# 1 NUCLEAR WASTE

## 1.1 HOW NUCLEAR REACTORS WORK

Fuel assemblies (consisting of numerous pellets) are added into the reactor as the fuel, with one pellet containing about the same amount of energy as a tonne of coal. These assemblies were filled with (typically) a mixture of uranium-235 and uranium-238 and are surrounded by ceramic and metals.

When a neutron collides with the uranium-235 atoms, that atom undergoes nuclear fission, which is a form of cluster decay; this in turn ejects even more neutrons, causing a chain reaction within the reactor. This is the fundamental principle of a nuclear reactor.

Nuclear fission is capable of generating large amounts of heat. Nuclear reactors and powerplants use this quality to generate electricity, by using this heat to evaporate water in vapour, which spins a turbine which generating electricity. However, the nuclear chain reaction used in a nuclear powerplant can quickly get out of hand – such as in the case of Chernobyl – and thus, to prevent overheating, water and control rods, which are made of neutron absorbing materials, are used. The water plays double duty here, acting as a coolant to control the heat in the reactor as well.

## 1.2 WASTAGE

Despite what public knowledge and media may say, nuclear reactor produces a surprisingly little amount of waste due to nuclear power's ability to extract large amount of energy from a little portion of; any waste is effectively contained within containment facilities run by various organisation around the world. This allows for the safe disposal of nuclear waste, unlike the by-products of fossil fuelled powerplant.

As well as that, nuclear power worldwide is predicted to produce about 400,000 tonnes of waste annually, however, it pales in comparison to the 33 billion tonnes of carbon dioxide produced by fossil fuels per year.

Furthermore, the depleted radioactive fuels can be recycled into more radioactive fuels which can continue to be reused within conventional nuclear reactors.

## 1.3 TYPES OF NUCLEAR WASTE

Nuclear waste is split up into three categories: low-level, intermediate-level, and high-level waste. Low-level waste is by far the most common form of nuclear waste, accounting for approximately

90% of the total volume of nuclear waste (see *Figure.1*). This includes items that have been lightly contaminated by radiation, such as the tools that are used in a nuclear reactor. Low-level waste is relatively easy to dispose of. They are compacted and stored in short-term storage and monitored carefully, and when it eventually becomes safe, is then disposed of as regular waste.

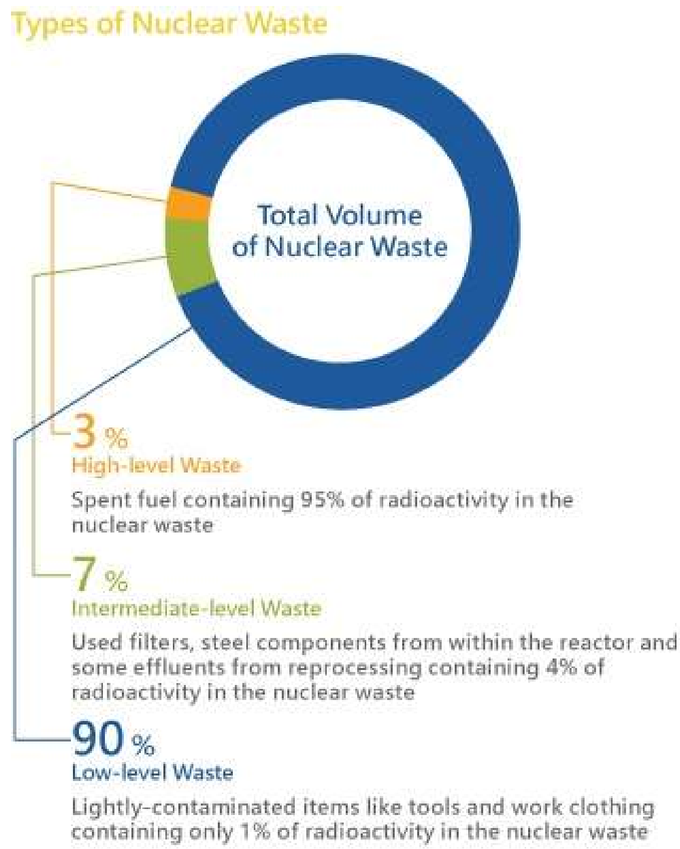


*Figure 1: A pie chart showing the portions of levels of nuclear waste*

Intermediate and high-level wastes are more dangerous and difficult to store, however, they are recyclable in most cases, which is employed by many countries. However, most countries have opted to store them in nuclear waste facilities (named repositories), such as Finland and the United States of America.

## 1.4 REPOSITORIES

By far the best way and easiest way of disposing of nuclear waste would be to store it deep underground until it decays enough to not be radioactive; a technique that is being implemented in the present and likely to continue being done so in the future. These facilities are known as repositories and are currently being used to store nuclear waste.

Several countries already have these repositories, while others are still undergoing the construction of them. Currently, large repositories are being built in both Sweden and Finland. Despite how undesirable these storage systems may seem, they are relatively safe, and there are no other great alternatives (yet) to storing nuclear waste.

For liquid nuclear waste, it is more difficult to store permanently in these repositories, as all the containers we build with eventually break over thousands of years; the time scaled needed for radioactive materials to decay. Currently, liquid nuclear waste is vitrified into glass, as this seems like a good alternative that will store these wastes for an extended period of time, but there is still uncertainty to how long "nuclear glass" can remain.

# 2 Nuclear Recycling

Rather than disposing of high-level nuclear waste, a great alternative would be to recycle these wastes. When considering this, it is important to understand that, in a nuclear reactor, uranium-235 is most often used as a main fuel, however, it comes mixed the much more common uranium-238, which is essentially useless. This means that only about 1% of the total possible energy is actually extracted in a nuclear powerplant, with most of it remaining in the uranium-238.

However, it is also this quality that makes nuclear fuel recyclable. If a neutron is added to uranium-238, it becomes uranium-239, which will quickly β decay (around 30 minutes) into neptunium-239, which in turn will become plutonium-239, which is another fuel that can be used in conventional nuclear reactors. Thus, nuclear fuel is recyclable.

## 2.1 Breeder Reactors

Breeder reactors are special nuclear reactors that can produce more fissile material than is put into the system. They can be likened to a standard nuclear reactor that has an inbuilt recycling system. Breeder reactors allow infertile material to become fertile, by hitting it with a neutron, making them unstable, which allows these reactors to utilise more of the energy in nuclear fuel; this makes them more efficient, but not quite renewable.

The reason that conventional reactors (using uranium-235) cannot do this is because the neutrons do not fly at a fast enough speed to transform uranium-238 to uranium-239. Thus, for breeder reactors that use uranium, they need to be fast reactors, meaning that the neutrons fly at a much higher speed than in a normal reactor.

However, this is still experimental technology, as it has not been developed due to fear that it would make nuclear weapons more accessible, as it will make the radioactive uranium-235 much more abundant.

## 2.2 THORIUM

The use of thorium-232 in nuclear reactors is an interesting proposition that has a lot of potential in the future to replace the standard uranium-235 reactors, and it comes with a variety of advantages, as well as some disadvantages.

Thorium on its own is not a fissile material and cannot undergo nuclear fission. However, similarly to uranium-238, it has the capability of transmuting into fissile element, making thorium-232 fertile. It must first have a neutron added to it, becoming thorium-233, which follows this decay chain: Thorium-233 $\xrightarrow{\beta}$ Protactinium-233 $\xrightarrow{\beta}$ Uranium-233.

Uranium-232 is another isotope of uranium that can undergo nuclear fission chains. Sadly, conventional reactors cannot use this thorium-uranium cycle, only the uranium-plutonium cycle, however, there exists massive thorium reserves in India (see *Figure.2*), and thus they are likely going to be the country leading thorium-reactor development.

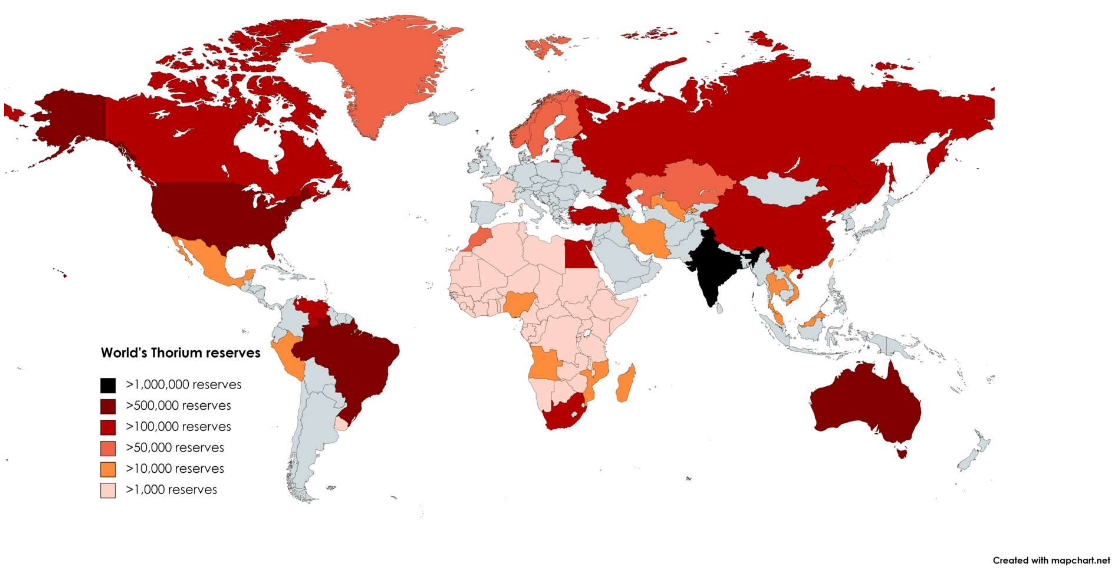


*Figure 2: A map showing the reserves of thorium in each country.*

Thorium is considered superior to uranium due to a variety of reasons. Firstly, there is more thorium that there is uranium on Earth (approximately 3 times more). Secondly, it does not produce any heavier elements unlike the uranium-plutonium cycle, meaning that the waste from thorium reactors will last considerably shorter than the waste of uranium reactors. Thirdly, it largely mitigates the ability to use it to create a bomb, as it itself is not fissile, and only the uranium-232 produced by it is.

However, the most interesting prospect for thorium is its possible usage in thorium breeder reactors, as thorium are perfectly suited for breeding. Thorium can use slow reactors, as much more neutrons are produced per fission reaction. The utilisation of thorium may encourage the development of breeder reactors, which will reduce the amount of nuclear waste that we produce.

# 3 CONCLUSION

Nuclear waste, although it may seem like a massive problem initially, appears to be not as grand of an issue, and certainly not as dangerous as the carbon emission from fossil fuel powerplants. Unlike the by-products of other types of powerplants, nuclear waste can be recycled, and such technologies exist in the present. Not only that, but everything we have not managed to recycle has designated long-term storage areas; such planning does not exist in other fields of energy. Additionally, nuclear power produces significantly less waste for an amount of energy, especially when compared to fossil fuels.

"Disposal and storage of radioactive waste is the fundamental problem associated with nuclear energy," is true in the sense that nuclear power produces waste that needs to be dealt with, but this is less of a statement that applies to nuclear power specifically, but rather any source of power.

On top of that, nuclear power still has lots of room to grow and develop, with new technologies that are currently under development, which can further mitigate the environmental impact of nuclear powerplants by reducing waste and increasing fuel efficiency. Nuclear powerplant is not yet sustainable, however, it is a good alternative to the dirty fossil fuel powerplants as we find a truly sustainable solution.

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