Radioactive Waste: Types and Management

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Abstract

Radioactive waste is the waste that is left out after the use of radioactive materials in nuclear reactors or during the production of nuclear weapons. Since, exploitation of radioactive materials was done on a large scale in the past few decades which resulted in production of tremendous amount of radioactive waste, radioactive waste management is a necessary step to deal with it. If not properly disposed, irradiation from radioactive waste will cause serious problems to humans and to the environment. While preparing this paper sincere effort was taken to give a succinct account of: (1) radioactive waste generation in different parts of the world. (2) Classification. (3) Processing. (4) Storage & (5) Treatment of radioactive waste.

Keywords: Radioactive waste, spent nuclear fuel, HLW, LLW

INTRODUCTION

Radioactive wastes entail radioactive materials which are usually by-products of nuclear power generation and other applications of nuclear fission or nuclear technology, used in fields such as research and medicine. Radioactive waste is deleterious to most forms of life as well as the environment, and is regulated by government agencies in order to protect human health and the environment.

GENERATION OF RADIOACTIVE WASTE

Radioactive waste is generated from a number of sources like nuclear fuel cycle and nuclear weapons reprocessing, medical wastes, industrial wastes, as well as naturally occurring radioactive materials (NORM). Amongst all these nuclear fuel cycle and nuclear weapons produce majority of waste. In nuclear fuel cycle radioactive waste is generated in front end as well as at back end of the cycle. Waste from the front end of the nuclear fuel cycle is usually alpha-emitting waste from the extraction of uranium. It often contains radium and its decay products where the back end of the nuclear fuel cycle mostly contains spent fuel rods, contains fission products that emit beta and gamma radiation, and actinides that emit alpha particles, such as uranium-234, neptunium-237, plutonium-238 and americium-241, and even sometimes some neutron emitters such as californium (Cf).Waste from nuclear weapons reprocessing likely to contain alpha-emitting actinides such as Pu-239 which is a fissile material used in bombs, plus some material with much higher specific activities, such as Pu-238 or Po. It also contains beta or gamma emitting tritium and americium but in very small a mount.Medical wastes generally contain beta particle and gamma ray emitters. Y-90 for treating lymphoma , I-131 for treating thyroid cancer, Sr-89 for treating bone cancer, Ir-192 for brachytherapy, Co-60 for brachytherapy and external radiotherapy , Cs-137 for brachytherapy, external radiotherapy are few isotopes used for medication.

Naturally-Occurring Radioactive Materials (NORM) which potentially includes all radioactive elements found in the environment. However, the term is used more specifically for all naturally occurring radioactive materials where human activities have increased the potential for exposure compared with the unaltered situation. Long-lived radioactive elements such as uranium, thorium and potassium and any of their decay products, such as radium and radon are examples of NORM. These elements have always been present in the Earth's crust and atmosphere, and are concentrated in some places, such as uranium ore bodies which may be mined.

The coal industry, oil and gas industry, metal mining and smelting,mineral sands, fertilizers industry, Building industry are few industries generally contain NORM.As of May 2014, there are 437 nuclear reactors operating for electricity generation and more 70 new nuclear plants are under construction. Over the past four decades, the entire industry has produced 71,780 metric tons of used nuclear fuel.

High-level radioactive waste is the byproduct of recycling used nuclear fuel, which in its final form will be disposed of in a permanent disposal facility. Where spent nuclear fuel is about 95 percent uranium. About 1 percent are other heavy elements such as curium, americium and plutonium-239, best known as fuel for nuclear weapons. Each has an extremely long half-life – some take hundreds of thousands of years to lose all of their radioactive potency.[1]

A typical nuclear power plant in a year generates 20 metric tons of used nuclear fuel. The U.S. has 71,862 tons of the waste but the nation has no place to permanently store the material, which stays dangerous for tens of thousands of years.

Illinois has 9,301 tons of spent nuclear fuel at its power plants, the most of any state in the country, according to industry figures. It is followed by Pennsylvania with 6,446 tons; 4,290 in South Carolina and approximately 3,780 tons each for New York and North Carolina. Japan on the other hand produces 20,000 tons of spent nuclear fuel by its nuclear power program. The quantity of fission product i.e. spent nuclear fuel produced each year at a full-sized commercial nuclear power plants is approximately 50,000 times the fission products of the Hiroshima bomb are created by Japanese nuclear power plants each year. Most of this waste is being temporarily stored at nuclear power plant sites and must remain segregated from the natural environment. [1]Australia produces about 45 cubic meters of radioactive wastes arising from these uses and from the manufacture of the isotopes – about 40 m^3 low-level wastes (LLW) and 5 m^3 intermediate-level wastes (ILW). By comparison, Britain and France each produce annually around 25,000 m of low level waste.

Transuranic waste began accumulating in the 1940s with the beginning of the United State's nuclear defense program. It is found that bedded salt which is free of fresh flowing water, easily mined, impermeable and geologically stable is an ideal medium for permanently isolating radioactive wastes from the environment.

TYPES OF RADIOACTIVE WASTE

There are five general types of radioactive waste according to The Environmental Protection Agency (EPA) which are as follows:

1. Low-level waste (LLW)-contaminated industrial waste.
2. Transuranic waste (TRUW) from the production of nuclear weapons.
3. Uranium mill tailings from the mining and milling of uranium ore.
4. Spent nuclear fuel (SNF) from reactors and High-level waste (HLW) Spent reactor fuel and other highly radioactive wastes generated at reprocessing plants.
5. Naturally occurring radioactive materials (NORM)

CLASSIFICATION OF RADIOACTIVE WASTE

Classification of radioactive waste differs from country to country. However, the INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) [3], which publishes the Radioactive Waste Safety Standards (RADWASS), has classified the radioactive waste into six categories which are as follows:

A . Exempt waste (EW).
B. Very short lived waste (VSLW).
C. Very low level waste (VLLW)
D. Low level waste (LLW).
E. Intermediate level waste (ILW).
F. High level waste (HLW).

A. Exempt waste (EW)

Exempt waste contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists of small concentrations of radio nuclides that it does not require provisions for protection from radiation. It consist material such as concrete, plaster, bricks, metals produced during operations on nuclear power sites. Such materials are not harmful and hence do not require disposal facility for it.

B. Very short lived waste (VSLW)

Very short lived waste (VSLW) has radio nuclides of very short half-life. his type of waste is harmful for short period of time as it undergoes radioactive decay in short period of time. Such waste is stored until the activity falls to the level of exempt waste where it is not harmful to an environment. Radioactive waste from industrial and medical applications which usually has short half-lives is examples of very short lived waste.

C. Very low level waste (VLLW)

The waste which arises from the operation and decommissioning of nuclear facilities with levels of activity concentration in the zone near or slightly above the levels specified for the clearance of waste material from regulatory control is called as VLLW. Waste with such a limited hazard, which above or close to the levels for exempt waste, is termed very low level waste. Safety from radiations of such waste is achieved by its safe disposal in engineered surface landfill type facilities.

D. Low level waste (LLW)

Low level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle which mainly comprises of paper, rags, tools, clothing, filters, reactor water treatment residues, medical tubes, injection needles, syringes, etc. It contains mostly short-lived radioactive material in very small amount. It does not require shielding during handling and transport and is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. Low level waste can be deposited near surface level and does not require shielding during handling and transport. It ranges from radioactive waste with an activity content level just above that for VLLW to radioactive waste with a level of activity concentration such that shielding is necessary for periods up to several hundred years. Low level wastes are disposed at varying depths from the surface down to 30 m.

E. Intermediate level waste (ILW)

Intermediate level waste is defined as waste containing long lived radio nuclides in quantities that need more isolation from the environment and generally require shielding. For example, the reactor's metal

cladding, resins, chemical sludge is classified as intermediate-level waste. Disposal of ILW is carried out at a depth ranging from a few tens to few hundred's of meter. It may be solidified in concrete or bitumen for safe disposal. Intermediate-level waste consist 7% of the
volume, and 4% of the radioactivity, of the world's radioactive waste.

F . High level waste (HLW)

High-level waste, such as that produced from reprocessing of spent nuclear fuel, accounts for just 3% of the volume, but 95% of the radioactivity, of the world's radioactive waste. High-level waste (HLW) is generated from the uranium fuel
and transuranic elements present in the nuclear reactor core. These materials are highly radioactive and have high temperature requiring shielding as well as cooling. HLW is mainly present in spent fuel and Separated waste from reprocessing the used fuel. It contains large concentrations of both short and long lived radio nuclides. Every year 12000 metric tons of new HLW is generated worldwide which can have innumerable harmful effects on an environment and hence, disposing it safely is of utmost importance. Recycling spent nuclear fuel is one of the ways available but as separated waste itself contains HLW, it is not a total solution. And thus, process of burying HLW deep inside geologically is the safest way to dispose this type.

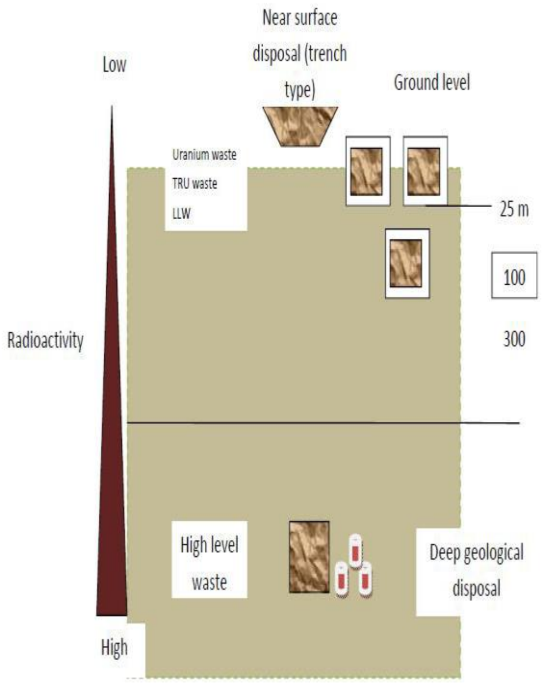

Fig 1: Disposal of Radioactive waste based on amount of radioactiveity. Source: Japan atomic energy agency. [2]

PROCESSING OF RADIOACTIVE WASTE

The basis of radioactive waste management is not difficult.Although, radioactive materials become less radioactive over a given time, the best way to dispose radioactive waste is to store them till they lose their radioactivity. Different radioactive materials have different half-lives, implying
different storage times. For example, cobalt-60, a radioactive isotope having a half life of 5 years has been used widely in medical field for cancer
treatment. Thus, 2 pounds of radioactive cobalt-60 five years later would decay to a one pound. Every five years the quantity decreases to half its original. Thus, after 10 half-lives have elapsed, the material becomes non radioactive.

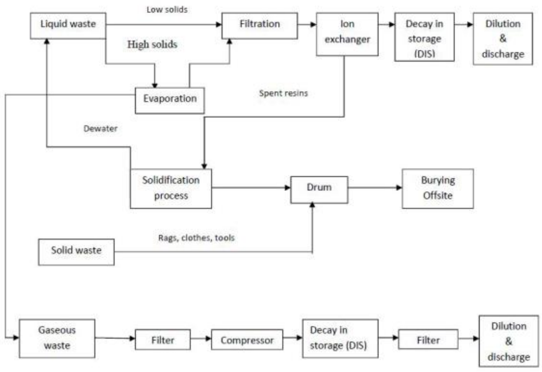

Fig 2: Block diagram of radioactive waste handling system. Source: [6]

Very short-lived radioactive wastes are disposed of by storing them in buildings until they are nonradioactive. HLW from nuclear fuel cycle require storage of thousand years, whereas ILW and LLW need hundred year or less for becoming non radioactive. [11] Since solids, liquids, and gases have different characteristics, each must be processed differently. The waste must also be
processed in such a manner as to minimize the risk of exposure to the public. The above block diagram shows the layout of a simple handling system for radioactive waste. Liquids are processed to remove the radioactive impurities.

These processes include [6]:

1. Filtering.
2. Routing through demineralizers,
3. Boiling off the water leading to evaporation which leaves
solid particles which are further treated as solid radioactive
wastes.
4. Storing the liquid for a specific time thereby allowing Decay in storage (DIS)

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After processing, the water has to be sampled. If samples indicate the water meets the required standards, water can be placed in the storage tanks for use in the plant or is safe to be released to the environment. If the sample does not satisfy the required standards, it will be sent for reprocessing. Materials remaining after evaporation will be mixed with some other material to form a solid a composite material such as ducrete. After mixing with a hardener, the material is processed as
solid radioactive waste.In the case of Gaseous wastes, they are filtered, compressed to take up less space, and are allowed to decay for some time period. After the required time has elapsed, a sampling test will be

done for the gases. If the required standards are fulfilled, the gases will be released to the atmosphere, or sometimes the gases will be reused in specific areas of the plant.

STORAGE AND DISPOSAL O F RADIOACTIVE WASTE

A. Deep geological repository.
B . Spent fuel pool.
C. Dry cask storage.
D. Ducrete.

A. Deep geological repository

A deep geological repository is provided beneath the ground level so as to provide storage for the HLW and to ensure safety from the radiations which can be deleterious to humans.

By providing such a facility it is made sure that the storage of radioactive waste is not affected by the human activity. It consists of a series of barriers naturally existing or technical built. These barriers provide radiation shield. [7]

In 2002, USA's DOE along with the Congress agreed upon the need for creating a facility for storage of the country's nuclear waste and used nuclear fuel. This led to the commission of a deep geological repository in Yucca Mountain. The Yucca Mountain was suitable due to various factors such as the geology of the location, hydrology and its dry climate. The deep geological repository at the Yucca Mountain allowed for the retrieval of the waste that was dumped. Since, large quantities of plutonium and uranium was stored in the repository, it was important that it allowed for the retrieval of these wastes in the future and thereby allowing the waste material to be recycled. [8] The waste isolation pilot plant (WIPP) in New Mexico, inculcated the irretrievability of the nuclear waste that was stored in the salts. This provided complete protection from radiation to humans, thus, allowing the transuranic waste to be stored for at least 10,000 years. While TRU is different from the high level waste that generated from use of nuclear fuel, the safe disposal of TRU in WIPP not only showed licensing process for a long term nuclear waste storage facility, but also opened up avenues for data and analysis on the geology, hydrology, chemistry and other scientific disciplines of waste disposal in salt. [8]

B. Spent fuel pool (SFP)

Spent fuel pools contain thermally controlled water, since, water serves as a natural and effective barrier to radiation [9]. As a result, spent fuel generated from nuclear fuel cycle is stored in these pools. When the spent fuel is removed from the reactor to be exchanged with new fuel, it is required that it is stored for a period of time in the spent fuel pool. The spent fuel must be kept under water due to the heat being generated by the decay of the fission products which helps in limiting the radiation levels in the area of the spent fuel pool. In course of time, the heat generated by spent fuel abates. This spent fuel is then transferred to the ground level where it is stored in specially designed casks which provide radiation shielding.

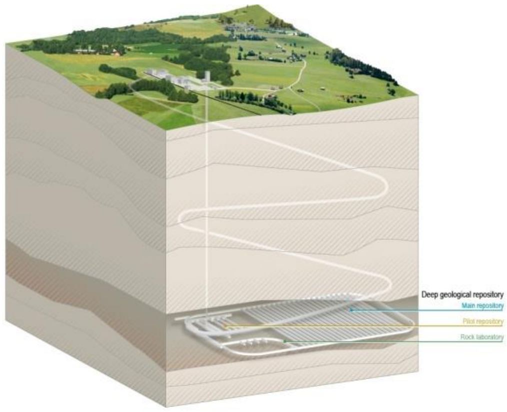

Fig 3: model for Deep Geological Repository
. Source: [7]

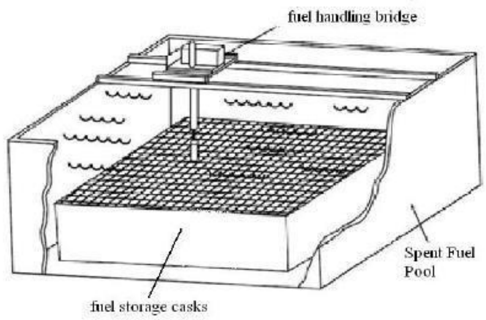

Fig 4: Schematic diagram of Spent Fuel Pool.
Source: [6]

C. Dry Cask Storage

After the HLW is cooled inside the spent fuel pool the radioactive waste is transferred to dry cask storage at the ground level. Casks are fabricated with steel which are either welded or bolted closed. The fuel rods inside are surrounded by inert gas. Ideally, the steel cylinder provides leak-tight containment of the spent fuel. Each cylinder is surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and people moving around it. Some Casks can be used for transportation as well storage purposes.

D. Ducrete

Depleted uranium concrete (DUCRETE) was developed at Idaho National Engineering and Environmental Laboratory (INEEL) [10] to restrain the neutrons emitted from materials of spent fuel pool and High level wastes, as a neutron shield. It contains uranium based aggregate and conventional concrete ingredients. The compression test results showed that the compressive strength of Ducrete is equivalent to that of the traditional concrete. The high density of Ducrete allows for liberty in the design of the cask to be considerably smaller in diameter than concrete casks. Since the cask cannot transport spent fuel, it can be

transported empty from the manufacturing facility to a storage site and later to a repository location. This feature facilitates
an economic advantage as current concrete storage systems cannot be transported, and, have to be built at each location where they are used.

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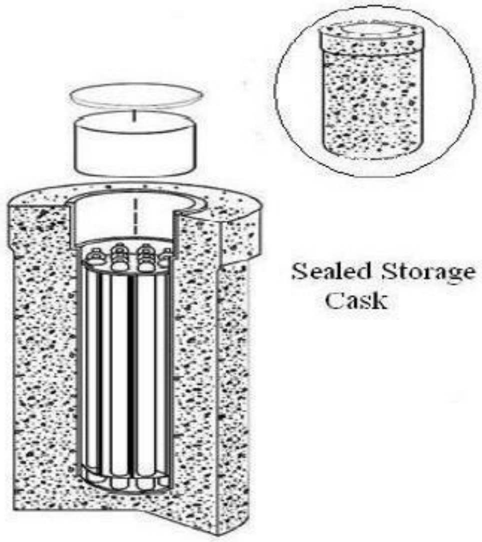

Fig 5: Schematic diagram of a Storage Cask.
Source: [6]

TREATMENT OF RADIOACTIVE WASTE

A. Radioactive waste Transmutation

In simple words, radioactive waste transmutation is method in which radioactive isotopes are converted into non radioactive isotopes. One example of radioactive waste transmutation is the radioactive isotope of iodine-129 which is a long lived and requires difficult disposal strategies. The radioactivity of iodine-129 is eliminated by bombarding it with neutrons, as it absorbs the neutron it gets converted into non radioactive
Xenon isotope.

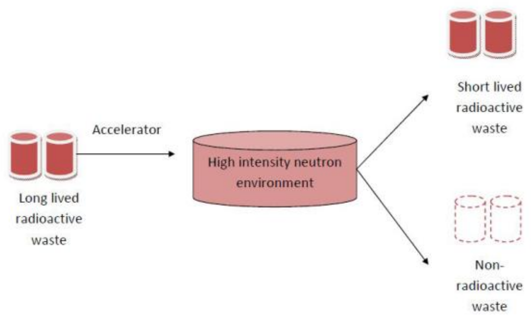

Fig 6 : process of nuclear transmutation. Source: [5]

B. Vitrification

Storage of radioactive waste for long period of time requires the waste into a form which will neither react nor degrade forextended periods of time and vitrification is one such method used to store it for long period. In this process, high-level waste is mixed with sugar and then calcined. Calcination is the process of passing the radioactive waste through a rotating tube, water from the waste is evaporated and de-nitrates the fission products to serve the stability of the glass produced. Most high-level wastes arise in a liquid form. Hence they are initially calcined which turns them into a solid form as water is evaporated from the waste. This product is then incorporated into molten glass in a stainless container and allowed to cool, giving a solid matrix and are stored. This process is being used in many countries including India, France, Japan, UK and USA and is the most preferred and safe process for management of separated HLW generated from
reprocessing. India has a unique distinction of having operating vitrification plant at Tarapur and Trombay.

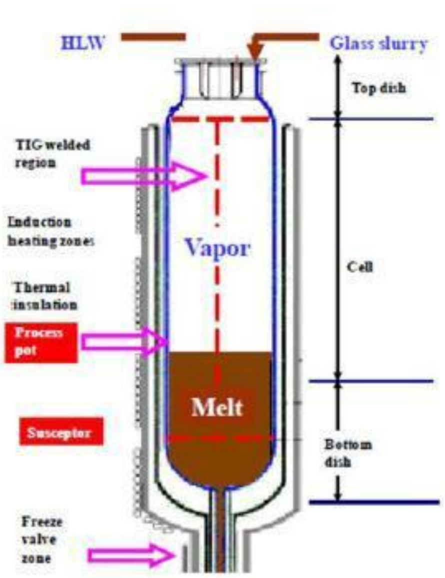

Fig 7: Schematic diagram of pot Melter used for Vitrification of HLW: Trombay

CONCLUSION

Radioactive waste must be diligently identified, classified, stored, transported, and disposed off after appropriate treatment. With the growth in number of nuclear reactors and mass production of nuclear weapons in different parts of the world, the radioactive waste generation has seen a significant increase. It is important to reduce the radioactivity of the high level waste which can be achieved by nuclear transmutation. Similarly, other methods of reprocessing such as using the low level radioactive waste in useable products like ducrete and vitrified products must be made possible. In sum, by wisely following the rules and regulations of radioactive waste management, public and the environment will be safeguarded by irradiation from the deleterious radioactive waste.

References

[1] World Statistics. Nuclear Energy Institute. [Online] http://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics.
[2] Nuclear Waste. Green action. [Online] http://www.greenactionjapan.org/modules/english0/index.php?id=8.
[3] CLASSIFICATION OF RADIOACTIVE WASTE. International Atomic Energy Agency. Vienna : IAEA, 2009. GSG-1.
[4] Japan atomic energy agency. Description of Radioactive Waste Disposal
in JAPAN. [Online]

http://www.jaea.go.jp/english/04/ntokai/backend/backend_01_04.html.
[5] Forsberg, charles W. strategies for radwaste management. ORNL.
[Online] http://web.ornl.gov/info/ornlreview/rev26-2/text/radmain.html.
[6] reactor concepts manual. USNRC technical training center. Vol. 10.
[7] swiss federal nuclear safety insoectorate. Ensi. [Online]
http://www.ensi.ch/en/waste-disposal/deep-geological-repository/.
[8] US member of commerce, Revisiting America's nuclear waste policy.
Institute for 21st Century Energy. s.l. : US member of commerce, 2009.
[9] Entergy corporation. Indian point energy center. [Online] Entergy
corporation. http://www.safesecurevital.com/safe-secure-vital/spent fuel.
html.
[10] W. J. Quapp, Starmet CMI,W. H. Miller, University of Missouri-
Columbia,James Taylor, Starmet CMI,Colin Hundley, Starmet
CMI,Nancy Levoy, Starmet Corporation DUCRETE: A Cost Effective
Radiation Shielding Material.. Chattanooga, TN : s.n., 2000.
[11] nuclear energy agency. partitioning and transmutation: making wastes
non radioactive. [Online] ORNL.
http://web.ornl.gov/info/ornlreview/rev26-2/text/radside1.html.
[12] BARC,DAE,Government of India. Radioactive Waste Management:
Indian scenario. Bhabha atomic research centre. [Online]
http://www.barc.gov.in/pubaware/nw_n4.html.