nucleareurope
Supporting a sustainable future

RADIOACTIVE WASTE AND SPENT FUEL

NUCLEAR

IS A LOW-CARBON ENERGY SOURCE

ENSURES SECURITY OF SUPPLY

IS ENVIRONMENTALLY, ECONOMICALLY AND SOCIALLY SUSTAINABLE

EU NUCLEAR INDUSTRY IN NUMBERS

ACCOUNTS FOR
25%
OF ELECTRICITY

ALMOST
50%
OF LOW-CARBON ELECTRICITY

SUPPORTS AROUND
1Mn
JOBS

TURNOVER OF
100bn
PER YEAR

September 2022

Introduction

Like all industries, electricity generation produces waste throughout its life cycle. All this waste must be managed in order to protect human health and minimize environmental impact. In terms of radioactive waste, this means either isolating it or reducing its radioactivity to ensure that the concentration of radionuclides released into the biosphere are harmless. The nuclear industry is a best in class example in the power sector when it comes to waste management, as all the waste it generates is managed efficiently and safely.

The nuclear industry produces large volumes of energy from a very small amount of fuel. The amount of radioactive waste produced per kWh during this process is also minimal.

Radioactive waste is a by-product from nuclear fuel manufacturing, operation of nuclear reactors, nuclear fuel processing plants, hospitals, industry, agriculture, and research facilities. During the decommissioning and dismantling of nuclear installations, large volumes of potentially contaminated materials are generated. In most cases, only a relatively small fraction of the total amount of waste needs to be disposed of as radioactive waste as most of the material (up to 97%) can be released as conventional material as is or after decontamination (removal of radioactivity, primarily from surfaces).

Nevertheless, material considered as radioactive waste must be properly managed and isolated during a predefined time.

This background paper provides information on the different aspects of radioactive waste.

1. Definitions

- Radioactivity

According to the IAEA Safety Glossary, 2018 Edition, radioactivity is "*the phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation.*"

Radioactivity is a natural occurring phenomenon that is found in, for example, sand, sea water, certain food, our own human bodies, etc.

Everything around us can be considered as being made up of atoms. Some atoms are unstable, and they contain a surplus of energy which lead them to transform and become other atoms. During this process, atoms expel their excess energy in the form of radiation invisible to the naked eye.[1]

- Radioactive material

Radioactive materials can be defined as a radioactive substance for which a subsequent use is planned or envisaged, possibly after processing and, where applicable, clearance.

- Radioactive waste

According to EURATOM Directive 2011/70, radioactive waste means any radioactive material in gaseous, liquid or solid form for which no further use is foreseen or considered.

- Half-life

Half-life is the time taken for the radioactivity of a radionuclide to decrease by half. For example, the radioactivity of nuclide Co-60 is five years, meaning its level of activity will be divided by two in just over five years.

[1] Andra-https://www.andra.fr/les-dechets-radioactifs/la-radioactivite/explication-du-phenomene.

2. Classification of radioactive waste

Each country has its own radioactive waste classification, ranging from the lowest category, which can be, depending on the country, either Very Low-Level Waste (VLLW) or Low-Level Waste (LLW), to the highest category which is High-Level Waste (HLW) including Spent Fuel. The difference in radioactivity levels between the two categories is very high. Spent fuel represents more than 99.9% of the radioactive inventory of a nuclear power plant despite representing only a very small part of the total mass of waste.

In most countries, material from a nuclear facility can be 'cleared' (and thus released from regulatory control) if its radioactivity falls below strict threshold values. In order to meet this threshold, the maximum dose of radiation should be significantly lower than background radiation. Countries which do not allow this practice of 'clearance' all material which comes from a nuclear facility must be treated and be disposed of as radioactive waste.

As mentioned above, up to 97% of the material from the dismantling of a nuclear power plant (NPP) can be subject to clearance for reuse, recycling, or disposal as conventional waste.

Example: the nomenclature by nucleareurope.[2]

CATEGORY	DESCRIPTION
Very low-level waste	• Waste that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near-surface, landfill-type facilities with limited regulatory control.
Low-level waste	• Waste that is above clearance levels, but with limited amounts of long-lived radionuclides (with half-life longer than 30 years). Such waste requires robust isolation and containment for periods of up to a few hundred years. It is suitable for disposal in engineered near-surface facilities
Intermediate level waste	• Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal.
High level waste	• Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long-lived radionuclides that need to be considered in the design of a disposal facility for such waste.

According to an internationally accepted definition, radioactive waste which does not contain significant levels of radionuclides with a half-life greater than 30 years is considered as "short lived radioactive waste". Otherwise it is considered as a long-lived radioactive waste.

The disposal of short-lived waste is considered as an established industrial practice in many countries with nuclear power plants. Such waste typically have has to be isolated for decades or even up to a few centuries. Long-lived waste containing long-lived radionuclides requires isolation from the biosphere for thousands of years.

Most EU Member States comply with the IAEA GSG-1 radioactive waste classification[3]. They use this classification system in order to provide information about their national inventories.

3. Radioactive waste and spent fuel inventories in the EU

Every Member State keeps an in-depth track of the radioactive waste produced in its territory and communicates this data to the European Commission (EC). On 17 December 2019, the EC released its lastest inventory of radioactive waste and spent fuel present in the EU. This report provides information on the volumes of radioactive

[2] nucleareurope- https://www.nucleareurope.eu/project/nuclear-waste/

[3] https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf

waste and should provide a breakdown in terms of waste category. It should be noted that materials which have been subject to clearance are not included in the numbers below:

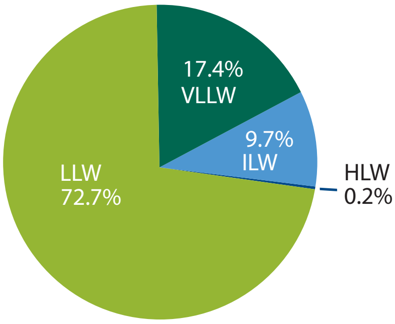


Figure 3: Distribution of the total radioactive waste in the EU by waste category at the end of 2016. [4]

Comparison of global EU spent fuel and radioactive waste – Total (m³ rounded to thousands)

Total	6th report 2004*	7th report 2007*	EC internal data 2010*	2013	2016	2030**
Total SF	38 000	45 000	53 000	54 000	58 000	76 000
Total Waste	**2 649 000***	**3 007 000***	**3 097 000***	**3 313 000**	**3 466 000**	**5 146 000**
VLLW	210 000	280 000*	414 000*	516 000	603 000	1 360 000
LLW	2 228 000*	2 435 000*	2 356 000*	2 453 000	2 519 000	3 322 000
ILW	206 000*	288 000*	321 000*	338 000	338 000	455 000
HLW	5 000*	4 000	5 000	6 000	6 000	9 000

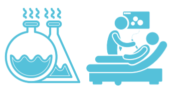
* Reviewed and updated data. For more information see Commission SWD(2017) 161 final, 15.5.2017.
** Commission estimate primarily based on the information reported by Member States and on the other sources when information was not available in second national reports.

4. Characterization, treatment and conditioning of radioactive waste

4.1 Sources of waste[5]

Naturally occurring radioactive materials (NORM) and technologically enhanced radioactive materials (TENORM)

- Soil, rock, sand
- Scale and sludge from oil and gas industry
- Residues from phosphate industry
- Desalination residues



Applications in industry, medicine, and research

- In hospitals, radioactive substances and ionizing radiation are used daily, both to detect and treat diseases
- Certain foods, not least spices, are irradiated to kill germs and preserve them longer
- Radioactive sealed sources are commonly used in industry for reservoir level measurementss, thickness of materials, to detect defects in welds, etc.
Radioactive sealed sources are also used in smoke detectors etc.
- Operation of research reactors for isotope fabrication. The isotopes are used in medical applications, industry and research

Nuclear Power Industry

- Nuclear fuel fabrication including uranium enrichment
- Operation & maintenance of nuclear installations
- Spent Fuel reprocessing. Reprocessing is an option in order to recycle nuclear fuel.
- Decommissioning and dismantling

[4] European Commission (2019). 2nd report on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects

[5] EURAD : https://www.ejp-eurad.eu/sites/default/files/2020 11/Erika%20Holt_EURAD_Training%20lecture_RW%20 conditioning_2020_0914_v2.pdf

4.2 Characterisation

Before any decision is taken on the handling and processing of a given material, it is essential to know and understand its source as well as the amounts and characteristics of the material. If there is no further potential use to the material, it should be classified as waste.

Characterization is defined as a technique which is used to gather information on the **physical, chemical, and radiological properties of a material.**

Characterisation helps to identify appropriate safety requirements, potential processing options and the potential for clearance for reuse, recycling or disposal as conventional waste. It is also of importance in the process to ensure compatibility and compliance with accepted radioactive waste storage and disposal criteria.

4.3 Pre-treatment, treatment and conditioning

There are three main steps in the processing of nuclear materials and waste: **pre-treatment, treatment, and conditioning.**

4.3.1 Pre-treatment

Pre-treatment can be defined "as any or all of the operations preceding waste treatment." [6] Pre-treatment comprises such operations as **collection, characterisation, segregation, adjustment, and decontamination**.

The main objectives of pre-treatment are:

1. To ensure that the acceptance criteria for treatment are fulfilled by characterisation, categorisation and decontamination etc.
2. To comply with the safety criteria, as needed, for the subsequent handling steps
3. To prepare for a successful treatment result (for example, decontaminate metals for clearance so that they can be melted)

Pre-treatment should be performed based on clear objectives, such as improved safety, lower radiation exposure, less waste for disposal as radioactive waste and lower costs in subsequent waste management operations. The benefit of a pre-treatment activity needs to be balanced against the investment required in radiation exposure and pre-treatment costs.

Decontamination - Plant for the decontamination of metal waste. Source Bilfinger (left), Cyclife Sweden (right)

[6] M.I. Ojovan, W.E. Lee, in An Introduction to Nuclear Waste Immobilisation (Second Edition), 2014

Pre-treatment: Example - Segregation

Segregation is where contaminated materials and radioactive waste are separated or kept separate according to radiological, chemical and/or physical properties, in order to facilitate waste handling and/or processing. The main factors considered in segregation are:

- Concentration of radionuclides
- Type and half-lives of radionuclides
- Type of material
- Other specifications or requirements to be fulfilled for further waste processing

4.3.2 Treatment

Treatment is defined according to the IAEA Safety Glossary, 2018[7] Edition as "*Operations intended to benefit safety and/or economy by changing the characteristics of the waste.*"

The main objectives of treatment are:

- Reduction in the volume of radioactive waste for disposal by implementing clearance, densification, destruction of organics, etc.
- Separation of radionuclides
- Change of properties/composition
- Destruction of organics, complexing agents etc.

Treatment should result in a predefined and appropriate material or waste form.

Treatment: Example

Volume reduction - Super Compactor for the compacting of radioactive waste. Source Bilfinger

Volume reduction – Melting and incineration. Source: Cyclife France/Cyclife Sweden

[7] IAEA Safety Glossary, 2018 Edition -https://wwwpub.iaea.org/MTCD/Publications/PDF/PUB1830_web.pdf

4.3.3 Conditioning

Conditioning is defined according to the IAEA Safety Glossary, 2018 Edition as "*Those operations that produce a waste package suitable for handling, transport, storage and/or disposal.*"

Conditioning may include the conversion of the waste into a solid waste form, enclosure of the waste in containers and, if necessary, provision of an overpack.

The choice of process(es) used depends on the level of activity and the type (classification) of waste. Nuclear waste management policy, national regulations and the set-up of interim storage and final disposal concepts and facilities will also influence the approach taken.

5. Storage solutions

According to the IAEA Safety Glossary, 2018 Edition, storage is "*The holding of radioactive sources, radioactive material, spent fuel or radioactive waste in a facility that provides for their/its containment, with the intention of retrieval.*"

5.1 VLLW, LLW and ILW

Storage facilities are either on the site of the nuclear facility where the waste was generated or may also be separate from the facility where the waste was produced. There are significant differences in storage requirements. VLLW and LLW may, for a short period of time, be stored in a weather protected shelter awaiting disposal while intermediate storage for a long period of time may require special storage facilities.

5.2 Spent fuel and HLW

Storage of spent nuclear fuel requires special casks or storage facilities.

There are two types of storage solutions for spent nuclear fuel:

- **Dry storage.** Storage in a gaseous medium, such as air or an inert gas. Dry storage of spent fuel can be performed outdoors with the fuel being placed in specifically designed high integrity casks placed in dedicated facilities.
- **Wet storage.** Storage in water or in another liquid.
    - o "*Wet storage consists of storing spent fuel assemblies or spent fuel elements in pools of water or other liquids, usually supported on racks or in baskets and/or in canisters that also contain liquid.*"[8] This methodology requires the construction of bunkered storage facilities.
    - o "*The liquid in the pool surrounding the fuel provides for heat dissipation and radiation shielding, and the racks or other devices ensure a geometrical configuration that maintains subcriticality*."

A facility which stores spent nuclear fuel or radioactive material/waste for a limited time is called an interim storage facility.

The purpose of an interim storage facility includes

- Letting HLW decay and reduce heat generation.
- Allowing short lived VLLW waste to decay to clearance levels and thus reduce the need for repositories.
- Storing material awaiting final disposal.

[8] Ibid.

Most of the time, interim storage facilities are located on the site of the nuclear power plant or occasionally on a separate, purpose-built site.

Storage of HLW, Belgium, (courtesy of BELGOPROCESS)

6. Disposal Solutions

According to the IAEA Safety Glossary, 2018 Edition, disposal is "*Emplacement of waste in an appropriate facility without the intention of retrieval*."

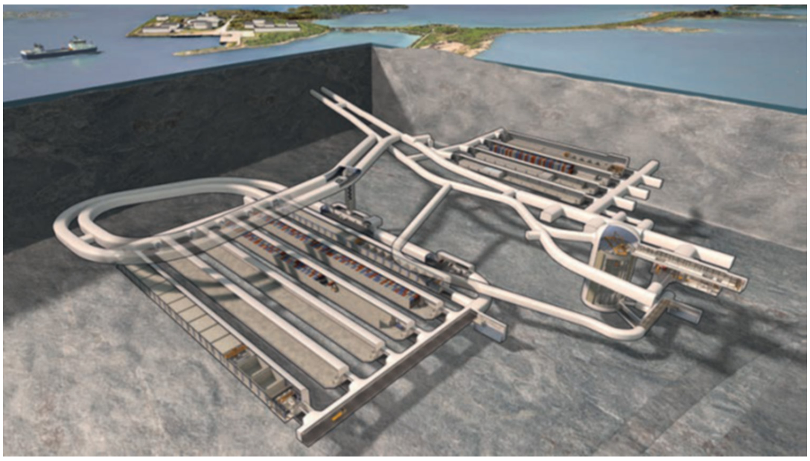
6.1 VLLW-ILW

VLLW to ILW are generally disposed of in surface and near surface disposal facilities that can be located either at ground level or in caverns below ground level.

- **Surface and near surface disposal facilities at ground level.** These facilities are located on or below the surface where the protective covering is a few metres thick. Waste containers are placed in vaults. When full, the vaults are backfilled and potentially covered and capped with an impermeable membrane and topsoil. These facilities may incorporate some form of drainage and possibly a gas venting system.

Source: Mochovce Repository, Slovakia. Covered disposal system with chambers protected by concrete panels (courtesy of JAVYS, Slovakia)

- **Near-surface disposal facilities in caverns below ground level.** Unlike near-surface disposal at ground level, where the excavation is conducted from the surface, shallow disposal requires the underground excavation of caverns. The facility is at a depth of several tens of metres below the Earth's surface and can be accessed through a shaft.



SKB's Final Repository for Short-Lived Radioactive Waste (SFR) in Sweden's Östhammar municipality accepts nuclear plant operational waste (as well as medical and research waste) and will be extended to accept waste from decommissioning nuclear plants. The image shows the existing facility towards the right and the planned extension in the left foreground (image courtesy SKB).

6.2 HLW and spent fuel

HLW and Spent Fuel are disposed of underground in geological disposal facilities.[9] "*A facility for radioactive waste disposal located underground (usually several hundred metres or more below the surface) in a stable geological formation to provide long term isolation of radionuclides from the biosphere*". The facility can also be located "in a geological disposal facility in the rock underlying the seabed" – this is called a sub seabed disposal.

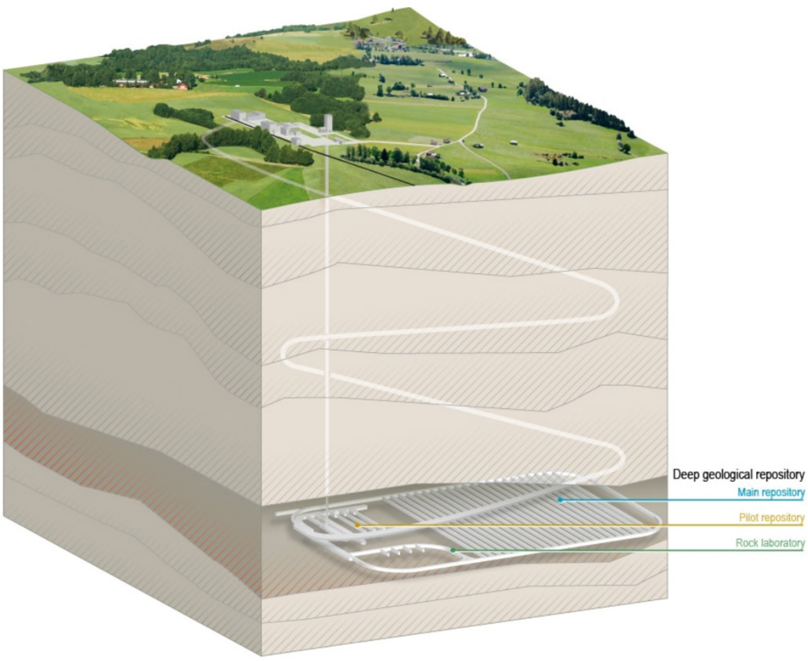


Illustration of a potential DGR design – Swiss Federal Safety Inspectorate (ENSI)

[9] See nucleareurope's background paper on Deep Geological Repository

Sources

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European Commission (2019). 2*nd report on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects.*

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About us

nucleareurope is the Brussels-based trade association for the nuclear energy industry in Europe. The membership of nucleareurope is made up of 15 national nuclear associations and through these associations, nucleareurope represents nearly 3,000 European companies working in the industry and supporting around 1.1 million jobs.

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