# What about the waste?

You probably already know that nuclear reactors make nuclear waste. But what is it? Is it wise to generate energy if this waste is produced? This page answers these questions, including how nuclear waste is produced, what its nature is, what the safe storage/treatment options are, and how it compares to waste generated by other energy sources.

# TL;DR (quick summary)

Nukes produce unbelievably little waste compared to other energy sources, and although it is toxic, we are confident that we have safe ways to store it until it has decayed to low levels. It should not dissuade us from deploying reactors to power substantial fraction of the planet. Also, advanced reactors offer ways to reduce waste further, and some can even recycle it (though this is not cheap).

# What is Nuclear Waste?

Nuclear waste is the material that nuclear fuel becomes after it is used in a reactor (/reactors.html). From the outside, it looks exactly like the fuel that was loaded into the reactor — assemblies of metal rods enclosing fuel pellets. But since nuclear reactions have occurred, the contents aren't quite the same.

Nuclear energy is released when a nuclear fuel atom snaps into two. The key component of nuclear waste is the leftover smaller atoms, known as fission products.

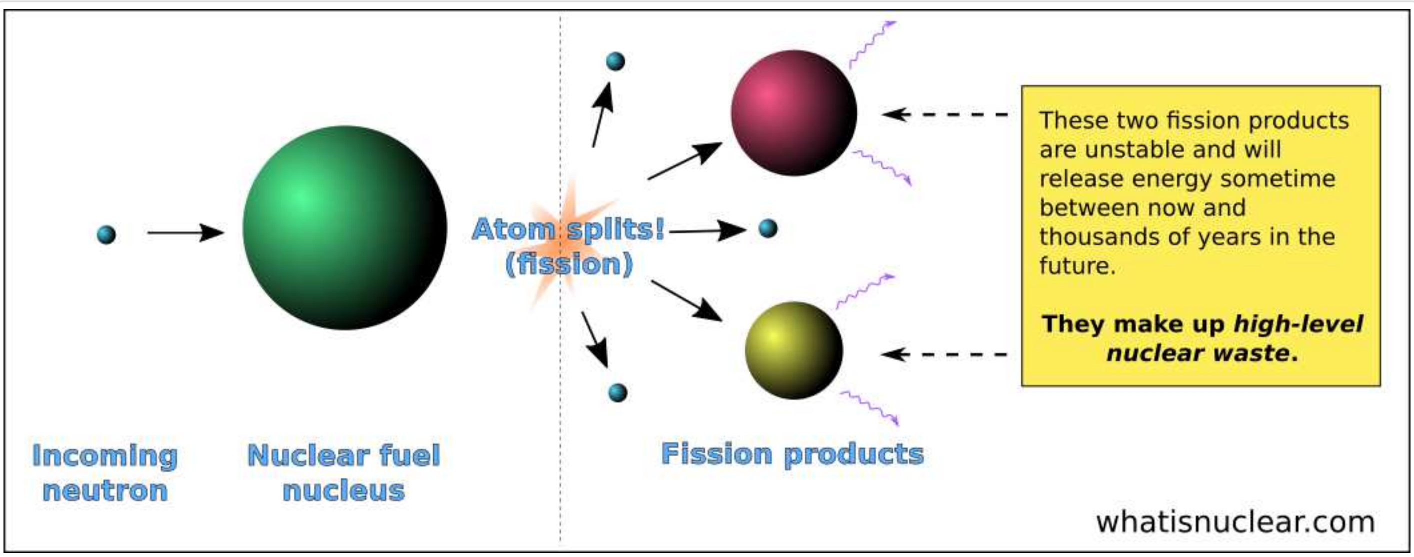



**Figure 1.** The fission process of a single atom. The large majority of the energy is released instantaneously but the rest of it comes out from the fission products over the years. That slowly released energy is what makes nuclear waste a hazard.

You never know which two fission products you're going to get for a given fission, but you always get the same average composition as billions upon billions of atoms split. You basically get a huge variety of stuff, shown below.

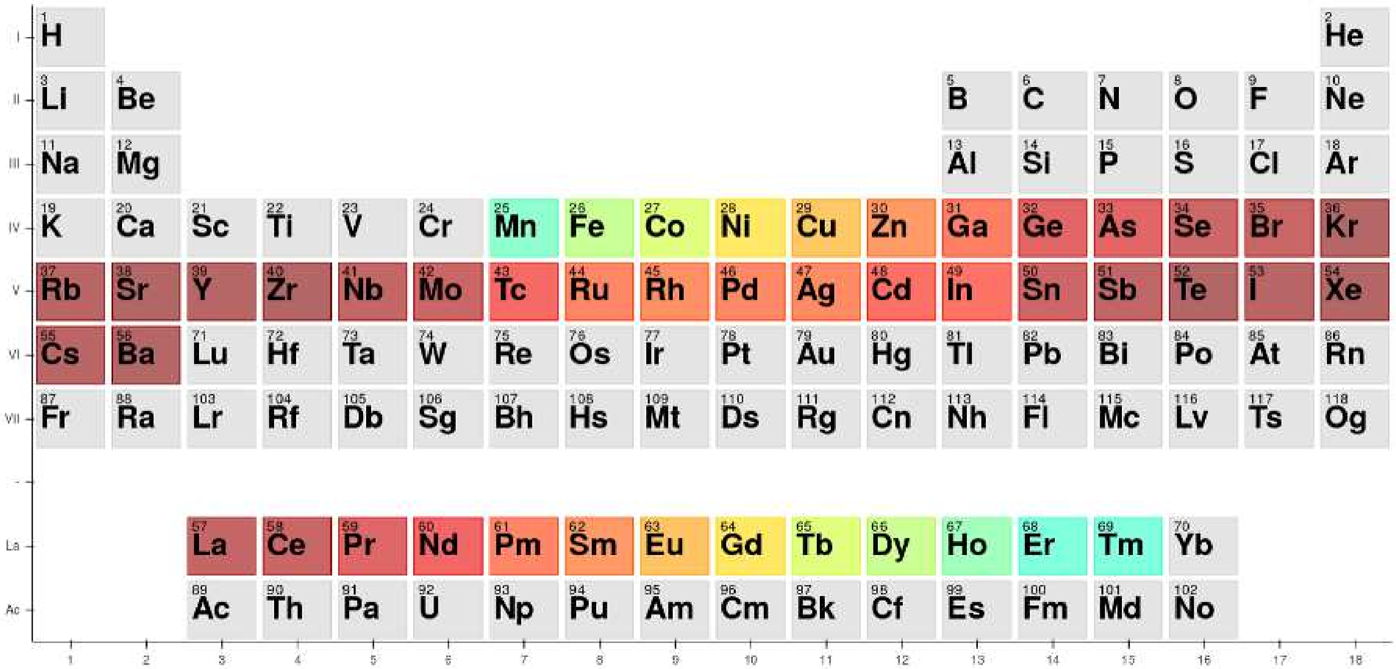



**Figure 2.** The fission products include radioactive isotopes (/isotopes.html) of the elements shown here. You can see that they span a wide variety of elements including alkali metals, transition metals, halogens, and even noble gases. The complex chemistry associated with this diversity is a key challenge in nuclear waste management. (Color is proportional to the log of the instantaneous yield.)

The waste, sometimes called *used fuel*, is dangerously radioactive (/radioactivity.html), and remains so for thousands of years. When it first comes out of the reactor, it is so toxic that if you stood close to it while it was unshielded, you would receive a lethal radioactive dose within a few seconds and would die of acute radiation sickness [wikipedia] (https://en.wikipedia.org/wiki/Radiation_poisoning) within a few days. Hence all the worry about it.

# What do we currently do with our nuclear waste?

In practice, the spent fuel is never unshielded. It is kept underwater (water is an excellent shield) for a few years until the radiation decays to levels that can be shielded by concrete in large storage casks. Options for final disposal include deep geologic storage and recycling. (The sun would consume it nicely if we could get into space, but since rockets are so unreliable, we can’t afford to risk atmospheric dispersal on lift-off.)

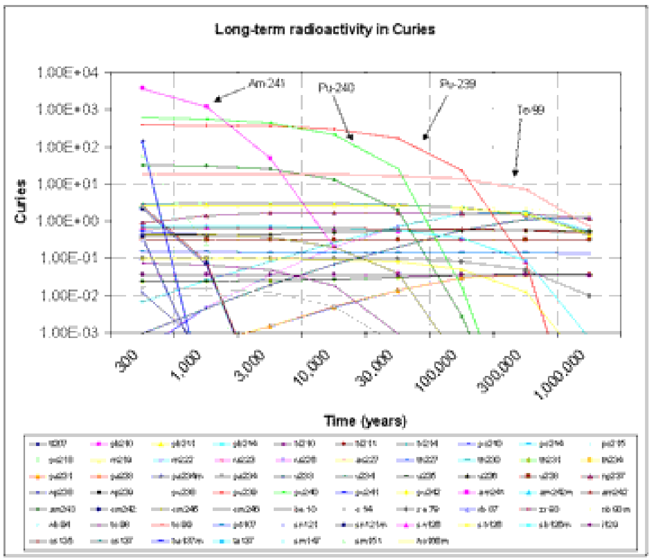
# How much nuclear waste does nuclear energy create?

If all the electricity use of the USA was distributed evenly among its population, and all of it came from nuclear power, then the amount of nuclear waste each person would generate per year would be **39.5 grams**. That’s the weight of seven U. S. quarters of waste, per year! A detailed description of this result can be found here (/assets/waste_per_person.pdf). If we got all our electricity from coal and natural gas, expect to have over 10,000 kilograms of $CO_2$/yr attributed to each person, not to mention other poisonous emissions directly to the biosphere (based on EIA emissions data (https://www.eia.gov/environment/emissions/ghg_report/ghg_carbon.php)).

If you want raw numbers: in 2002, there were 47,023.40 metric tonnes of high-level waste in the USA. 105,793 GW-days of thermal energy has been produced by nuclear power plants throughout the years to create that waste. Also in 2002, operating reactors added 2,407.20 metric tonnes [1] (1 metric tonne = 1000 kg).

# Composition of nuclear waste

Spent nuclear fuel composition varies depending on what was put into the reactor, how long the reactor operated, and how long the waste has been sitting out of the reactor. A typical US reactor's waste composition is laid out in **table 1**. Notice that most of the Uranium is still in the fuel when it leaves the reactor, even though its enrichment has fallen significantly. This Uranium can be used in advanced fast reactors (/fast-reactor.html) as fuel and is a valuable energy source. The **minor actinides**, which include Neptunium, Americium, and Curium, are very long-lived nuclides that cause serious concern when it comes to storing them for more than 100,000 years. Fortunately, these are fissionable in fast reactors and can thus be used as fuel! This still would leave us with the **fission products**. The decay of each nuclide vs. time is shown in Figure 3.




(/img/waste-curies-long.gif)

**Figure 3.** A chart of the activity of all the radioactive nuclides as a function of time up to 1 million years from 1 MT of nuclear waste, burned to 45 MWd/kg. Click for a larger view. Data was computed with ORIGEN-S from Oak Ridge by whatisnuclear.com.

**Table 1.** Heavy metal composition of 4.2% enriched nuclear fuel before and after running for about 3 years (40,000 MWD/MT). Minor actinides include neptunium, americium, and curium. This table does not include structural material such as zirconium and stainless steel.

| | Charge | Discharge |
|---|---|---|
| **Uranium** | 100% | 93.4% |
| **Enrichment** | 4.20% | 0.71% |
| **Plutonium** | 0.00% | 1.27% |
| **Minor Actinides** | 0.00% | 0.14% |
| **Fission products** | 0.00% | 5.15% |

# What to do with nuclear waste

Currently, nuclear waste created in the US is stored underwater in spent fuel pools near nuclear power plants. Assuming the DOE eventually licenses the Yucca Mountain repository in Nevada, this waste will eventually be stored deep underground. Since Yucca Mountain is on the Nevada test site, and since the area is geologically stable, the location is suitable. However, the repository is designed to a certain capacity of nuclear waste. If it ever opens, it will fill quickly thanks to the build-up of waste throughout the last few decades and another repository will need to be constructed. However, there are ways around this.

## Recycling nuclear waste

As mentioned previously, nuclear waste is over 90% uranium. Thus, the spent fuel (waste) still contains 90% usable fuel! It can be chemically processed and placed in advanced fast reactors (/fast-reactor.html) (which have not been deployed on any major scale yet) to *close the fuel cycle*. A closed fuel cycle means much less nuclear waste and much more energy extracted from the raw ore.

France and Japan currently recycle spent fuel, although they only recycle one time before disposal. The US had a recycling program that was shut down because it created Plutonium, which is arguably the easiest material with which to make a nuclear weapon. Were some plutonium diverted in the recycling process, a non-nuclear entity could be one step close to building a bomb. However, under programs such as the (now stalled) GNEP [wikipedia] (https://en.wikipedia.org/wiki/International_Framework_for_Nuclear_Energy_Cooperation), proliferation-free waste recycling can exist.

**See Also** See our main recycling page (/recycling.html) for a more thorough discussion of recycling.

The longest living nuclides in nuclear waste are the ones that can be used as fuel: plutonium and the minor actinides. If these materials are burnt in fuel through recycling, nuclear waste would only remain radioactive for a few hundred years, as opposed to a few hundred thousand. This significantly reduces concerns with long-term storage.

## Help from Thorium Fuel

We could switch from Uranium/Plutonium based fuel to Thorium/Uranium-based fuel (/thorium.html). This would allow for recycling and breeding without creating any plutonium or minor actinides whatsoever. Fission products are still created, of course, and some of them are quite long-lived, but reducing the minor actinides is a benefit of Thorium.

You will find more discussion of proliferation on our nonproliferation page (/non-proliferation.html). Please remember to contact us (/contact.html) with your comments or questions.

## More details for the curious

Nuclear reactors are typically loaded with Uranium Oxide fuel, $UO_2$. Neutrons are introduced to the system, and many of them are absorbed by uranium atoms, causing them to become unstable and split, or fission, into two smaller atoms known as fission products. Sometimes, the uranium absorbs a neutron and does not fission, but rather transforms to a heavier isotope (/recycling.html) of uranium, such as U-239. U-239 beta-decays to Np-239, which in turn beta-decays to Pu-239. The heavier nuclide may then absorb another neutron to become an even heavier element. These heavier atoms are known as transuranics. Nuclear waste, with regard to nuclear reactors, is the collection of nuclides left over after a reactor has extracted some energy out of nuclear fuel. Many of the isotopes are very radioactive for a very long time before they decay to stability. The radioactivity causes the spent nuclear fuel to continue emitting heat long after it has been removed from the reactor. A few of the radioactive isotopes in the mix of spent fuel are gaseous and need to be carefully contained so that they do not escape to the environment and cause radiation damage to living things. Other types of nuclear waste exist, such as low level waste from other applications. This discussion focused on high-level waste (HLW), the spent nuclear fuel from nuclear power reactors.

# References

- Fission product yields from The National Nuclear Data Center (http://www.nndc.bnl.gov/sigma/index.jsp?as=235&lib=endfb7.1&nsub=11)

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