Federal Ministry
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Climate Action, Environment,
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Nuclear Waste – No Reason Not to Worry

The world's first commercial nuclear power plant began feeding power into the grid in the Soviet Union in 1954. Sixty-seven years and 19,000 reactor operating-years[1] later, the world has yet to see a functional final repository for the most hazardous radioactive waste.

The oldest Homo sapiens fossils discovered in Africa are 300,000 years old. That is roughly how long it takes for the plutonium isotope Pu-239 to largely decay. Plutonium is a heavy metal that basically does not occur in nature. It was mankind that brought large amounts of it into the world.

Figure 1: Jebel Irhoud – The oldest-known fossil of the human species, discovered in Morocco

Source: photograph Wikipedia, https://commons.wikimedia.org/wiki/File:Jebel_Irhoud_1._Homo_Sapiens.jpg

[1] International Atomic Energy Agency (IAEA), "Power Reactor Information Service", see https://pris.iaea.org/pris/, accessed on 12 July 2021.

As with many other radioactive substances, plutonium is produced during the operation of nuclear power plants and serves as fuel at the same time. Once the nuclear fuel is used, it is unloaded from the reactor and stored underwater in a cooling pool. Without the shielding provided by the water, the high level of radioactivity emitted by the fuel elements would kill a human being within a minute.[2]

After nearly seven decades of nuclear power generation, there is still no safe final repository for highly radioactive waste available anywhere in the world. In Europe alone, over 60,000 tonnes of spent nuclear fuel are awaiting a destination for eternity.[3] Four fifths of the hot stuff are currently stored in swimming-pool-like cooling structures. The loss of the shielding water, e.g. through earthquakes, airplane crashes, acts of sabotage or a terrorist attack would cause the toxic waste to self-ignite and lead to the release of a large share of the radioactive inventory. The impact on densely populated regions would absolutely dwarf the disasters in Chernobyl or Fukushima.[4]

The generation of radioactive waste begins with uranium mining, then continues in the enrichment plants and during fuel element manufacturing. Irradiated and contaminated waste is also generated in nuclear reactors, and during plutonium separation in so-called reprocessing plants.[5] By far the highest levels of radioactivity are found in irradiated fuel elements and, if these have been processed, in canisters of vitrified waste that can no longer be used for reactor operation. Low- and intermediate-level wastes, generated especially in uranium mines, dominate in terms of volume and weight.

To operate just one single nuclear power plant, over 100,000 tonnes of uranium ore must be extracted – per year. The Wismut mine, located on the territory of the erstwhile German Democratic Republic (GDR) and operated until 1996, left behind over

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[2] GA Andrews GA, JA Auxier, CC Lushbaugh, “The Importance of Dosimetry to the Medical Management of Persons Exposed to High Levels of Radiation”, In *Personal Dosimetry for Radiation Accidents*, International Atomic Energy Agency, 1965.

[3] Excluding Russia and Slovakia, according to Manon Besnard et al., “World Nuclear Waste Report”, 2019, see http://www.worldnuclearwastereport.org, accessed on 19 November 2020.

[4] Frank von Hippel and Michael Schöppner, “Reducing the Danger from Fires in Spent Fuel Pools”, *Science & Global Security*, 2016, see http://scienceandglobalsecurity.org/archive/sgs24vonhippel.pdf, accessed on 29 March 2021.

[5] Reprocessing involves the shearing and dissolution of the highly active fuel elements in a chemical factory and filtering out plutonium and residual uranium. A reprocessing plant not only generates plutonium and uranium, but also large amounts of radioactive waste from a previously compact waste form. In the process, considerable amounts of radioactivity are released into the environment.

300 million cubic metres of radioactive mining waste and 160 million cubic metres of contaminated sludges. Some 4,000 Wismut workers have died of lung cancer.[6]

Uranium concentrate is extracted from the ore and is further processed via several conversion stages into fuel elements. Waste is produced at every step of the way. That being so, a nuclear power plant annually generates around 1,400 cubic metres of waste when uranium concentrate is converted, 130 cubic metres during enrichment, 230 cubic metres during fuel element production, and 300 cubic metres during operation of the reactor. This totals over 2,000 cubic metres, in addition to the 25 tonnes of highly radioactive spent fuel and the mining waste at the beginning of the chain.[7] The waste volume is reduced by incineration or compaction, but it increases again with packaging for shipment and disposal.

A few countries, notably France, operate reprocessing plants that give rise to additional waste streams. Moreover, all these radioactive facilities will need to be dismantled at some point, resulting in even more waste streams. Out of a total of 189 nuclear power plants that have been closed, only 20 have been decommissioned. Of these, only half have been returned to "green field" status, free for any other use.

From Storage to Final Disposal: An Unresolved Problem

Radionuclides are unstable atoms. Depending on the degree of their instability, they decay at a faster or slower pace and emit hazardous radioactivity in the process. Radioactivity causes cancer and other serious illnesses. Long-lived, highly radioactive nuclear waste in particular must be shielded permanently and reliably from the biosphere. The term "storage" describes the handling of nuclear legacies over a certain period of time, whereas "final disposal" is the term used for the final stage. Even in a "final repository" for highly radioactive waste – no such socially and scientifically accepted facility exists anywhere in the world—nuclear waste remains a hazard over entire geological ages that span a million and more years.

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[6] Manon Besnard et al., "The World Nuclear Waste Report", November 2019, see https://worldnuclearwastereport.org/wp-content/themes/wnwr_theme/content/World_Nuclear_Waste_Report_2019_Focus_Europe.pdf.

[7] These amounts vary strongly depending on reactor type and mode of operation, see IAEA, "Estimation of Global Inventories of Radioactive Waste and Other Radioactive Materials", 2007.

A half-life is the duration of decay required for the activity of a given radionuclide to diminish by half. Only after ten half-lives has a radionuclide substantially decayed. Out of 1,000 kg, only 1 kg (= 0.1%) of the nuclide subsists, and yet it must still be safely contained.

During normal operation, a nuclear power plant produces a cocktail of radioisotopes. Some are short-lived, i.e. radioactivity decays after a relatively short time. For example, half of iodine-131 transforms into other—usually more stable—isotopes within 8 days. Other radioisotopes take several years to decay. Heavy hydrogen tritium with a half-life of 12.3 years, for example, decays into helium. Other radionuclides have extremely long half-lives: Iodine-129 has a half-life of 17 million years, plutonium-239 still 24,000 years.

Therefore, a final depository for nuclear waste must hold lots of different radioactive waste materials while guaranteeing safety over many half-lives, in other words, over time periods that are beyond the grasp of human imagination. One million years is three times as long as homo sapiens has been around on Earth. 5,000 years ago, the Egyptians built the pyramids. And the radioactive legacy of our generation is supposed to be kept safe underground for a period that is 200 times longer.