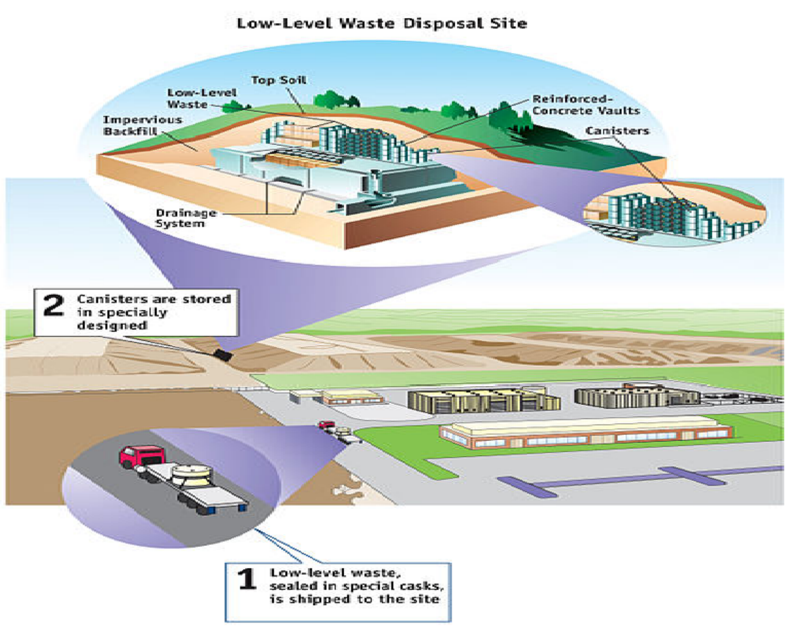
Nuclear Waste...what to do with it?
-Nirupama Sensharma

Radioactive waste is usually produced as a byproduct of electricity generation in a nuclear power plant or other applications of nuclear technology such as medicine and research. It is commonly referred to as *Radwaste.* Radwaste can be either in solid, liquid or gaseous form.

Nuclear waste is a cause for concern because it is *non-biodegradable*, meaning that it does not decompose naturally. Secondly, it causes a number of health hazards for anyone who comes into contact with the radiation emitted from this waste. Its disposal and treatment hence requires extreme precaution and care. Various government regulatory bodies have been set up to govern the nuclear waste disposal process.

The major sources that produce nuclear waste are:
1) Spent fuel from nuclear reactors
2) Waste left after reprocessing of spent fuel
3) Waste obtained from dismantling of nuclear weapons
4) Waste from industrial, medical and other sectors

The waste coming out of a nuclear reactor is usually the spent fuel. It consists of the particles left behind after the splitting of uranium atoms and might also contain some quantity of unused uranium and plutonium. Over time, these accumulate within the reactor and need to be taken out and replaced with fresh fuel for efficient operation of the reactor. The radioactive products in the spent fuel decay over time but some of them are extremely long lived. For example, Plutonium-239 has a half-life of 24,000 years (*Half-life is the time it takes for a radioactive nucleus to decay to half its original number)*. It means that these will remain active for a very long time and therefore must be shielded from humans and the environment in an effective and efficient manner.



Radioactive waste is usually characterized as *Low-Level* and *High-Level waste*. Low-Level waste usually includes material used to handle the highly radioactive parts of nuclear reactors and waste from medical procedures like rags, paper, tools, filters etc. It is easy to dispose off. The activity level of the products involved is relatively small such that it can decay and reduce its radioactivity to a safe level within a small time. Temporary storage for a period of 10 to 50 years in shallow landfill sites is usually employed for such kind of waste. Post that, the waste is safe enough and can be disposed off as normal refuse. Worldwide, low-level waste comprises 97% of the total volume but only 5% of the radioactivity of all the nuclear waste produced.

Storage of nuclear waste demands a proper handling as well. There are different ways of handling the different forms of radioactive waste. Any solid waste is at first retained or stored in safe locations and tests are conducted to identify the nature of the waste. If the waste is produced in a large volume, the first step is to put it in an incinerator and the ashes are sent to labs for proper analysis. This is then followed by a proper disposal in accordance with safety norms. Examples include contaminated equipments, clothing etc.

To deal with liquid wastes, its activity is checked and monitored as the first step. If the activity is found to be low enough to pose any threat, the liquid waste is diluted and released in the sea. However if the activity is found to be high, the liquid waste is concentrated and contained until the activity levels fall below the danger levels as specified by the Government and other regulatory bodies.

Gaseous wastes are also dealt with in a similar manner as liquid wastes. They are held for some time to monitor activity. When the activity comes down below any possible danger levels, the contaminated gas is diluted and released high in the air through a stack.

The principle followed for the dilution and release of any kind of waste by monitoring its activity is based on *ALARA (A*s *L*ow *A*s *R*easonably *A*chievable). The waste is treated or contained for as long as it takes for the activity to reduce to as low levels as possible. Only after such a stage is reached, the waste in it gaseous or liquid form is released.

The second kind is the *High-Level* waste. It consists of the spent fuel itself and the waste generated from radioactive reprocessing facilities. High-Level waste includes considerable quantities of uranium, plutonium and other highly radioactive elements formed within the reactor. Most of these emit large amounts of radiation and produce considerable heat. This leads to additional requirements of cooling as well as special shielding during handling and transport. Also, these are extremely long lived (some longer than 100,000 years) requiring them to be stored for very long periods to allow the activity level to settle down to a safe value. High-Level waste comprises only 3% of the total volume but 95% of the radioactivity of all the nuclear waste produced.

Depending on the activity level of waste, it requires either a *short-term* or a *long-term* storage. A 10 year storage is usually recommended for any kind of nuclear waste. This process is called *Decay-and-Delay*. The reduction in radioactivity during short-term storage makes handling and shipment of nuclear waste much easier.

Long term storage is usually employed for high-level wastes. Long term refers to a period of thousands of years. There are specific regulatory bodies that ensure the safety and security of this kind of waste over geologic time periods. It is ensured that the waste does not escape to the outside environment by any accident, natural calamities like earthquakes or any malicious action. The security is maintained over the time that the waste requires to decay to safe levels.

At present, the only viable option for a long-term storage is to create large stable rock formations on land. Containers made of borosilicate glass are filled up with nuclear waste. This glass has the capacity to prevent any nuclear radiation from leaking out. The container is enclosed in yet another water-tight metal container and buried deep underground. Such underground burial locations are usually chosen to be in a less-populated area. This method of disposal by burial depends on the natural decaying ability of the radioactive materials. The waste is buried deep under the earth for thousands of years and allowed to settle into a safe level of activity.

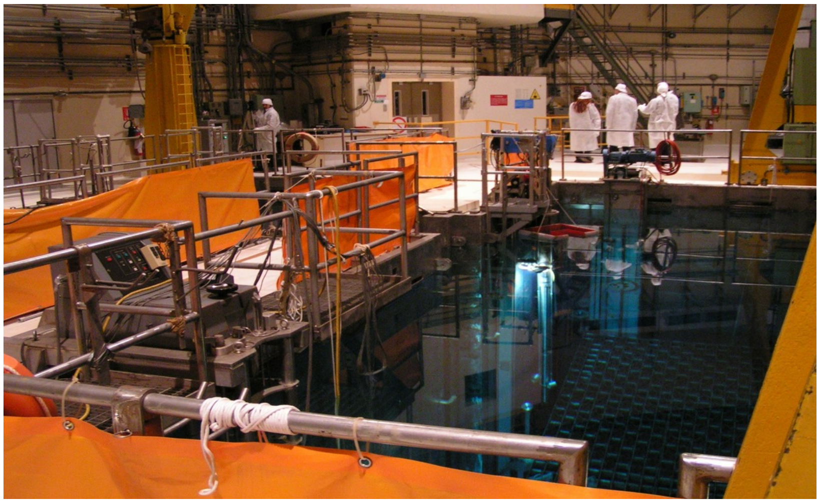
Long-term storage in such glass containers under the sea-bed is another option that might be considered. There is little groundwater circulation under the sea-bed thereby reducing the possibility of radioactive material contaminating ground water available for human consumption. However this method of disposal involves enormous cost and the difficulty of burying the waste under the sea is also great. These drawbacks are at present keeping us away from exploring this option.

Reprocessing is a viable long-term method for dealing with nuclear waste. This process involves taking the waste and separating the components depending on their usefulness. Reprocessing is usually carried out for the spent fuel taken out of a power reactor. Since the spent fuel can have appreciable amounts of unused uranium and plutonium, the reprocessing can enable us to separate these unused elements and reuse them in another reactor cycle. Nuclear reprocessing reduces the volume of high-level waste but does not help in reducing the activity or heat generated by it. The waste that has been reprocessed but is not active enough to be used in a reactor, therefore would still need a geological waste repository.

Radioactive waste coming out of a reprocessing plant are mostly in gaseous and liquid form. The activity level of the wastes at this point is very high and needs special treatment. *Vitrification* is one treatment method that is generally employed at this point. Vitrification is done for stabilization of the waste into a form which will not react or degrade for an extended period. A series of steps involving chemical treatment changes the waste into a sludgy paste. This paste is fed into an induction furnace with fragmented glass. The molten fluid coming out of the furnace is poured into long cylindrical stainless steel containers. When cooled, the fluid vitrifies into a glass form which is a new substance in which the waste products are bonded into the glass matrix when it solidifies. This glass form is very highly resistant to attack by water and therefore serves as a very safe and contained disposal method for nuclear waste.

A typical 1000 MWe light water reactor plant discharges 30-35 megatons of spent fuel per year. This generates about 3.2 m^3 of high level solid waste in borosilicate glass matrix. If made into cylinders of 0.3 m diameter and 3 m length, only 15 such containers will be filled.

Another method of disposal employed for the high-level waste coming out of a reactor is storage in *Spent Fuel Pools*. These are typically 12 m deep storage pools situated at the reactor site and is specially designed for the reactor in which the fuel was used. Since spent fuel rods generate large amounts of heat and radiation, they are moved from the reactor and contained in the pool. Water quality of the pool is tightly controlled to prevent the fuel from degrading. The pool water is continuously cooled to remove the heat produced by the spent fuel assemblies. Pumps circulate water from the pool to heat exchangers and then back to the pool. The water temperature in normal operating conditions is held below 122^0F. The air in the room housing the pool is also continuously monitored and treated.



Spent Fuel pool from the shutdown Caorso Nuclear Power plant in Italy.

Spent nuclear fuel that has already been cooled in the pool for about a year is sent for *Dry Cask Storage*. It is another method of storing high-level radioactive waste. These casks are typically steel cylinders that are welded or bolted closed. These steel cylinders provide leak-tight containment of the spent fuel. Each cylinder is surrounded by additional steel, concrete or other material to provide radiation shielding to workers. Some of these cask designs can be used for both storage and transportation purposes.

Containers for Dry Cask Storage

Another scientific method is to convert the waste into *SYNROC*. Synroc is short for Synthetic Rock. It is composed of three minerals – hollandite, zirconolite and perovskite and a small amount of metal alloy. These are combined into a slurry and some portion of high-level waste is added to it. This mixture is then dried at 1382^0F to produce a powder which is then compressed within stainless steel containers at a temperature of 2102^0F. The result is a cylinder of hard, dense and black synthetic rock. If stored in a liquid form, nuclear waste can enter the environment and cause widespread damage. As a solid, these risks are greatly minimized.

Currently, no country has a complete system for storing high-level waste permanently but some countries are coming up with plans to start the procedure within the next ten years. All the proposed disposal techniques involve multiple barriers to isolate the waste from the environment for at least 100,000 years.

Since humans have never attempted to do anything on this sort of a timescale, most environmental groups have strongly opposed the disposal methods. Currently waste from Nuclear power plants is held in temporary storage facilities until Governments, regulatory bodies and environmental groups come to a common understanding of such long-term disposal methods.

It has been well understood that nuclear power is accompanied by nuclear waste. Though the amount of this waste is smaller than that produced by any other energy source, it definitely needs proper addressing of the disposal issues. Our long term dependence on Nuclear power will surely require long term plans under the explicit supervision of regulatory bodies to be incorporated.