2	PWR (VVER)	950 Mwe	NPCIL	9/2009, 12/09	item-specific
Kalpakkam PFBR	FBR	470 Mwe	Bhavini	2010	unlikely
Total (6)		2976 Mwe			

Rawatbhata also known as Rajasthan/RAPS
Dates are for start of commercial operation.

Kaiga 3 started in February, was connected to the grid in April and went into commercial operation in May 2007. Unit 4 was scheduled about six months later, but as it and RAPP-5 were to load fuel in late 2007, due to the shortage of uranium, they are up to a year behind the original schedule. Start up of RAPP-5 is anticipated shortly as the construction is complete.

In mid-2008, Indian nuclear power plants were running at about half the capacity due to a chronic shortage of fuel. Some easing is likely in the near future due to the new Turamdih mill in Jharkhand state coming on line.

In 2005, four sites were approved for eight new reactors. Two of the sitesKakrapar and Rawatbhata, are to have 700 MWe indigenous PHWR units, Kudankulam is to have imported 1000 MWe light water reactors alongside the two being built there by Russia, and the fourth site is greenfield for the 1000 MWe LWR unitsJaitapur in the Konkan region. In April 2007, the government passed the approval for construction of the first four of these eight units.

Table 3.4: Power Reactors Planned or Firmly Proposed

Reactor	Type	MWe net, each	Project control	Start operation
Kakrapar 3 & 4	PHWR	640	NPCIL	2012
Rawatbhata 7 & 8	PHWR	640	NPCIL	2012
Kudankulam 3 & 4	PWR - VVER	1000	NPCIL	
Jaitapur 1 & 2	PWR	1000	NPCIL	
To be identified	PWR x 2	1000	NTPC	2014
To be identified	PHWR x 4	640	NPCIL	
To be identified	FBR x 4	470	Bhavini	2020
To be identified	AHWR	300	?	2020

For reactor table: first ten units 'planned', next 9 'proposed'.

NPCIL is reported to be evaluating a site for up to 6000 MWe of PWR nuclear capacity at Pati Sonapur in Orissa. Major industrial developments are planned in that area. Orissa was the first Indian state to privatise electricity generation and transmission. The state demand is expected to reach 20 billion kWh/yr by 2010.

NPCIL is also reported to be planning the construction of a 1600 MWe plant in the northern state of Haryana, one of the country's most industrialised states, by 2012. The state has a demand of 8900 MWe, but currently generates less than 2000 MWe and imports 4000 MWe. The $2.5 billion plant would be situated at the village of Kumaharia, near Fatehabad and paid for by the state government.

Apparently in anticipation of easing nuclear trade restriction, the National Thermal Power Corporation (NTPC) brought forward the consideration of a 2000 MWe nuclear power plant to be in operation by 2014. It would be the utility's first nuclear plant and also the first conventional nuclear plant not built by NPCIL. Both organisations are government-owned and NTPC is planning to increase its total installed capacity from 26 to 51 GWe by 2012 (72% of it is coal).

Nuclear Power capacities of 1300 MWe by March 2007 and 6140 MWe by March 2012 (including PFBR of 500 MW(e) and AHWR of 300 MW(e) are proposed to be added to take the total nuclear power capacity to 9935 MW(e)) by the year 2012. The goal, as already mentioned, is to reach a total nuclear power capacity of about 20,000 MW(e) by the year 2020.

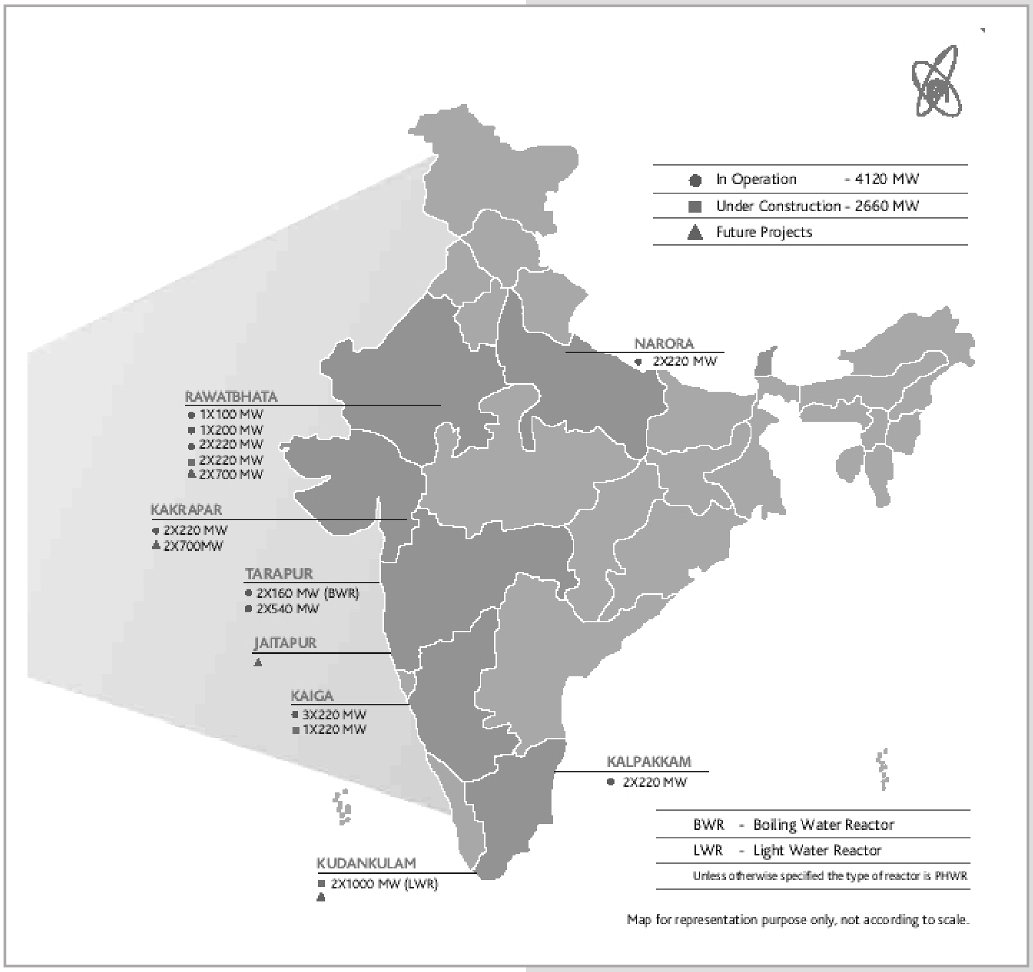
In July 2008, the Department of Atomic Energy (DAE) said that the large energy gap projected for 2050 can be bridged if 40-GWe capacity PWRs plus the fuel uranium are imported during 2012-20. Used fuel from these PWRs would be reprocessed and the plutonium can be used to launch a series of FBRs, which would largely eliminate the energy deficit in 2050. With US agreement and Nuclear Supplier Group approval, this plan may see the light of the day.

New DevelopmentsThe 123 Agreement

After having developed its programme in complete isolation for decades, the 123 Agreement is said to breathe in new life and make India's nuclear goals more achievable. India has an ambitious programme to increase its nuclear energy generating capacity to 20,000 MWe by 2020 and double it by 2030. While its domestic three stage programme continues to use its own uranium resources, the defenders of the Agreement feel that by adding additional capacity quickly, the country would meet its target soon.

The Agreement primarily opens the door for cooperation in civil nuclear energy with other countries. India is already discussing similar bilateral cooperation agreements on civil nuclear energy with France and Russia. The Agreement provides for full civil nuclear energy cooperation covering nuclear reactors and aspects of associated nuclear fuel cycle including enrichment and reprocessing. It paves the way for nuclear trade, transfer of nuclear material, equipment, components and related technologies and enhances cooperation in nuclear fuel cycle activities. The transferred material and equipment will be put under IAEA safeguards. It grants prior consent to reprocess nuclear material and transfer nuclear material and its products. To bring this into effect, India will have to establish a national reprocessing facility to reprocess the safeguarded nuclear material.

Nuclear Facilities in India

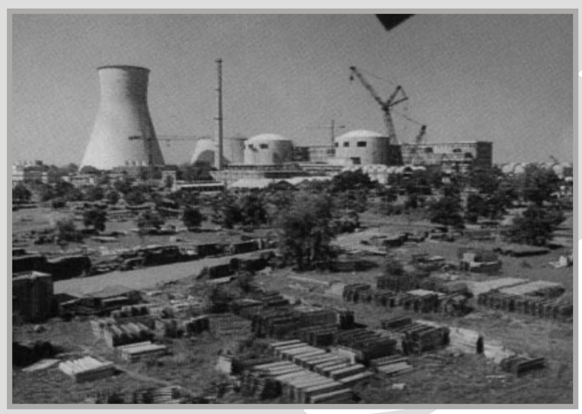


Kaiga Atomic Power Project 3 & 4

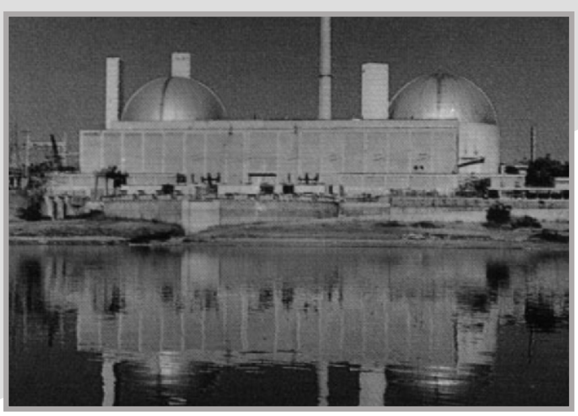
Kudankulam Atomic Power Project

Tarapur Atomic Power Station

Madras Atomic Power Station (MAPS)



Kakrapar Atomic Power Station



Rajasthan Atomic Power Station

Narora Atomic Power Station

URANIUM RESOURCES IN INDIA

India has modest uranium resources, with 54,470 tonnes Uranium (U) as reasonably assured resources and 23,500 tonnes as estimated additional resources in situ.[6] India has reserves of 290,000 tonnes of thoriumabout one quarter of the world total and these are intended to fuel its nuclear power programme for a longtime. The Indian uranium deposits are extremely low grade (by far less than 0.1% U), uranium production costs are several times the world market price and the environmental impacts are comparatively large due to the vast amounts of uranium mill tailings that are produced.

Mining and processing of uranium have been carried out by Uranium Corporation of India Ltd, a subsidiary of the Department of Atomic Energy (DAE), at Jaduguda and Bhatin since 1967; Narwapahar since 1995; and Turamdih since 2002all of these are in Jharkhand. These facilities are underground, and the last two are modern. A common mill, located near Jaduguda, processes 2,090 tonnes per day of ore.[7] The capacity of this mill has recently been upgraded.

In 2005 and 2006, with an investment of almost US$ 700 million, work was started to open further mines in Jharkand at Banduhurang, Bagjata and Mohuldih; in Meghalaya at Domiasiat-Mawthabah (with a mill) and in Andhra Pradesh at Lambapur-Peddagattu (with a mill 50km away at Seripally), both in the Nalgonda district.

In Jharkand, Banduhurang is India's first open cut mine and was commissioned in 2007. Bagjata is an underground one and due for production sometime in the end of 2008, though there had been earlier small operations between 1986 and 1991. The Mohuldih underground mine is expected to operate from 2010. Development work has already started there. A new mill at Turamdih in Jharkhand, with a 3000 t/day capacity, is to be commissioned soon.

In Andhra Pradesh the Lambapur-Peddagattu project in Nalgonda district has environmental clearance for one open cut and three small underground mines. UCIL is hopeful of starting the development work by 2009. In August 2007 the government approved a new US$ 270 million underground mine and mill at Tummalapalle near Pulivendula in Kadapa (Cuddapah) district, for commissioning in 2010.

In Meghalaya, close to the Bangladesh border, the Domiasiat-Mawthabah mine project (also called as Nongbah-Jynrin) is in a high rainfall area. Environmental approval for this and the Nongstin mine in Meghalaya has been reported.

UCIL plans to invest roughly Rs 31 billion [US$ 679 million] in opening new mines and setting up processing plants in Jharkhand, Andhra Pradesh and Meghalaya.

Mining in Jaduguda

From 1967, the Uranium Corporation of India Ltd (UCIL) has been producing uranium at Jaduguda in the Singhbhum (East) district of Jharkhand state (formerly a part of Bihar state)an area inhabited by tribal people. The underground mine is located about 150 kilometres west of Calcutta and is working on a vein type deposit with an ore grade in the 0.042% - 0.051% U range.[8]

According to some reports, the existing Jaduguda mines could supply uranium only until 2004. This has however been refuted by UCIL. The Jaduguda uranium mill processes not only the ore from the Jaduguda mine, but also ores from the nearby Bhatin, Narwapahar, Turamdih (since November 2002), and Banduhurang (since 2007) mines. In addition, the mill was also processing pre-concentrates from the uranium recovery plants at the Rakha, Surda and Mosaboni copper mines (uranium as a by product of copper production). This has however currently stopped.

The mill has a capacity of 2,100 t ore per day, and a production capacity of 175 t U per year. The production details were not made available by the UCIL. Though, according to the World Nuclear Association (WNA), it produced 230 t U in 2002. With a capacity of 3,000 t ore per day, and production capacity of 190 t U per year, the mill at Turamdih will process ore from Banduhurang and Turamdih mines once it is fully commissioned.

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[6] WISE and NIRS, 'India to Start up New Uranium Mines', *Nuclear Monitor* # 595, October 24, 2003. A Publication of World Information Service on Energy (WISE) and the Nuclear Information and Resource Service (NIRS).
[7] Official Figures Reported by UCIL.
[8] WISE and NIRS, 'India to Start up New Uranium Mines', *Nuclear Monitor* # 595, October 24, 2003. A Publication of World Information Service on Energy (WISE) and the Nuclear Information and Resource Service (NIRS).

Mining in Andhra Pradesh

Tummalapalle Project, Cuddapah (Kadapa)

The foundation stone for the mine at Tummalapalle village in Kadapa was laid in August 2008 and UCIL is building the mine and mill at a cost of Rs 11.29 billion ($268.8 million). The mining project involves extraction of uranium from underground mines in 879 hectares spread over five villages Mabbuchintalapalle, Thummalapalle, Rajukuntapalle, Bhoomayagaripalle and Kottala. UCIL expects to extract 3,000 tonnes of ore per day. The uranium concentration is very meagre at 0.039%. The lifespan of the project is stated to be 30 years.[9]

According to members of the NGO, Mines, Minerals and People (MM&P), nearly a million tonnes of waste would have to be disposed of every year and the design of the tailings pond is incremental. They have also questioned the need for taking up such mining in a densely-populated area in the Kadapa district with over 12,000 people in the region being affected by it.

Lambapur Peddagattu Project, Nalgonda

With 11.02 million t of uranium ore reserves containing 4,800 t U at an ore grade of 0.044% U[10], the LambapurPeddagattu deposit is a "medium-sized deposit of moderate-grade" under Indian circumstances. The near-surface deposit was discovered during the early 1990s, adjacent to the unconformity contact between basement granites with overlying Proterozoic Srisailam Quartzite close to the north-western margin of the Cuddapah basin, 120 km southeast of Hyderabad.

Two underground mines are projected for Peddagattu, while one open-cut and one underground mines are proposed at Lambapur. The uranium mill was initially proposed to be set up in the Dugyal and Mallapuram villages18 kilometres away from the mines, with a capacity of 1,250 t of ore per day for 20-25 years and an annual mill production of 131 t U. UCIL plans to acquire 526.65 hectares for the mines and 318.25 hectares for the processing plant. An investment of Rs 18 billion [US$ 393 million] is proposed for setting up two uranium mining and milling plants in Nalgonda and Kadapa districts in Andhra Pradesh.

The new mines at Lambapur and Peddagattu are planned to be located along the Adivasi habitations. Mining will be conducted over 400 hectares of the Rayaram reserve forest. The Rajiv Gandhi-Nagarjunasagar Tiger Reserve is less than 6 kilometres from the proposed mining area, though no industrial activity shall be permitted within 25 kilometres of a notified sanctuary, according to the Indian Wildlife Act.

The initial siting of uranium mill was just 3 kilometres away from the Azmapuram reserve forest and just one kilometre from the Nagarjunasagar dam that supplies water for irrigation while the Akkampalli reservoir is 4 kilometres away, which is the off take point for Hyderabad's new drinking water supply scheme.

The Andhra Pradesh State Pollution Control Board had rejected the proposal to set up a uranium mining unit and processing plant at Lambapur/Peddagattu and Mallapuram villages respectively in Nalgonda district. The Consent For Establishment (CFE) Committee rejected the proposal for the *processing plant* at Mallapuram, in the vicinity and catchment of the Nagarjunasagar reservoir. The reservoir, built to supply Hyderabad with water already contains uranium concentrations in the 2 - 3 μg/L range. That is above the former WHO 2 μg/L preliminary guidance (WHO's current preliminary guidance is 15 μg/L). Expert opinion is that once mining of uranium ore is permitted in the Lambapur-Peddagattu belt, the leaching of radionuclides into the Nagarjunasagar reservoir will only increase.

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For the proposed uranium mine in the Lambapur/Peddagattu area, the Technical Committee suggested safeguards for its operations.[11] UCIL has now shifted the processing plant site from Mallapuram to Seripally. The proposed site is 55 km away from the former and 28 km from Nagarjunasagar reservoir.

UCIL has been trying to influence the public opinion in favour of the project. It sent representatives of local villages to the Jaduguda mining area and some of them became 'spokespersons' for the UCIL. However, opponents doubt if these people went to Jaduguda at all as they reportedly saw lush green fields and all round development in Jaduguda.

UCIL has reportedly made incorrect claims related to the environmental impact of mining low grade uranium ore as against countries like Canada where the ore grade is 2-12 per cent. This, according to UCIL, translates into lower risks to human health and the environment in Andhra Pradesh. With these kinds of untrue claims, UCIL denies the fact that low grade ore needs tremendous amounts of ore being mined and milled, leaving huge quantities of waste tailings. Mines, Minerals & People (MM&P) has calculated that after 20 years of mining, about 7.5 million metric tons of potentially radioactive waste would be produced.

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9 http://www.wise-uranium.org/upin.html.
10 http://www.wise-uranium.org/upin.html.
11 P. Balu, "Uranium mining in Andhra may pose health hazard", *Times of India*, 30 January 2004.

Mining in Meghalaya

The Domiasiat Project: West Khasi Hills

With a uranium content of 7,819 t U and an ore grade of 0.085% U[12], Domiasiat is, under Indian circumstances "a relatively high-grade deposit", located at Meghalaya in north-eastern India. The deposit falls in a very high rainfall area and is almost inaccessible half the year. The ore body is spread over a large area in two distinct blocks with the deposits just 45-50 meters below the surface. UCIL plans to have two large open-cut mines in the area. The mill will have a capacity of 1,370 t of ore per day, and will produce 160 - 200 t U per year, for 22 years.

Opposition from the local Khasi tribe has been preventing UCIL from developing the mine at Domiasiat so far. However, according to the Atomic Energy Act of 1962, the Government of India can override local governments on nuclear issues.

Future Exploration Work

The Department of Atomic Energy (DAE) intends to mine uranium in the country, irrespective of whether it would import the radioactive ore from abroad or not. After the agreement which was signed between New Delhi and Washington for nuclear cooperation, got clearance, India can now import uranium from abroad. Under the accord, India has agreed to separate its civilian and non-civilian nuclear programme. However, the imported nuclear fuel would not be allowed to be used in non-civilian facilities. Also to ensure that the country's nuclear programme is not dependent upon the implementation of the Indo-US civil nuclear deal, the government is investing heavily in uranium exploration. According to the Atomic Energy Commission Chairman, Anil Kakodkar, an amount of Rs 7-8 billion (US$ 142-162 million) would be invested in exploration of uranium deposits in the country during the 11th Five Year Plan period from 2007-2012.

DAE has established presence of 6,632 tonnes of additional uranium resources in West Khasi Hills district in Meghalaya; Nalgonda district of Andhra Pradesh, and Sikar district in Rajasthan. Specific locations for some significant uranium mineralisation that has been intercepted include: Chitrial and Banganapalle in Nalgonda district, and Koppunuru in Guntur district, both in Andhra Pradesh; Alva Bade Kandkiras block of Bastar district in Chhattisgarh; Rohil in Sikar district, Rajasthan; Raghunathpura - Khalra in Mahendragarh district in Haryana; and Mahadek sediments at Lostoin and Wahkyn in West Khasi Hills district, Meghalaya.

Table 3.5: India's Uranium Mines and Mills (Existing and Announced)

State	Mine	Mill	Operating Year	tU/ year
Jharkhand	Jaduguda	Jaduguda	1967 (mine) 1968 (mill)	175 total from mill
	Bhatin	Jaduguda	1967	
	Narwapahar	Jaduguda	1995	
	Bagjata	Jaduguda	2008*	
	Turamdih	Turamdih	2003 (mine) 2008 (mill)	190 total from mill
	Banduhurang	Turamdih	2007	
	Mohuldih	Turamdih	2010	
Meghalaya	Kylleng-Pyndengsohiong (Domiasiat) Mawthabah	Mawthabah	2012 expected	340
Andhra Pradesh (Nalgonda)	Lambapur-Peddagattu	Seripally	2012 expected	130
Andhra Pradesh (Caddapah)	Tummalapalle	Tummalapalle	2010	220

12 WISE and NIRS, 'India to Start up New Uranium Mines', *Nuclear Monitor* # 595, October 24, 2003. A Publication Of World Information Service on Energy (WISE) and the Nuclear Information and Resource Service (NIRS).

Drilling was initiated in areas of Nalgonda in Andhra Pradesh; Raigarh in, Chattisgarh; Belgaum in Karnataka; Durg in Chhattisgarh and Shivpuri district in Madhya Pradesh. Promising uranium anomalies were located in the Proterozoic and Phanerozoic basins at various places in the country.

The country aims to more than double the uranium reserves for its nuclear energy programme. The cabinet has approved steps to boost uranium supplies by an additional 75,000 tonnes. India has an estimated 61,000 tonnes of uranium reserves, according to the Department of Atomic Energy.[13]

FUEL FABRICATION AND REPROCESSING

The technology of conversion of yellow cake into nuclear grade uranium and the fabrication of fuel bundles for power reactors was first developed at Trombay in 1959. For industrial scale manufacture of nuclear fuel assemblies and zircaloy structural materials for power reactors, the Nuclear Fuel Complex (NFC) was set up at Hyderabad in 1971. NFC is a major industrial unit of DAE and is responsible for the supply of nuclear fuel bundles and reactor core components for all the nuclear power reactors operating in India. It is a unique facility where natural and enriched uranium fuel, zirconium alloy cladding and reactor core components are manufactured under one roof starting right from the raw materials.

NFC undertakes refining and conversion of uranium, which is received as magnesium diuranate (yellowcake) from the uranium processing plant in Jaduguda. The main 400 t/yr plant fabricates PHWR fuel which is unenriched. The impure MDU is subjected to nitric acid dissolution followed by solvent extraction and precipitation with ammonia to get Ammonium Di-uranate (ADU). By further steps of controlled calcination and reduction, sinterable uranium dioxide powder is formed which is then compacted in the form of cylindrical pellets and sintered at high temperature to get high density uranium dioxide pellets. A majority of the reactors in India use natural fuel that does not require enrichment.

For PHWR fuel, the cylindrical UO_2 pellets are stacked and encapsulated in thin walled tubes of zirconium alloy, both ends of which are sealed by resistance welding using zircaloy end plugs. A number of such fuel pins are assembled to form a fuel bundle that can be conveniently loaded into the reactor. The fuel bundles for PHWR 220 Mwe and PHWR 500 Mwe consist of 19 and 37 fuel pins respectively. For BWRs, two types of array fuel assemblies, namely 6x6 and 7x7, are fabricated.

A small (25 t/yr) fabrication plant makes fuel for the Tarapur BWRs from imported enriched (2.66% U-235) uranium. The enriched uranium hexafluoride is subjected to pyrohydrolysis and converted to ammonium di-uranate which is treated in the same way as natural ADU to obtain high density uranium dioxide pellets.

The mixed uranium-plutonium carbide fuel for FBTR is fabricated at BARC since 1979. For fabrication of indigenous mixed oxide (MOX) fuel assemblies for BWR at TAPS, the Advanced Fuel Fabrication Facility (AFFF) was set up at Tarapur.

Heavy water is supplied by DAE's Heavy Water Board, and the seven plants under operation at Baroda, Hazira, Kota, Manuguru, Talcher, Thal-Vaishet and Tuticorin are working at their intended capacity.

A very small enrichment plant insufficient even for the Tarapur reactors is operated by DAE in Rattehalli, Karnataka. The Rattehalli Rare Materials Plant (RMP), located near Mysore is a pilot-scale gas centrifuge uranium enrichment plant, with several hundred centrifuges. It is generally believed to be capable of producing several kilograms of HEU (highly enriched uranium) each year. The two US-built light water reactors at Tarapur are the only civil reactors in India that require low-enriched uranium fuel. All other Indian power reactors use natural uranium fuel and heavy water as a moderator. Consequently, India does not have large-scale uranium enrichment facilities. The unsafeguarded facility which was built in the late 1980's is reported to be intended at enriching uranium for future use in fuelling nuclear-powered submarines.

Used fuel from the civil PHWRs is reprocessed by BARC at Trombay, Tarapur and Kalpakkam to extract reactor-grade plutonium for use in fast breeder reactors. Small plants at each site were supplemented by a new Kalpakkam plant of some 100 t/yr capacity. This plant was commissioned in 1998 and is being extended to reprocess FBTR carbide fuel. Apart from this, all reprocessing uses the Purex process. Further capacity is being built at Tarapur and Kalpakkam with the aim for it to come on line by about 2010.

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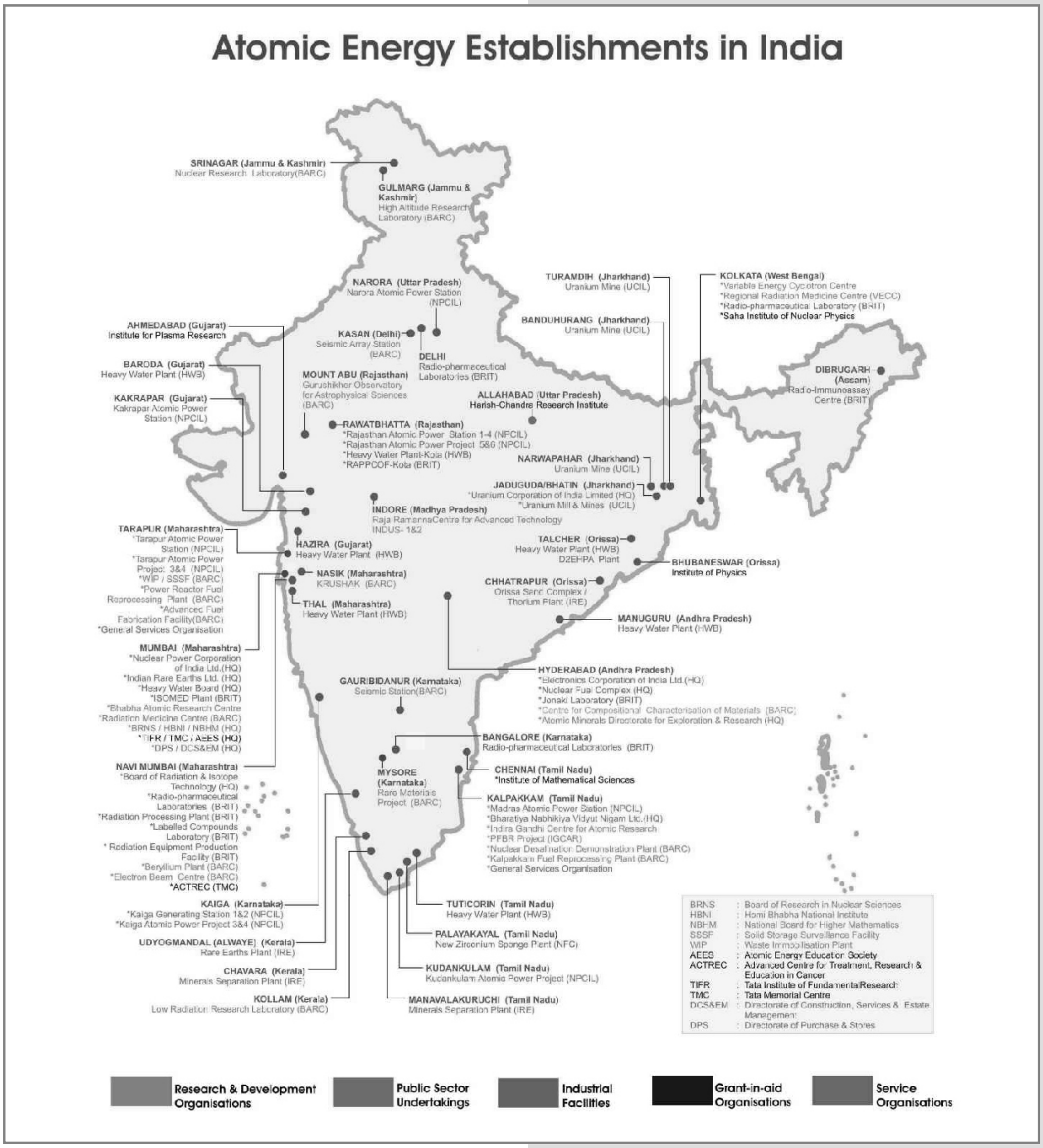
[13] "India to double uranium reserves for energy sector", *Reuters India,* 8 August 2008

In 2003, a facility was commissioned at Kalpakkam to reprocess mixed carbide fuel using an advanced Purex process. Future FBRs will also have these facilities co-located. The PFBR and the next four FBRs to be commissioned by 2020 will use oxide fuel. After that, it is expected that metal fuel with higher breeding capability will be introduced and burn-up is intended to increase from 100 to 200 GWd/t.

To close the FBR fuel cycle, a fast reactor fuel cycle facility is planned to coincide with the need to reprocess the first PFBR fuel.

Under plans for the India-specific safeguards to be administered by the IAEA in relation to the civil-military separation plan, several fuel fabrication facilities will come under safeguards.



Radioactive Waste in India

4

India claims that the safe and effective management of radioactive waste has been given utmost importance from the very inception of its nuclear industry and that it covers the entire range of activities from handling, treatment, conditioning, transport, storage and finally disposal. Radioactive waste management is also associated with the decontamination and decommissioning activities in India since some of the facilities in India like power plants, fuel fabrication plants and reprocessing plants have now been in operation for more than three decades.

While sources and varieties of radioactive waste are many, the underlying objective that is said to govern the management of all such waste is the protection of man and environment, now as well as in the future, from potential hazards arising from such wastes. Safe radwaste management involves the application of technology and resources in a regulated manner so that the public, workers and the environment are protected in accordance with accepted standards.

In India, the necessary codes and safety guidelines for achieving this objective are provided by the Atomic Energy Regulatory Board (AERB) in conformity with the principles of radiation protection as formulated by the International Commission on Radiation Protection (ICRP).

STEPS IN MANAGEMENT OF RADIOACTIVE WASTE

Various stages in management of radioactive waste as adopted in India are shown below. These include waste characterisation, treatment, conditioning, storage, disposal, surveillance/ monitoring, etc. Various options available for treatment, conditioning, storage and disposal of these wastes depending on their physical forms are also indicated. The descriptions presented herein are intended to be general and apply to the management of radioactive waste from mining and milling, fuel-fabrication, nuclear power generation, medical and industrial application of radioactive materials and environmental restoration. These apply to radioactive waste that's generated during the operational period as well as during the decommissioning of a facility. The applicability of these steps therefore is likely to vary depending on the type of radioactive waste.

Table 4.1: Management of Radioactive Waste

CHARACTERIZATION		TREATMENT			CONDITIONING
		LIQUID WASTE	SOLID WASTE	GASEOUS WASTE	Cementation
LL	Liquid	Chemical Treatment	Compaction	Scrubbing	Polymerisation
IL	Solid	Ion Exchange	Incineration	Adsorption/Absorption	Bituminisation
HL	Gaseous	Reverse Osmosis	Size Fragmentation	Prefiltration	Vitrification
		Evaporation	Repackaging	High Efficiency Filtration	

INTERIM STORAGE	DISPOSAL		ENVIRONMENTAL MONITORING/CONTROL
• Alpha Contaminated Waste	LIL Waste Short lived	HLW & Long Lived Waste	• Monitoring of water, soil, vegetation, near waste management facility.
• Wastes requiring treatment / conditioning in future	• Earth/Stone lined trenches	• Deep Geological Disposal	• Monitoring of environment near nuclear facility.
• Vitrified waste for cooling pending disposal	• Reinforced Concrete trenches		• Institutional control of near surface disposal facility for 300 years.
	• Tile Holes		

The waste is first characterised in order to determine its physical, chemical and radiological properties and to facilitate documentation, record keeping and acceptance of radioactive waste from one step to another. Characterisation may be applied in order to segregate radioactive materials either for exemption, reuse and disposal methods or to assure the compliance of waste packages with requirements for storage and disposal.

Storage

Storage of radioactive waste involves maintaining the radioactive waste so that:

(i) isolation, environmental protection and monitoring are provided, and

(ii) actions involving treatment, conditioning and disposal are facilitated.

In some cases, storage may be practised for primarily technical considerations, such as storage of radioactive waste containing mainly short-lived radionuclides for decay and subsequent release within the authorised limits, or storage of high-level radioactive waste for thermal considerations prior to geological disposal. In other cases, storage may be practised for reasons of economics or policy.

Treatment

Pre-treatment of waste is the initial step in waste management that occurs after waste generation. It consists of, for example, collection, segregation, chemical adjustment and decontamination and may include a period of interim storage. This initial step is extremely important because it provides, in many cases, the best opportunity to segregate waste streams. For example, for recycling within the process or for disposal as ordinary non radioactive waste when the quantities of radioactive materials contained are exempt from regulatory controls. It also provides the opportunity to segregate radioactive waste, for example, for near surface or geological disposal.

Conditioning

Conditioning of radioactive waste involves those operations that transform radioactive waste into a solid form that's suitable for handling, transportation, storage and disposal. The operation includes immobilisation of radioactive waste, placing the waste into containers and providing additional packaging. Common immobilisation methods include solidification of low and intermediate level radioactive waste in cement or polymer, and vitrification of high-level liquid waste in a glass matrix. This immobilised waste, in turn, may be packed in containers ranging from the common 200 L steel drum to high integrity thick-walled containers, depending on the nature of radionuclides and their concentrations.

Disposal

Disposal is the final step in the radioactive waste management system. It consists mainly of the emplacement of radioactive waste in a disposal facility with reasonable assurance for safety, without the intention of retrieval and without reliance on long term surveillance and maintenance. The safety, mainly achieved by isolation, is attained by placing barriers around the radioactive waste in order to restrict the release of radionuclides into the environment. The barriers can be either natural or engineered and an isolation system can consist of one or more barriers. A system of multiple barriers gives greater assurance of isolation and assists in minimising the release of radionuclides to the environment. Barriers can either provide absolute containment for a period of time, such as the metal wall of a container, or may retard the release of radioactive materials to the environment, such as a backfill or host rock with a high absorption capability. During the period when the radioactive waste is contained by a system of barriers, the radionuclides in the waste undergo decay, thereby reducing hazard with time. The barrier system is designed according to the disposal option chosen and the radioactive waste forms involved.

Although disposal of most types of radioactive waste is by concentration and containment, disposal may also comprise the discharge of effluents (for example, liquid and gaseous waste) into the environment within authorised limits, with subsequent dispersion. The authorised limits are site specific and vary from coastal to inland sites.

RESIDUAL WASTE FROM FRONT-END FUEL CYCLE

URANIUM MINING AND WASTE ROCK

Uranium ore is currently mined in the mineralised zone of the Singhbhum Thrust Belt. Uranium bearing minerals occur in very finely disseminated forms. Both surface and underground mining of uranium ores produce large amounts of this radioactive waste material. Uranium mining wastes comprise several types of waste:

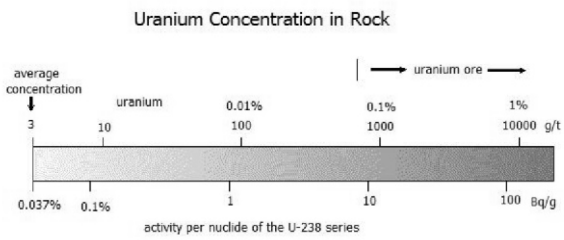
- overburden (soil and rock that is covering a deposit of ore, such as uranium. It usually contains at least trace amounts of the ore plus radioactive decay products);

- unreclaimed, sub-economic ores (ores that have too little uranium to be profitable, called “protores”;

- “barren” rock (rock containing no ore); and

- drill cuttings

Most commonly, overburden is also referred to as Waste rock. Since waste rock contains elevated concentrations of radioisotopes compared to normal rock, these are a matter of concern.



Waste rock is produced during both- open cut (or open cast) and underground mining, though the amount of excavated rock is much higher in case of an open cut mine (approximately 45 times greater). In case of open cut, the soil, vegetation, and rock above the ore body (called the overburden) must also be removed. This waste rock is put in piles or "dumps". All these piles threaten people and the environment even after the shutdown of the mine due to the release of radon gas and seepage water that contains radioactive and toxic materials.

Out of the five mines currently operational in India (all in Jharkhand State), only the Banduhurang mine is an open cut mine. The poor ore quality of Indian deposits demands that large amounts of ore be mined to get the uranium. A visit to the site revealed large heaps of waste rock on the road side in Narwapahar, East Singhbhum, an underground mine in India. Although the status of waste rock at other sites is not known, it may not be wrong to expect similar practice at other mining sites as well.

The UCIL officials however report disposing of the waste rock in a "well engineered waste yard created within the mine premises. Once saturated, the dump yard would be stabilised through efforts like grass turfing and plantation of indigenous varieties with the goal of restoring the site topography". They also report using this overburden at the time of mine closure.[14] It is backfilled in the ore pit to ensure that no void is left underground. While no mine has yet been closed in India, UCIL reports of 'progressive mine closure' as an approach wherein a small part of mine is closed every year. Most commonly, the mine overburden is not classified as a radioactive waste and the need for its placement in radioactive waste disposal facilities is not felt in many countries. UCIL too claims overburden to be completely harmless.

In the case of an undisturbed uranium deposit, the activity of all decay products remains constant for hundreds of millions of years. The radiation is virtually trapped underground and exposures are possible only if contaminated groundwater that is circulating through the deposit is used for drinking. Radon is of no concern for deep deposits. Though it can travel through underground fissures, it decays before it can reach the surface.

The situation changes completely when the deposit is mined: Radon gas can escape into the air, ore dust can be blown by the wind, and contaminants can leach and seep into surface water bodies and groundwater. The alpha radiation presents a radiation hazard upon ingestion or inhalation of uranium ore (dust) and radon. The gamma radiation, together with beta radiation, presents an external radiation hazard.

The Atomic Energy Act does not specify controls on uranium mining overburden. Neither the AERB nor the DAE regulates the disposal of conventional (open pit and underground) mining wastes. Other legal statutes, however, call for protection of public and the environment from exposures to both the hazardous and toxic characteristics of these wastes. Protection of people and the environment from the adverse effects of mining activities therefore stays an underlying principle

There is no exact total of these wastes. The quantum is expected to be significant and with new open pit mines under development, this is expected to increase manifold. One such dump of overburden located at Narwapahar (see photo) is hardly a kilometre away from the agricultural fields and the nearest village. UCIL, as a practice, may have added a thin layer of mud over the waste rock to prevent erosion as well as radiation exposure to nearby communities, but it seems inadequate since the mud cover, along with the overburden, is continuously blown away with the wind and rains into people's homes; agricultural fields; and the nearby river.

Waste rock and overburden has often been processed into gravel or cement and used for road and railroad construction. VEB Hartsteinwerke Oelsnitz in Saxony, for example, is known to have processed 200,000 tonnes of material per year into gravel containing 50 g/t uranium. In Jaduguda too, the villagers have reported similar practices.

[14] Shared in a personal interview by Mr. Acharya, Director (Technical), UCIL.

The overburden from Jaduguda and Bhatin mines were given out to people to use in their houses as well as used during road construction. This practice poses a threat to people's health and the environment due to continuous release of radon gas and other radionuclides from such sources. People do say that this practice has now stopped. No inventory of such sites where the overburden may have been used is presumably maintained by UCIL.

Transportation of waste rock to the dump is also critical. The current practice involves transporting the ore or the waste rock in open trucks covered by tarpaulin. People claim the practice to be rather recent. Earlier, there was no cover and the spill over of the content from the overloaded trucks, with at times even people sitting over those piles, was a common sight. People feel that the tarpaulin cover is still not adequate though it may have reduced the spillage. Accidents would have further aggravated the problem and resulted in contaminating a larger area. No such accident has come to light, either reported by local people or by the UCIL.

To keep groundwater out of the mine during operation, large amounts of contaminated water are pumped out and released into rivers and lakes. When the pumps are shut down after the closure of the mine, there is a risk of groundwater contamination from the rising water level. In view of the Jaduguda mine nearing the exhaustion level, this would be another area of concern post the mine's closure.

MILLING AND THE TAILINGS

Ore from Jaduguda, Bhatin, and Narwapahar mines (and in future, Bagjata too) is processed in the centralised processing plant/ mill located close to Jaduguda mines. The commissioning of the Turamdih mill that will process ore from Turamdih, Banduhurang (and Mohuldih too) is yet to be completed.

The Uranium is extracted in the mills through the hydro metallurgical process. After three stages of crushing, the crushed ore undergoes two stages of wet grinding. The slurry is filtered to obtain uranium liquor. This uranium liquor is purified and concentrated by the ion exchange method and further precipitated as 'yellowcake' (U_3O_8). This is thickened, washed, filtered and dried in the spray dryer and finally packed in drums and transported to the Nuclear Fuel Complex in Hyderabad to be processed into fuel pellets. The slurry or the 'tailings' are left behind for disposal.

Uranium mill tailings are dumped as sludge in the 'tailing pond' (or tailing dam). Jaduguda has three such tailing ponds, of which tailing pond-III is active; tailing pond-II is currently not in use but will be in use in the future; and the tailing pond-I has been closed. A new tailing pond has been built near the Turamdih mill. Local activists ascribe community protest to be the reason for siting the pond at a new location while UCIL says it's the distance factor.

The mining operation in Jaduguda and Bhatin started in 1967 and the mill commissioned in 1968 with more operations being added to it over the years. The net result is accumulation of huge piles of waste in the three ponds. The amount of sludge produced is nearly the same as that of the ore milled. Generally speaking, at a grade of 0.1% uranium, 99.9% of the material is left over. In Indian conditions, the sludge output would be much higher given the poor ore quality that stands at under 0.05%. These ponds impound tens of millions of tonnes of radioactive waste and cover more than 100 acres. The largest such piles in the US and Canada contain up to 30 million tonnes of solid material. In Saxony, Germany the Helmsdorf pile near Zwickau contains 50 million tonnes, and in Thuringia the Culmitzsch pile near Seelingstädt, 86 million tonnes of solids. The size of the dumps in India is not known. An estimate suggests 4.1 million tones of waste from uranium mining and milling (till 2000).[15]

Characteristics of Uranium Mill Tailings

Apart from the portion of uranium removed, the sludge contains all the constituents of the ore. As long lived decay products such as thorium-230 and radium-226 are not removed, the sludge contains 85% of the initial radioactivity of the ore. Due to technical limitations, all of the uranium present in the ore can not be extracted. Therefore, the sludge also contains 5% to 10% of the uranium initially present in the ore. In addition, the sludge contains heavy metals and other contaminants such as arsenic, as well as chemical reagents used during the milling process.

Mining and milling removes hazardous constituents in the ore from their relatively safe underground location and converts them to fine sand first and then to sludge, whereby the hazardous materials become more susceptible to dispersion in the environment. Moreover, the constituents inside the tailings pile are in a geochemical disequilibrium that results in various reactions causing additional hazards to the environment. For example, in dry areas, salts containing contaminants can migrate to the surface of the pile, where they are subject to erosion. If the ore contains the mineral pyrite (FeS_2), then sulfuric acid forms inside the deposit when accessed by precipitation and oxygen. This acid causes a continuous automatic leaching of contaminants.

[15] M. V. Ramana, Dennis George Thomas and Susy Varughese, 'Estimating Nuclear Waste Production in India', *Current Science*, 10 December 2001, 81(11): 1458-62.

Radon-222 gas emanates from tailings piles and has a half life of 3.8 days. This may seem short, but due to the continuous production of radon from the decay of radium-226, which has a half life of 1600 years, radon presents a long term hazard. Further, because the parent product of radium-226, thorium-230 (with a half life of 80,000 years) is also present, there is a continuous production of radium-226.

With a steady 10 km per hour wind, Radon gas could travel nearly 1000 km before half of it has decayed. This gas presents a major threat to mine workers and nearby residents alike. It emits alpha radiation as it decays into radioactive bismuth, polonium and lead. Inhaling or ingesting radon (it is water soluble) poses a unique health hazard as the body becomes exposed to the chemical properties of the various decay products as well as their radioactivity. After about 1 million years, the radioactivity of the tailings and its radon emanation will have decreased so that it is only limited by the residual uranium contents, which continuously produces new thorium-230.

Potential Hazards from Uranium Mill Tailings

Radionuclides contained in uranium tailings emit 20 to 100 times as much gamma-radiation as natural background levels on deposit surfaces. Gamma radiation levels decrease rapidly with distance from the pile.

The radium-226 in tailings continuously decays to the radioactive gas radon-222**,** the decay products of which can cause lung cancer. Some of this radon escapes from the interior of the pile. Radon releases are a major hazard that continues even after uranium mines are shut down. The U.S. Environmental Protection Agency (EPA) estimates the lifetime excess lung cancer risk of residents living nearby a bare tailings pile of 80 hectares at two cases per hundred.

Since radon spreads quickly with the wind, many people receive small additional radiation doses. Although the excess risk for the individual is small, it cannot be neglected due to the large number of people concerned. EPA has estimated that the uranium tailings deposits existing in the United States (in 1983) can cause 500 lung cancer deaths per century.

Tailings deposits are subject to many kinds of erosion**.** Due to the long half-lives of the radioactive constituents involved, the safety of the deposit has to be guaranteed for very long periods of time. After rainfall, erosion gullies can form; floods can destroy the whole deposit; plants and burrowing animals can penetrate into the deposit and thus disperse the material, enhance radon emanation and make the deposit more susceptible to climatic erosion. When the surface of the pile dries out, the fine sands are blown by the wind over adjacent areas. Storms blowing up radioactive dust over villages located in the immediate vicinity of Jaduguda mill tailings piles have been reported. In a similar case reported from villages near Wismut's uranium mill, elevated levels of radium-226 and arsenic were found in dust samples from these villages.

There have been occurrences of tailings pond overflowing during rains, resulting in contaminated water coming into the villages and out flowing into the river. Around 30,000 people live in 15 villages within 5 km of the Jaduguda complex. The first tailings pond is located only 50m away from the village, Dungridih, and the tailings pipe (to the second and third tailings ponds) is just outside the village boundary. People have reported using the dams to graze livestock and 'play soccer'. The dams are constructed on traditional routes to the forest and connecting people with their relatives, so they are forced to use the dam sites as thoroughfares.

Since the issue came under a scanner after being widely reported, UCIL has, in the last decade, put efforts in fencing the area and deploying guards (and erecting warning signs as well). This may have made access difficult but not totally impossible. In fac, in the course of the study, one could see women from nearby villages collecting wood and fodder barely 10 meters from the active tailing pond.

The signage erected at the village exit leading to tailings pond-3 is found lacking in informing communities about the potential hazards of the mill tailings

According to UCIL, while 'theoretically' the tailings carry a potential danger to people living around it, the danger is almost negligible. At the edge of the tailing pond, the radiation levels are close to the background levels, or so the company claims. UCIL does admit that ideally the area around these tailings should be uninhabited for reasons of safety and 'worst case scenario'. It defends itself by further adding that relocation of tribal people is not advisable and hence UCIL has adopted as a policy, minimal dislocation during implementation of its projects unless the health of the people is threatened severely. Dungridih, it says, is within safe distance from both, the pond as well as the tailing pipe. Only 5-6 families are within close distance, but they are on that area illegally since the land belongs to UCIL. There is a stalemate at present on the rehabilitation package offered to these families and therefore they continue to live in the area.

Seepage from tailings piles is another major hazard. Seepage poses a risk of contamination to ground and surface water. Residents are also threatened by radium-226 and other hazardous substances like arsenic in their drinking water supplies and in the fish from the area. The seepage problem is very important with acidic tailings, as the radionuclides involved are more mobile under acidic conditions. In tailings that contain pyrite, acidic conditions automatically develop due to the inherent production of sulphuric acid, which increases the migration of contaminants to the environment.

In village Chatukocha (in Jaduguda), located half a kilometre from the third tailing dam, villagers reported ground water contamination. They reported a rise in skin diseases, cancer cases and miscarriages in t early-2000. This, they say, has improved since the village has now made a complete shift to the piped water (provided by UCIL) to meet their water requirements, including for their livestock.

UCIL officials however completely deny the charge and claim the groundwater to be free from any radioactivity. They claim that the water is safe for consumption and the water pipeline has been laid in the villages not due to contamination but under their social development programme. UCIL collects water samples from all the nearby villages on a monthly basis and have not found any reason for concern. Interestingly though, these test results have never been made public. UCIL also claims that all the three dams are well engineered. Prior to their construction, the percolation rate was studied and a lining provided at places where the permeability was found to be higher than the threshold. The villagers were not able to substantiate the claim. Some even reported that no such study had been carried out for the siting of the ponds. It has been more the convenience and distance that drove UCIL to construct the dams, all adjacent to one another. The latest dam is around two kilometres from the mill and the tailings to the pond are transported through a pipeline, both under- and over-ground.

The structural integrity of the tailings dam is another concern. Tailings dams are often not of stable construction. At times they have been made from sedimentation of the coarse fraction of the tailings sludge. In Jaduguda, large pits have been used for the purpose. There is an earthen dam on one side while the other sides are protected by hills. The first tailings pond was cruder. It was only in the late 1980s that UCIL took up dam repair work and provided an external stone lining to the dam to provide strength on the outside. The same was then done for all subsequent dams.

Stone lining on the tailings dam exterior for strutural integrity

Further danger to the ponds may arise if these are built on geologic faults as in the case of Culmitzsch and Trünzig in Thuringia. This would subject them to the risk of an earthquake. It could not be ascertained if the tailings ponds in Jaduguda are located on any fault line. The impact that earthquakes can have in the area is also difficult to predict. But the threat of a dam failure due to these reasons can not be ruled out. Moreover, strong rain can also cause dam failures.

It is not surprising that dam failures have occurred again and again. Some examples from other parts of the world are:

- 1977, Grants, New Mexico, USA: spill of 50,000 tonnes of sludge and several million litres of contaminated water.

- 1979, Church Rock, New Mexico, USA: spill of more than 1000 t of sludge and about 400 million litres of contaminated water.

- 1984, Key Lake, Saskatchewan, Canada: spill of more than 100 million litres of contaminated liquids.

Due to their fine sandy texture, dried tailings have been used for construction of homes or for landfills. In homes built on or from such materials, high levels of gamma radiation and radon were found. The U.S. Environmental Protection Agency (EPA) estimates the lifetime excess lung cancer risk of residents of such homes at 4 cases per 100. Such use has not been reported from Jaduguda. But due to the fact that the tailings have been unprotected for decades, the possibility cannot be completely ruled out.

Tailings for the purpose of backfilling into the mines are transported to the mining sites in open trucks that are covered with tarpaulin on a daily basis. The trucks that carry the ore to the mill take back the tailings. Spillage during transportation might happen, besides there is a threat of accident as well. The conditions under which these are stored and handled during backfilling operations are not known.

Besides these issues, accidents have been a common occurrence at the tailings sites in Jaduguda. The most recent case of tailings pipe burst took place on August 16, 2008, near the Jadugoda village of Dungridih, spewing the village with uranium waste. The waste entered five houses in the village as well as spread onto the village lanes. The incident was brought to the notice of UCIL by the villagers following which the supply of uranium tailings to that pipe was stopped. The repair work was taken up the following morning[16].

Earlier, in June 2008, there were reports of a flow-in of uranium waste from the Turamdih tailings pond in the Talsa village following heavy rainfall. The radioactive waste had spilled over into the village ponds, wells and fields. Apprehending a threat to lives, the villagers reportedly stopped fetching water from the wells and ponds. The UCIL admitted the spillover but said there was no threat to life due to radiation. A team of scientists from the Bhabha Atomic Research Centre visited the affected village and collected water samples for analysis. The results are not known. According to UCIL, the affected family has been given compensation equivalent to one year's crop. In fact, in 2006, the East Sighbhum district administration had served a show-cause notice on the UCIL for unauthorised mining in Fuljhari, Turamdih and two other new mines in Keuradungrui. According to East Singhbhum Deputy Commissioner (DC) Nitin Kulkarni, UCIL had started mining illegally while the applications for mining were pending with the State Government[17].

Tailings in the nearby house

An old man showing the tailings pipe leak

On February 21, 2008, there was a new tailings pipeline burst in the area. This caused a uranium mill tailings spill that the reached nearby homes. According to UCIL, the spill comprised about 40 m^3 of liquid. Following the burst, UCIL reported of having taken steps including periodic replacement of pipes and installation of pressure transmitters in the discharge pipelines[18].

Then on April 10, 2007, again a pipeline burst near Jaduguda caused a uranium mill tailings spill. According to UCIL, the spill was caused from damage to the rubber lining of the tailings pipeline "by a wooden log left inside the pipe during replacement", and comprised of 1.5 tons of solids and 20 m^3 of liquid. The external radiation dose was 1 micro Sv. The spilled material was contained within the earthen bund constructed beside the channel and did not reach any water body or public domain[19].

[16] Reported by JOAR activists in a personal interview.
[17] *Ranchi Express* October 16, 2006, cited on the website of WISE Uranium Project. http://www.wise-uranium.org/umop.html.
[18] UCIL's response dated April 29, 2008 to the application filed by Shri Prakash under RTI.
[19] Ibid.

On December 25, 2006, the tailings pipeline carrying uranium mill tailings from the Jaduguda uranium mill to the third tailings dam broke, spreading tailings into a tributary of the river Subranarekha. The toxic sludge spewed into a creek for nine hours before the flow of the radioactive waste was shut off. Consequently, a thick layer of toxic sludge on the surface of the creek

Waste water channel at tailings pond-3 to carry effluent from the pond to the effluent treatment plant.

killed scores of fish, frogs, and other riparian life. The waste from the leak also reached a creek that feeds into the Subarnarekha River, seriously contaminating the water resources of communities living hundreds of kilometres along the way.

According to UCIL, the spill was caused from damage of the rubber lining and metal of the tailings pipeline "due to prolonged use", and comprised of 6-8 tons of solids and 60 m^3 of liquid. The external radiation dose reported was 5-6 micro Sv[20]. The average natural background level in Jaduguda area is 2.66 mSv/yr.

This was not the first such accident. In 1986, a tailings dam had burst open and radioactive water flowed directly into the villages. Surprisingly, UCIL had no alarm mechanism to alert the company in cases of such a disaster. Instead, it was the villagers who had arrived at the scene of the accident soon after the pipe burst that informed the company of the toxic spill.

Tailings Treatment and Disposal

Two types of waste are generated while processing uranium ore liquor depleted in uranium from ion exchange unit after uranium recovery and filtered cake depleted in uranium from filtration of leached slurry. According to UCIL, both are neutralised with lime stone and lime slurry to precipitate the remaining radionuclides along with heavy metals. The neutralised slurry is classified and the coarse fraction is pumped back to the mines for backfilling the voids. This forms almost three quarters of the tailings. The remaining one quarter, which is in form of fine particles, is pumped into the tailings pond where slime settles and clear water is decanted through decantation wells. This water is sent to the effluent treatment plant for re-treatment.

According to UCIL, it has a composite scheme for reclamation of water and effluent re-treatment to make the final discharged effluent environmentally safe. Water from the all the mines is collected, clarified and reused in the ore processing plant. The tailings pond effluent is also clarified and a part of this is sent to an ore-processing plant for reuse. The remaining is treated with barium chloride and lime, clarified and the settled precipitates are sent back to tailings pond. The harmless liquor is discharged.

Local activists however challenge this claim. They maintain that the company has been directly discharging waste water into the river without treating it. The channel (visible in the picture) is used to carry waster from the tailings to the effluent treatment located within the premises of Jaduguda mill. A similar channel has been built for purpose of rain water. In support of their various claims, they point at the high incidence of dead fishes in the river. Fishes with skin diseases are also common. These claims could not be ascertained in the short span of time. UCIL has rubbished this allegation completely.

Sources also point that the obvious idea of bringing the tailings back to where the ore has been taken from, does not in most cases lead to an acceptable solution for tailings disposal. Although most of the uranium was extracted from the material, it has not become less hazardous, in fact that's quite to the contrary. Most of the contaminants (85% of the total radioactivity and all the chemical contaminants) are still present, and the material has been brought by mechanical and chemical processes to a condition where the contaminants are much more mobile and thus susceptible to migration into the environment. Therefore, dumping the tailings in an underground mine cannot be afforded in most cases. There they would be in direct contact with groundwater after halting the pumps (upon mine closure).

The situation is similar for deposit of tailings in former open pit mines. Here too, immediate contact with ground water exists, or seepage presents risks of contamination of ground water. Only in the case of the presence of proven impermeable geologic or man-made layers can the contamination risk to ground water be prevented. An advantage of in-pit deposition is relatively good protection from erosion.

[20] Ibid.

The active tailings pond near Chatikocha

In France and Canada, on the other hand, the concept of dumping the tailings in former open pits in groundwater has been pursued or proposed at several sites in recent years. In this case, a highly permeable layer is installed around the tailings to allow free groundwater circulation around the tailings. Since the permeability of the tailings is lower, it is anticipated (by the proponents) that there is nearly no exchange of contaminants between tailings and groundwater. A similar method is being tested in Canada for the disposal of uranium mill tailings in lakes (called "pervious surround disposal"). Recent proposals deny the necessity of an artificial permeable layer around the tailings, since the surrounding rock would provide high enough permeability.

In most cases, tailings have to be dumped on the surface, as is done in the case of India, for lack of other options. Here, the protection requirements can more easily be controlled by appropriate methods, but additional measures have to be performed to assure protection from erosion.

Standards for Uranium Mill Tailings Management

In the early years of uranium mining after World War II, the mining companies often left sites without any cleaning up after the ore deposits were exhausted. Often, in the United States, the mining and milling facilities were not even demolished, not to mention reclamation of the wastes produced. In Canada, uranium mill tailings were often simply dumped in one of the numerous lakes.

The untenability of this situation was, for the first time, recognised by the U.S. legislation, which defined legal requirements for the reclamation of uranium mill tailings in 1978. On the basis of this law, regulations were promulgated by the Environmental Protection Agency and the Nuclear Regulatory Commission. These regulations not only define the maximum contaminant concentrations for soils and admissible contaminant releases (in particular for radon), but also the period of time in which the reclamation measures taken must be effective: 200-1000 years. The reclamation action thus not only has to assure that the standards are met after completion of the reclamation work, but for the first time, a long-term perspective is included in such regulations. A further demand is that the measures taken must assure safe disposal for the prescribed period of time without active maintenance. If these conditions cannot be met at the present site, the tailings must be relocated to a more suitable place.

Considering the actual period of time the hazards from uranium mining and milling wastes persist, these regulations are of course only a compromise, but they are at least the first step. Regulations for the protection of groundwater were not included in the initial legislation; as they were declared in January 1995. Last but not the least, public involvement is given an important role in planning and control of the reclamation action.

Based on these regulations, various technologies for the safe and maintenance-free confinement of the contaminants were developed in the United States during the subsequent years. The reclamation efforts also include the decontamination of nearby homes built from contaminated material or on contaminated landfills.

In Canada, on the contrary, authorities decide the measures to be taken for reclamation on a site-by-site basis. There are no legal requirements. The Atomic Energy Control Board (AECB) has proclaimed rough guidelines; and it decides, together with the mine and mill operators, the necessity of measures to be taken. Therefore, it is no surprise that the Canadian approach results in a much lower level of protection. The proposals for the management of the uranium mill tailings in the Elliot Lake area, Ontario, for example, include no other "protective barrier" than just a water cover.

The practices in India are governed under the Atomic Energy Act, but the implementation of its provisions is clearly lax. For example, the Atomic Energy Act states that there should be no habitation within five kilometres of a waste site or uranium-tailings pond and even though Jadugoda has been in operation for more than 30 years, seven villages stand within one and a half kilometres of the danger zone. One of them, Dungardihi, begins just 40 meters away! UCIL has also found a way to go past the AERB guidelines that limits the effective dose to occupational workers at 100 mSv/yr in a sliding block of five years and not more than 30 mSv/yr in a year. It makes use of a 'revolving door' contractor arrangement, whereby workers are dismissed as soon as they show signs of increased doses.

Further, the requirement of a protective barrier such as a water cover to check radiation has not been maintained. One can see that the tailings have been discharged without any kind of cover. So although the solids are mostly contained, the liquids, gasses and fine dust particles are being rapidly cycled into the environment.

Public information has again been poor. The radiation levels and related sickness have never been revealed to the workers as well as the general public by the UCIL. In another communication[21], the company has claimed that the radiation levels and discharge details have been displayed at various installations as per the guidelines of Pollution Control Board. It also reports of having conducted a Public Awareness Programme in schools, colleges and nearby villages, jointly with BARC and Indian association for Radiation Protection to educate the people on the subject. The villagers do not recount any such programme. Further, no public notices were found in the area aimed at educating the public about the hazards.

Reclamation of Uranium Mill Tailings Deposits

To reclaim a uranium mill tailings pile according to principles of a safe long-term isolation, detailed investigations have to be performed in advance to assess the site.

If the tailings pile presents an immediate hazard, then intermediate protective measures can be taken in parallel, such as installation of a cover against windblown dust, or collection of seepage waters. These measures, however, should not conflict with the long-term measures to be taken later. The site must be appropriate for tailings disposal from the view of geology and hydrology:

- it should not be located on a geologic fault,
- it should not be threatened by the risk of earthquakes,
- natural impermeable layers should be present,
- the site should not be located in the flood plain of rivers,
- the phreatic level should be rather deep,
- any seepage should not present a risk to ground water,
- deposits of clay materials appropriate for lining and covering the deposit should not be located too far away,
- the site should be remote from residential areas, and so on.

During investigation of the site, the ground water flow has to be monitored to allow development of computer-based three- dimensional ground water models. These models can be used for prediction of effects of supposed or real contaminant releases. In some circumstances; it may become necessary to move all the material to an intermediate storage place to allow for the installation of a liner below the final deposit. An example for this procedure was the tailings deposit at Canonsburg, Pennsylvania, USA. In some very unfortunate circumstances, it even may become necessary to move the whole material to a safer site for permanent disposal. This procedure was preferred at 11 sites in the U.S., involving a total of 14.36 million m^3 of tailings.

To prevent seepage of contaminated water, a liner must be installed below the deposit if no natural impermeable layer is present. For this purpose, appropriate lining materials have to be selected. A multi-layer liner may become necessary. To increase mechanical stability, the following management options may be applied: dewatering of the sludge, smoothening of the slopes and installation of erosion protection.

On top of the pile, an appropriate cover has to be installed for protection against release of gamma radiation and radon gas, infiltration of precipitation, intrusion of plants and animals, and erosion. This cover, in most cases, consists of several different layers to meet all the requirements. Moreover, catchment, collection and treatment of seepage water are necessary to release the purified waters to the surface water. In the long term, water treatment would no longer be necessary.

[21] UCIL's response dated April 29, 2008 to the application filed by Shri Prakash under RTI.

Finally, it has to be determined if, and to what extent, contaminated material was used in the surrounding area for construction or landfill purposes. Such contaminated properties should be included in the reclamation programme.

While this sounds quite comprehensive, no such plan has been disclosed by UCIL. Tailings pond-1 has long been closed but no reclamation plan has been formalised or implemented. It is not clear if even a mud cover has been provided on the tailings after its closure. The site gives an abandoned look which is clear from the picture.

The UCIL did share its end-of-life plan for treatment of tailings ponds that will be stabilised with a mud cover and then rehabilitated. According to UCIL, consultations with the Forest Research Institute, Dehradun are currently in progress to select the plant varieties to rehabilitate the area.

Disposal of Other Materials
The lack of sites for disposal of toxic and nuclear waste has led to proposals to dump these hazardous wastes in uranium mill tailings piles or in former uranium mines. For example:

- In Thuringia, toxic industrial waste was dumped on top of the Trünzig A tailings pile. In addition, it was planned to cover this toxic waste with an additional 5 meter layer of domestic waste, but this was not realised due to protests of residents.
- Hazardous liquids were dumped on the top of a waste rock pile of the Ronneburg uranium mine in Thuringia. These would have to be disposed of before the pile can be reclaimed.
- In Saxony, scrap contaminated with radioactivity from the shut down Crossen uranium mill is to be dumped in the Helmsdorf uranium mill tailings pile.
- In France, there are discussions to dump industrial low activity radioactive wastes in the uranium mill tailings deposit at l'Écarpière (Loire Atlantique).

When closing down a uranium mill, large amounts of radioactively contaminated scrap are produced which have to be disposed off in a safe manner. In the case of Wismut's Crossen uranium mill, to reduce cost, some of the scrap is intended to be disposed off in the Helmsdorf tailings. But there it can produce gases and thus threaten the safe final disposal of the sludge.
The Jaduguda tailings dams, too, became the nuclear waste dump for the entire country. Wastes from the Nuclear Fuel Complex in Hyderabad and the BARC Rare Materials Plant in Mumbai, Mysore, Gopalpur on sea, as well as medical radwastes from an unknown number of sources were being returned to Jaduguda. This came to light when local people began to find syringes, bags and IV pipes from hospital wastes buried in the tailings. Drums were also reportedly seen on trains coming to Jaduguda. The practice stopped after protests from people. It is now widely believed that the company still imports this waste and is feeding it through the mill, crushing it before discharging it into the dams. UCIL refutes this completely and asserts that no waste from other sites is being cast off into the dams. On another occasion, it admitted that "a small amount of raffinate cake" from Hyderabad was coming to Jaduguda. It is likely that some of these materials are gamma radiation emitters, adding to the radiation hazard posed to everyone in the area.

UCIL affirms disposing all other waste generated at the mill site into the tailings ponds. The pipes used to transport the tailings to the dam too qualify for such a disposal. The fact that the used contaminated pipes were seen lying scattered in large numbers near and around the tailings site (presumably left from the repair and maintenance work) however points at the seriousness with which UCIL follows its safety guidelines. It would not be surprising to see these pipes landing in the scrap market, along with other scrap and thus landing up in some industrial/ consumer product (See Box below).

Indian company supplies radioactive elevator buttons to Otis in France

France's Nuclear Safety Authority (ASN) found that the elevator buttons used by Otis and supplied by French company, Mafelec were using materials sourced from an Indian supplier. 20 French workers who had handled these buttons had been exposed to excessive levels of radiation. Mafelec informed ASN about the radiation levels emitted by the elevator buttons. ASN found that the contaminated material, which had arrived in August and was used by Otis Elevator Co, contained faint traces of cobalt 60, a radioactive form of the metal cobalt in its elevator buttons.

The radiation had exposed 20 of the 30 workers at Mafelec, which had supplied the buttons to Otis, to a dose of between 1 and 3 millisieverts- an incident which is marked at level 2 on a scale of 7 on the International Nuclear Event Scale. This is due to the exposure of more than 10 people to doses exceeding the legal safe limits. ASN said that the contamination posed no threat but has raised the alert level as a precautionary measure.

Investigations conducted by the Indian Atomic Energy Regulatory Board had named Bunts, Laxmi, SKM Steels, Vipras Castings, and Pradeep Metals as suppliers of products that have been contaminated with cobalt 60 to many countries. The investigation found out that Bunts and Laxmi Electronics, who had sold the buttons to Mafelec, had sourced the steel from SKM Steels, which in turn, had obtained the raw material containing radioactive material from a foundry called Vipras Casting. Vipras Casting recycles scrap purchased from dealers who import steel scraps from Europe and the US and sells it to various steel companies in India.

The Atomic Energy Regulatory Board and labour ministry is now trying to identify Indian workers who could have been exposed to the radioactive material right from the source of the raw material to the finished product. In India, factories that handle imported steel scraps are not required to install radiation detectors to check scrap, but the government has a programme to put radiation monitors at ports to check the cargo. Experts believe that the cobalt 60 could have come from different countries, which supply scrap metal to Indian firms for recycling. These included parts from decommissioned nuclear reactors, hospital radiation equipment, foreign ships sent to Indian ports for dismantling or the hulls of foreign nuclear submarines.

One commentator said that some western countries have been dumping their toxic wastes in India, with the Indian government turning a blind eye to this situation. This time, the material has gone back to the western country. India does not have strict enforcement to check radioactive hazardous waste from entering the scrap market and also lacks facilities for the decontamination of scrap.

Meanwhile, the Swedish government said that the steel items imported from India and delivered to four factories in Sweden had showed faint traces of radioactivity, but it was not recalled since the levels of cobalt 60 in the steel were considered as not harmful.

8 November 2008; Source:
http://www.domainb.com/economy/environment/20081108_indian_company.html.

If the mixing of uranium mill tailings and other wastes is allowed, then the reclamation of the tailings piles becomes even more difficult, if not impossible, because a best fit method always can be found for a single contaminant only. In the past, there have also been reports that the drums used to transport yellowcake to the fuel fabrication plant were lying abandoned at the nearby station (Rakha). Locals claim that those drums were used. Though it cannot be ascertained if any such drums have been taken away by people in the vicinity for their personal use[22], the possibility cannot be completely negated.

A shocking media report in a Pakistan Daily[23] describes India's processed uranium selling in the International black market. Citing 'WMD Insights'a reputable US-based magazine, the report states that India's Jaduguda uranium mines in Jharkhand are becoming notorious for the smuggling of processed uranium, or 'yellow cake' which is being sold in the international black market. More recent reports dealing with international discussions on the smuggling of nuclear and radioactive materials have said that uranium ores stolen from the Jaduguda mines in India have found their way to Nepal, from where they are sold to international buyers. Citing another report that appeared in Indian newspaper, *Vijay Times*[24], the media wrote, 'In an alarming development, smugglers are sending highly radioactive yellow cake or processed uranium, used in making nuclear weaponry, to Nepal through the clandestine narcotic route via the Jharkhand-Bihar-West Bengal conduit, and it is suspected that the destination might be Al Qaeda.' This report has not been independently corroborated. Some believe that these allegations may be an attempt by Pakistan to project India as an irresponsible state in light of the developments around the US-India civilian nuclear

[22] Interview with Shri Prakash, JOAR.
[23] 'India's processed uranium selling in Internationall black market', *Daily Times*, Pakistan, 27 February 2007.
[24] Amlan Home Chowdhury, "Is Al-Qaeda Getting Jharkhand Uranium?" *Vijay Times* (Bangalore), April 30, 2006

Health and Environmental ImpactSome Reports

There is enough evidence available to support that tailings are hazardous and contain 85% percent of the radioactivity in the original ore along with heavy metals and chemical toxic materials from mill reagents. They are known to contain a fraction of uranium isotopes and 10 decay products from thorium 230 (half life of 75,000 years) to polonium 210. Some of these radionuclides have high radiotoxicity when ingested or inhaled. These cause permanent production of a radioactive gas radon 222, which is known to be carcinogenic. The chemical toxicity, heavy metals and acid can be 100 kg/ ton. As already mentioned in this report, it is extremely difficult to find a cause-effect relation in case of any disease and radiation exposure. The people of Jaduguda are not exposed to 'high' levels of radiation in the course of normal operations. In some cases, people have lived here for more than 30 years with low-level radiation, which acts in subtle and barely understood ways.

The damage is not always obvious. A phenomenon known as 'genomic instability' allows mutations to skip generations, lying dormant until called into play in the grandchildren or great-grandchildren of the exposed person. Seen in this context, uranium mines expose people and other living creatures to radiation-emitting substances in their most dangerous form: millions of tonnes crushed into particles as fine as dust, ready for uptake into the biosphere. Likewise, any impact on environment cannot be convincingly zeroed down to any one factor. The fact that radiation does have an impact on human health and environment cannot be ignored. There is enough evidence in support of this.

❖ A small study was conducted by Dr. N.K. Upadhya between February and June 1997 at the request of Rana Gautam, a journalist working for the *Times of India* office at Jamshedpur. Tests were conducted to look into the environmental impacts of the tailings. The first test found elevated levels of chlorides, sulphates and calcium in the river water downstream of the mine. The results of the second test, which involved evaluation in a radioisotope laboratory of radiation levels in:

… Aquatic grasses in tailings pond-1: 1 rad
… Fruits of aquatic grasses from tailings pond-3: 3 rad
… Fruit from Kendu plant near tailings pond-1: 3 rad
… Chironomous larvae from tailings pond-1: 9 rad
… Chironomous larvae from river: 7 rad
… Gastropod shell from tailings pond one: 15 rad
… Gastropod shell from river: 15 rad

These findings would seem to support the contention that bio-magnification is occurring; that is, the radioisotopes and doses delivered are increasing as we go higher up the food chain. By way of comparison, background radiation is normally averaged at 0.1 rad and 50 rad is considered enough to cause "premature aging, genetic effects and some risk of tumours".

❖ At the insistence of JOAR, the State of Bihar conducted its own survey on the health impacts of the mine. The environment committee of the Bihar Bidhan Parishad (Legislative Council) spent two years on the study and filed its last report in December 1998. A medical team sampled water around the tailings dams and examined 54 people suspected of suffering from radiation-related illness. The report confirmed that UCIL was dumping nuclear waste from other sites into the tailings dams, and that uranium was leaching into the river and also that people were living too close to the mine. The team expressed concern at the fact that the tails dams were unfenced, that waste water was returning to the treatment plant in open drains and that there were no warning signs around the plant[25]. But overall the findings were ambivalent. K.K. Beri, the then UCIL Technical Director, had written to the deputy commissioner's office informing him that the 54 people identified by the medical team were not suffering from diseases caused by uranium radioactivity, and they are dismissed in the final report: "As regards the cause-effect relationship of these diseases with radioactivity, we can neither establish nor exclude the same at this stage.[26]" The committee recommended that a complete health survey be undertaken. This was duly carried out by a medical team dominated by doctors from BARC and the UCIL chief medical officer. It found that the diseases found in Jaduguda were not related to radiation, blaming instead poor nutrition, malaria, alcoholism and genetic abnormalities[27].

The environment committee had, however, made a recommendation that people be evacuated to a distance of 5 km from the mines and tailings ponds. This recommendation, like much of the bulk of the report, has been ignored by UCIL and the government alike.

[25] Azizur Rahaman and Jayanta Basu, 'Uranium Mining in Jaduguda, Bihar: Living in Death's Shadow', *Sunday Magazine* (Calcutta) 4-10 April, 1999.
[26] Julian West, "Thousands at Risk of Poisoning from 'India's Chernobyl', *Sunday Telegraph*, 25 April, 1999, Issue 1430.
[27] Manish Tiwari, "A Deformed Existence", Down to Earth, 15 June 1999.

❖ According to a JOAR/ BIRSA Survey conducted in seven villages within 1km of the tailings dams, 47% of the women reported disruptions to their menstrual cycle and 18% said they had suffered miscarriages or given birth to stillborn babies in the last 5 years. 30% reported some sort of fertility problem. Nearly all women complained of fatigue, weakness and depression. Overall, the survey found a high incidence of chronic skin disease, cancers, tuberculosis, bone and brain damage, kidney damage, nervous system disorders, congenital deformities, nausea, blood disorders and other chronic diseases[28]. The most visible and heartbreaking impact of the mine, according to the research, has been deformed children. Low-level radiation causes genetic damage, slowly degrading the DNA material held within eggs and sperm an inheritance upon which the whole human race depends. Once the genes have been damaged, there is no hope of repair. As regards the cause-effect relationship of these diseases with radioactivity, it can neither be established nor excluded at this stage, concluded the survey findings.

❖ Between May and August 2007, the Indian Doctors for Peace and Development (IDPD), in association with International Physicians for Prevention of Nuclear War (IPPNW) and Jharkhandi Organisation Against Radiation (JOAR), studied the health hazards faced by miners working in the Uranium Corporation of India Limited (UCIL) and came out with a detailed survey report. One survey concentrates on villages within the radius of 2.5 km from the mines, and a similar one was undertaken in villages about 30 km from the mining areas. A total of 2,118 and 1,956 households were studied in two phases. The survey findings have revealed that more childrenabout 9.5% of the newborns are dying each year due to extreme physical deformity. Primary sterility is becoming common with 9.6% per cent of women not being able to conceive even three years after marriage. Cancer deaths in nearby villages are about 2.87% and 68.33% people are dying before the age of 62[29].

❖ In 2001 and 2002, Hiroaki Koide from the Research Reactor Institute at Kyoto University performed field trips to monitor the environmental impacts of the Jadugoda uranium mine. He monitored external gamma dose rate, radionuclide concentrations in soil and radon concentration in air. The main conclusions were:

- The contamination from the uranium mine has spread in Jadugoda:
  - The external gamma dose rate exceeds 1 mSv/y in the villages and reaches 10 mSv/y around the tailings ponds.
  - The soil surrounding the tailings ponds is contaminated by uranium. Particularly high contamination levels were found in the village of Dungridih that borders the first tailings pond. In other villages, no serious contamination was found.
  - Radon emanated from tailings ponds spreads contamination.
  - Waste rock from the mine used for construction material spreads contamination.
- Other findings include:
  - The first tailings pond showed contamination by cesium. This fact shows that radioactivity was brought in from a source other than the uranium mine.
  - Product uranium concentrate is dealt with carelessly and was found dispersed at Rakha Mine railway station.

❖ Near Jadugoda mine, an independent study by experts recorded that the yearly dose of nuclear radiation exposure was 58 times more than the allowed international standard of 100 millirem. An environment committee of Bihar legislative council, headed by Gautam Sagar Rana, had pointed out in its report the health hazards to which miners working in the uranium mines and the tribals (residing close to the tailings ponds used for dumping of nuclear wastes) are exposed. Children in the 15 villages surrounding the uranium mines show signs of genetic mutation and over 60% of the workers manning the tailings ponds are afflicted with serious ailments like bone, blood and kidney disorders, brain damage, cancer, paralysis, tuberculosis and nausea.

❖ "Small animals, including mice, monkeys and rabbits, had disappeared from the area. Kendu fruits have mutated into seedless varieties, and cows are being born without tails. Fish are being discovered with unknown skin diseases[30]."

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[28] Azizur Rahaman and Jayanta Basu, 'Uranium Mining in Jaduguda, Bihar: Living in Death's Shadow', *Sunday Magazine* (Calcutta) 4-10 April, 1999.
IDPD, 'Black Magic of Uranium at Jadugoda: Study on Health Status of Indigenous People around Jadugoda Uranium Mines in India',
[29] Indian Doctors for Peace and Development, 2007.
[30] Interview with Shri Ghanshyam Biruli, President, JOAR.

❖ UCIL has claimed not seeing any effects of radiation on its workforce; nonetheless, for the only years that figures are available, the death toll has been heavy. 17 workers died in 1994, 14 in 1995, 19 in 1996 and 21 in 1997.

Since many workers in the plant are local villagers, a large number of employees have been exposed to the information campaign being waged by JOAR and other groups. As a result, unrest and discontent among the workforce is particularly high. UCIL has responded by using private labour companies to hire contract labourers who are dismissed as soon as they show any signs of illness. Regular employees do wear radiation-measuring devices inside the plant and underground, but they are never told what doses are recorded and if they fall sick, they are treated at the plant hospital. Their medical records are kept a closely-guarded secret. Once a week, these workers carry their uniforms home to be hand washed by their wives and children, yet another exposure pathway. In the absence of any independent study, anecdotal evidence suggests that the mine workers are suffering from an epidemic of lung cancer, skin disease and other chronic ailments. Nobody knows how many of them have died.[31]

WASTE FROM FUEL FABRICATION PLANTS

Very little information has so far been made available on the waste management practices at the Nuclear Fuel Complex and also at other fuel fabrication and enrichment plants. An estimate puts the figure of waste generated during fuel fabrication process at 2000 m3 (till 2000).[32]

Out of the 16 reactors, 14 are PHWR based on Canadian design. These do not require enriched uranium. Only BWR reactors run on enriched Uranium. This means that Indian fuel cycle does not generate much of the depleted uranium as waste from the enrichment process. However, this does not mean that there is no waste generated. Small amounts of waste get generated during fuel conversion and fabrication. These are largely Low level waste and are disposed at these facilities itself.

As per the information available on NFC website, the production operations at NFC generate solid, liquid and gaseous effluents. It reports having an elaborately organised programme of effluent management. Without detailing out the waste management practices, the website states that the Health Physics Unit, the Safety Engineering Division and Effluent Management Division keep a continuous watch to ensure that the threshold limits for radioactive and chemical discharges are never exceeded. The nitrate values from liquid effluents are recovered in specially designed and constructed solar evaporation ponds and sold to interested customers. Solid low activity Uranium wastes in the form of raffinate cake is periodically transported to UCIL, Jaduguda for reprocessing. Similarly, solid anhydrous magnesium chloride is sold to the magnesium industry for recovery of metallic magnesium. The control of gaseous emissions like chlorine, nitrogen oxides and sulphur oxides is achieved by means of dedicated scrubber and packed column towers with suitable absorbing media. The exhaust carrying particulate matter is passed through a series of primary filters, electrostatic precipitators and absolute filters for the removal of radioactive and other dust particles and then let out through tall stacks so that the external releases are far below the permissible limits.

Fuel Fabrication Facilities

- Enriched Fuel Fabrication Plant; location: Hyderabad; BWR type fuel; 25 tHM/yr; start date: 1974; safeguarded
- New Uranium Oxide Fuel Plant; location: Hyderabad; PHWR type; 300 tHM/yr; start date: 1998; makes PHWR fuel pellets
- PHWR Fuel Fabrication Plant; location: Hyderabad; 300 tHM/yr; start date: 1974; makes PHWR fuel bundles
- Advanced Fuel Fabrication Facility; location: Tarapur; 20 tHM/yr; start date: circa 1990; makes MOX fuel for PFBR, BWR, and PHWR; R&D
- New Uranium Fuel Assembly Plant; location: Hyderabad; PHWR type; 600 tHM/yr; start date: unknown; under construction
- MOX Breeder Fuel Fabrication; location Kalpakkam; pilot scale; start date: unknown; makes MOX fuel

JOAR has reported seeing drums being received from Nuclear Fuel Complex (NFC) for disposal of waste in Jaduguda. They suspect that NFC has been sending all its waste to Jaduguda for disposal in the tailings pond. While NFC declares that it sends raffinate cake to Jaduguda for reprocessing, UCIL denies receiving anything back from NFC. The drums in which the yellowcake is transported is also considered as waste due to radioactivity content. The practice for their disposal is not known. It is hoped that these drums are not finding their way out of these establishmentsand into the homes of people.

[31] Azizur Rahaman and Jayanta Basu, 'Uranium mining in Jaduguda, Bihar: Living in Death's Shadow', *Sunday Magazine* (Calcutta) 4-10 April, 1999.
[32] M. V. Ramana, Dennis George Thomas and Susy Varughese, 'Estimating Nuclear Waste Production in India', *Current Science*, 10 December 2001, 81(11): 1458-62.

Besides, another concern is the transportation of yellowcake to the fuel processing plant. This is done both by road as well as rail at least twice a month. UCIL claims strict adherence to transportation guidelines and reports no accident so far. However, in July 2007, the media reported the overturning of a trailer that was transporting a container with 62 drums of radioactive yellow cake from Jaduguda to the Nuclear Fuel Complex into the fields at Narsannapeta in Srikakulam district in Andhra Pradesh. The Department of Atomic Energy denied any spillage and reported no change in the background radiation levels.

In November 2002, a blast occurred in the Natural Uranium Oxide Fuel Plant (NUOFP) of the Nuclear Fuel Complex (NFC). The top lid of the process plant hit the asbestos sheet roof, which fell off. Seven persons were working in the plant at the time, but no one was injured. Uranium-bearing liquid contained in the plant spilled onto the ground and collected in a pit. It was later taken back into the process plant. After the blast, the Health Physics Unit of the NFC monitored the area and declared there was no airborne activity and people were allowed to resume their work in the other plants at the NFC.[33]

The operations were resumed in April 2003 by AERB. A specialist investigation committee of the AERB confirmed that the explosion was due to what is known as "Red Oil Reaction" uncontrolled chemical reaction involving hot organic liquid and aqueous nitrate solution. The NFC management has now modified the process to exclude the evaporation step
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RESIDUAL WASTE FROM BACK END FUEL CYCLE

Waste management facilities at various nuclear installation sites have been operating for more than four decades. The Head of Waster Management Division at BARC feels that the Indian experience in management of nuclear waste from power plants, fuel reprocessing and allied installations is rich and comparable with international practices.

Each year, nuclear power generation facilities world-wide produce about 200,000 m^3 of low and intermediate level waste and 10,000 m^3 of high level waste (including spent fuel that's been designated as waste). Before getting into waste management practices, it is important to understand the policy framework with regard to radioactive waste management.

The national policy for radioactive waste management is based upon the universally-adopted philosophy of: delay and decay of short lived radionuclides; concentration and containment of radioactivity as much as practicable, and; dilution and dispersion of low-level activity to the environment well below the nationally-accepted levels which are in line with international practices.

The national policy for radioactive waste management is broadly as follows:

a. Discharge through gaseous, liquid and terrestrial routes are as low as reasonably achievabletechnical, economic and social factors are taken into account.
B. Low and intermediate level solid/solidified waste are emplaced in near surface shallow land repository that is specially engineered for this purpose.
c. High-level and alpha contaminated liquid waste from spent fuel 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 necessary period . Thereafter, these solidified waste products will be emplaced in a suitably engineered deep geological repository.
D. Alpha-contaminated waste not qualifying for near surface disposal is provided suitable interim storage pending its disposal in a deep geological repository.
e. Spent radiation sources are either returned to the original supplier or handed over to a radioactive waste management agency identified by the regulatory body.
f. Co-location of near surface disposal facility with the nuclear installations.
g. In the Indian context, spent fuel is a resource material and needs to be processed for recovery and recycling of fissile material. Each reprocessing plant therefore hasa co-located vitrification plant.
h. The regulatory body determines the period for which active control of the shallow land repository (like monitoring, surveillance, remedial work) of the repository should be maintained by the waste management agency. Thereafter, passive control (like permanent markers and land use restrictions) will be passed on to the Central Government, the agency for institutional control. Institutional control may span a period of 300 years comprising, typically, 100 years of active control and 200 years of passive control so as to allow decay of most of the radionuclides present in the waste rendering them

[33] Syed Amin Jafri , 'Blast in AP Nuclear Fuel Complex harmless', *Rediff* dated November 18, 2002.

Classification of waste is very important from the safety as well as process consideration point of view. Important parameters which are taken into account include physical, chemical, radiological and biological properties as well as criticality aspects and origin of waste. Classification of waste into different categories is useful in their segregation, selection of appropriate treatment process, storage and disposal. The concentration of radioactivity also varies depending upon the source of generation.

Radioactive wastes are generated in various forms: **solid, liquid or gaseous**.

Solid radioactive wastes are also classified as compressible or non-compressible and combustible or non-combustible depending upon the corresponding physical nature. They are further divided on the basis of type and content of radioactivity. Radioactive waste management facilities have been set up at various sites in India, as detailed in Table 4.2 below. Some of these facilities have been in operation for more than 40 years.

Gaseous Waste

In order to control and minimise discharge of activity through air route in conformity with the principle of ALARA, all nuclear installations must have an elaborate off-gas cleaning system. The choice of system depends on specific activity, type of radioactivity, particulate density and its size distribution, specific volatile radioisotopes and their concentration, etc.

India has developed a 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.

Liquid Waste

Low and Intermediate Level Liquid Waste

Low-level waste is generated from reactor operations, off-gas scrubbers of nuclear facilities, active floor drains, decontamination centre, laboratories, drainage from change room and showers as well as during management of high and intermediate level waste. These waste streams require treatment to reduce their activity concentration to a level at which they are allowed to be discharged according to the national regulations.

The processes that are employed for treatment of this type of waste are filtration, chemical treatment, ion-exchange, steam evaporation, solar evaporation and membrane processes. Some of the processes presently under operation at various sites include:

Table 4.2: Waste Management Facilities in India

Site	Year of commissioning	Nuclear facility
Coastal		
Trombay	1956	Research reactors, fuel fabrication plant, fuel reprocessing plant, research laboratories, isotope production, waste immobilisation plant (WIP)
Tarapur	1969	BWR (2 × 160 MWe), fuel reprocessing plant, fuel fabrication plant, WIP
Kalpakkam	1984	PHWR (1 × 170 Mwe; 1 × 220 MWe), fuel reprocessing plant, research laboratories, Research reactor (FBTR), WIP under construction
Inland		
Rajasthan	1972	PHWR (1 × 100; 1 × 200; 2 × 220 MWe), isotope facility
Narora	1989	PHWR (2 × 220 Mwe)
Kakrapar	1993	PHWR (2 × 220 Mwe)
Kaiga	2000	PHWR (2 × 220 Mwe)

Chemical Treatment

Liquid wastes with low levels (373.7×10^6 Bq/L) of activity containing Strontium 90 and Caesium 137 as the major radionuclides are treated by co-precipitation using chemicals like barium chloride, sodium sulphate, potassium ferrocyanide, copper sulphate, etc. Subsequent to precipitation, the resultant sludge from clarifloculator is further concentrated by decantation, filtration and centrifugation. The resulting solids containing the bulk of the radioactivity originally present in the liquid waste are immobilised in cement matrix before disposal.

Ion exchange

A variety of sorbents and ion exchangers are used in India for the treatment of diverse types of radioactive aqueous waste streams. Conventional synthetic organic ion exchange resins are used for clean-up of spent fuel storage pool and for polishing of effluents from chemical treatment of low-level waste. Amongst inorganic materials, synthetic zeolites, the clay mineral vermiculite and ammonium molybdophosphate (AMP) have found industrial application. While vermiculite is used for decontamination of low-level effluents, a synthetic zeolite is used for reduction of Cs 137 activity in spent fuel storage pool water. Granulated AMP is used for consolidating Cs 137 in acidic effluents.

A treatment process based on radionuclide separation by selective ion exchange is used for the effective management of alkaline intermediate level reprocessing waste streams. As a result of this treatment, the intermediate level waste is split into two streams, viz., a small volume of high-level waste and a large volume of low-level waste, which is treated and discharged to the environment. An ion exchange plant is in regular operation at Tarapur. The successful use of a unique transportable shielded ion exchange facility was also recently demonstrated at Trombay. In this process, an indigenously developed resorcinol formaldehyde polycondensate resin (RFPR) is used in repeated loading elution-regeneration cycles for efficient removal of Caesium 137 which is the major radionuclide present. Waste processing throughput of 400 L/h is achieved using 100 L columns. A chelating iminodiacetic acid resin is used for the removal of 90Sr traces.

Evaporation

Evaporation is widely used for concentrating the liquid waste as it gives very high volume reduction factor as well as high decontamination factor. Both steam and solar evaporation methods are employed. Evaporation based on steam heating is used for waste of low volume and high activity. Design is normally based on thermo-siphon principle to minimise maintenance problem.

Solar evaporation, sometimes referred to as zero release operation, is a preferred mode of evaporation for larger volumes of waste with low activity (373.7×10^6 Bq/L) at sites, which have favourable climatic conditions such as high ambient temperature, low humidity and high wind velocity. The north Indian state of Rajasthan has such favourable conditions and solar evaporation pond for low-level liquid waste generated by nuclear power plant is in operation there.

Membrane Processes

Membrane based processes like reverse osmosis and ultra filtration are used essentially for treatment of low-level liquid waste. These are generally employed in combination with other treatment methods like chemical treatment or ion-exchange process to further improve the decontamination. A reverse osmosis plant of capacity 100m3/day is in operation for treatment of low-level (373.7×10^6 Bq/L) waste at Trombay. The volume of waste is normally reduced by a factor of 10 and decontamination factor of 810 is achieved in this process.

Conditioning of Intermediate Level Liquid Waste and Spent Ion Exchange Resin

Intermediate level radioactive liquid waste is conditioned depending on the compatibility of the matrix with waste, chemical and mechanical durability of solidified product, cost of processing, throughput and disposal options. Cementation and polymerisation methods are normally adopted in India for management of this type of waste. Spent ion exchange resins are immobilised in polymer matrix.

Cementation

Cement and cement composites are extensively used for immobilisation of low-level radioactive concentrates, chemical sludge, etc. Cementation process offers advantage due to low cost and operational simplicity, higher throughput and product of acceptable quality. Special cement formulations have been developed by blending cement with suitable additives to improve product characteristics.

Cementation facilities having in-drum mixing system using reusable agitator for conditioning of radioactive waste are installed at various sites. Cementation process has also been used for in situ immobilisation of intermediate level waste in specific cases. In situ cementation results in large waste processing rate with extremely low exposure to the workers.

Polymerisation

Polyester styrene been selected and is in use in India for immobilisation of ILW concentrates and spent ion exchange resin from nuclear power stations and other facilities. This matrix has also been used for in situ solidification of low-heat generating liquid waste from reprocessing plant.

In resin fixation plant, radioactive spent resins are hydro pneumatically transferred to resin storage tank. A batch of 90 kg resin is transferred to a specially designed product drum kept on load cell. Excess water is removed by vacuum de-watering system. Mixing assembly is then mounted on this product drum. Requisite amount of polyester styrene polymer is premixed with optimized concentration of accelerator (dimethyl aniline) and catalyst (benzoyl peroxide). This polymer is then gradually poured into a product drum with constant stirring. These resin fixation facilities exist at nuclear power plant sites in Narora (Uttar Pradesh), Kakrapar (Gujarat) and Tarapur (Maharashtra).

Management of high-level Liquid Waste

High-level Liquid Waste (HLW) generated during reprocessing of spent nuclear fuels is concentrated by evaporation and stored in stainless steel tanks. These storage tanks require cooling and continuous surveillance. Liquid storage in stainless steel tanks is at best an interim step and a three-step strategy for management of HLW has been adopted in India.

This involves:

i) Immobilisation of waste oxides in stable and inert solid matrices;
ii) Interim retrievable storage of the conditioned waste under continuous cooling;
iii) Disposal in deep geological formations.

HLW management facility is co-located near reprocessing plants so as to avoid any radiation hazard/exposure to the public during transportation. Pumping of HLW from reprocessing plant to vitrification plant is an involved job. Main waste transfer stainless steel pipe is enclosed in a secondary stainless steel pipe and this outer pipe is isolated from the surroundings by a stainless steel box. The annulus between two pipes is continuously monitored during waste transfer operation. The stainless steel box is enclosed in a high integrity underground RCC trench which connects the two facilities.

In order to meet the challenging task of vitrification of HLW, research and development work was started in India in the late 1960's encompassing various areas of HLW conditioning including formulation of matrices for immobilisation of HLW and their characterisation. This was followed by research and development of process, equipment and assemblies to condition HLW into an inert and stable waste form of acceptable quality. These efforts have finally culminated in the design and construction of the first Indian vitrification facility at WIP, Tarapur and interim storage facility at Solid Storage and Surveillance Facility (SSSF), Tarapur. The second vitrification facility has been commissioned at BARC, Trombay to manage HLW generated during reprocessing of spent nuclear fuel from research reactors at site. In India, borosilicate glass matrix has been adopted for vitrification of HLW. Suitable modifications to this basic matrix have been developed in order to take care of specific chemical species like sulphate and sodium. Conditioned products are evaluated for various properties like product melt temperature, waste loading, homogeneity, thermal stability, radiation stability and chemical durability.

The multi-cell multi-compartment concept has been adopted at Waste Immobilisation Plant, Trombay so as to facilitate segregation of equipment and ease of maintenance. The process cells are equipped with remote handling systems. Tarapur is a single cell WIP. An off-gas cleaning system consisting of condenser, scrubber, chiller, demister and absolute HEPA filter is used to treat the gas before discharge through a 100m tall stack to the atmosphere.

Vitrified waste canisters are further enclosed in secondary stainless steel containers called overpacks. The overpacks may contain radioactivity up to 10^6 Ci generating about 34kW of decay heat and they need to be cooled continuously to maintain centre line glass temperature below softening temperature to minimise devitrification. A third Waste Immobilisation Plant is being set up at Kalpakkam. It has been designed for the treatment and conditioning of high-level liquid waste generated during reprocessing of irradiated fuel from Pressurise Heavy Water Reactors and Fast Breeder Reactors.

Management of Organic Liquid Waste

Organic liquid waste is generated from reprocessing plants in the form of spent PUREX solvent (30% tri-butyl-phosphate in diluent), which has undergone chemical and radiolytic degradation with repeated use. The spent solvent is treated by the 'alkaline hydrolysis' process. The treatment leads to the recovery of diluent virtually free of activity and tri-butyl-phosphate. The aqueous bottom arising from alkaline hydrolysis process is immobilised in cement. An incineration facility is also available for thermal destruction of non-recyclable diluents.

Management of Solid Waste

Radioactive solid wastes produced at different stages of nuclear fuel cycle cover a wider range of materials, sizes, shapes and degrees of contamination. These wastes are categorised depending on the radiation field, concentration and type of radioactivity. They are segregated as compressible or non-compressible and combustible or non-combustible. A major portion of the total solid waste has low activity and is either combustible or compressible. Specially designed incinerators are employed for burning the combustible wastes achieving a volume reduction of about 50. Hydraulically operated baling press is used to compress low active non-combustible waste to obtain volume reduction of five.

As a typical example, various research reactors and nuclear laboratories at BARC, Trombay generate approximately 600 m3 of radioactive solid waste annually. The major portion of this waste is received in standard 200 L carbon steel drums. The waste is categorised with the help of an assaying system, based on radioactivity content and radionuclides present. A real time digital imaging system is used to segregate compactable and non-compactable low-level waste. The compactable waste packed in drums is pelletised using 200 tonnes hydraulic press. All operations are controlled by programmable logic controller based control system. Apart from drum pelletisation, the system is also equipped for the compaction of used HEPA filters.

Storage and Disposal of Radioactive Waste

The present practices in India for the storage and disposal of various categories of solid waste are briefly described below.

Near Surface Disposal Facilities (NSDF**)**

As a national policy, each nuclear facility in India has its own near surface disposal facility co-located. There are seven NSDFs currently operational within the country. These are located at Trombay, Tarapur, Kalpakkam, Kota, Narora, Kakrapar and Kaiga. These NSDFs in India have to address widely varied geological and climatological conditions. The various disposal modules currently adopted in NSDFs are:

(i) stone-lined earth trenches (SLT),

(ii) reinforced concrete trenches (RCT) and

(iii) tile holes (TH).

The different types and categories of wastes disposed of in these modules are listed below:

Table 4.3: Solid Waste Categories and Disposal Options

Category	Surface dose/activity	Disposal options	Nature of waste
I	**<2 mGy/h**	**Stone lined earth trenches**	**Paper trash, concrete chips, cotton mops, rubber items, etc.**
II	**2-20 mGy/h**	**RC trenches**	**Contaminated equipment, hardware and filters**
III	**20-500 mGy/h**	**RC trenches**	**Conditioned/processed concentrates, sludges, spent resins**
	>500 mGy/h	**Tile holes**	**Hardware from reactors, highly contaminated equipment, conditioned spent resins, etc.**
IV	**Waste bearing alpha activity (<4000 Bq/g)**	**RC trench and tile holes**	**Solidified alpha waste with (y activity**
	(>4000 Bq/g)	**Tile holes**	

These modules are generally below ground. However, depending upon the local geo-hydrological conditions, these could be partly or completely above ground.

Salient features of the disposal modules are given below:

Stone-lined earth trenches
These are employed for potentially active waste (Category I packages having surface dose rate less than 2 mGy/h). These are shallow excavations in soil, 14m deep and provided with stone lining for stability and integrity. On completion of the disposal operation, these trenches are backfilled and closed by providing a soil cover nearly one meter thick. Vermiculite, bentonite and native soil having good sorption properties are used as backfill materials.

Reinforced concrete trenches
These are employed for Category II and III wastes having surface dose rate less than 220 mGy/h and 20500 mGy/h, respectively. These trenches are planned zone-wise and are modular in construction.

A typical trench is 4.8m deep, 2.5m wide and 15m long. The outer containment wall thickness varies from 350 mm at the top to 750 mm at the bottom. Each zone of trenches is serviced by either a gantry or a mobile crane. Adequate waterproofing is provided all around to prevent ingress of groundwater. During the rains, partially filled trenches are protected using mobile covers. On completion of the filling operation, these trenches are closed by pre-cast concrete slabs which also provide necessary shielding. Adequate sealing and water proofing is provided subsequent to closure of the battery.

Tile holes
Tile holes are used for disposal of Category IV wastes and also for waste packages of Category III, which do not qualify for disposal in RC trenches. Waste packages in 200 L standard packing containing conditioned waste with more than 4000 Bq/g of alpha activity and surface contact dose above 500 mGy/h due to beta and gamma activity are retrievably stored in these tile holes. These are circular vaults, nearly 4m below ground level having an average inside diameter of 710 mm. These are made of 6 mm thick carbon steel shell with 25 mm thick concrete lining on both sides and provided with adequate waterproofing.

Surveillance
Provisions for monitoring and surveillance are incorporated in the design of the disposal facility. Boreholes 47m deep are provided at appropriate locations and the groundwater samples are monitored periodically. Soil and vegetation samples from the site are also periodically investigated for any uptake of radioactivity. Radiation survey of the entire site is carried out at predetermined intervals. The RC trenches are provided with inspection pipes to monitor the inside condition after closure of the trench. The entire disposal site is totally closed by a physical security wall to avoid unauthorised access.

Performance Assessment
Performance assessment of NSDFs is systematically undertaken through field investigations and predictive modelling. This assessment is based on a good physical understanding of the waste forms, waste packages, backfill materials and the engineered barriers. Models have been developed to predict the probability of failure as a function of target lives for various safety indices such as concrete cover thicknesses, climatic factors, maintenance period for the structure, water to cement ratio, water proofing, etc. The modelling studies for a typical RC trench under limiting conditions have predicted a minimum service life of nearly 240 years. This period is sufficient for the decay of major radionuclides like Sr 90, Cs 137 to 99% of their original contribution. Thus, the source term itself reduces substantially.

Safety Assessment
Safety assessments have been carried out for each of the NSDFs. These take into account the nature of the facility, the radioactive inventory, geological, the hydro-geological and geochemical behaviour of the site, pathways and possible scenarios for release and transport of radioactivity. Based on these inputs, mathematical models were generated. Release and transport calculations through various barriers were determined leading to the radiological dose estimates.

Estimates of radioactive inventory for a typical costal NSDF catering to an operating power reactor, a reprocessing plant and a fuel fabrication facility are of the order of 30,000 TBq. The major radionuclides of concern are Cs 137, Sr 90 and Co 60. Based on this inventory, maximum possible radiological dose at a distance of 500 m is almost negligible after a period of 730 years from the closure of the disposal facility. This dose is contributed mainly by 90Sr through groundwater drinking pathway. Maximum possible radiological dose by human intrusion scenario is of the order of 10-6 Sv/annum by excavation inhalation pathway.

Interim Storage of Vitrified Waste

High-level vitrified wastes are characterised by decay heat and need to be cooled to a level where transportation and disposal in geological repository become viable and economical. This period of cooling is also used to generate data on the product behaviour under constant surveillance and monitoring. These data are essential for prediction of long-term behaviour of the vitrified products. These requirements necessitate interim storage of overpacks spanning over 30 years and more.

In India, one such storage and surveillance facility co-located with a vitrification plant is already operational at Tarapur. This facility has a capacity for storing nearly 1760 overpacks with an inventory of nearly 80,000,000 TBq of radioactivity. The facility consists of an underground outer vault (hydraulic) of dimensions 74.5m X 31.5m X 5.2m and houses two inner vaults (thermal) of sizes 34.0m X 25.2m X 2.5m each. The overpacks are suspended vertically from the top slab. A concrete roof of 1.2m thickness provides adequate radiation shielding. The wall temperature in the thermal vault is expected to be 90-110 ◦C when the vault is full.

Removal of decay heat (design value of 3.8 kW/overpack) from the overpack is achieved by natural convective ventilation induced by a 100m high stack. Air-cooling system has been designed on the basis of storage unit geometry, array design, filling pattern and stack dimension. This is an inherently self regulating system and takes care of the changes in decay heat. The cooling system ensures that the temperature within the vitrified waste product, under no circumstances, exceeds the softening point of the vitrified mass. Currently, around 150 overpacks are stored at the facility.

Geological Disposal

Disposal of high-level waste in deep geological repository envisages emplacement of vitrified wastes at depths of about 500-600m in appropriate host rocks, like granite, granite gneisses, charnockite, basalt and other geological set ups. The Indian programme on geological repository commenced in the early 1980's with underground experiments in an abandoned section of a gold mine at a depth of 1000 m. The investigations were mainly directed towards development of methodology for in situ assessment of thermo-mechanical behaviour of the host rock (amphibolites) and to develop and validate the mathematical models. It also addressed the development of associated instrumentation for the measurements and monitoring.

Selection of a few suitable sites for development of site-specific Underground Research Laboratory (URL) possibly leading to the setting up of a pilot repository is being pursued. The investigations involve extensive geo-scientific investigations and other state of the art methods and technologies. Major attributes of significance considered at each site for selection include lithological formation, seismicity, rainfall, economic minerals occurrences, geohydrology, vegetation cover, population, archaeological monument,s etc. The above methodologies have led to the screening of an area of nearly 0.6 million km^2 mainly occupied by granites. The above approach has yielded a few zones admeasuring 525 km^2 lying in different geographic domains for further characterisation.

A layout for an underground research laboratory has been conceived based on the site-specific investigations. The URL design being considered has multiple chambers for in situ experiments to generate design data for geological repository in future. The layout considered extends over an area of about 4 km^2 and considers emplacement of around 10,000 high-level waste overpacks on a pit mode. It is proposed to have four main tunnels branching from the central shaft. Each main tunnel will have disposal tunnels on either side with boreholes to emplace the radioactive waste overpacks.

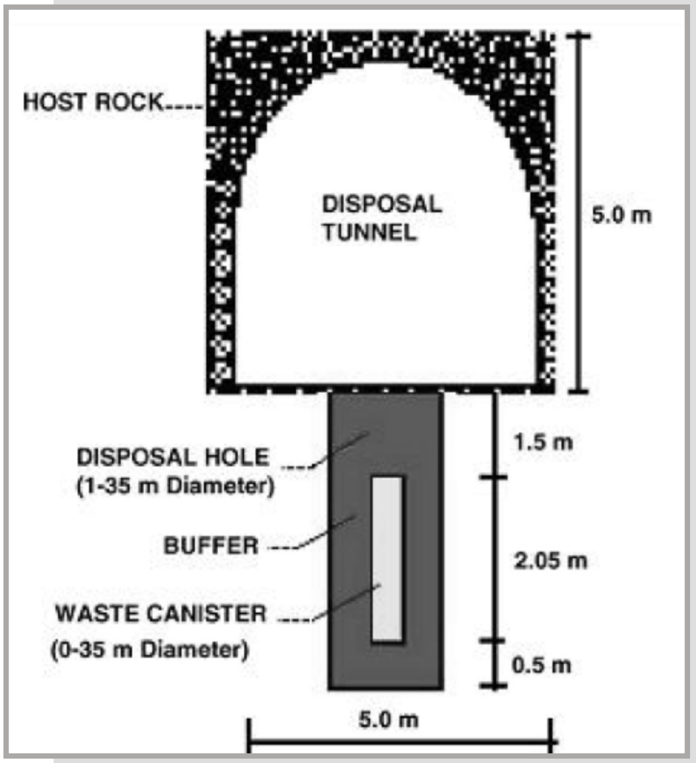

Figure 4.1: Cross section of a disposal tunnel with the vertical emplacement of waste overpacks in the disposal hole.

The fact that India's nuclear programme is not as vast and the country has adopted a closed fuel cycle allowing it to reprocess part of its waste that further reduces the quantum of waste generated and there is no urgency as such to look for options for final disposal. It may be another 15-20 years when India comes up with its own final repository of waste. No site has so far been identified or short listed. The country however supports national repositories as against the multinational approach as has been proposed by few countries.[34] One of the criteria for site selection is that it should be away from dense population; not be a place of tourist significance or ecologically sensitive. While it may be possible to find such an area, is it possible to guarantee that the area will not get inhabited in the coming 100 years if not more?

While authorities claim that no site has yet been shortlisted for final disposal, the media has in the past reported the nuclear wastes to be permanently buried at a site in Rajasthan or Madhya Pradesh. Quoting Mr. K Balu, Director of the nuclear recycle group at BARC, one report says that "a decade of nationwide hunt for a safe long-term nuclear waste repository has narrowed the search to these two states. We are in stage-2, where we have identified in these states 100 square kilometre areas suitable for burying the wastes. In stage-3, we will close in on an area of just five square km, he said. Right now drilling is going on in Rajasthan. The selection of sites with stable geological granitic rocks deep underground involved the co-operation of agencies such as Geological Survey of India (GSI)."[35]

The current BARC Director, Dr. S. Banerjee has however reiterated that there is no urgency to build the waste repository because the quantity of nuclear wastes generated by India is small.[36]

Management of Spent Radiation Sources

Radiation sources of various types and strengths containing Cobalt 60, Strontium 90, Technetium *99*, molybdenum-*99*, Iodine 125, Iodine-*131*, Caesium 137, Iridium 192 and Radium 226, are used in hospitals, industries and research institutes all over the country. The strength of spent sources varies from millicuries to thousands of curies depending upon the area of application.

After their utility period is over, the spent sources are immobilised in cement grouts to make them suitable for disposal in engineered near surface disposal facilities. Waste management facilities located at Trombay and Kalpakkam are the nodal centres for storage/disposal of spent radiation sources.

Handling Technology

Remote handling, robotics and automation are essential for operation and routine maintenance of waste management plants handling high radioactivity. The Department of Atomic Energy in India with the participation of Indian industry has developed all essential equipments for such applications. Development efforts are underway to improve the technology and to make available suitable technologies for decommissioning of such plants whenever the need arises.

Chemical processing operations in waste management plants are carried out in "hot cells" with heavy shielding (approximately 1.5m of concrete) around the equipment. The general philosophy of remote handling is to employ a "work station concept" consisting of a radiation shielding window (RSW), master slave manipulator (MSM) and a cell crane. These equipments have been standardised for such applications.

Decommissioning of Nuclear Installations

The Atomic Energy Regulatory Board in India has made it mandatory for all nuclear installations to incorporate provisions for in situ decontamination and de-commissioning provisions from design stage until the end of the operational phase. India has experience from decommissioning/ refurbishment of research reactors, major systems of power reactors and also radiochemical installations including reprocessing plant. A major activity as a part of the refurbishment of operating power reactors at Rajasthan and Madras covers the replacement of coolant channels. The replaced channels, end fittings and other components are volume reduced and disposed of after conditioning. As a strategy, material from decommissioning will be recycled in the nuclear industry as and when possible.

As a part of the programme for conditioning of decommissioning waste, development activities are underway for cutting and size reduction of metallic components using techniques like under-water plasma and lasers. In order to achieve further volume reduction, technologies for melting and super compaction are being developed.

Research and Development in Waste Processing Technology

India has decades of experience and expertise in management of radioactive waste. It is recognised that the technologies currently adopted are adequate, but sufficient scope exists for improving these technologies so as to enhance process performance and meet future challenges.

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[34] Interview with Dr. S. Banerji, Director BARC and Dr. K. Raj, Head NRG, BARC.

[35] PTI Report, 'N-waste to be buried in Rajasthan, MP', Indian Express (Mumbai), August 18, 1999.

[36] Shared by Dr S. Banerjee during an informal discussion.

Development and induction of cross-cutting technology have to be adopted not only to meet the challenges posed by approach to near-zero discharges, but also to address recycling and recovery of valuable resources from these wastes leading to a positive impact on the environment. Besides, waste management in India has to meet the requirements of advanced fuel cycles for fast breeder reactors and advanced heavy water reactors.

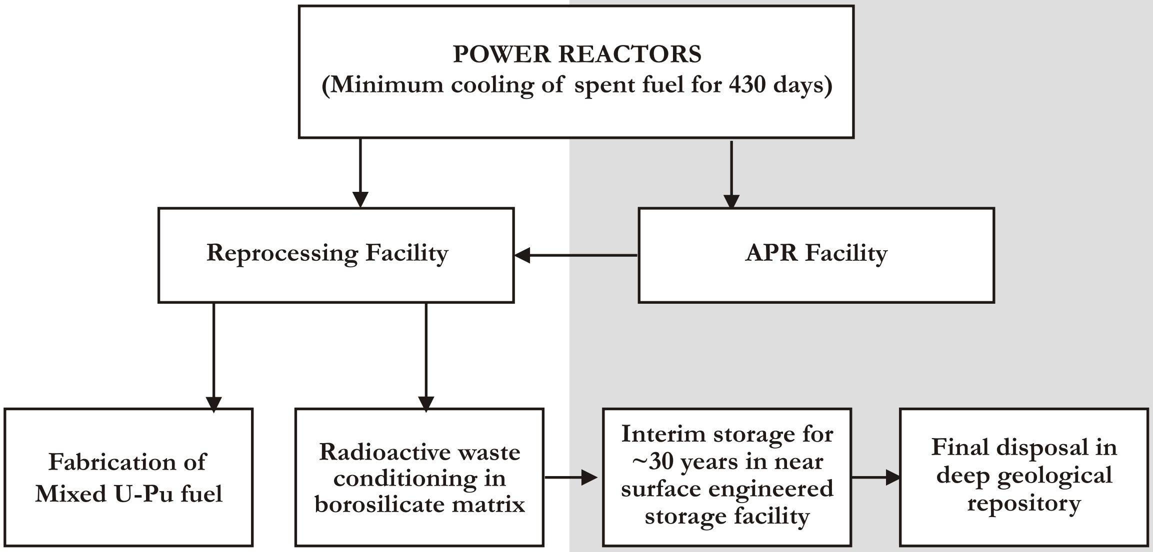
High volumes and low activity levels characterise low and intermediate level wastes. Hence, attention is focused on technology development that can lead to downsizing of equipment, effective decontamination and minimisation of secondary wastes. In this direction, technologies finding a vital role include synthesis and use of specific sorbents, ultra filtration and management of spent solvents by alkaline hydrolysis, development of advanced oxidative techniques for destruction of organic ion exchange resins, etc.

As already indicated, the effective treatment of alkaline intermediate level-reprocessing waste is now possible because of the development of cesium-selective resorcinol formaldehyde polycondensate resin (RFPR). Adoption of this treatment scheme enables the recovery of Cs 137 in kilocurie quantities. In a plant being set up at the Waste Immobilisation Plant, Trombay, the recovered Cs 137 will be further processed and immobilised in a vitreous matrix for use as the radiation source in blood irradiators. The removal of nitrates present in reprocessing effluents is essential before such effluents can be discharged to the environment after treatment for removal of radioactivity. Laboratory and bench scale studies have shown that biological denitrification is an effective process for the destruction of nitrates. Efforts are presently underway to set up a flow-through bioreactor as a demonstration facility for this purpose.

SPENT FUEL MANAGEMENT

In the context of India's nuclear fuel cycle, spent fuel (or used fuel) is not considered a waste but a resource. Since India has adopted a closed fuel cycle on a 'reprocess to recycle mode', the storage of spent fuel prior to reprocessing forms a part of the spent fuel management policy.

The spent fuel discharged from the reactors is temporarily stored at the reactor pool. After a certain cooling time, the spent fuel is moved to the storage locations either on or off reactor site depending on the spent fuel management strategy. As India has opted for a closed fuel cycle for its nuclear energy development, reprocessing of the spent fuel, recycling of the reprocessed plutonium and uranium and disposal of the wastes from the reprocessing operations (as detailed above) forms the spent fuel management strategy. Since the reprocessing operations are planned to match the nuclear energy programme, storage of the spent fuel in ponds is adopted prior to reprocessing. Transport of the spent fuel to the storage locations has to be carried out adhering to international and national guidelines.



India has 16 operating power reactors and three research reactors. The spent fuel from the two safeguarded BWRs is stored at-reactor (AR) storage ponds. A separate wet storage facility away-from-reactor (AFR) has been designed, constructed and made operational since 1991 for additional fuel storage. Storage facilities are provided in ARs at other reactor locations to cater to 10 reactor-years of operation. A much lower capacity spent fuel storage is provided in reprocessing plants on the same lines of AR fuel storage design. Since the reprocessing operations are carried out on a need basis, to cater to the increased storage needs, two new spent fuel storage facilities (SFSF) are being designed and constructed near the existing nuclear plant sites to take maximum advantage of infrastructure, nearness to operating reactor and the approved site for nuclear facility. Wet storage of the spent fuel is the most commonly adopted mode all over the world. Recently, an alternate mode viz. dry storage has also been considered. India has designed, constructed and operated lead shielded dry storage casks and is operational at Rawatbhata. A dry storage cask made of concrete with stainless steel cavity was also designed for spent PHWR fuel.

The depth of pools is based on minimum biological shielding of 3 metres above top-most tray of the stack. Water not only helps cool the used fuel, but also acts as a shield for radiation. The radiation levels estimated at water surface and at working level are less than 1 μSv/hr.

Fuel transportation is subject to highly explicit safety and security regulations, constantly updated by international and national experts. It is noted that the radioactive material transportation regulations comprise two distinct objectives: security or physical protection, consisting in the preventive losses, disappearances, thefts or misappropriation of nuclear materials; safety, which consists in controlling the irradiation, contamination and criticality hazards inherent in the transportation of radioactive materials, with a view to ensuring that man and the environment remain unaffected by the potential pollution involved. Certain principles underline the transport regulations set up by the IAEA and the universally-adopted rule is that transport safety must be based on three lines of defence, namely the concept of a package, the reliability of transport and the efficacy of specific resources to deal with an accident. Spent fuel transport is carried out in “type B” packages, designed to withstand severe accident conditions, simulated by tests, validated by approval certificates and subject to inspection.

While spent fuel is not a waste in the strict sense of the term, the fact remains that it requires cooling for five to ten years before the same can be reprocessed. The cooling time may be as long as ten years and during that period, it is a 'waste' since it can not be put to any 'immediate use'. Spent fuel poses severe risks. The most serious risk being loss of the pool water that cools and shields the highly radioactive spent fuel assemblies. Water loss could expose spent fuel leading to a catastrophic fire with consequences potentially worse than a reactor meltdown.

On average, spent fuel ponds hold five to 10 times more long-lived radioactivity than a reactor core. Particularly worrisome is the large amount of cesium 137 in fuel ponds, which contain anywhere from 20 to 50 million curies of this dangerous isotope. With a half-life of 30 years, cesium 137 gives off highly penetrating radiation and is absorbed in the food chain as if it were potassium. As much as 100 percent of a pool's cesium 137 would be released into the environment in a fire. In comparison, the 1986 Chernobyl accident released about 40 percent of the reactor core's 6 million curies of cesium 137 into the atmosphere, resulting in massive off-site radiation exposures[37]. Storing this waste in dry casks introduces separate storage, packaging and security problems. This triggers an evacuation requirement, and could render large area of land uninhabitable and cause cancer fatalities in large numbers. The use of a little imagination shows that a pool fire would be a regional and national disaster of historic proportions.

Several events could cause a loss of pool water, including leakage, evaporation, siphoning, pumping, earthquake, accidental or deliberate drop of a fuel transport cask, reactor failure, or an explosion inside or outside the pool building. Industry officials maintain that personnel would have sufficient time to provide an alternative cooling system before the spent fuel caught fire. But if the water level dropped to just a few feet above the spent fuel, the radiation doses in the pool building would be lethal.

Issues from back-end Processes

Nuclear reactors themselves have serious environmental and public health impacts. Radioactive air and water pollution is released through the routine operation of all nuclear reactors. A wide range of radioactive isotopes are released with varying radioactive and chemical propertiessome toxic, some not, some more radioactive than others, some lasting minutes, some lasting billions of years.

[37]*Bulletin of the Atomic Scientists*, 2002, http://www.thebulletin.org/issues/2002

Studies elsewhere have revealed that living near a nuclear facility increases chances of dying from breast cancer. A nationwide survey of 268 counties within 80 km miles of 51 nuclear reactors found breast cancer deaths in these "nuclear counties" to be 10 times the national rate from 1950 to 1989[38]. Furthermore, Strontium-90, a radioactive pollutant released only from nuclear reactors, ended up in milk and bones, contributing to bone cancer and leukemia. Studies of Sr-90 in baby teeth found levels 30-50% higher in teeth of children living near reactors. Background levels have risen with continued use of nuclear reactors, rising to levels comparable to when atmospheric nuclear bomb tests contaminated the nation in the 1940s and '50s[39].

Licensed to Kill[40] Impact on Marine Life

Reactors require huge amounts of cooling water, which is why they are often located near rivers, lakes or oceans. The damage to marine life caused by the nuclear power industry using the once-through cooling system, has been sparsely reported and largely overlooked. Reactors with cooling towers or ponds can use 75-80 million litres of water per day. A typical two-unit reactor using once-through cooling takes in about a square mile of water 14 feet deep each day.

The initial devastation to marine life and ecosystems stems from the powerful intake of water into the nuclear reactor. Marine life, ranging from sea turtles down to delicate fish larvae and microscopic planktonic organisms vital to the ocean ecosystem, is sucked irresistibly into the reactor cooling system. Some of these animals are killed when trapped against filters, grates, and other structures, or, in the case of air-breathing animals like turtles, seals and manatees, they drown or suffocate.

The reactors present additional hazards by expelling water warmed to a higher temperature than the water into which it flows. Recent research findings suggest that even small elevations in temperature over long periods can alter the abundance of many species of marine life. Consequently, indigenous species around discharge systems are displaced and replaced by others unnatural to that environment. Periodically, reactors are shut down, the flow of warm water stops, and the temperature of the waterway into which it flows abruptly drops. This can result in cold stunning of the species occupying the waters.

According to the Ministry of Environment and Forests (MoEF), the temperature of the discharged water should not be higher than 7°c above that of the sea. But temperature increases at India's coastal nuclear reactors exceed this norm: 7.7°c (Tarapur 1&2), 8.4°c (maps 1&2 at Kalpakkam), and 9.5°c (for Tarapur 3&4). Taking the case of Kondakulam alone, if all six 1,000 mw reactors are built, they will release over 13 times the heat discharged by the two MAPS reactors (220 mw each). Either the increase in the temperature of the water will be higher than at Kalpakkam, or the amount of seawater circulated will be minimally 13 times greater. In either case, the impact on marine life will be significantly higher. Further, Kodankulam lies at the edge of the Gulf of Mannar, one of the world's richest marine biodiversity areas with 3,600 species of flora and fauna, 377 of them endemic. Thermal discharges from the plant are liable to affect this precious biological reserve. No less important is the plant's likely impact on the region's marine fisheries. The three districts account for 70 percent of the state's fish catch and generate over Rs 2,000 crore in annual exports[41].

Health Consequences of Routine Operations in India

The only power station in India around which there has been a scientific study[42] of health consequences on the local population is the Rajasthan Atomic Power Station (RAPS) located at Rawatbhata near Kota in central India. This study carried out by Sanghamitra and Surendra Gadekar with the help of a team of doctors and local health workers, which surveyed five villages (total population: 2860) within ten kilometres of the plant and compared them with four other villages (total population: 2544) more than fifty kilometres away was done in 1991 and published in 1993.

They found "chronic (health) problems which included long-duration fevers, skin and eye problems, continual digestive tract problems, joint pains, body aches, lethargy and general debility, were two to three times higher" than was found in the control villages 50 km away. Tumours were far above the national average and deformities were recorded at 77.5 per thousand (compared to a 14-state average of 9.8 per 1000[43].) Abortions, stillbirths, one-day deaths (deaths within 24 hours of birth) and congenital abnormalities were all much higher in the villages close to the power station. The average life expectancy was 11 years lower close to the reactor[44]. It is crucial to note that there has never been a major accident at Rawatbhata. These effects were the product of routine emissions of radiochemicals into the air and water over a period of 17 years.

[38] Environmental Radiation from Nuclear Reactors and Childhood Cancer in Southeast Florida, *Radiation and Public Health Project*, 9 April 2003.
[39] Parliament of Australia. Water Requirements of Nuclear Power Stations. 4 December 2006, no. 12, 2006-07, ISSN 1449-8456.
[40] Report by Linda Gunter, Safe Energy Communication Council, www.safeenergy.org.
[41] Praful Bidwai and M.V. Ramana, 'Home, Next to N-Reactor',*Tehelka*, June 23, 2007.
[42] *Anumukti* Volume 6 ,Number 5, (April / May 1993). Also published in *International Perspectives in Public Health* (Volume 10, 1994); in People's tribunal on Chernobyl, and also in Nuclear Energy and Public Safety (1996).
[43] Manish Tiwari, 'A Deformed Existence', *Down to Earth*, 15 June, 1999.
[44]'An Overview of the Indian Nuclear Program', Report to the No Nukes Asia Forum 1997, Philippines.

Contamination at the Babha Atomic Research Centre[45]

A major radioactive leakage from ill-mantained pipelines in the vicinity of the CIRUS and Dhruva reactor complex at the Bhabha Atomic Research Centre, 15 km from the heart of Bombay, is found to have caused severe soil contamination. Evidence also points to the possibility of the leakage having taken place for a number of years, thereby causing an outflow of contamination towards the sea. The leakage was first detected by reactor workers on December 13, 1991, when a fountain of water shot out onto the lawn between the reactor and the sea. The plant management surmised that the sea-water pipeline must have burst, even though the entire area is criss-crossed with many other lines, carrying radioactive and chemical effluents. The establishment set six contract labourers on the task of digging a pit, to reach the burst pipeline, eight feet below the surface. These workers wore no protective gear or radiation monitoring badges.

The presence of radioactivity in the area may never have come to light had it not been for an alert official in the office of the Radiation Health Inspectorate at the complex, who got wind of the incident and sent for a water sample from the puddle in the excavated pit. The activity recorded in the water sample was 40 becquerel/ml. The contract labourers who had worked for almost eight hours inside the pit on December 13 and 14, 1991, were thereafter hastily pulled out, given a bath, new sets of clothing and packed off home. There is no evidence of the labourers having been subject to radiation monitoring tests.

However, the authorities sought to deduce the dosage the labourers had received. On December 19, department personnel dug a small portion from the bottom of the excavated pit. During a 12-minute period, the whole body dose recorded by the DRD (a radiation monitoring badge) ranged from 10 to 30 millirems (mR). Extrapolating on this observation, the radiation exposure of the contract labourers was held to be in the range of 300 to 1,000 mR. (A normal chest X-ray gives a dose of 70 to 150 mR. This would amount to the labourer receiving 12 X-rays during the course of work.)

Tests done in the excavated pit showed a radiation dosage ranging from 200 to 700 mR/hour, while in one specific spot, described as the "Hot Spot area below the chamber" (inspection chamber along the pipeline), it zoomed to 2,000 mR/hour. Recording of the "soil specific activity level" revealed the presence of Cs-137. In 50 percent of the samples, Cs-137 activity was 1-10 k Bq/gm and in the other 50 percent of samples, it was 10- 60 k Bq/gm. Samples of vegetation in the area also revealed contamination, and birds and insects in this area are its carriers into a wider area. 325 drums of contaminated soil were sent to the Waste Management Department. The department has said that the solid active storage would get exhausted if the entire quantity of contaminated soil is to be excavated and stopped further consignments.

According to publications authored by BARC scientists, the "acceptable limit" for Cs-137 is 0.13 Bq/ml in sea water. In the UK, the permissible limit of Cs-137 in soil is 900 Bq/kg (or 0.9 Bq/gm). Taking the average activity figures found in the CIRUS drums, around 27 k Bq/gm, shows that the activity is 30,000 times higher than permissible limits in the UK. Circumstantial evidence at CIRUS points to discharge of Cs- 137 into the Arabian Sea where, despite the impact of dilution, the chances of it being imbibed by marine life are real.

The radioactive wastes came from the Rod Cutting Building, where all uranium and plutonium fuel used in the reactor is stored for years in large pools of water to allow decay and cooling of radioactivity before further treatment. To maintain purity, the storage pool is periodically washed with acid and the effluents are dangerously radioactive. This discharge is piped to the waste treatment facility in a planned manner and should never be allowed into the sea, atmosphere or land. Yet, the pipeline carrying this deadly waste, also at other times, acted as a storm-water outlet. The system envisaged that by closing valves, the active discharge would be diverted to waste management, but in reality, for whatever reason, the untreated wastes flowed towards the sea.

The damage to the Concrete Inspection Chamber along the pipelin, where the highest activity is found as also the sea water outfall pipe (made of half-inch thick steel and lined by two-inch thick RCC) which crosses the ceramic pipe, is evidence of the slow, corrosive force at work.

Worse still, the plant management was aware of leakage occurring in this same pipe, at the same spot in 1978, but did nothing. At that time, during the construction of the Dhruva septic tank, several hundred metres away towards the sea, Cs-137 was found in the soil. The sample analysis read 20 Bq/ml. The source of leakage was traced to this same pipeline and inspection chamber. Apart from isolating the pipeline and inspection chamber for a while, no attempt was made to replace the decaying pipe-line. The report was filled and forgotten, sources allege.

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[45] Rupa Chinai, *Sunday Observer*, 6 September, 1992.

Irregularities Reported at BARC[46]

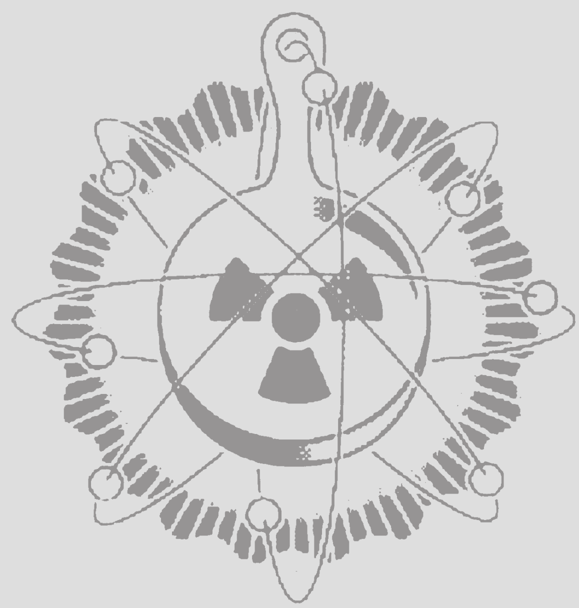
The Comptroller and Auditor General (CAG) pointed out irregularities in the procurement of components for nuclear waste management at the Bhabha Atomic Research Centre's (BARC) Tarapur plant. The CAG observed that BARC bought important components for the Tarapur plant's incinerator system for Rs 53 lakh between May 1993 and March 1999. But these components were not installed even nine years later though they relate to the vital nuclear waste management system at the plant. BARC had got the incinerator system, HEPA filters, heat exchangers, bag houses and draft cooling towers with accessories along with other supporting items. The incinerator system was required for waste management at the "Away From Reactor" (AFR) storage facility at the Tarapur plant to improve the management of low level radioactive waste and minimise the disposal cost. However, the equipment was yet to be commissioned. The delay in commissioning of the system led to disposal of radioactive waste by the existing method of being stored in trenches without reduction in volume.

BARC had contended that the technology for development of the proposed incinerator system was not readily available and, thus it took considerable time for the development of the incinerator and procurement of its components. It, however, argued that non-availability of the incinerator had not affected existing programmes. But the CAG rejected BARC'S reasoning. It said the argument was not acceptable as BARC had to dispose of the low level nuclear waste by using the existing method requiring a huge area. Thus, the objective of introducing efficient ways of low-level nuclear waste management by minimum disposal cost had not been achieved even after nine years and expenditure of Rs 53 lakh.

Under reporting of Accidents

The number of accidents in any industry is a common indicator to assess its safety. The Indian nuclear industry often boasts of a clean, accident-free track record to prove the fact that the industry is safe and well managed. Very few accidents have been reported from the industry. It is difficult to say if this is because the number of accidents has actually been few or if the industry has managed to keep itself well guarded and has carefully fed only the desirable information out to the public.

According to a study published by Tampere University of Technology in 2005, India's annual industrial fatality rate is 11.4 people per 100,000 workers and the accident rate 8,700 per 100,000 workers. Fatality rate was reported as 5.2 people for US and 3 per 100,000 for France. The figures may not seem alarming. The same report further adds that there is gross underreporting of industrial accidents. The same can apply to nuclear industry as well. Carl Thayer, South East Asia expert with the Australian Defence Force Academy has shared his concern about the developing world saying that "corrupt officials in licensing and supervisory agencies in the region can undermine the best of IAEA guidelines and oversight[47]."



[46]'Irregularities at BARC', *Times of India*, March 22, 2006.
[47]George Jahn, 'Nuke Rebirth Comes With New Worries', *Associated Press,* 12 January 2008

5

Estimating
Radioactive Waste in India

There is very little information publicly available on the exact quantum of waste generated by different steps in the fuel cycle followed in the Indian nuclear programme. An indicative figure provided by BARC[48] about the quantum of high level waste generated during the process is 1.5 m^3 of waste for every tonne of spent fuel reprocessed and after going through vitrification is 40 L. In the case of low level waste, the estimates range from 10-20 m^3 per day. Besides this, there is no official estimate on the waste that has been generated since the start of nuclear programme in the country. The only such estimate available is by M. V. Ramana et al[49] based on standard methodologies and public sources of information.

These estimates of the amount of waste produced are based on the amount of fuel irradiated by ten power reactors and the two research reactors. Recently commissioned reactors are not included. In all (i.e. till 31 December 2000), approximately 1,963 tonnes of uranium have been irradiated in the PHWRs, 397 tonnes in the BWRs and 533 tonnes in the research reactors. The spent fuel from the Tarapur BWRs has not been reprocessed. So the irradiated fuel from these two reactors would remain in the form of spent fuel and should be added to the waste inventory. All the other spent fuel is reprocessed.

Having estimated the amount of fuel irradiated, by working backwards, the amount of fuel fabricated, uranium mined and milled and the corresponding amount of waste generated has been calculated. The amount of waste generated during reprocessing has also been estimated. This takes into account that the low enriched uranium used in the Tarapur BWRs is imported. However, it is made into fuel elements within the country. Therefore, it too would contribute to the waste generated in the process of fuel fabrication, though not to the waste generated during uranium mining and milling. Indigenous fuel is used in all the other reactors.

Assuming that there is 0.5% loss in uranium during conversion and manufacture of fuel elements, the total amount f uranium required by the PHWRs increases to 1,973 tonnes, by the BWRs to 399 tonnes, and by the research reactors to 536 tonnes. The amount of waste generated during the process of fuel fabrication is approximately 0.7 m^3 of low level waste (with alpha activity) for every tonne of uranium used to manufacture fuel in case of Canadian PHWR. Hence, the total amount of low-level waste from fuel fabrication is 2,036 m^3. During milling, a 97% uranium recovery rate that is typical of uranium mills was assumed. Therefore, the total amount of uranium that must be mined to fuel the PHWRs and research reactors is 2,509 tonnes.

On an average, Indian uranium ores contain about 0.067% of U_3O_8 which has dropped to about 0.03% with continued mining. The conservative estimate has taken into account the former figure. Therefore, the total amount of uranium ore mined would be about 3.7 million tonnes. Including process reagents and refinery wastes, which contribute a little over 11% to the waste generated, the total amount of waste produced during mining and milling is 4.1 million tonnes. Using the lower figure for uranium ore grade of 0.03% would increase this estimate to 9.3 million tonnes.

The volume of low-level solid waste generated in a typical power reactor facility (with two reactors) is reported to be 200 m^3 per year; the corresponding figure for research reactors is 60 m^3 per year. This may be somewhat smaller than the actual amount. For example, in 197677, RAPS I generated approximately 120 m^3 of solid waste. In 1982-83, the two RAPS reactors together generated 260.8 m^3 of solid waste. However, the estimates have used the figure of 100 m^3 per power reactor per year.

Since there were no estimates available for intermediate-level reactor waste production in India, estimates from Canadian PHWRsof 6,871 m^3 of waste produced of which 88 m^3 was intermediate-level waste and the remaining 6,783 m^3 was low-level waste have been used. This translates to an annual low-level waste volume per unit generating capacity of 0.45 m^3/MWe, which is the same as those reported for Indian 220 MWe PHWRs. Based on available estimates, the amount of intermediate level waste produced every year by each 220 MWe PHWR, is therefore 1.3 m^3. In the case of CIRUS and Dhruva, the two research reactors, the ILW was estimated at 0.8 m^3 per year. For the Tarapur BWRs, the estimate for waste produced was 0.77 m^3/MWe of generating capacity. Therefore, the annual waste production is 125 m^3 for each of the 160 MWe Tarapur BWRs of which ILW is estimated at 1.6 m^3 per year.

The estimates on the low and intermediate-level waste generated till December 2000 by nuclear reactors is given in the Table below.

[48] Personal interview with K. Raj, Head, Waste Management Division, BARC, Trombay.
[49] M. V. Ramana, Dennis George Thomas and Susy Varughese, 'Estimating Nuclear Waste Production in India', *Current Science*, 10 December 2001, 81(11): 1458-62.

Table 5.1: Cumulative Low Level and Intermediate Level Waste Production

Name	Date of commencement	Intermediate level waste (m3)	Low level waste (m3)
RAPS 1	16 December 1973	35.1	2700
RAPS 2	1 April 1981	24.7	1900
MAPS 1	27 January 1984	20.8	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 1993	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 1960	32.0	2400
Dhruva	10 August 1985	12.0	900
Total		281.0	21650

Further, the irradiated fuel from the PHWRs is earmarked for reprocessing at the Power Reactor Fuel Reprocessing (PREFRE) Facility in Tarapur with the reprocessing capacity of 100 MT/year and at Kalpakkam Reprocessing Plant (KARP) with capacity of 125 MT/year. The estimate of the amount of waste generated assumes that all the spent fuel generated in PHWRs has been (or will be) reprocessed. Similarly, it is assumed that the 50 MT/year Trombay reprocessing facility has reprocessed all the spent fuel from the CIRUS and Dhruva reactors.

The researchers feel that the assumptions have been conservative and may underestimate waste generation. Also, it does not take into account the waste generated during decommissioning of nuclear facilities or during maintenance operations like coolant channel replacement. This could be significant: coolant channel replacement in the RAPS-II reactor, for example, produced '200 tonnes of radioactive waste comprising 306 coolant tubes, 612 end-fittings, 612 garter springs, 612 shield plugs, etc. Waste generation from the FBTR and smaller research reactors and associated fuel cycle facilities and operations has also been kept out.

Table 5.2: Total Nuclear Waste Generation in India

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

Reprocessing spent fuel produces waste comprising 84% of low-level waste; 14% of Intermediate-level waste; and 2% of High-level waste. Modern reprocessing plants generate about 0.4 to 1 m^3 of HLW per tonne of spent fuel reprocessed. But older plants generate more. In India, the Department of Atomic Energy reported that till 1985, 440 m^3 of HLW had been produced. This figure has been used to estimate the amount of HLW generated per tonne of spent fuel reprocessed as 2 m^3. Therefore, the HLW inventory resulting from reprocessing all the fuel irradiated till 31 December 2000 is 4,992 m^3. The corresponding cumulative production of ILW and LLW is 34,944 and 2, 09,664 m^3 respectively.

An issue closely linked to quantum of waste is the total cost for managing and disposing it. The costs for waste management are integrated into the total cost of electricity. It represents 3% of the total cost of nuclear power. In absolute terms, it costs Rs 5 crore/ MWe in case of new plants. BARC holds that the cost is directly proportional to the quantum of waste generated. As a policy, the agency therefore strives to achieve volume reduction in case of the waste. The estimated cost of final disposal is not known.

6

Legislative and Regulatory Framework

The following legislative framework is available in the country which deals with the issue of radioactive waste, either directly or indirectly.

National Legislation

The **Atomic Energy Act 1962** and rules framed there under provide the main legislative and regulatory framework pertaining to atomic energy in the country. It was enacted to provide for the development, control and use of atomic energy for the welfare of the people of India and for other peaceful purposes and for matters connected therewith. The Act also provides the Central Government with the powers to frame rules or issue notifications to implement the provisions of the Act. The rules framed under the Act are laid on the floor of both the houses of the Parliament. However, for locating and operating Nuclear Power Plants (NPPs), in addition to the provisions of the Atomic Energy Act, the provisions of several other legislations related environment, land use, etc have also to be met. The provisions of these acts are enforced either by Central or State (Provincial) Government, as the case may be. Some of these important legislations that have a bearing on the establishment of NPPs are summarised below.

Atomic Energy Act 1962

The legislative and regulatory framework for the atomic energy in the country was first formulated by the constituent assembly in 1948 and was called as Atomic Energy Act 1948. In the same year, the Government of India constituted a high powered Atomic Energy Commission to implement the Government policy to harness the benefits of atomic energy. In 1954, Government of India created the Department of Atomic Energy (DAE) for implementing government policies pertaining to atomic energy. With the creation of DAE, AEC was reconstituted in accordance with the Government resolution dated March 1, 1958, to frame policies and advise the Central Government on matters pertaining to Atomic Energy.

The Atomic Energy Act of 1948 was repealed by the Parliament in the thirteenth year of the republic and the Atomic Energy Act 1962 was enacted. The Atomic Energy Act 1962 was amended in 1986 by Parliament through the Atomic Energy (amendment) Act, 1986 (No. 59 of 1986). This amendment primarily addressed section 6 of the Act, which deals with the disposal of uranium in minerals, concentrates and other materials containing uranium in its natural state. The amendment was brought in to enhance the exercise of monitoring and control of the nuclear material. In 1987, the Act was further amended (No. 29 of 1987) to give impetus to the activities related to design, construction and operation of NPP. The following paragraphs briefly describe the salient provisions of this act.

A. *Powers of the Central Government in the Domain of Atomic Energy:*

Section 3 of the Act describes the powers of Central Government in the domain of atomic energy including the powers:

i) to produce, develop, use and dispose of atomic energy;

ii) to provide for the production and supply of electricity from atomic energy and for taking measures conducive to such production and supply and for all matters incidental thereto;

iii) to provide for control over radioactive substances or radiation generating plant in order to
- prevent radiation hazards;
- secure public safety and safety of persons handling radioactive substances or radiation generating plant; and
- ensure safe disposal of radioactive wastes,etc. The Central Government is also empowered to fulfil the responsibilities assigned by the Act either by itself or through any authority or Corporation established by it or a Government company.

B. *Control over Mining or Concentration of Prescribed Substances:*

Section 4 to section 13 of the Act give wide-ranging authority to the Central Government for harnessing and securing the prescribed substances useful for atomic energy. The Act is comprehensive about the discovery of uranium or thorium (section 4), control over mining or concentration of substances containing uranium (section 5), disposal of uranium (section 6), power to obtain information regarding materials, plant or processes (section 7), power of entry and inspection (section 8), power to do work for discovering minerals (section 9), compulsory acquisition of rights to work minerals (section 10), compulsory acquisition of prescribed substances, minerals and plants (section 11), compulsory acquisition not sale (section 11-A), compensation in case of compulsory acquisition of a mine (section 12), and novation (contract law or business law) of certain contracts (section 13).

C Control over Production and Use of Atomic Energy:

Section 14 of the Act gives the Central Government control over production and use of atomic energy and prohibits these activities except under a license granted by it. This includes control for the acquisition, production, possession, use, disposal, export or import of any of the prescribed substances; or of any minerals or other substances specified in the rules; or of any plant designed or adopted or manufactured for the production, development and use of atomic energy or for research into matters connected therewith; or of any prescribed equipment. Subsection 2 of this section gives the Central Government powers to refuse license or put conditions as it deems fit or revoke the license. Sub section 3 of this section of the Act also gives the Central Government powers to frame rules to specify the licensees, the provisions in the areas of control on information, access, measures necessary for protection against radiation and safe disposal of harmful by-products or wastes, the extent of the licensee's liability and the provisions by licensee to meet obligations of the liability either by insurance or by such other means as the Central Government may approve of.

D. Control over Radioactive Substances:

Section 16 of the Act gives the Central Government power to prohibit the manufacture, possession, use, transfer by sale or otherwise, export and import and in an emergency, transport and disposal of any radioactive substances without its written consent.

E. Special Provisions as to Safety:

Section 17 of the Act empowers the Central Government to frame rules to be followed in places or premises in which radioactive substances are manufactured, produced, mined, treated, stored or used or any radiation generating plant, equipment or appliance is used. This section gives the Central Government authority to make rules to prevent injury being caused to the health of the persons engaged or other persons, caused by the transport of radioactive or prescribed substances and to impose requirements, prohibitions and restrictions on employers, employee and other persons. It also gives the Central Government authority to inspect any premises, or any vehicle, vessel or aircraft and take enforcement action for any contravention of the rules made under this section.

F. Special Provisions as to Electricity:

Section 22 of the Act gives the Central Government the authority to develop national policy for atomic power and coordinate with national and state authorities concerned with control and utilisation of other power resources for electricity generation to implement the policy. It authorises the Central Government to fulfil the mandate either by itself or through any authority or corporation established by it or a Government Company.

G. Administering Factories Act, 1948:

Section 23 gives the Central Government authority to administer the Factories Act, 1948 to enforce its provisions including the appointment of inspection staff in relation to any factory owned by the Central Government or any Government Company engaged in carrying out the purposes of the Act.

H. Offences and Penalties:

Section 24 of the Act gives provision for imposing penalties. Whoever contravenes any order or any provision of the Act shall be punishable prosecution with imprisonment, or with fine, or both.

I. Delegation of Powers:

Section 27 of the Act gives the provision for the Central Government to delegate any power conferred or any duty imposed on it by this Act to any officer or authority subordinate to the Central Government, or state government, as specified in the direction.

J. Power to Make Rules:

Section 30 of the Act gives the provisions for the Central Government to frame rules for carrying out the purposes of the Act. Exercising these powers, the Central Government has framed the following rules to implement the following provisions of the Act:

i) Atomic Energy (Radiation Protection) Rules 2004: The Atomic Energy (Radiation Protection) Rules, 1971 was framed to establish the requirement of consent for carrying out any activities for nuclear fuel cycle facilities and use of radiations for the purpose of industry, research, medicine, etc. This rule was revised in the year 2004 with Atomic Energy (Radiation Protection) Rules 2004.

ii) Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987: The Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987 establishes the requirements for the disposal of radioactive waste in the country.

Iii) Atomic Energy (Control of Irradiation of Food) Rules, 1996: The Atomic Energy (Control of irradiation of Food) Rules, 1990 were framed to regulate the irradiation of foods in the country. These rules were revised as Atomic Energy (Control of Irradiation of Food) Rules, 1996.

ii) Atomic Energy (Working of the Mines, Minerals and Handling of Prescribed Substances) Rules, 1984: These rules regulate the activities pertaining to mining, milling, processing and/or handling of prescribed substance.

iii) Atomic Energy (Factories) Rules, 1996: The Central Government exercising the powers conferred by sections 41, 49, 50, 76, 83, 112 and all other enabling sections of the Factories Act, 1948, (63 of 1948), read with sections 23 and 30 of the Atomic Energy Act, 1962, (33 of 1962) had framed the Atomic Energy (Factories) Rules, 1984 to administer the requirement of Factories Act in the nuclear establishment of the country to ensure industrial safety. These rules were revised by Atomic Energy (Factories) Rules, 1996.

iv) Atomic Energy (Arbitration Procedure) Rules, 1983: In exercise of the powers conferred by Section 21 of the Atomic Energy Act, 1962, Central Government framed the Atomic energy (Arbitration Procedure) Rules, 1983 to regulate arbitration procedure for determining compensation.

Environment (Protection) Act 1986

The Environment Protection Act, 1986 and Environment (Protection) Rules, 1986 provide for the protection and improvement of environment and matter connected therewith. The Act empowers the Central Government to take all such measures it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environmental pollution.

All projects or activities, including expansion and modernisation of existing projects or activities require prior environmental clearance from the Central Government in the Ministry of Environment and Forests (MoEF) on the recommendations of an Expert Appraisal Committee (EAC).

Other Applicable Legislation

There are some other applicable legislation whose provisions have to be met for locating and operating NPPs in the country. These legislations include:

- The Water (Prevention & Control of Pollution) Act, 1974
- The Air (Prevention & Control of Pollution) Act, 1981
- The Water (Prevention & Control of Pollution) Cess Act, 1977
- The Hazardous Waste (Management & Handling), Rules 1989
- Indian Explosive Act 1884 and Indian Explosive Rule 1983
- Disaster Management Act 2005

Like in several other areas, it is felt that while the available regulatory framework is quite comprehensive, the implementation is lax. This can be said with certainty in the case of mining and milling operations.

7

Concepts of Final Disposal Worldwide

The long timescales over which some of the waste remains radioactive led to the idea of deep geological disposal in underground repositories in stable geological formations. Isolation is provided by a combination of engineered and natural barriers (rock, salt, clay) and no obligation to actively maintain the facility is passed on to future generations. This is often termed a multi-barrier concept, with the waste packaging, the engineered repository and the geology all providing barriers to prevent the radionuclides from reaching humans and the environment.

A repository is comprised of mined tunnels or caverns into which packaged waste would be placed. In some cases, (e.g. wet rock) the waste containers are then surrounded by a material such as cement or clay (usually bentonite) to provide another barrier (called buffer and/or backfill). The choice of waste container materials and design and buffer/backfill material varies depending on the type of waste to be contained and the nature of the host rock-type available. Excavation of a deep underground repository using standard mining or civil engineering technology is limited to accessible locations (for example, under land or near shore), to rock units that are reasonably stable and without major groundwater flow, and to depths of between 250m and 1000m. At a depth greater than 1000m, excavations become increasingly technically difficult and correspondingly expensive.

Deep geological disposal remains the preferred option for waste management of long-lived radioactive waste in several countries, including Argentina, Australia, Belgium, Czech Republic, Finland, India, Japan, Netherlands, Republic of Korea, Russia, Spain, Sweden, Switzerland and USA. Hence, there is much information available on different disposal concepts; a few examples are given here. The only purpose-built deep geological repository for long-lived ILW that is currently licensed for disposal operations is in the USA. Plans for disposal of spent fuel are well advanced in Finland, Sweden and the USA, with the first facility scheduled for operation by 2010. In Canada and the UK, the policy of deep disposal is currently undergoing review.

Sweden: The Disposal Concept for Spent fuel and other long-lived Radioactive Waste in Strong Fractured Rocks

The Swedish proposed disposal concept uses a copper container with a steel insert to contain the spent fuel. After placement in the repository, the container would be surrounded by a bentonite clay buffer to provide a very high level of containment of the radioactivity in the wastes over a very long time period. Similar concepts have been developed in other countries such as Finland for use with spent fuel.

The deposits of pure copper in the world have proven that the copper used in the final disposal container can remain unchanged inside the bedrock for extremely long periods of time if the geochemical conditions are appropriate (reducing groundwater). The discovery of ancient copper tools, many thousands of years old, also demonstrate the long-term corrosion resistance of copper, making it a credible container material for long-term radioactive waste storage.

Belgium, France, Netherlands and Switzerland: Disposal of Spent Fuel and Vitrified HLW in Clay

The Belgian disposal concept proposes that spent fuel and HLW is placed in high integrity steel containers and then emplaced in excavated tunnels within ductile (self-sealing) clay. The very low permeability of the clay leads to virtually no groundwater flow over long time periods. Waste would be backfilled with excavated clay or, alternatively, could be emplaced into unlined secondary tunnels where the clay would be allowed to creep into contact with the waste containers. Similar systems have been proposed in the Netherlands and, using less plastic clays, in France and Switzerland.

United States: Disposal of Defence Derived Transuranic Waste (Similar to long-lived ILW) in Layered Salt Strata

The Waste Isolation Pilot Plant (WIPP) for defence wastes has been operational since 1999. For this repository, natural rock salt is excavated from a several metres-thick layer sandwiched between other types of rock 650 metres below ground level. The wastes placed in these excavations contain large volumes of long-lived ILW, usually in steel containers. The steel containers are then placed in concrete overpacks. A backfill material is then used to surround the overpacks. The primary purpose of the backfill is to provide control of the chemical environment. Containment of the radionuclides in the waste form mostly relies on the almost complete absence of water flow in the salt.

United States: Disposal of Spent fuel and High Level Waste at Yucca Mountain
Yucca Mountain, located in the remote Nevada desert, is the proposed site for the construction of a US national repository to store spent fuel and high level waste from nuclear power and military defence programmes. The repository will exist 300 metres underground in an unsaturated layer of volcanic tuff rock.

Waste will be stored in highly corrosion-resistant double-shelled metal containers, with the outer layer made of a highly corrosion-resistant metal alloy and a structurally strong inner layer of stainless steel. Drip shields made of corrosion-resistant titanium will cover the waste containers to divert moisture and provide protection from possible falling rocks or debris. Containment relies on the extremely low waste table which lies approximately 300 metres below the repository and the long-term durability of the engineered barriers.

The site is currently preparing a license application to proceed with construction of the repository. The repository is scheduled for operation in 2010.

Germany and the Netherlands: Salt Domes
Salt environments are also available in northern Germany and the Netherlands although these are salt domes rather than bedded formations. In Germany, the former salt mines at ASSE and Morsleben have been used for LLW and ILW disposal though this has now been suspended. The decommissioning process is now being investigated to determine the method for backfilling and sealing the repository. It has been proposed that salt domes could be used for the disposal of heat-generating HLW and spent fuel. The site at Gorleben was selected in the 1970's for this purpose, but there is currently a moratorium on further exploratory work there. A feature of salt environments is the very low rate of (perhaps even absence of) groundwater flow and the gradual self-sealing of the excavations due to creep of the salt.

United Kingdom: Nirex Phased Disposal Concept
The Nirex Phased Disposal Concept has been developed for relatively large volumes of ILW and LLW, usually cemented into stainless steel containers. These containers would be emplaced into a repository in a host rock environment below the water table. The waste would be monitored and remain retrievable and the groundwater managed to prevent contact with the wastes, until such a time that the repository is sealed. When this happens, the waste will be surrounded (backfilled) by specially formulated cement and the repository allowed to resaturate. The cement would provide a long lasting alkaline environment that contributes to containment of the waste by preventing many radionuclides from dissolving in the groundwater. Similar cement-based schemes for ILW disposal have been proposed in France, Japan, Sweden and Switzerland.

Multinational Repositories
Not all countries are adequately equipped to store or dispose of their own radioactive waste. Some countries are limited in area, or have unfavourable geology and therefore siting a repository and demonstrating its safety could be challenging. Some smaller countries may not have the resources to take the proper measures on their own to assure adequate safety and security, or they may not have enough radioactive waste to make construction and operation of their own repositories economically feasible. It has been suggested that there could be multinational repositories located in a willing host country that would accept waste from several countries. Other terms for such shared repositories include "international" and "regional". They could include, for example, use by others of a national repository operating within a host country, or a fully international facility owned by a private company operated by a consortium of nations or even an international organisation. However, for the time being, many countries would not accept under their national law nuclear waste from other countries.

Other Ideas for Disposal

Numerous options for long-term nuclear waste management have been considered in the past. The table below highlights a number of these.

Ideas	Examples
Long-term above ground storage	• investigated in France, Netherlands, Switzerland, UK and USA • not currently planned to be implemented anywhere
Disposal in outer space (proposed for wastes that are highly concentrated	• investigated by USA • investigations now abandoned due to cost and potential risks of launch failure
Deep boreholes (at depths of a few km's)	• investigated by Australia, Denmark, Italy, Russia, Sweden, Switzerland, UK and USA • not implemented anywhere
Rock-melting (proposed for wastes that are heat-generating)	• investigated by Russia, UK and USA • not implemented anywhere • laboratory studies performed in the UK
Disposal at subduction zones	• investigated by USA • not implemented anywhere • **not permitted by International agreements**
Sea disposal	• implemented by Belgium, France, Federal Republic of Germany, Italy, Japan, Netherlands, Russia, South Korea, Switzerland, UK and USA • **not permitted by International agreement**
Sub seabed disposal	• investigated by Sweden and UK (and organisations such as NEA/OECD) • not implemented anywhere • **not permitted by International agreement**
Disposal in ice sheets (proposed for wastes that are heat-generating)	• investigated by USA • rejected by countries that have signed the Antarctic Treaty or committed to providing solutions within national boundaries
Direct injection (only suitable for liquid wastes)	• investigated by Russia and USA • implemented in Russia for 40 years and in USA (grouts) • investigations abandoned in USA in favour of deep geological disposal of solid wastes

Some of these options are described here:

Above Ground Storage

Above ground storage is normally considered an interim measure for the management of radioactive waste. France investigated it within the framework of the 1991 law on waste for HLW, but not as a means of final disposal. ZWILAG in Switzerland and Ahaus and Gorleben in Germany are examples of operating interim long-term above ground storage for HLW. However, controlled surface storage over longer time periods (greater than a couple of hundred of years) has also been suggested as a long-term waste management option.

Long-term above ground storage involves specially constructed facilities at the earth's surface that would be neither backfilled nor permanently sealed. Hence, this option would allow monitoring and retrieval at any time without excessive expenditure.

Suggestions for long-term above ground storage broadly fall into two categories:

- Conventional stores of the type currently used for interim storage, which would require replacement and repackaging of waste every two hundred years or so;
- Permanent stores that would be expected to remain intact for tens of thousands of years. These structures are often referred to as 'Monolith' stores or 'Mausoleums'.

The latter category of store is derived from the principle of "guardianship", where future generations continue to monitor and supervise the waste. Both suggestions would require information to be passed on to future generations, leading to the question of whether the stability of future societies could be ensured to the extent necessary to continue the required monitoring and supervision.

No country is currently planning to implement long-term (i.e. greater than a few hundred years) above ground storage. However, France is investigating long term interim storage, but not necessarily above ground. Long-term above ground storage has been considered as part of the range of management concepts in Switzerland by EKRA (Expert Group on Disposal Concepts for Radioactive Waste). The expert group (EKRA) observed that it was unclear what additional steps would be necessary to show how the long-term above ground storage concept could be brought to the state of development, which is comparable with that of geological disposal and they recommended geological disposal as the preferred option.

Space Disposal

Disposing of used fuel by sending it into space has been considered and advocated in the past. Of all disposal methods, it has the greatest potential to isolate the wastes permanently from the biosphere. Although it is technically possible, its costs would be very high. Studies have indicated that the number of flights required to transport high volume of radwaste would be impractical; space disposal could be feasible only for very small volume of reprocessed high-level wastes. The risk of catastrophic accidents is estimated to be about one per cent per flight, and thus that the radiological risk of disposal in space is higher than for geological disposal.

Ice Sheet Disposal

Disposal of spent nuclear fuel in ice sheets has also been suggested in the past and at first sight appears to be feasible. However, it has not been extensively researched. The idea has the advantage of placing the waste in a slowly changing environment devoid of living organisms. Canadian glaciers are too small for this method. So ice sheets in Greenland or the Antarctic would have to be employed. Correspondingly, the wastes would have to be transported over great distances. Moreover, treaty obligations preclude disposal in the Antarctic.

Seabed Disposal

Proposals for seabed disposal range from placing spent fuel on or beneath deep oceanic plains, far from continental margins, to placing it in zones of subsidence along continental margins such as the Pacific coast. The former proposal was studied over 10 years and partially demonstrated by an international seabed working group. Many scientists consider it to be the best disposal option. It is potentially safe, except for transportation accidents where containers could not be recovered. Preliminary estimates suggest that its costs could compare favourably with those of other disposal methods. Sites away from the continental margins have the advantages of being located in geologically stable areas, as well as being well removed from areas of human habitation or intrusion and areas of important biological and mineral resources. Obligations under the London Dumping Convention (1972) prohibit seabed disposal. So, such approaches would require re-negotiated international acceptance and an international regulatory framework.

Partitioning and Transmutation

Partitioning and transmutation is the name given to a waste treatment process in which certain long-lived radionuclides are partitioned (separated) from high level waste and transmuted by irradiation in a nuclear reactor or in an accelerator. This, in theory, converts the longer lived radionuclides into shorter lived ones, or ones that are stable.

Partitioning and transmutation consists of:

- Partitioning: selected radionuclides are separated by a chemical process, from the high level waste. The actinides (other than uranium and plutonium) are the only species usually considered for separation, hence the acronym "PTA".

- Fabrication of the separated radionuclides to convert the long-lived radionuclides into isotopes with short half-lives or ones that are stable.

The perceived benefits of PTA are that the process reduces the long-term radio toxicity of radwaste; makes the task of final disposal simpler by reducing the number, size and costs of repositories; increases the total energy production from the fuel cycle; and makes final disposal more acceptable to the public.

Partition and transmutation has been the subject of extensive international studies, principally by the European Commission, OECD/NEA and the IAEA. The overall conclusion is that PTA is an expensive option, involving huge investment in research and facilities. The benefits in terms of reduction in radiological risk and increased energy production were determined to be small. The PTA concept was therefore unattractive on cost-benefit and radiological grounds.

Substantial R&D programmes on PTA are however being pursued in several countries. Progress has been made in the development of PTA processes, but there are several unresolved difficulties and further development is required before any could be implemented. Actinides could be transmuted in fast reactors. But the transmutation of the key long-lived fission products is a difficult problem.

Transmutation in accelerators is being looked at in several countries. The circumstances in those countries which reprocess their waste are such that PTA would make a very limited impact on radioactive waste management, as PTA has no realistic potential to contribute positively to the management of ILW, nor indeed LLW, including PCM wastes, at the present time.

Table 7.1: Waste Management for Used Fuel from Nuclear Power Reactors

Country	Policy	Facilities and progress towards final repositories
Belgium	Reprocessing	• Central waste storage at Dessel • Underground laboratory established 1984 at Mol • Construction of repository to begin about 2035
Canada	Direct Disposal	• Nuclear Waste Management Organisation set up in 2002 • Deep geological repository confirmed as policy, retrievable • Repository site search from 2009, planned for use 2025
China	Reprocessing	• Central used fuel storage in Lan Zhou • Repository site selection completed by 2020 • Underground research laboratory from 2020, disposal from 2050
Finland	Direct Disposal	• Programme start in 1983, two used fuel storages in operation • Posiva Oy set up 1995 to implement deep geological disposal • Repository under construction near Olkiluoto, open in 2020
France	Reprocessing	• Underground rock laboratories in clay and granite • Parliamentary confirmation in 2006 of deep geological disposal • Bure is likely repository site to be licensed 2015, operating 2025
Germany	Reprocessing but moving to direct disposal	• Repository planning started 1973 • Used fuel storage at Ahaus and Gorleben salt dome • Geological repository may be operational at Gorleben after 2025
India	Reprocessing	• Research on deep geological disposal for HLW
Japan	Reprocessing	• High-level waste storage facility at Rokkasho since 1995 • High-level waste storage approved for Mutsu from 2010 • NUMO set up 2000, site selection for deep geological repository Under way to 2025, operation from 2035

Russia	Reprocessing	• Sites for final repository under investigation on Kola peninsula • Various storage facilities in operation
South Korea	Direct Disposal	• Waste programme confirmed 1998 • Central interim storage planned from 2016
Spain	Direct Disposal	• ENRESA established in 1984, its plan accepted in 1999 • Central interim storage probably at Trillo from 2010 • Research on deep geological disposal, decision after 20101
Sweden	Direct Disposal	• Central used fuel storage facility CLAB in operation since 1985 • Underground research laboratory at Aspo for HLW repository • Site selection for repository in two volunteered locations
Switzerland	Reprocessing	• Central interim storage for HLW at Zwilag since 2001 • Central low & ILW storages operating since 1993 • Underground research laboratory for high-level waste repository, with deep repository to be finished by 2020
United Kingdom	Reprocessing	• Low-level waste repository in operation since 1959 • HLW from reprocessing is vitrified and stored at Sellafield • Repository location to be on basis of community agreement New NDA subsidiary to progress geological disposal
USA	Direct Disposal, but reconsidering	• DoE responsible for used fuel from 1998, $28 billion waste fund • Considerable research on repository at Yucca Mountain, Nevada • 2002 decision that geological repository be at Yucca Mountain

8

International Experiences: Lessons for India

Achievements and Obstacles in the Search for a Solution to Nuclear Waste Disposal

The issue of the disposal of nuclear waste is an international phenomenon and a common challenge for all countries using nuclear power and thus who are consequently struggling to find a solution to the problem of nuclear waste. The problem has a clear political aspect in that it is essentially interlinked with discussions over the use of nuclear power, and it has even been identified as having the ability to become the 'Achilles Heel' of the nuclear power industry as the seeming inability to successfully address this issue constantly undermines public confidence in the use of nuclear power. Furthermore, such matters are loaded with ethical issues such as those concerned with the taking of responsibility for outcomes connected to the use of nuclear energy and the 'opportunity costs' of nuclear energy use. Furthermore, such issues go to the ethical concerns of inter-generational justice (i.e., the present generation enjoys the benefits of energy produced by use of nuclear power and thus has the responsibility of solving the problem of what to do with its waste by-product. At the same time, voices are often heard to the effect that it is important to give scope to the ability of future generations to solve such issues in the way they consider most suitable).

The technicalities surrounding safety and the risks involved in disposal raise the sensitivity of the issue as a whole. It is however argued that technical solutions have now been found as regards disposal of nuclear waste. As yet however, public support and public 'acceptance' of such findings are more difficult to achieve. Nuclear power itself seems to generate more fear about democracy versus state control over people and the environment than other environmental issues. The siting of nuclear power plants has been accomplished with only symbolic input from the public. While procedures for siting nuclear power plants seem unclear to many observers and critics, radwaste repository siting procedures are even more ambiguous.

A modern society demands both formal and informal ways of involving the general public in complicated decision- making processes. The decision on waste management policy and the siting of waste management facilities is thus no exception. The combined effects of the negative image of nuclear waste (related to nuclear weapons and antinuclear energy campaigns, the perceived secrecy of the handling of all matters connected to nuclear waste, and general levels of secrecy in the nuclear energy sector throughout the 1980s), reflect the reality of long-time perspectives and technically complicated issues, and call for transparency and openness in order to receive the public support necessary to implement a waste disposal scheme and to alleviate the negative perceptions often held by the general public in connection with nuclear waste.

The decision making for a repository is a long and difficult process which raises a lot of debate and concern among the general public. Among the possible reasons for this is simply the intrinsic and intangible hazard associated with anything nuclear, the obvious connection to nuclear weapons and the elongated time frames within which such processes are carried out. A further reason for negative public reaction regarding nuclear waste disposal is the perceived secrecy of the nuclear industry and the historic legacy of non-communication. This raises the issues of democratic legitimacy in the nuclear waste discussion.

The entrenched fear and mistrust of the nuclear technology, 'the dread factor', is identified in the experience of the Canadian Environmental Assessment Panel as an important element in decision-making processes concerning nuclear matters as it will affect public confidence in the results from such processes. The project will have effects over a long time, which is a cause for uncertainty, both technical as well as societal (changes in attitude and perception that may change over time). The long time frame of the project also gives rise to ethical considerations as the decision will have a significant effect on future generations.

Studies show that there was declining support towards nuclear waste from the end of the 1970's to the beginning of the 1980's so that in almost every opinion poll in Western Europe ,the majority of citizens were against the siting of nuclear waste facilities. The reasons for the declining local acceptance of nuclear facilities is considered to be closely linked to the nuclear accidents in Three Mile Island and in Chernobyl and the public's perceptions or risks attuned to radioactive waste. The negative reactions of local residents towards the possible siting of a nuclear waste facility are classified under the NIMBY (not-in-my-backyard) phenomenon that is familiar to every country which has nuclear power plants.

The change in attitude has been particularly dramatic in the proposed host communities as the examples of unsuccessful siting proposals in the 1980's demonstrate. Studies carried out in Finland and the USA illustrate the potential for opposition to nuclear waste facilities where the majority of citizens said no to nuclear waste.

The results from those communities in Washington and Nevada that were located close to the siting place were however quite supportive of the plan. Such communities have been termed 'nuclear oases,' where the industry has provided the basic livelihood for the residents for decades and therefore attitudes there are different form those in other places. These examples identify the need to contextualise the residents' concern by embedding their attitudes in those historical and geographical circumstances from which they have arisen. Although it is emphasised that communities have different ways of defining risks, different ways of giving priority to risks and different ways of dealing with risky activity, it is to some extent a collectively shared risk perception. It is also important to recognise however that local concerns are also linked to wider national and international structures.

Overview of National Development

The prospects for the future use of nuclear energy differ in different parts of the world.

In **Western Europe,** the peak has been reached and almost no new nuclear reactors have been put into operation during the last decade with emphasis turning to ways of carry through a nuclear phase-out (SKB, 2000). Examples of this can be seen in Sweden and in Germany, where the government and four nuclear energy companies have reached agreement that the reactors shall gradually be phased out.

In the former **Eastern bloc** countries, the improvement of safety has been emphasised, both with regard to the nuclear installations themselves and to the disposal of nuclear waste. However, financial constrains make this work difficult whilst reactors are being closed down due to insufficient safety levels. Moreover, some new construction is taking place in Russia, the Ukraine and the Czech Republic.

The situation in **North America** is similar to that of Western Europe. The number of reactors in the USA has remained stable during the last few years and Canada is in the middle of closing down eight of its twenty-two reactors.

As to **South America**, in Mexico, Argentina and Brazil, there are no extensive plans for construction of new nuclear energy plants although a new reactor came on-line in Brazil in the autumn 2000. **Asia** is the only region in the world where the use of nuclear energy is on the increase. This can be linked to rapid economic development and population increase. Most reactors are being built in China, with additional high peaks of activity in South Korea, Japan and India, all of whom have plans for new construction.

Legislation in the OECD countries establishes the set of overall principles to be applied in the disposal of radioactive wastes. Such legislative guidelines have been designed within the framework of advice from the IAEA and, in Europe, the European Commission. The legislation also determines the organisation responsible for developing and operating disposal facilities and those responsible for regulating the operation and safety of such facilities. The level of requirement regarding implementation of the processes and relationship to other planning processes however differs across national legislative systems.

The methods that have been selected for managing and disposing of spent nuclear fuel and nuclear waste also vary to some degree across different countries.

Finland

The Nuclear Energy Act and its accompanying Decree provide a distinct framework for the implementation and research of waste management in Finland. According to the legislation, the producers of nuclear waste are responsible for all measures needed for disposing of the waste in a safe manner and for the costs involved. The nuclear energy operators have established a common company, Posiva that is responsible for both the siting and operation of geological disposal.

On the basis of the Nuclear Energy Act, the Council of State regulates the use of nuclear energy in Finland, the Ministry for Trade and Industry (KTM) grants the required license and the Finnish Centre for Radiation and Nuclear Safety (STUK), supervises the safety of the use of nuclear energy. For the construction of a final disposal facility, a decision in principle (DiP) is needed from the Council of State. In its decision, the Government shall consider whether the construction project is in line with the overall interest of society. In particular, the Government shall pay attention to the need for such a facility, to the suitability of the proposed site and to the environmental impacts from the proposed practice. The decision needs to be ratified by Parliament before it is enforced. Apart from the decision in principle, separate construction and operating permits are needed for the encapsulation plants and for the final disposal repository at a later stage. Prior to obtaining a decision in principle, an agreement is needed from STUK on the final disposal system and an approval from the municipality in which the facility is to be constructed.

The supervising state authorities, the Ministry of Trade and Industry and the Finnish Centre for Radiation and Nuclear Safety (STUK), have financed an independent, publicly administered research programme (JYT) on nuclear waste management. Three programmes were carried out.

The first set of programmes were designed to provide the authorities with information and research results relevant to ensuring the safety of nuclear waste management, though the third programme emphasised not only technical planning and safety requirements, but also independent evaluations of the societal, socio-psychological and communicational aspects of final disposal.

The siting process was started at the beginning of the 1980's when an extensive survey was carried out on bedrock conditions resulting in a large number of prospective areas for repository being identified. By 1987, field research had been started at five sites and detailed investigation was underway by 1993 in four areas: Romuvaara in Kuhmo, Kiveety in Äänekoski, Olkiluoto in Eurajoki. Hästholmen in Loviisa entered the process at a later stage. An EIA process was carried out in all the four candidate municipalities and the EIA programme was completed in 1998. The EIA report was submitted to the Ministry of Trade and Industry in May 1999.

Recent Developments:
In May 1999, a contract was established between Posiva and Eurajoki municipality regarding the construction of a repository in connection with the nuclear factory in Olikiluoto, on the proviso that the government and the local authority both gave permission. Subsequently, in May 1999, Posiva filed an application for a policy decision (Decision in Principle, DiP) on the final disposal facility for spent fuel for the Olkiluoto site in the municipality of Eurajoki. STUK issued a favorable statement on the application on 11 January 2000, where it stated that all the necessary safety criteria were met. The municipal council of Eurajoki took a decision supporting the selection of Olkuluoto as a repository site on 24 January 2000. The votes in the municipal council were 20 in favour and 7 against. Thus, Eurajoki is the very first municipality in the world to approve of the final disposal of high-level nuclear waste within it own boundaries. On 21 December 2000, the Council of State made the Decision in Principle (DiP) and on 18 May, the Finnish Parliament ratified the Decision in Principle on the final disposal facility for spent nuclear fuel in Olkiluoto, Eurajoki. The construction of the final disposal facility is scheduled to begin after 2010, with the facility becoming operational in 2020.

The Application of EIA to the Process:
Posiva's EIA for the final disposal of nuclear waste covers the four candidate municipalities where the possibilities of final disposal of spent fuel were being investigated. The implementation of the EIA stands out as something "beyond the norm" and has indeed been dubbed "the EIA of the century" in Finland. The plan was lodged within the EIA process for almost three years. In accordance with the Espoo Convention, the EIA report was also submitted for review by neighbouring countries, Estonia, Russia and Sweden.

Great Britain
In Great Britain, discussion is mainly centred on the development of methods and the selection of sites for disposal of low and intermediate level waste. The active search for a deep disposal site and for a repository for high-level radioactive waste should however be put on hold for a period of fifty years whilst the waste itself will be kept in intermediate storage at the power plants and at Sellafield.

The Secretary of State at the Department of the Environment and the Secretaries of State for Scotland and Wales are responsible for the development of policy questions that concern the management of nuclear waste. The government also has an advisory committee, the Radioactive Waste Management Advisory Committee (RWMAC) at its disposal that was established in 1978 to offer independent advice to Ministers on radioactive waste management issues.

The NII (Nuclear Installation Inspectorate), the Environmental Agency and the SEPA (Scottish Environment Protection Agency) are the authorities regulating the storing of radioactive waste in the nuclear plants in the UK. NIREX, an organisation established by the nuclear industry at the beginning of the 1980s, has the responsibility of developing facilities and systems for the storage of low and medium-level nuclear waste. The handling of high-level nuclear waste is outside the bounds of NIREX's area of responsibility. NIREX's area of concern thus focuses on the search for a place to deposit low and medium level radioactive waste from the reprocessing plant at Sellafield, which is comparable to that which is deposited in the Swedish repository for radioactive operational waste, SFR, in Forsmark.

In 1989, NIREX presented two candidate sites and in 1995, an application was submitted for planning permission to construct a research laboratory at a prospective repository site at Sellafield in Cumbria. The facility itself was simply one step in the overall investigation of the site's suitability as a repository, and can be most closely compared with the detailed characterization stage of the Swedish programme.

Cumbria County Council reviewed the planning application and refused planning permission in 1995. Among the criticisms seen to emerge from Cumbria County was that insufficient consideration had been paid to the general public in the conduction of the siting process. Nirex appealed the decision to the Secretary of State for the Environment.A Planning Inquiry ensued, which included prolonged negotiations with the local authority and the general public on the siting process and the location.

In March 1998, the Secretary of State rejected the appeal to build a Rock Characterisation Facility beneath Sellafield in Cumbria on the grounds that the site was not considered suitable for the intended purpose.

The decision, however, placed UK policy back to square one in respect of its plans for the disposal of intermediate level radioactive waste. The UK nuclear waste programme was evaluated by a House of Lords Select Committee on Science and Technology that resulted in a report entitled, "The Management of Nuclear Waste" published on 10 March 1999.

The conclusions of the House of Lord Select Committee report included:

- The major problem of nuclear waste management in the United Kingdom is the legacy from the past. The legacy has to be dealt with, whether there are future programmes or not.
- The current United Kingdom strategy for management of long-lived wastes is fragmented. An integrated strategy is needed for all long-lived wastes and decisions are needed soon on which materials are to be declared wastes.
- Of the many methods for the long-term management of nuclear wastes that have been suggested and studied worldwide, only two are now being advocated. We found that the majority view from the scientific and technical community is that wastes should be emplaced in deep geological repositories. The minority view, held particularly by members of environmental pressure groups, is that wastes should be stored on or near the ground surface indefinitely, while a research and development programme is conducted to find the best means to manage them in the longer term.
- The Committee concluded that the preferred approach is phased geological disposal in which wastes are, following surface storage, emplaced in a Repository in such a way that they can be monitored and retrieved. The repository would be Kept open while data are accumulated, and only closed when there is sufficient confidence to do so.
- Public acceptance of a national plan for the management of nuclear waste is essential and it has to be achieved at the local level (i.e. close to potential repository sites), as well as within the country as whole.
- Openness and transparency in decision making are necessary in order to gain public trust, but they are not in themselves enough. Mechanisms must be used to include the public, or groups within it representing a wide spectrum of views, in decision making.
- At the local level, offering compensation for blight and benefits in exchange for hosting a national disposal facility would do much to achieve acceptance.

The RWMAC reviewed the process and issued its findings in a report "The Radioactive Waste Management Advisory Committee's Advice to Government on: Establishing Consensus on the Results of Science Programmes into the Disposal of Radioactive Waste", issued in May 1999. Among the issues identified by the RWMAC in order to improve future processes were:

- A more appropriate organisational structure and planning framework
- Greater Government commitment to dealing with the long-term problem of radioactive waste, notably with regard to the securing of a deep repository solution
- More openness and transparency at every stage of the planning process
- More clearly defined responsibilities and accountabilities

A further issue complicating the planning process was the need to further clarify who takes what decision and at what time on the basis of what remit, and in light of what evidence. Potential conflict remains between national and local decision-making systems. Furthermore, the RWMAC expressed a concern over the competence of local level staff, i.e. whether a local planning inspector has the expertise necessary to evaluate adequately the issues relating to the safe siting of a national radioactive waste repository.

On 25 October 1999, the Government issued its response to the House of Lords report. Among the findings of the response was that the Government agreed that identifying and implementing a management option for radioactive wastes, which commands widespread public support, would be a long process. It notes that in the model proposed by the Committee, it would take about four years to gain agreement on policy and a further twenty years after that for a repository, the Committee's chosen solution, to come into operation. The government emphasises the importance of widespread public support and an open and transparent decision-making process. The subsequent steps will be decided upon as a result of consultation with those involved in various management options for radioactive waste.

France

In France, the approach to nuclear waste management is to reprocess all spent fuel and dispose of vitrified high-level waste. Responsibility for the nuclear waste programme is held by a governmental agency, ANDRA. In the late 1980's, ANDRA identified four candidate sites for a repository following a systematic selection procedure. The plans for site investigation were met by extensive protests in the selected areas and the government stopped the site selection programme and introduced in 1991 new legislation where disposal of nuclear waste was abandoned. According to the new legislation however, future research should concentrate on identifying ways of conducting the disposal of high-level radioactive waste, and by 2006 should sufficient background material be assembled, it is hoped that the government could make a decision on the most suitable alternative. Furthermore, two sites for underground laboratories should be identified, one of which may later be developed into a repository.

An important element of the new legislation was the notion that future activities ought to be based on the voluntary participation of the municipalities involved. A Member of Parliament was identified as a mediator in identifying such sites. Furthermore, he had the authority to offer the municipalities a sum of around 10 15 million francs in financial compensation per year. The site investigation process was re-launched and three sites were proposed. ANDRA held hearings with local politicians and the general public from the candidate and neighbouring communities.

Recent Experiences:

In 1999, the government granted ANDRA permission to develop an Underground Research Laboratory (URL) in Heute-Marne. As a part of the construction process, the municipality receives fiscal support of 60 million francs per year. At the same time, the French government rejected the application for a research laboratory in Vienne. As part of the search for a new location for the underground laboratory, 15 granite areas were identified on scientific grounds and approved by the National Review Board (CNE) in September 1999. In accordance with the law of December 1991, installation of a nuclear laboratory is subject to a consultation with the elected officials and populations of the sites concerned. A three-member notation committee (composed of a prefect and two engineers, mandated by the Government) was appointed by government in November 1999 to meet with elected officials in the locations in question. The aim of the mission was not to convince people to accept a laboratory, but to inform local populations on the project in order to gather their opinions. The meetings were met by extensive local opposition and only three visits were made.

Furthermore, national opposition to the underground laboratories, including the Green party, organised protest meetings; the General and Regional Councils carried motions against the URL project; and hundreds of mayors within the 15 selected areas joined the opposition to the URL. In early June, the government ordered the mission to halt its consultations. The government has stated that it will pursue the construction of underground laboratories, but the new methods need to be found for consultation and to create a local dialogue.

USA

In the USA, it has been decided that nuclear waste shall be disposed of in a deep geological repository. The US policies governing the permanent disposal of high-level waste are defined by the Nuclear Waste Policy Act of 1982 (NWPA), the Nuclear Waste Policy Amendments Act (NWPAA) of 1987 and the Energy Policy Act of 1992. These acts specify that the high-level waste will be disposed of underground, in a deep geologic repository. Three federal agencies are responsible for disposing of spent fuel and high-level radioactive waste:

The US Department of Energy (US DOE) is responsible for developing the deep geologic repository which has been authorided by Congress for disposing of spent fuel and high level waste. It is also responsible for determining the suitability of the proposed disposal site as well as for developing, building and operating the geologic repository.

The Nuclear Regulatory Commission (NRC) is responsible for licensing the repository and ensuring that the DOE's proposed repository site and design comply with EPA's standards.

The Environmental Protection Agency (EPA) is responsible for developing environmental standards that apply to both DOE-operated and NRC-licensed facilities.

Other key actors include Office of Civilian Radioactive Waste management (OCRWM) within the U.S. Department of Energy (DOE) and the Nuclear Waste Technical Review Board (NWTRB) and the Department of Transportation that is responsible, along with the NRC, for regulating the transportation of these wastes to storage and disposal sites.

Congress decided in 1987 to designate Yucca Mountain as the single candidate site for characterisation as a potential geologic repository. This does not mean that Yucca Mountain has been selected for a repository, but that it will be the only site thoroughly examined at this point in time for site characterisation. Following the site characterisation, the DOE is required to prepare a recommendation for a potential site as a candidate for a geological repositor, and to submit it to the President and then to Congress.

The DOE's recommendation shall include preliminary comments from the NRC concerning the extent to which site characterisation and the waste form proposal for the recommended site seem sufficient for inclusion in any potential license application. The Nuclear Waste Policy Act directed both the Environmental Protection Agency (EPA) and the NRC to publish standards and criteria for the storage and disposal of high-level radioactive waste. The NRC's role in licensing a geologic repository has two objectives. The first is to ensure that the DOE has complied with the applicable standards, and the second is to ensure that public health and safety have been adequately protected. The Energy Policy Act directed the EPA to contract with the National Academy of Sciences (NAS) to provide technical inputs into the provision of standards in this area. The financing of the operation is conducted through the use of a special 'nuclear waste fund' that the waste producers are required to pay into in order to finance the management of the spent nuclear fuel.

Draft Environmental Impact Statement:
The DOE published a draft EIS for public comment for a Geological Repository on Spent Nuclear Fuel and High-Level Radioactive Waste in August 1999. The draft EIS provides information on the potential environmental impacts that could result from the proposed action to construct, operate, monitor and eventually close a deep underground repository at Yucca Mountain, in Nye County, Nevada. The draft EIS also analyses an alternative to the proposed action: namely a non-action alternative. The EIS further analyses the potential impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. The analysis also includes the use of active institutional controls (controlled access, inspection, maintenance, etc.). The DOE has held 21 public hearings where the report has been presented. The period for submitting comments closed in February 2000 and the DOE is in the process of reviewing the input and will prepare a Final EIS in 2001.

On 4 May 2001, the OCRWM initiated the public comment period on the Secretary's consideration of the Yucca Mountain site for possible recommendation to the President. In addition to the Draft Environmental Impact Statement, the Department has issued the Yucca Mountain Science and Engineering Report, which summarises the scientific and technical information developed through more than 20 years of studies on the site. Furthermore, the OCRWM has issued a Supplement to the Draft Environmental Impact Statement, which updates the information presented in the 1999 Draft Environmental Impact Statement.

Canada
The official strategy for the disposal of nuclear waste in Canada is deep geological repository in granite. The Canadian government runs three separate organisations that address policy issues and deal with the legislation that is relevant to nuclear safety and radiation protection and research and development regarding the storage of nuclear waste; NRCan (Natural Resources Canada), CNSC (Canadian Nuclear Safety Commission) and the AECL (Atomic Energy of Canada Limited). The last one is responsible for conducting research in relation to nuclear waste and developing workable solutions.

The research phase, including field studies and the construction of an underground laboratory was concluded in 1992, and an Environmental Impact Assessment was produced on the methods of disposal that were submitted to the authorities in 1994. In 1989, the Canadian Environmental Assessment Agency Panel was established by the Canadian government and given the task to review the storage concept. This body was made up of experts in the fields of technology and sociology. The procedure also encompassed a system by which non-governmental organisations and the general public could apply for funds to enable them to offer an informed viewpoint on the AECL's report. The panel operated over a period of almost ten years and in this time oversaw a series of hearings in several places across the country. The hearings were conducted in three phases; the first phase addressing socio-political questions; the second pertaining to technology; and the third phase which entailed the setting up of a number of local hearings throughout Canada.

The Panel's final report, based upon the results from this stage, states that the AECL's concept holds, from technical viewpoint, though public support is still lacking for the nuclear waste process. The panel gave the following recommendations to the government:

- Creating an independent agency for managing nuclear waste
- Review the requirements issued by the safety authority
- Change and develop the siting process so it takes public opinion into greater consideration and establishes a plan for public participation
- Developing a procedure for ethical and social assessment
- Developing and comparing other alternatives for managing the spent nuclear fuel

Moreover, it was the Panel's opinion that in the period preceding the implementation of these measures, the siting process should be halted. In the light of this experience, Canada is developing a new approach in the siting work and the old legislation has been revised.

In December 1998, the Canadian government gave a response to the panel's report where it stated that it agreed with most of the panel's recommendations. Among the points made by the government was that the responsibility for the final disposal and financing of the management of the spent fuel shall rest with the producers themselves. Thus, it became necessary for the energy company to establish a separate organisation to take care of all aspects of policy regarding the final disposal of nuclear waste. The energy companies shall establish a specific fund to take care of the financial aspects of disposal and they shall present their approach to the government, including a comprehensive public participation plan.

Cross-national Similarities and Differences

The issue of nuclear waste is an international phenomenon. It is a topical issue for all countries using nuclear power and consequently struggling with nuclear waste issues. The problem of nuclear waste is however no longer seen merely as a problem for technical specialists alone, but increasingly as a social problem, demanding the attention of politicians, activists and civil society more generally. On the basis of the review of the national experiences related to finding a solution to the nuclear waste disposal issue that have been outlined above, substantial differences are evident. These differences relate both to the methods used to address the issue of nuclear waste, and to the priority given to finding a permanent solution, as well as to the decision-making process of nuclear waste disposal, and the organisation of the process and the allocation of responsibilities.

The discussion over the choice of method for nuclear waste disposal is closely linked to that of the priority given to finding a permanent solution to the nuclear waste issue, and to the issue of time spectrum also. In the **United States,** the issue of nuclear waste has been identified as being one of high priority, and according to current plans, the repository will be in operation as soon as 2010. In **Finland** and **Sweden,** the search for a solution to the nuclear waste disposal issue has been afforded a high political priority with emphasis firmly on finding a permanent solution. In **France,** the search for a site for geological repository for spent nuclear fuel was abandoned by a new legislation in 1991 after extensive protests in the late 1980's. The recent development to locate underground research laboratories has furthermore been met by local and national opposition. In the **UK,** it has been decided that active measures related to deep disposal and to the search for a site for the repository site for high-level radioactive waste shall be put on hold, and thus that the highly active waste shall be stored, at least for a period of 50 years. The work carried out hitherto has primarily focused on the final disposal of low to medium-level radioactive waste, as detailed studies have been carried out on the deep disposal of low and intermediate level waste. In **Canada,** substantial preparatory work has gone into finding a suitable solution to the issue of high-level nuclear waste and underground research studies have been conducted since the 1980's. However, with regard to the latest developments concerning the final geological disposal of high-level nuclear waste and spent fuel, which as yet have not been approved, the timeframe for the work naturally remains unclear

Current Situation

The process of the permanent disposal of nuclear waste has not as yet begun in any country, though the countries that have progressed furthest down this policy road towards a solution to the issue of nuclear waste disposal are Finland and the USA. Indeed, furthest progress in terms of the model of a deep geological repository has been made in Finland, where the selection process has been completed, as has the Environmental Impact Assessment process, where an agreement has been reached with a host community and the government has approved the proposals. In the USA, the method for waste disposal has also been decided upon, and preparation work has been undertaken in applying to the President for final decision. A draft Environmental Impact Statement has been prepared and circulated across the state and the final EIA is under preparation. France, Canada and Great Britain have all experienced substantial setbacks in their initial approaches leading to the re-evaluation of their procedures. In France, such difficulties were met by changes in the legislation and by the creation of a new decision-making structure along with new opportunities for public influence. In Canada, the method of nuclear waste disposal has been challenged, whilst in Great Britain, such complications predominantly relate to the identification of a suitable site. In all such cases, however, the main criticism related to aspects of the decision-making process, in particular to the lack of public access to the process and thus to the demand for increased opportunities for participation and influence.

Common to the experience of all these countries is the fact that finding a solution to the nuclear waste issue is no longer viewed as solely a technical issue, but rather has now assumed a political magnitude such that it has engaged politicians, activists and civil society more generally.

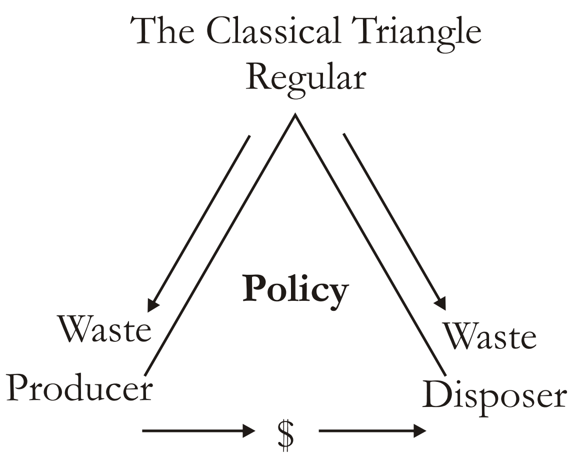
9

Institutional Reference Framework

In discussing institutional arrangements, particular attention is paid to the relationships betweenand the responsibilities ofthe State, the Regulator, Waste Producers and the national Waste Management Organisation. The IAEA provides guidance relating to the establishment of appropriate radioactive waste management structures and also to international analogues.

The model of the IAEA guidance on radwaste management infrastructure is sometimes referred to as the "classical triangle" principle. The model separates the three roles of the Regulator, the Waste Producer and the Waste Disposer. **Each has separate responsibilities and must exhibit independence from the other.** The classical triangle is shown diagramatically below. However, the triangle also has another dimension, in that the arrangements should be underpinned by firm Government policy on radwaste, on the basis of the guidance on responsibilities set out by the IAEA.

Figure 8.1: The Classical Triangle



As one would expect, most countries separate the role of waste producer from the regulatory body and the radioactive waste agency itself. In practical terms, the radioactive waste management organisation would face regulatory and cost pressures from the regulator and waste producers respectively, giving it an incentive to find safe but efficient solutions.

International examples of the "classical triangle" approach can be mostly found in Europe. However, precise arrangements differ in detail in that there are examples where some aspects of disposal are undertaken by the waste producers. This has happened to an extent in the UK where BNFL and UKAEA (waste producers) have responsibility to dispose of low-level waste (LLW) at Drigg and Dounreay respectively; and in Finland where IVO and TVO, the operators of the two nuclear powers stations sites, manage LLW and short-lived ILW disposal facilities on those sites. It should be emphasised that, the precise arrangements should not stray far from the IAEA principles outlined earlier. However, they may differ in their detail to reflect national differences in economic, social, political, legal, institutional and geographic structures.

India's Institutional Framework

India has a very peculiar institutional arrangement. The nuclear establishment in the country, as already pointed out, enjoys unique access to political authority and is protected from external oversight. Unlike most policy matters where the cabinet has the ultimate authority, the Atomic Energy Commission (AEC) is under the direct charge of the Prime Minister. This structure makes it difficult for most politicians or bureaucrats, let alone the public, to challenge nuclear policies or practices.

The AEC, set up under the Atomic Energy Act, exercises overall control of all activities relating to commercial use of nuclear energy. The AEC formulates policies for the DAE and ensures the policies are implemented. The Atomic Energy Regulatory Board (AERB) has been set up to oversee and enforce safety in *all* nuclear operations. This has been modified in 2000 to exclude nuclear weapons facilities.

The actual execution of these policies is carried out by the Department of Atomic Energy (DAE). The DAE has set up a number of associated or subsidiary organisations. Among government-owned companies, the Nuclear Power Corporation (NPCIL) is responsible for designing, constructing and operating the nuclear power plants within the first stage of nuclear power programme. The breeder reactors are the responsibility of another government-owned company called BHAVINI and the Uranium Corporation of India Limited (UCIL) is in charge of mining and milling of uranium. These establishments are responsible for managing and disposing the low and intermediate level waste that they produce. The Bhabha Atomic Research Centre (BARC) is also entrusted with the task of managing and disposing low-, intermediate- and high-level waste generated in reprocessing plants (also under BARC).

The Independence Factor

The AERB, which in an ideal world would perhaps be an independent body reporting directly to Parliament, has no power to truly regulate the nuclear industry. The AERB reports to the Atomic Energy Commission (AEC), which is headed by the head of the DAE. This arrangement makes AERB subservient to DAE.

To add, NPCIL is not independent of DAE. The NPCIL website states that the "Nuclear Power Corporation of India Limited is a Public Sector Enterprise under the administrative control of the Department of Atomic Energy (DAE), Government of India." So is the case with UCIL and BHAVINI. With DAE also exerting an administrative control over AEC, the independence of the regulatory body is questionable. Not just this, in the past, the Chairman of the Nuclear Power Corporation (NPCIL) has served as a member of the AEC as in the case of Dr. V. K. Chaturvedi, a former Chairman & Managing Director of Nuclear Power Corporation of India Limited and also a Member of the Atomic Energy Commission. This arrangement has allowed NPCIL to exercise administrative powers over the AERB directly. This lack of independence is in direct contravention of the international Convention on Nuclear Safety, to which India is a signatory. It is also relevant to point here the regular practice of 'borrowing' personnel from other organisations by AERB to carry out some of the functions, including safety studies. This too results in the independence being compromised.

10

Summary of Key Issues and Findings

India has, since the very inception, followed a three stage nuclear programme that requires the country to close its fuel cycle. This is a positive step towards proper and safe Radioactive Waste Management. Unlike countries that treat the entire spent fuel as waste, India believes in reprocessing of fuels which renders the waste product relatively less toxic because of absence of Plutonium and Uranium and its smaller size. The Waste Disposal is thus easy and manageable.

A rough comparison has been drawn for a typical 1000 MWe light water reactor that produces about $20m^3$ (27 tonnes) of used fuel per year, which corresponds to a $75m^3$ disposal volume following encapsulation. If that used fuel is reprocessed, $3m^3$ of vitrified waste is produced, which is equivalent to a $28m^3$ disposal volume following placement in a disposal canister. Additionally, research is on to explore the possibilities of extracting, for example, Caesium from the waste stream for its usefulness in medicine and industry.

India is guided by the basic principles of *Reduce, Reuse* and *Recycle* in waste management. It is recognised that a qualified team of experts and scientists form the backbone of India's nuclear programme. Despite decades of isolation, the country has indigenously developed technology which is well at par with the global standards.[50]

Endeavours are being made to constantly improve and upgrade the existing technology and put it into use in the new facilities. This also applies to waste management technologies and processes. Still there remains much scope for improvement . Some critical issues which have come to fore in course of the study are summarised here. While some issues demand corrective action, others are meant to serve as 'food for thought' for the various agencies involved in the country's nuclear programme:

The most common criticism levelled at the programme time and again is the lack of transparency. There is very little information output in the public domain from these establishments. While almost all the agencies were found to lack transparency in their operations, there were certain degrees of variations also detected It is no secret that the Indian nuclear establishment has progressively insulated itself from outside gaze and the same is reflected in the Atomic Energy Act. The Act empowers the government *"to restrict the disclosure of information in any form whatsoever, which relates to an existing or proposed atomic energy plant or its operation"*. The reason often cited for imposition of secrecy has been to safeguard the country's research interests. This seems to be a baseless argument. The truth probably lies in the dual nature of atomic power. But even so, that should not limit people outside these establishments from accessing information about the programme. The mere fact that the information touches upon some aspects of the nuclear programme should not automatically render it 'classified'.

One parameter to assess the transparency has been the organisational website. All the institutions involved have their own websites. The reactors do not have any web presence though, except for a page on the NPCIL website with only basic details. Finding information therefore becomes difficult. and those that do maintain a dedicated website, the information found is elementary. A need to make its website more informative, especially for UCIL, was felt in particular,. The seemingly fundamental information such as the ore quality or the quantity of the ore that is mined each day in Jaduguda, has also been labelled as classified.

The other parameter has been their responsiveness to communication or accessibility of officials. A majority of the establishments were found to be non responsive to the requests for information. It is reflected in the fact that people (from communities) have often resorted to the Right to Information to seek information from the establishments. This information should ideally have been made available by the concerned agencies on their own. Information coming out of the agencies, either in response to the RTI or otherwise, was often found sketchy. This surely is an area for improvement.

The nuclear programme is highly subsidised and huge government resources are being pumped into developing the same. The citizens of the country in general and the affected communities in particular, should as a matter of right, have access to programme details especially those directly concerning them. It should be understood that lack of transparency breeds with it lack of accountability and together they raise suspicion and distrust among people. In the light of recent developments,the country will have to open up to international scrutiny and hopefully the information would trickle down to people within the country.

[50] Interview with K. Raj, Head Waste Management Division, BARC.

Closely linked to the above is lack of public participation. There is no public participation at any stage of the process of siting, designing or building the nuclear facilities. T.S. Gopi Rethinaraj's comment in an article for the *Bulletin of the Atomic Scientists* (1999) seems an appropriate reflection of the situation: "The department [of atomic energy] has happily exploited the ignorance of India's judiciary and political establishment on nuclear issues. In the past, it has even used the Atomic Energy Act to prevent nuclear plant workers from accessing their own health records. While nuclear establishments everywhere have been notorious for suppressing information, nowhere is there an equivalent of India's Atomic Energy Act in operation. Over the years, in the comfort of secrecy, India's nuclear establishment has grown into a monolithic and autocratic entity that sets the nuclear agenda of the country and yet remains virtually unaccountable for its actions"

Facts coming out from the communities in course of the discussion corroborate this statement to some extent. UCIL, for example, has been reported as not sharing information with the workers about their own health. Similarly, findings from the water samples from the area that are regularly collected and tested by UCIL are not made public. Interestingly, UCIL has been facing huge criticism from the local population for its 'malpractices'. There are repeated allegations of radiation exposure to workers and of groundwater contamination in the area due to mining and milling operations. UCIL has been calling these charges as baseless and claims that the radiation levels in the area are well within the acceptable limits. If these claims are accurate, it would be in UCIL's interest to make its operations more transparent and make public all the records and findings.

The designing process too has been non-participatory. The communities are not consulted when selecting sites for any nuclear facility. They have often been 'informed' about the upcoming project when some land acquisition is involved. The Ministry of Environment and Forests (MoEF) mandates holding public hearings as an essential component of the process of approving all major projects with large ecological impacts. Many projects have got approval in absence of proper public hearing and when these are held, they prove to be a mere act of tokenism.

Even the entire process of conducting Environmental Impact Assessments (EIA) has been questionable. Seldom are the EIA reports shared or discussed with the 'affected communities.' It would be interesting to learn the process adopted by various agencies before finalising the site, say for a tailings pond or for a reactor, or any other facility, for that matter. The biggest concern is that the same practices would also apply when selecting the site for geological repository for final disposal of radioactive waste.

It would be worth adding here the point on public awareness. It should be understood that 'awareness' is not the same as 'participation', but even that was found missing in the programme. During interaction with community people in mining areas, it was mentioned that there have been no initiatives taken up the concerned agencies to inform and educate them about the hazards of radiation and specific activities. In Jaduguda, despite the siting of tailings ponds in the range of 50-100 metres from the nearest villages, people learnt about radiation not from the company, but after seeing and experiencing the impacts from the mining and milling activities and later through public awareness campaigns run by JOAR. In fact, it is felt that information given out by UCIL underplays the real threats. The notices erected by the corporation near the tailings ponds carry languages such as: 'walking over the tailings pond is unhealthy and undesirable' or "no object in the pond is fit for human or animal consumption. Any unauthorised use of the same is prohibited" (translation from Hindi). These do not adequately explain the dangers from the tailings and precautions to be taken by the villagers.

It is equally important that the workers engaged in these establishments are made aware about the peculiar nature of activity and the threat that it poses to their health. In case of uranium mining, it was shared that sometimes workers themselves do not fully understand the dangers. This is further complicated by the fact that the area has other mines as well and the workers fail to comprehend how one is dangerous while other is not.

It would also not be wrong to assume that the reactors were originally located away from the dense population which has now changed over time with cities expanding and occupying areas near to these sites. A study has revealed that the health of population near reactor sites is adversely affected in the course of its normal operations. Any accident will worsen the situation. An active information campaign is critical. DAE maintains that regular awareness programmes are conducted with school children and communities. In that case, it could be stated that DAE's efforts are not sufficient to meet the real challenges and need to be further strengthened.

The coverage of these awareness activities should be expanded to include non-uranium mines as well. It should be understood that the mining pockets have been selected since it was feasible to extract ore from those areas. This does not mean that the uranium deposits are strictly limited to those pockets. There could be uranium deposits in other parts in smaller quantities posing a threat to other miners. The main concern is that these areas are not under DAE and therefore go unregulated.

Contrary to the claims made by the community, UCIL holds that the tailings are completely safe. This is on the presumption that the ore quality in India is low (barely 0.04%). There is enough evidence to suggest the hazards of tailings on human health based on which any agency should apply **precautionary principles** in their approach without the need for further evidence on the adverse impacts. It should also be recognised that poor ore quality means that more ore has to be mined to get the requisite amount of uranium. This results in additional exposure of the workers.

Issue of overburden and waste rock is also a concern. Against the company's claims, these are not completely safe. In the past, overburden has been given to people to use in their houses. Overburden has also been processed into gravel or cement and used for road construction. While the practice may have stopped in the recent years, it is not clear if the company has any firm long-term plans of managing it apart from using it as a landfill within the mining areas (or probably as a backfill in the mine). Besides the quantum, transportation and spillage is also an issue.

It is also doubtful if the company has been maintaining an inventory of all such sites where the overburden was used. A national inventory of places where radioactive rocks may have been used years ago is crucial. If radioactive rocks are present, this should be written in official documents. Additionally, an elaboration of a national strategy and creation of storage facilities for radioactive rocks is needed. Further suggested is the creation of a **national fund** to help out the citizens willing to get rid of radioactive rocks situated in their property. As already pointed out, radioactive material containing uranium-radium 226 will permanently generate radon gas. Lung cancer risks are especially high if the gas accumulates inside the buildings (when the structure is constructed over a landfill).

To keep groundwater out of the mine during operation, large amounts of contaminated water are pumped out and released into rivers and lakes. When the pumps are shut down after closure of the mine, there is a risk of groundwater contamination from the rising water level. In view of the Jaduguda mine nearing the exhaustion level, this would be another area of concern post mine closure. A comprehensive plan to tackle the situation in the future needs to be chalked out and shared with the potentially-affected communities.

It is not clear if the tailings ponds in Jaduguda are engineered. UCIL admitted to them as 'partially engineered' based on the permeability test. There is a probability of ground water contamination due to the leachate from the tailings pond. Nearby villagers have reported falling sick after consuming ground water and in Chatikocha village, for example, people have completely stopped using ground water since they believe that the rise in diseases in early 2000 was due to ground water contamination. Additionally, the level of contaminants in water post-treatment (before being released into the river) is also worth investigating. The community claims that radioactivity in the water released into the river has affected marine life.

There have been cases of dams overflowing during heavy rains and of the tailings pipe bursting, thus causing heavy spillage at various sites. This may have resulted in contamination of the surrounding areas. It would definitely be worth investigating the downstream sediments and aquatic plants for contamination issues. These may be so high that that these may well qualify as 'Radioactive waste'. A clean-up plan and strategy to control further damage in these areas needs to be chalked out, planned and subsequently executed. Affected people must be identified and compensated. More importantly, there is definitely a need to learn from the past mistakes.

The safety threat posed by nuclear reactors is undeniably very high. A nuclear accident in a populous nation like India can cause massive damage to the human life. India has adopted a policy of co-location of near surface disposal facility with the nuclear installations to avoid transportation, but the need for transportation of highly radioactive waste for reprocessing or for interim storage and then later for final disposal still remains. In such a vast country, traversing long distances increases the risk of accident and with it, goes up the risk of exposure to people and environment.

All such facilities also face threats in the form of disasters. The Tsunami, though did not cause much damage, did catch the establishments off-guard. Likewise, the Tarapur and Kalpakkam sites lie in the seismic zone III (as per the Indian Standard (IS-1893: 2002)).

Safety issues have come to light in the past when faulty or inferior construction has resulted in collapse of structures. A practice of subcontracting down to various levels has been noticed at the time of construction. This practice is often linked with the issue of 'corners cutting' and inferior quality, thereby compromising with the safety of the structure.

The government must ensure that proper safeguards are implemented at the new (as well as old) nuclear sites and there is transparency in the process of selection and management of the sites. There is a need for a specific response plan by the government in case of disaster. BARC official[51] shared details about the disaster management plan in Tarapur (and hopefully did the same at other locations as well). The agency has reported distributing information pamphlets among the public and taking up disaster preparedness work with teachers and *sarpanch*s. Shelters have been identified and an exhibit is on display that is frequented by villagers. It is hoped that the agency reviews its disaster preparedness plan from time-to-time. It would also be in the interest of the larger public for the agency to put the disaster management plan and any other relevant information on its website. In the light of recent developments, India would also need to guard itself from becoming a dumping ground for obsolete technology, more so in the light of the resumption of trade with other countries. This is another safety challenge before the country.

With the construction and operation of new nuclear plants, and a manifold increase in waste from these plants, along with the amounts generated by the old plants, it is imperative that the government chalks out a carefully planned strategy for proper handling and disposal of radioactive waste. In a nation with such a high population density, it is difficult to imagine where the government would plan to dispose the nuclear waste off. Even if such a site is identified, it is certainly difficult to assume that there would be no habitation around it even after several hundred of years. A comprehensive nuclear waste management plan must be shared with the nation as this issue holds an ethical aspect to it as well.

Geological repository is just a concept with no proven track record. This contravenes with the policy of inter-generational equity. The establishments in India feel that there is no urgency to find final solutions immediately and we can wait for another 15-20 years. However, without knowing the ultimate storage solution for waste, how we can commit ourselves to a programme of nuclear waste management as both of these are closely linked. Until certain otherwise, we can not be sure if our packaging i.e. the form that the waste is currently managed in is the correct one for the chosen long term management option or not.

Both, near surface as well as deep burial sites, are being created or planned over large areas. These require proper record keeping and long term surveillance. A well laid out strategy of how these would be secured, maintained and passed on to future generations is urgently called for, even before starting with work on the same. Another big challenge is figuring out how to alert our distant descendants to perilous nuclear waste entombed hundreds of metres below the ground. Language evolves fast and choosing the right signs and language to warn people of a potentially fatal stockpile is important.

Leaks in the system are suspected. There have been reported circumstances where the allowed used drums (carrying radioactive material) and tailings pipes have pilfered their way into people's homes or in the scrap market; and from there into consumer products and other materials.

Besides, the scrap that's landing into the country from other parts of the world has reportedly included parts from decommissioned nuclear reactors, hospital radiation equipment, and foreign ships that were sent to Indian ports for dismantling or the hulls of foreign nuclear submarines. The matter came to light a year back in a case of castings exports. The subject gained prominence recently after the elevator case where France's Nuclear Safety Authority informed the AERB about the contamination. In 2004, Bhushan Steel had unknowingly imported missile scrap from Iran, which exploded in the factory. In India, the facilities that are handling steel scrapeither from within the country or imported should be required to install radiation detectors to check scrap. The government also needs to put into place a programme to make radiation monitors mandatory at ports to check cargo to prevent public exposure.

In a positive development, AERB had, in November 2008, recommended to the Engineering Export Promotion Council (EEPC) that radiation checks be made mandatory. The council would take it up with the concerned ministries. AERB head (radiological safety division) S.P. Agarwal recommends checking at all levels of value-addition to prevent contamination from passing onto the next levels. Ex-EEPC chairman Rakesh Shah informed that the council has been demanding the commerce ministry to come out with a regulation to make checking mandatory for scrap coming to the country.[52]

[51] K Raj, Head Waste Management Division, BARC Trombay at the 'Dissemination Workshop on Study on Radioactive Waste', 2 December 2008, Toxics Link, New Delhi.
[52] Ishita Ayan Dutt, 'AERB Moots Mandatory Checks for Radiation', *Business Standard* (Kolkatta), 18 November, 2008.

The thrust on Nuclear energy has gained prominence since it is considered as clean energy. Some scientists and other experts are beginning to raise a different question about nuclear power. A British NGO, Oxford Research Group, argues that while the nuclear plants may not generate carbon dioxide while they operate, the other steps necessary to produce nuclear power, including mining of uranium and storing of waste, result in a substantial amount of carbon dioxide pollution. Further, nuclear will become more carbon-polluting over the passage of time. The reason is that it will become more difficult to do things like extracting uranium ore and storing nuclear waste since these will require more materials, equipment, and energy. If the prime benefits of the technology are under considerable doubt, it becomes crucial that we re-look at our strategy and ensure that we are on the right track.

While the legal and regulatory framework seems to be in place, implementation has been lacking. Rules have been openly flouted. A glaring example is siting of tailings ponds close to the habitation. There could be more such irregularities at various ends. The thrust should be on strengthening the regulatory mechanism, especially in light of expansion of the nuclear programme.

However, the centralised regulatory structure makes it impossible to plug the implementation gap. As we are aware, industrial pollution is common in India and irregularities in operation are plenty. This is despite the decentralised setup of the Pollution Control Boards, which are the regulatory authorities. Based on experience, it seems unrealistic to expect a centralised agency like AERB to regulate every aspect of the programme. This would become an even bigger challenge with the massive expansion planned for the industry in the coming years. The challenge is to regulate the use of radioisotopes in industry and medicine (again owing to their large network). With the more recent threat of 'dirty bombs', any leaks in the system can prove fatal.

Responding to the study findings, DAE official[53] maintained that AERB has, over the years, been expanding its manpower to gear itself to the challenge of regulating a growing industry. He added that the AERB's centralised structure has proved effective so far and the same shall be maintained in the future. He also shared that the entire world over, all the regulatory agencies have a centralised set up.

In a media report[54], AERB Chairman S.K. Sharma revealed the Board's plan of setting up two regional centresone at Rajarhat in Kolkata and the other near the Safety Research Institute in Kalpakkam near Chennai to meet the increasing regulatory requirements of both nuclear power and non-power applications. With the signing of the 123 Agreement with the US, the workload for AERB would increase with a large number of Light Water Reactors (LWR) planned for the next 10-15 years. The AERB would also recruit 100 experts during the 11th Five Year Plan for the country's expanding nuclear power programme with import of Light Water Reactors from Russia, France and the US.

In another press statement[55], Head of Radiation Safety Division, AERB, Dr. S.P. Aggarwal, disclosed the plans for decentralisation to inspect X-ray machines. Stating that inspecting the mushrooming x ray centres in the country is a tedious task, the Board was said to be advocating a policy of decentralisation for checking these centres. As per the figures available with the AERB, there are 50,000 X-Ray centres, while the CT scan number stands at 3,000 and cath labs, 1,500. AERB has data of around 45,000 X-Ray centres. The Board has listed 52 vendors for the supply of X-ray machines in the country, 12 of which are imported. But the elaborate guidelines for procuring licence for setting up of the X Ray centres, as listed by the AERB, lose relevance in the absence of adequate manpower with the Board to check whether these are being adhered to or not. If these proposed moves are implemented, that surely would be a positive step.

Independence: Another critical issue facing AERB is that although it is expected to be an independent body reporting directly to the parliament, the Board has no power to truly regulate the nuclear industry. The AERB reports to the Atomic Energy Commission (AEC), that is headed by the head of the DAE. Thus, DAE exercises administrative powers over the AERB. In fact, in the past, the Chairman of the Nuclear Power Corporation (NPCIL) has served as Member AEC exerting control over AERB. In an ideal situation, the role of waste producer should be separate from the regulatory body and the radioactive waste agency itself. In practical terms, the radioactive waste management organisation would face regulatory and cost pressures from the regulator and waste producers respectively, giving it an incentive to find safe but efficient solutions. In response, SK Malhotra[56] on behalf of DAE shared that in the years to come, the Board may become completely independent. He felt that when a country like France has managed to achieve this recently, it would be unrealistic to expect India to do the same soon.

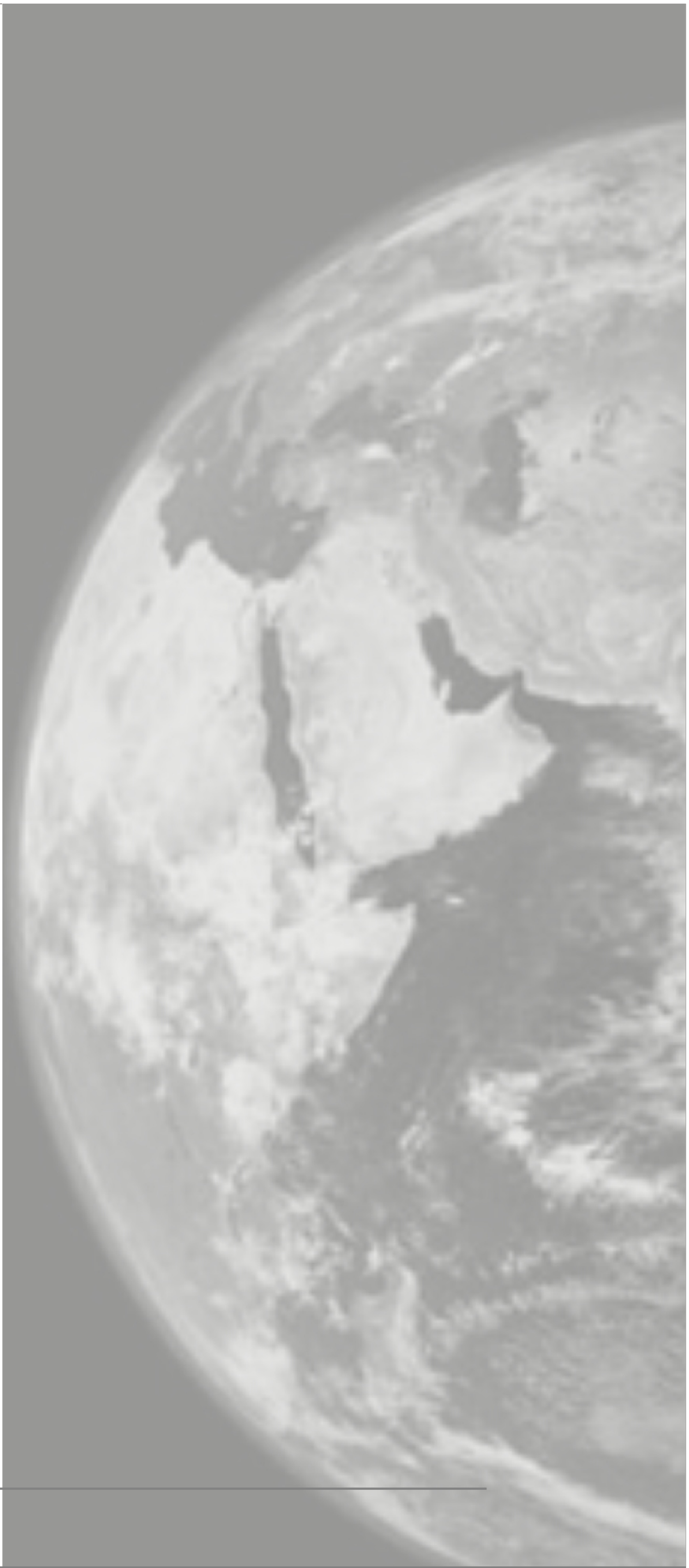
[53] SK Malhotra, Head Public Awareness Division, Department of Atomic Energy at the 'Dissemination Workshop on Study on Radioactive Waste'. 2 December 2008, Toxics Link, New Delhi
[54] PTI Report, 'AERB Regional Centres to Come up in Kolkata, Chennai', www.livemint.com, 10 October, 2008.
[55] Neelam Sharma, 'AERB Proposes Decentralisation to inspect X-ray Machines in Country', *Express India*, 16 November, 2007.
[56] During the 'Dissemination Workshop on Study on Radioactive Waste'. 2 December 2008, Toxics Link, New Delhi

Regulatory Change: Several regulatory issues must be spelled out clearly before the country progresses on this front. Financing such a large programme cannot be managed by the government alone and the law needs to be amended suitably to allow Private and Foreign sector participation. It is pertinent to note that at present FDI is prohibited in the Atomic Energy sector.

Liability Clause: Another big concern in the industry is regarding the liability clause in case of a mishap. As per the present liability regime in the country, there is an absolute liability on the enterprise which is engaged in a hazardous or inherently dangerous activity irrespective of reasonable care, and is not subject to any of the exceptions to strict liability. Currently, the Union Government bears this liability for Nuclear Power Corporation of India Ltd, a State-owned firm and the only player permitted to operate nuclear power stations in the country. It would have to enact a fresh 'Nuclear Liability' law (or a policy framework on the issue of nuclear liability) that clearly spells out the compensation amount and the guarantor in case of a mishap when the private sector is allowed entry into the nuclear space.

Under the 123 Agreement, the government of India will have to give liability waivers to foreign nuclear plant makers and operators since entities to insure such plants do not exist. This would mean that in the event of a nuclear disaster, the government of India would have to bear the cost of compensating the hundreds of thousands that could die and the millions that could be injured, not to mention the severe impact on the environment. The government should lay out its liability plans to prevent another Bhopal.

To conclude, Sustainable development demands that environmental needs are integrated into the development agenda. Adequate focus must be placed on management and safe disposal of any waste that is generated in the due course of the programme. We cannot afford a lax attitude while dealing with radioactive waste that has the potential to endanger lives not only of the present generation, but also of many more to come. The country may have taken giant strides in the nuclear industry, but it has not yet 'matured' enough. Learning from others' experiences is undoubtedly beneficial. Every country may have its unique needs, but there are also several commonalities to be found.



Glossary

Actinide: An element with atomic number of 89 (actinium) to 102. Usually applied to those above uranium - 93 up (also called transuranics). Actinides are radioactive and typically have long half-lives. They are therefore significant in wastes arising from nuclear fission, e.g. used fuel. They are fissionable in a fast reactor.

Activation product: A radioactive isotope of an element (e.g. in the steel of a reactor core) which has been created by neutron bombardment.

Activity: The number of disintegrations per unit time inside a radioactive source. Expressed in becquerels.

ALARA: As Low As Reasonably Achievable, economic and social factors being taken into account. This is the optimisation principle of radiation protection.

Alpha particle: A positively-charged particle from the nucleus of an atom, emitted during radioactive decay. Alpha particles are helium nuclei, with 2 protons and 2 neutrons.

Atom: A particle of matter which cannot be broken up by chemical means. Atoms have a nucleus consisting of positively-charged protons and uncharged neutrons of the same mass. The positive charges on the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.

Background radiation: The naturally-occurring ionising radiation which every person is exposed to, arising from the earth's crust (including radon) and from cosmic radiation.

Base load: That part of electricity demand which is continuous, and does not vary over a 24-hour period. Approximately equivalent to the minimum daily load.

Becquerel: The SI unit of intrinsic radioactivity in a material. One Bq measures one disintegration per second and is thus the activity of a quantity of radioactive material which averages one decay per second. (In practice, GBq or TBq are the common units).

Beta particle: A particle emitted from an atom during radioactive decay. Beta particles may be either electrons (with negative charge) or positrons.

Biological shield: A mass of absorbing material (eg thick concrete walls) placed around a reactor or radioactive material to reduce the radiation (especially neutrons and gamma rays respectively) to a level safe for humans.

Boiling water reactor (BWR): A common type of light water reactor (LWR), where water is allowed to boil in the core thus generating steam directly in the reactor vessel. *(cf PWR)*

Breed: To form fissile nuclei, usually as a result of neutron capture, possibly followed by radioactive decay.

Burn: cause to fission.

Burnable poison: A neutron absorber included in the fuel which progressively disappears and compensates for the loss of reactivity as the fuel is consumed. Gadolinium is commonly used.

Burnup: Measure of thermal energy released by nuclear fuel relative to its mass, typically Gigawatt days per tonne (GWd/tU).

Calandria: (in a CANDU reactor) a cylindrical reactor vessel which contains the heavy water moderator. It is penetrated from end to end by hundreds of calandria tubes which accommodate the pressure tubes containing the fuel and coolant.

CANDU: Canadian deuterium uranium reactor, moderated and (usually) cooled by heavy water.

Chain reaction: A reaction that stimulates its own repetition, in particular where the neutrons originating from nuclear fission cause an ongoing series of fission reactions.

Cladding: The metal tubes containing oxide fuel pellets in a reactor core.

Control rods: Devices to absorb neutrons so that the chain reaction in a reactor core may be slowed or stopped by inserting them further, or accelerated by withdrawing them.

Conversion: Chemical process turning U_3O_8 into UF_6 preparatory to enrichment.

Coolant: The liquid or gas used to transfer heat from the reactor core to the steam generators or directly to the turbines.

Core: The central part of a nuclear reactor containing the fuel elements and any moderator.

Critical mass: The smallest mass of fissile material that will support a self-sustaining chain reaction under specified conditions.

Criticality: Condition of being able to sustain a nuclear chain reaction.

Cross section: a measure of the probability of an interaction between a particle and a target nucleus, expressed in barns (1 barn = 10^{-24} cm^2)

Decay: Disintegration of atomic nuclei resulting in the emission of alpha or beta particles (usually with gamma radiation). Also the exponential decrease in radioactivity of a material as nuclear disintegrations take place and more stable nuclei are formed.

Decommissioning: Removal of a facility (eg reactor) from service, also the subsequent actions of safe storage, dismantling and making the site available for unrestricted use.

Delayed neutrons: neutrons released by fission products up to several seconds after fission. These enable control of the fission in a nuclear reactor.

Depleted uranium: Uranium having less than the natural 0.7% U-235. As a by-product of enrichment in the fuel cycle it generally has 0.25-0.30% U-235, the rest being U-238. Can be blended with highly-enriched uranium (eg from weapons) to make reactor fuel.

Deuterium: "Heavy hydrogen", a stable isotope having one proton and one neutron in the nucleus. It occurs in nature as 1 atom to 6500 atoms of normal hydrogen, (Hydrogen atoms contain one proton and no neutrons).

Disintegration: natural change in the nucleus of a radioactive isotope as particles are emitted (usually with gamma rays), making it a different element.

Dose: The energy absorbed by tissue from ionising radiation. One gray is one joule per kg, but this is adjusted for the effect of different kinds of radiation, and thus the sievert is the unit of dose equivalent used in setting exposure standards.

Element: A chemical substance that cannot be divided into simple substances by chemical means; atomic species with same number of protons.

Enriched uranium: Uranium in which the proportion of U-235 (to U-238) has been increased above the natural 0.7%. Reactor-grade uranium is usually enriched to about 3.5% U-235, weapons-grade uranium is more than 90% U-235.

Enrichment: Physical process of increasing the proportion of U-235 to U-238.

Fast breeder reactor (FBR): A fast neutron reactor (qv) configured to produce more fissile material than it consumes, using fertile material such as depleted uranium in a blanket around the core.
Fast neutron: neutron released during fission, travelling at very high velocity (20,000 km/s) and having high energy (c 2 MeV).

Fast neutron reactor: A reactor with no moderator and hence utilising fast neutrons. It normally burns plutonium while producing fissile isotopes in fertile material such as depleted uranium (or thorium).

Fertile (of an isotope): Capable of becoming fissile, by capturing neutrons, possibly followed by radioactive decay; eg U-238, Pu-240.

Fissile (of an isotope): Capable of capturing a slow (thermal) neutron and undergoing nuclear fission, e.g. U-235, U-233, Pu-239.

Fission: The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of energy and usually one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron and thus becoming unstable.

Fissionable (of an isotope): Capable of undergoing fission: If fissile, by slow neutrons; otherwise, by fast neutrons.

Fission products: Daughter nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary daughters. Usually highly radioactive.

Fossil fuel: A fuel based on carbon presumed to be originally from living matter, eg coal, oil, gas. Burned with oxygen to yield energy.

Fuel assembly: Structured collection of fuel rods or elements, the unit of fuel in a reactor.

Fuel fabrication: Making reactor fuel assemblies, usually from sintered UO_2 pellets which are inserted into zircalloy tubes, comprising the fuel rods or elements.

Gamma rays: High energy electro-magnetic radiation from the atomic nucleus, virtually identical to X-rays.

Genetic mutation: Sudden change in the chromosomal DNA of an individual gene. It may produce inherited changes in descendants. Mutation in some organisms can be made more frequent by irradiation (though this has never been demonstrated in humans).

Giga: One billion units (eg gigawatt = 10^9 watts or million kW).

Graphite: Crystalline carbon used in very pure form as a moderator, principally in gas-cooled reactors, but also in Soviet-designed RBMK reactors.

Gray: The SI unit of absorbed radiation dose, one joule per kilogram of tissue.

Greenhouse gases: Radiative gases in the earth's atmosphere which absorb long-wave heat radiation from the earth's surface and re-radiate it, thereby warming the earth. Carbon dioxide and water vapour are the main ones.

Half-life: The period required for half of the atoms of a particular radioactive isotope to decay and become an isotope of another element.

Heavy water: Water containing an elevated concentration of molecules with deuterium ("heavy hydrogen") atoms.

Heavy water reactor (HWR): A reactor which uses heavy water as its moderator, eg Canadian CANDU (pressurised HWR or PHWR).

High-level wastes: Extremely radioactive fission products and transuranic elements (usually other than plutonium) in used nuclear fuel. They may be separated by reprocessing the used fuel, or the spent fuel containing them may be regarded as high-level waste.

Highly (or High)-enriched uranium (HEU): Uranium enriched to at least 20% U-235. (That in weapons is about 90% U-235.)

In situ leaching (ISL): The recovery by chemical leaching of minerals from porous orebodies without physical excavation. Also known as solution mining.

Ion: An atom that is electrically-charged because of loss or gain of electrons.

Ionising radiation: Radiation (including alpha particles) capable of breaking chemical bonds, thus causing ionisation of the matter through which it passes and damage to living tissue.

Irradiate: Subject material to ionising radiation. Irradiated reactor fuel and components have been subject to neutron irradiation and hence become radioactive themselves.

Isotope: An atomic form of an element having a particular number of neutrons. Different isotopes of an element have the same number of protons but different numbers of neutrons and hence different atomic mass, eg. U-235, U-238. Some isotopes are unstable and decay (qv) to form isotopes of other elements.

Light water: Ordinary water (H_20) as distinct from heavy water.

Light water reactor (LWR): A common nuclear reactor cooled and usually moderated by ordinary water.
Low-enriched uranium: Uranium enriched to less than 20% U-235. (That in power reactors is usually 3.5 - 5.0% U-235.)

Low-level wastes: Mildly radioactive material usually disposed of by incineration and burial.

Megawatt (MW): A unit of power, = 10^6 watts. **MWe** refers to electric output from a generator, **MWt** to thermal output from a reactor or heat source (eg the gross heat output of a reactor itself, typically three times the MWe figure).

Metal fuels: Natural uranium metal as used in a gas-cooled reactor.

Micro: one millionth of a unit (eg microsievert is 10^{-6} Sv).

Milling: Process by which minerals are extracted from ore, usually at the mine site.

Mixed oxide fuel (MOX): Reactor fuel which consists of both uranium and plutonium oxides, usually about 5% Pu, which is the main fissile component.

Moderator: A material such as light or heavy water or graphite used in a reactor to slow down fast neutrons by collision with lighter nuclei so as to expedite further fission.

Natural uranium: Uranium with an isotopic composition as found in nature, containing 99.3% U-238, 0.7% U-235 and a trace of U-234. Can be used as fuel in heavy water-moderated reactors.

Neutron: An uncharged elementary particle found in the nucleus of every atom except hydrogen. Solitary mobile neutrons travelling at various speeds originate from fission reactions. Slow (thermal) neutrons can in turn readily cause fission in nuclei of "fissile" isotopes, e.g. U-235, Pu-239, U-233; and fast neutrons can cause fission in nuclei of "fertile" isotopes such as U-238, Pu-239. Sometimes atomic nuclei simply capture neutrons.

Nuclear reactor: A device in which a nuclear fission chain reaction occurs under controlled conditions so that the heat yield can be harnessed or the neutron beams utilised. All commercial reactors are thermal reactors, using a moderator to slow down the neutrons.

Nuclide: elemental matter made up of atoms with identical nuclei, therefore with the same atomic number and the same mass number (equal to the sum of the number of protons and neutrons).

Oxide fuels: Enriched or natural uranium in the form of the oxide UO_2, used in many types of reactor.

Plutonium: A transuranic element, formed in a nuclear reactor by neutron capture. It has several isotopes, some of which are fissile and some of which undergo spontaneous fission, releasing neutrons. Weapons-grade plutonium is produced in special reactors to give >90% Pu-239, reactor-grade plutonium contains about 30% non-fissile isotopes. About one third of the energy in a light water reactor comes from the fission of Pu-239, and this is the main isotope of value recovered from reprocessing used fuel.

Pressurised water reactor (PWR): The most common type of light water reactor (LWR), it uses water at very high pressure in a primary circuit and steam is formed in a secondary circuit.

Radiation: The emission and propagation of energy by means of electromagnetic waves or particles. *(cf ionising radiation)*

Radioactivity: The spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation.

Radionuclide: A radioactive isotope of an element.

Radiotoxicity: The adverse health effect of a radionuclide due to its radioactivity.

Radium: A radioactive decay product of uranium often found in uranium ore. It has several radioactive isotopes. Radium-226 decays to radon-222.

Radon (Rn): A heavy radioactive gas given off by rocks containing radium (or thorium). Rn-222 is the main isotope.

Radon daughters: Short-lived decay products of radon-222 (Po-218, Pb-214, Bi-214, Po-214).

Reactor pressure vessel: The main steel vessel containing the reactor fuel, moderator and coolant under pressure.

Repository: A permanent disposal place for radioactive wastes.

Reprocessing: Chemical treatment of used reactor fuel to separate uranium and plutonium and possibly transuranic elements from the small quantity of fission product wastes, leaving a much reduced quantity of high-level waste (which today includes the transuarnic elements). *(cf Waste, HLW).*

Separative Work Unit (SWU): This is a complex unit which is a function of the amount of uranium processed and the degree to which it is enriched, ie the extent of increase in the concentration of the U-235 isotope relative to the remainder. The unit is strictly: Kilogram Separative Work Unit, and it measures the quantity of separative work (indicative of energy used in enrichment) when feed and product quantities are expressed in kilograms. Eg, to produce one kilogram of uranium enriched to 3.5% U-235 requires 4.3 SWU if the plant is operated at a tails assay 0.30%, or 4.8 SWU if the tails assay is 0.25% (thereby requiring only 7.0 kg instead of 7.8 kg of natural U feed). About 100-120,000 SWU is required to enrich the annual fuel loading for a typical 1000 MWe light water reactor. Enrichment costs are related to electrical energy used. The gaseous diffusion process consumes some 2400 kWh per SWU, while gas centrifuge plants require only about 60 kWh/SWU.

Sievert (Sv): Unit indicating the biological damage caused by radiation. One Joule of beta or gamma radiation absorbed per kilogram of tissue has 1 Sv of biological effect; 1 J/kg of alpha radiation has 20 Sv effect and 1 J/kg of neutrons has 10 Sv effect.

Spallation: the abrasion and removal of fragments of a target which is bombarded by protons in an accelerator. The fragments may be protons, neutrons or other light particles.

Spent fuel: Used fuel assemblies removed from a reactor after several years use and treated as waste.

Stable: Incapable of spontaneous radioactive decay.

Tailings: Ground rock remaining after particular ore minerals (e.g. uranium oxides) are extracted.

Tails: Depleted uranium *(cf. enriched uranium)*, with about 0.3% U-235.

Thermal reactor: A reactor in which the fission chain reaction is sustained primarily by slow neutrons, and hence requiring a moderator *(as distinct from Fast Neutron Reactor).*

Transmutation: Changing atoms of one element into those of another by neutron bombardment, causing neutron capture and/or fission. In an ordinary reactor neutron capture is the main event, in a fast reactor fission is more common and therefore it is best for dealing with actinides. Fission product transmutation is by neutron capture.

Transuranic element: A very heavy element formed artificially by neutron capture and possibly subsequent beta decay(s). Has a higher atomic number than uranium (92). All are radioactive. Neptunium, plutonium, americium and curium are the best-known.

Uranium (U): A mildly radioactive element with two isotopes which are fissile (U-235 and U-233) and two which are fertile (U-238 and U-234). Uranium is the basic fuel of nuclear energy.

Uranium hexafluoride (UF_6): A compound of uranium which is a gas above 56°C and is thus a suitable form in which to enrich the uranium.

Uranium oxide concentrate (U_3O_8): The mixture of uranium oxides produced after milling uranium ore from a mine. Sometimes loosely called yellowcake. It is khaki in colour and is usually represented by the empirical formula U_3O_8. Uranium is sold in this form.

Vitrification: The incorporation of high-level wastes into borosilicate glass, to make up about 14% of it by mass. It is designed to immobilise radionuclides in an insoluble matrix ready for disposal.

Waste:
High-level waste (HLW) is highly radioactive material arising from nuclear fission. It can be what is left over from reprocessing used fuel, though some countries regard spent fuel itself as HLW. It requires very careful handling, storage and disposal.

Low-level waste (LLW) is mildly radioactive material usually disposed of by incineration and burial.

Yellowcake: Ammonium diuranate, the penultimate uranium compound in U_3O_8 production, but the form in which mine product was sold until about 1970. See also Uranium oxide concentrate.

Zircaloy: Zirconium alloy used as a tube to contain uranium oxide fuel pellets in a reactor fuel assembly.

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- International Atomic Energy Agency (IAEA): www.iaea.org
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- Uranium Corporation India Limited (UCIL): www.ucil.gov.in
- WISE Uranium Project: www.wise-uranium.org
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