Energy Education Science and Technology
2005 Volume(issue) **14(2):** 93-102

Evaluation of existing treatment techniques and various problems associated with nuclear waste management

B.V. Babu*, S. Karthik

Birla Institute of Technology and Science, Department of Chemical Engineering,
Pilani 333031(Rajasthan), India

Received 23 April 2004; accepted 20 May 2004

Abstract

This paper deals with the study of radioactive waste generation and their treatment techniques. The wastes that are generated during the front and back end of the nuclear power production are classified are low, intermediate and high level waste. The various existing process for the treatment for the waste like, reprocessing, pyroprocessing, transmutation, and options available for the disposal of the wastes are studied. Based on this overall study, the wastes are evaluated for their hazard and various questions are raised and an attempt is made is answer them.

Keywords: Nuclear waste; Nuclear waste management; Reprocessing; Pyroprocessing; Disposal options; Transmutation; SYNROCK

1. Introduction

Nuclear materials are mined, processed, utilized, stored, transported, conditioned, and disposed. They are involved in applications from medical research and applications to fueling nuclear power reactors to the dismantlement of nuclear weapons to cleaning up contaminate sites. They are essential ingredients in energy, national security and environmental programs. Regardless of their dangers, large quantities of civil as well as military waste are being disposed off in temporary and questionable ways, often in the immediate vicinity of the nuclear power plants or other nuclear related facilities. Dispersed radioactivity has contaminated these areas to such a degree that they pose a deadly threat to human life. Some examples are Savannah River

*Corresponding Author: Tel.: +91-1596-245073; Fax: +91-1596-244183
E-mail address: bvbabu@bits-pilani.ac.in (B. V. Babu).

and Hanford, U.S.A.; Kyshtym and Chernobyl in U.S.S.R., and Sellafield (Windscale) in England [1]. Other nuclear sacrifice areas have been created as a result of nuclear bomb testing carried out by U.S.A., France, Russia., England, China, and India. The released, long-lived radioactivity cannot be stopped from spreading in food chains via air and water. Thus, the global connections make the world's nuclear waste everyone's concern. Most countries lack the sense of responsibility and the physical qualifications for initiating a safe storage program for existing wastes

Further, many nuclear nations also are at risk from earthquakes and volcanoes, which in the blink of an eye can destroy safety programs and spread nuclear waste throughout the biosphere. With such dangers lurking around nuclear waste management, some questions are raised in this paper regarding the future of nuclear waste and an attempt is made to answer them.

2. Radiation and classification of wastes

Radiation is the emission and propagation of energy through matter or space. As radiation penetrates matter, it interacts with the environment and energy is transferred to the surrounding atoms, resulting in their ionization. Inside an organic tissue, the ionized atom may enter into abnormal chemical combinations. The net effect is the destruction of living cells and damage of exposed tissue. The wastes generated during the power production have to be handled carefully depending on their radioactivity [2]. The wastes are generated during the following stages of nuclear power generation:

- Mining and milling of uranium
- Processing and fabrication of fuel
- Use in reactor
- Treatment of spent fuel

These wastes are classified based on their radioactivity as follows

- **Mine Tailings**

  The following are the hazards involved during mining

  1. After uranium mining, about 80% of the radioactivity of the original ore remains in the ‘tailings’. These tailings are the mining waste, which is usually dumped near the mine site.
  2. The main type of radiation of the uranium ore is alpha radiation. Alpha radiation is about 20 times more dangerous than beta and gamma radiation when it enters human body.
  3. The most dangerous isotope in the tailings is the gaseous radon-222 which decays into solid radon daughters which emits alpha radiation. It is continually being produced in the tailings as a decay product and can carry four of the six alpha decays of the tailings to distant locations. The fine milling, combined with erosion and dispersion of the tailings, will facilitate its escape. The gaseous radon spreads the contamination over thousands of kilometers.
  4. The ore also contains isotopes of bismuth, actinium and lead which emit alpha radiation.

- **Low-level Waste** is generated from hospitals, laboratories and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, and 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. Usually it is 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** contains higher amounts of radioactivity and may require special shielding. It typically comprises resins, chemical sludges and reactor components, as well as contaminated materials from reactor decommissioning. Worldwide it makes up **7% of the volume** and has **4% of the** radioactivity of all radwaste. It may be solidified in concrete or bitumen for disposal. Generally short-lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) will be disposed of deep underground.
- **High-level Waste** may be the spent fuel itself, or the principal waste from reprocessing. While only **3% of the** volume of all radwaste, it holds **95% of the radioactivity**. It contains the highly radioactive fission products and some heavy elements with long-lived radioactivity. It generates a considerable amount of heat and requires cooling, as well as special shielding during handling and transport. If the spent fuel is reprocessed, the separated waste is vitrified by incorporating it into borosilicate (Pyrex) glass, which is then sealed inside stainless steel canisters for eventual disposal deep underground. On the other hand, if **spent reactor fuel** is not reprocessed, all the highly radioactive isotopes remain in it, and so the whole fuel assemblies are treated as high-level waste. This spent fuel takes up about nine times the volume of equivalent vitrified high-level waste which results from reprocessing and which is encapsulated ready for disposal.

3. Treatment techniques

Some of the existing techniques for the treatment of these nuclear wastes are categorized into 4 groups such as Reprocessing, Pyroprocessing, Transmutation and SYNROCK, whose details are as given below:

- **Reprocessing:**

Reprocessing is primarily done to recover uranium and plutonium. Spent fuel assemblies removed from a reactor are very radioactive and produce heat. They are therefore put into large tanks or "ponds" of water which cool them and three meters of water over them shield the radiation. The fuel elements are dissolved in concentrated nitric acid [3].The fuel elements contain uranium and plutonium. Plutonium is produced during the course of nuclear power production, where U-238 absorbs a neutron to become U-239 which undergoes two successive beta (β^-) decays to form Pu-239 with neptunium Np-239 as an intermediate. This is shown in the following reaction:

$$^{238}U_{92} + n \rightarrow {}^{239}U_{92} \xrightarrow{\beta^-} {}^{239}Np_{93} \xrightarrow{\beta^-} {}^{239}Pu_{94}$$

Chemical separation of uranium and plutonium is then undertaken by solvent extraction. Uranium is returned to the input side of the fuel cycle - to the conversion plant prior to re-enrichment [5]. The plutonium, as an oxide, is then mixed with depleted uranium left over from an enrichment plant to form fresh mixed oxide fuel (MOX, which is UO_2+PuO_2), consisting of about 7% plutonium mixed with depleted uranium, is equivalent to uranium oxide fuel enriched to about 4.5% U-235, assuming that the plutonium has about 60-65% Pu-239. The remaining liquid after Pu and U are removed is high-level waste, containing about 3% of the spent fuel in the form of fission products and minor actinides (Np, Am, Cm). It is highly radioactive and continues to generate a lot of heat. It is conditioned by calcination and incorporation of the dry material into borosilicate glass.

- **Pyro-processing**

Pyro-metallurgical processing ('pyro-processing') to separate nuclides from a radioactive waste stream involve several techniques like volatilization, liquid-liquid extraction using immiscible metal-metal phases or metal-salt phases, electro-refining in molten salt, fractional crystallization, etc [2]. They are generally based on the use of either fused (low-melting point) salts such as chlorides or fluorides (eg. LiCl+KCl or LiF+CaF_2) or fused Separating (partitioning) the actinides contained in a fused salt bath involves electrodeposition on a cathode, extraction between the salt bath and a molten metal (e.g. Li) or oxide precipitation from the salt bath. The uranium metal fuel is dissolved in LiCl+KCl molten bath, the U is deposited on a solid cathode, while the stainless steel cladding and noble metal fission products remain in the anode and are consolidated by melting to form a durable metallic waste form. The transuranics and fission products in salt are then incorporated into a zeolite matrix which is hot pressed into a ceramic composite waste.

- **Transmutation**

Transmutation of one radionuclide into another is achieved by neutron bombardment in a nuclear reactor or accelerator-driven device [3]. A high-energy proton beam hitting a heavy metal target produces a shower of neutrons. The fuel may be uranium, plutonium or thorium, possibly mixed with long-lived wastes from conventional reactors. The objective is to change long-lived actinides and fission products into significantly shorter-lived nuclides. Some radiotoxic nuclides, such as Pu-239 and the long-lived fission products Tc-99 and I-129, can be transmuted (fissioned, in the case of Pu-239) with thermal (slow) neutrons. The minor actinides Np, Am and Cm (as well as the higher isotopes of plutonium) [4], all highly radiotoxic, are much more readily destroyed by fissioning in a fast neutron energy spectrum, where they can also contribute to the generation of power.

- **SYNROCK**

Synroc is a particular kind of "Synthetic Rock", comprising geo-chemically stable natural titanate minerals that have immobilized uranium and thorium for billions of years. These can incorporate into their crystal structures nearly all of the elements present in high-level radioactive waste (HLW) and so immobilize them. Originally some 57% of Synroc was titanium dioxide (TiO_2). Synroc can take various forms depending on its specific use and can be tailored to immobilize particular components in the HLW. The original form, Synroc-C, was intended mainly for the immobilization of liquid HLW arising from the reprocessing of light water reactor fuel. The main minerals in Synroc-C are hollandite ($BaAl_2Ti_6O_{16}$), zirconolite ($CaZrTi_2O_7$) and perovskite ($CaTiO_3$). Zirconolite and perovskite are the major hosts for long-lived actinides such as plutonium (Pu), though perovskite is principally for strontium (Sr) and barium (Ba). Hollandite principally immobilizes cesium (Cs), along with potassium (K), rubidium (Rb) and barium. Synroc-C can hold up to 30% HLW by weight.

4. Disposal of nuclear wastes

The following are the aspects to be considered for the disposal [5] of nuclear wastes:

- Immobilize waste in an insoluble matrix, eg borosilicate glass, Synroc (or leave them as uranium oxide fuel pellets - a ceramic).
- Seal inside a corrosion-resistant container, eg stainless steel.
- In wet rock: surround containers with bentonite clay to inhibit groundwater movement.
- Locate deep underground in a stable rock structure.
- Site the repository in a remote location.

There are three types of disposal options considered: shallow earthen structures, belowground vaults and an underground mine.

- **Shallow earthen mines**, commonly referred to as engineered trenches, are generally preferred for the disposal of low-level waste in dry climates region [5]. It involves placing waste on a stable structural pad with clay barrier walls. The containers are tightly stacked and compacted with earth sand and gravel.
- **Below ground vaults** are sub-surface reinforced concrete structures. The containers are stacked as in shallow mines [5] and a permanent roof slab of reinforced concrete is installed once the vault is full.
- **An underground mine** disposal facility could be a previously existing mine or an excavation constructed specifically for the disposal of low level waste.

While deep geological disposal of nuclear wastes is potentially permanent, if it is desired to make them retrievable by future generations there is no problem with enabling this, and provision for it can readily be made. The question of cost is important.

5. Results and discussion

The overall study of the nuclear power production and the disposal of the radioactive wastes suggest that at present no foolproof solution for this problem. There is widespread environmental concern about reprocessing, its transport issues, environmental discharges and waste production.

The negative side of reprocessing that was identified during the course of this study is:

- Reprocessing causes the transport by road, rail and sea of spent fuel to a reprocessing plant and the return transport of the resulting high-level waste and plutonium from the plants of the most hazardous shipments of toxic waste there are today [4].
- Commercial reprocessing of spent fuel results in huge discharges of radioactivity into the sea and atmosphere - virtually all of Europe's radioactive pollution comes from reprocessing plants - and its marine pollution has been measured as far away as the west coast of Greenland.
- Reprocessing of spent fuel increases the volume of radioactive waste by up to 160 times. The amount of actual radioactivity is not changed - the industrial process of reprocessing just spreads the radioactivity over a vastly greater volume. Most of the waste is low-level, but there is also plutonium-contaminated intermediate-level waste and a small quantity of high-level waste which is so radioactive and hot it must be continually cooled for at least 50 years before anything can be done with it.
- There is widespread concern about the health risks of reprocessing, especially clusters of childhood leukemia around reprocessing plants.
- Finally reprocessing is the only way of producing plutonium for use in nuclear weapons.

Instead of reprocessing it can be argued that spent fuel, like other nuclear waste, should be stored above ground at, or as near as possible, to the point of production. But here again the concentration of uranium and plutonium is so high that direct storage of spent fuel may lead to further complications. Though the geological repositories for dumping are carefully selected it will also be vulnerable to natural disasters like earthquakes and volcanoes and also terrorist strikes.

The overall study raises the following questions (Q) for which the possible suggestions (A) are provided below:

Q1. How are the environmental effects that arise due to power generated from nuclear reactors different from that which arises from coal fired boilers?

A1. The production of electricity from any form of primary energy has some environmental effect. A balanced assessment of nuclear power requires comparison of its hazards and environmental effects with those of the principal alternative, coal-fired electricity generation. A comparative study on the wastes generated from the nuclear power plant and the coal fired plant is shown in Table-1.

We can see that the gases emitted from the nuclear power generation are the least when compared to that of power generated from coal, gas and hydro. Thus switching over to nuclear power generation would drastically reduce the emission of greenhouse gases, and thereby reduce the global warming. But there are so many other uncertain factors regarding the hazards concerning nuclear power that at present such a drastic change to nuclear power cannot be made.

Q2. What other industrial wastes decay over time so that their hazard steadily diminishes?
A2. It is relevant to compare the toxicity of nuclear wastes with that of common industrial

poisons and poisonous gases used every day by industry. Arsenic, of course, is routinely distributed to the environment as an herbicide and in treated timbers. Unlike nuclear wastes, it has an infinite life. Barium is not uncommon, and chlorine is in widespread domestic and industrial use. Considering the quantities available, these are arguably more hazardous than nuclear wastes.

Table 1. A comparative study between hazards due to nuclear power and power generated from coal.

Serial No.	Nuclear power	Coal fired power
1.	The mining of uranium has several disadvantages. The presence of radon gas and other radioactive elements like radium makes uranium mining hazardous. Most of the mines are open cut so that they are naturally ventilated. At a uranium mine ordinary operating procedures normally ensure that there is no significant water or air pollution.	The environmental effect of coal mining today is also small except that larger tracts may require subsequent rehabilitation, and in certain areas acid mine drainage can be a problem.
2.	Nuclear power stations and reprocessing plants release small quantities of radioactive gases (e.g, krypton-85 and xenon-133) and iodine-131.	In the case of coal combustion small quantities of uranium, radium and thorium present in the coal cause the fly ash to be radioactive, the level varying considerably.
3.	If uranium is used in a nuclear power reactor, these emissions do not occur.Every 22 tonnes of uranium (26 t U_3O_8) used saves about one million tonnes of CO_2 relative to coal.	Every 1000 MWe power station running on black coal means CO_2 emissions of about 7 million tones per year. If brown coal is used, the amount is about 9 million tones. Also huge amounts of sulphur dioxide and oxides of nitrogen are released
4.	According to various statistics the accidents involved in a nuclear reactor are very few. But even a minor accident can caused significant damage to human life and continue to affect the generations to come	A major reason for coal showing up unfavorably is the huge amount of it which must be mined and transported to supply even a single large power station as they are not located close to the mining areas
5.	A person living next to a nuclear power plant receives less radiation from it than from a few hours flying each year deemed unacceptable.	Anyone downwind of a coal-fired power plant can expect it to have an effect on the air quality, possibly even to the extent of affecting health accidental exposures as well as predictable normal exposures.

(*1) see Fig-1. Comparison between the emission of greenhouse gases from various sources.

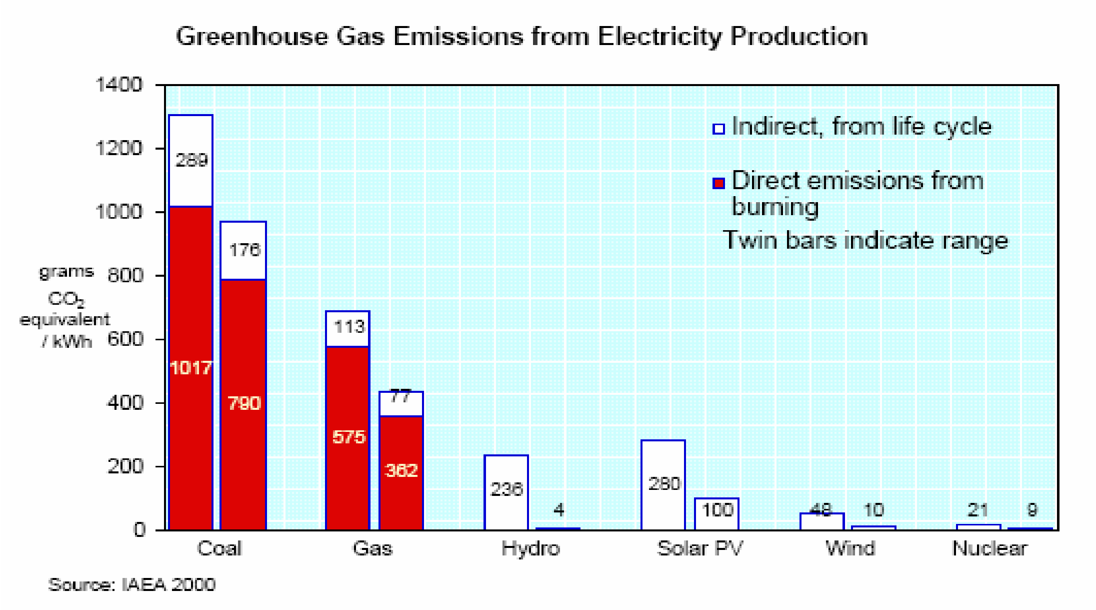

Fig. 1. Comparison between the emission of greenhouse gases from various sources.

Q3. What can be done with the existing waste?

A3. This is a question of solidarity and responsibility towards us, the coming generations and even towards life itself. The utmost must be done, with all available resources as soon as possible, to take care of the waste that already exists. Otherwise, the whole problem will be left to the coming generations. This means that people opposed to nuclear power must not only support meaningful research but demand that it be given all resources that can be mobilized.

Q4. What right do we have to produce more waste?

A4. For this question, judgment must be based upon the technical and scientific possibilities for finding a solution that eliminates the danger now and forever. We must guarantee the utmost safety for the wastes for hundreds of thousands of years in the future.

Q5. Will society be able to build, operate and guard the necessary facilities? And how many of the approximately 30 countries embroiled in nuclear technology will be able to afford such costs?

A5. Perhaps most of the industrial countries, but not many third world countries. It is not realistic to think that the third world nations which presently struggle to meet their basic needs have the resources to set aside large sums of money for future nuclear waste programs.

Are we capable of judging how the coming generations of human beings will react to the nuclear waste they inherit? The unknown aspects are so great that it is not morally acceptable to produce nuclear waste based upon the hope of future solutions.

6. Conclusions

The continued use of nuclear power in the world is based on, among other things, the assumption that there is a solution to every waste problem. However, there is no natural law stating that every technical or scientific problem actually has a solution. The waste problem is not solved and may not have a satisfactory solution at all. The problem starts right from the mining of uranium ore to the disposal to the spent fuel. The questions posed expose the dangers to come as a result of nuclear waste. This objective of this paper is to understand the concept of nuclear waste production and its management. It can be safely concluded that with even with the technology available, we are still dependent on time to neutralize the radioactive waste. And only hope that future generations find a technology to achieve this or generate power by some other means.

References

[1] Jones PMS. Nuclear Power, Policy and Prospects, John Wiley and Sons, Chichester, 1987, pp. 131-155.
[2] Tomlinson RE. Radioactive Wastes from Nuclear Fuel Cycle, AICE, New York Vol.72, 1976, pp. 102-109.
[3] Rippon S. Nuclear Energy, William Heinemann Ltd., 1984, pp. 105-125. "Proceedings of the Second Nuclear Engg. and Science Conference", MIT, Vol 1., Pergamon Press, Symposium Publications Division, New York; 344-347:348-352.
[4] Gurnham CF. Industrial Wastewater Control, Academic Press, London, 1965; 429-451.
[5] Mawson CA. Management of Radioactive Wastes, D.Van.Nostrand Company, Inc., Canada, 1973.