ATTACHMENT 1: Information sources & materials

https://www.independent.co.uk/news/world/ukrainian-nuclear-power-plant-fire-kursk-b2594806.html (12.8.2024)

> Russian forces lit a fire at the site of the occupied Zaporizhzhia nuclear power plant in southern Ukraine, Ukrainian President Volodymyr Zelenskiy has said.
>
> Radiation levels were normal, he said, although the blaze is visible from Ukrainian-held territory.
>
> A local official in the Ukrainian city of Nikopol said that Russian forces were rumoured to have set fire to a large number of tyres in the cooling towers, Reuters reported. Russia claimed the fire was started by nearby shelling.
>
> The U.N.'s International Atomic Energy Agency (IAEA) nuclear watchdog, which has a team at the vast six-reactor plant, said its experts had seen strong, dark smoke coming from the northern area of the plant following multiple explosions.
>
> The IAEA said there had been no reported impact on nuclear safety at the site. "Team was told by (the nuclear plant) of an alleged drone attack today on one of the cooling towers located at the site," it wrote on X.
>
> Mr Zelenskiy published video showing belching black smoke that appeared to be coming out a cooling tower with a blaze burning at its foot.
>
> "Currently, the radiation indicators are normal. But as long as Russian terrorists retain control over the nuclear plant, the situation is not and cannot be normal," he said.
>
> The reactors at the plant located close to the front line of the war in Ukraine are not generating power but the facility relies on external power to keep its nuclear material cool and prevent a catastrophic accident.

IAEA (International Atomic Energy Agency) – Waste Heat

(International Atomic Energy Agency, https://www.iaea.org › newscenter › news › what-is-nucl..) 15 June 2021, accessed 18.11.2024)

> 'About 33% of the thermal energy produced in nuclear reactions is converted into (nuclear-powered) electricity. The remaining 67% is released, for example, into the sea, etc., as waste heat. Therefore, waste heat recovery and its use in nuclear power plants (NPPs) are important for increasing the power generation efficiency.'

This is consistent with the following information about the same.

> 'Nuclear and thermal power plants dispose large amounts of waste heat into oceans, rivers, lakes, and air. Based on the heat generated by nuclear reactors, power plants usually have a generation end efficiency of 33–35% and about 60% of waste heat. There are a few cases in which such waste heat was used for fish farming, farm cultivation, seawater desalination, etc. Large-scale nuclear power plants (NPPs) are often located far from energy-consuming areas, so the recovery

and effective utilization of their waste heat is an important issue. There is also no technology for converting the waste heat of NPPs into electricity.'

(https://www.sciencedirect.com/science/article/abs/pii/S0306261921001975?__cf_chl_tk=8WPyACdVB3nokpsX9PHrEmWE4bD9GdsoKEmQZFozgGE-1731878948-1.0.1.1-RFAqedBekMc0R6xFT5sbWynqeeCleZ7fvunu872Rvsk, accessed 18.11.2024

Information on tritium from Canadian government website https://www.cnsc-ccsn.gc.ca/eng/resources/fact-sheets/tritium/

In water

The most common form of tritium is tritiated water, which is formed when a tritium atom replaces a hydrogen atom in water (H_2O) to form HTO.

HTO has the same chemical properties as water and is odourless and colourless.

Tritiated water has a biological half-life of 10 days, but in the body, a small amount binds to proteins, fat and carbohydrates with an average 40-day half-life.

In food

Some of the tritium released into the environment can get into nutrients such as carbohydrates, fats or proteins. Tritium consumed in food (organically bound tritium) poses a slightly greater health risk, as the body retains it longer than tritiated water. This means the tritium atom is more likely to decay while in the body, possibly damaging cells. The body can repair this type of damage on its own.

Health effects

Tritium is a relatively weak source of beta radiation, which itself is too weak to penetrate the skin. However, it can increase the risk of cancer if consumed in extremely large quantities.

Tritium can enter the body through inhalation, ingestion or absorption through the skin.

https://www.sciencedirect.com/science/article/abs/pii/B9780080450438000064
I. Greaves FRCP, FCEM, FIMC, RCS(Ed), DTM & amp; H, DMCC, DipMedEd, RAMC; P Hunt MBBS, DipIMC(RCSEd), MCEM, MRCSEd, DMCC, RAMC,
in Responding to Terrorism, 2010.

Particulate radiation
Alpha (α) particles consist of two neutrons and two protons (Table 6.1) and are equivalent to helium nuclei. Because of their weight and charge, they travel only short distances and are unable to penetrate human skin. Alpha particles are dangerous only when they are inhaled, ingested or absorbed through a wound. When they do interact with biological material they are very damaging because of their relatively large mass and double charge.

Beta (β) particles are electrons. They do not interact as strongly with atoms as alpha particles and are lighter. As a result they have a greater range and are more penetrating. They are capable of passing through the dermis, but clothing including standard personal protective equipment (PPE) offers some protection against them. Radiation burns can occur with prolonged exposure but generally beta particles, like alpha particles, are only harmful when inhaled, ingested or absorbed through a wound.

Neutrons are uncharged and therefore have a long range. They penetrate everything except thick concrete and hydrogen-rich material such as water. Neutrons are usually only emitted during the moment of nuclear detonation or accident. For the same deposited dose of energy, neutrons are 20 times more damaging to tissues than gamma rays when they do interact with biological material.

Electromagnetic radiation
Gamma rays and X rays are electromagnetic waves. As the wavelength of electromagnetic waves decreases, their energy increases. Both gamma and X rays lie at the low-wavelength, high-energy end of the spectrum of electromagnetic radiation (Fig. 6.1). Both forms of radiation are highly penetrant and are only stopped by significant thicknesses of lead, concrete or water.

Radioactive Waste: Production, Storage, Disposal
U. S. Nuclear Regulatory Commission
Office of Public Affairs (May 2002)

High-level radioactive waste consists of “irradiated” or used nuclear reactor fuel (i.e., fuel that has been used in a reactor to produce electricity). The used reactor fuel is in a solid form consisting of small fuel pellets in long metal tubes. (page 2)

Currently, there are no permanent disposal facilities in the United States for high-level nuclear waste; therefore commercial high-level waste (spent fuel) is in temporary storage, mainly at nuclear power plants. (U.S.NRC page 4)

About one-fourth to one-third of the total fuel load is spent and is removed from the reactor every 12 to 18 months and replaced with fresh fuel. The spent nuclear fuel is high-level radioactive waste. (Above, page 7)
(“Radioactivity” refers to the spontaneous disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.) (Above p 3)

How hazardous is high-level waste? Spent nuclear fuel is highly radioactive and potentially very harmful. Standing near unshielded spent fuel could be fatal due to the high radiation levels. Ten years after removal of spent fuel from a reactor, the radiation dose 1 meter away from a typical spent fuel assembly exceeds 20,000 rems per hour. A dose of 5,000 rems would be expected to cause immediate incapacitation and death within one week. (Above p 12) See following reference)

[M]any of the radioactive elements in spent fuel have long half-lives. For example, plutonium-239 has a half-life of 24,000 years, and plutonium-240 has a half-life of 6,800 years. Because it contains these long half-lived radioactive elements, spent fuel must be isolated and controlled for thousands of years. (Above p 12 of 40)

When a disposal facility ceases operations, a post-closure period of maintenance and monitoring is required to confirm that the closed site is safely performing as expected before transfer to a government custodial agency for long-term control. (RK emphasis added) Access to the site may be restricted for a long time, but NRC and state regulations do not allow reliance on institutional controls after 100 years following site closure. After 100 years, passive controls, such as custodial care, waste markers and land records, will be relied on to prevent disturbance of the emplaced waste. (p 30) (Underlining added)

[RK: The foregoing could imply that the nuclear waste material is suitably situated and contained. However, I have found no reference here or elsewhere to an existing, functioning, high level nuclear waste repository. A future exception will be the Finnish purpose-made facility, which is now expected to begin accepting nuclear waste in 2026. Another is the Waste Isolation Pilot Plant (WIPP) in New Mexico, United States, a deep geologic repository for the disposal of **defense-related transuranic waste**. (https://www.gao.gov/nuclear-waste-disposal)]

https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste#:~:text=Some%20storage%20of%20fuel%20assemblies,now%20in%20dry%20storage%20casks.

What are the problems with dry cask storage?
In addition to high cost, the low production rate of the cask is another limiting factor. It has to improve in order to catch up the increasing need for temporary spent fuel storage. There are other issues of dry casks such as additional chance of human errors and radiation risks.19 Mar 2014

https://www.chathamhouse.org/2024/07/cybersecurity-civil-nuclear-sector

A combination of factors – from energy security and decarbonization agendas to the emergence of small modular reactors (SMRs) that potentially make nuclear energy more accessible – are prompting many countries to consider adopting, or increasing their use of, nuclear energy. But the prospect of more nuclear power plants, many of them more digitally connected than in the past, coming into operation in more countries makes ensuring the cybersecurity of civil nuclear infrastructure more critical than ever.

This paper considers the evolving cyberthreats that the civil nuclear sector faces both in peacetime and during conflict. It outlines key vulnerabilities in the sector,

including the use of older or bespoke software, a safety culture insufficiently attuned to digital and cyber risks, and the emergence of novel risks around the use of SMRs and microreactors. The paper then outlines the existing international legal frameworks that already apply to the issue and can help protect the civil nuclear sector from cyberthreats, and proposes steps to improve cybersecurity. These steps include doing more to interpret and leverage international law in the relevant areas, and enhancing operational protections such as cyber incident-response planning.

Summary

The expansion in the use of nuclear energy worldwide highlights the need for robust cybersecurity measures to protect civil nuclear infrastructure from cyberthreats. This paper explores the evolving cybersecurity risks that the civil nuclear sector faces both in peacetime and during conflict, and examines which protections international law offers. It also proposes steps – drawing on international law specifically, or involving global and regional cooperation as well as national structures and best practices more generally – for improving the cybersecurity of civil nuclear infrastructure.

Key cybersecurity vulnerabilities in the civil nuclear sector stem from a range of technical and non-technical factors, including the use of older software, the targeting of personnel by threat actors, and the lack of sufficient sector-wide awareness of – and collaboration on – cybersecurity.

Existing international law already offers robust safeguards against cyberthreats to civil nuclear infrastructure, though no single legal regime specifically addresses such risks. Whether through general rules or specific legal regimes, international law requires states to refrain from conducting, or to prevent, cyber operations targeting civil nuclear facilities. In addition, it requires states to redress the effects of such incidents when they occur.

General rules applicable to cyber-nuclear risks and harms include sovereignty, non-intervention, the prohibition on the use of force, and due diligence obligations. International human rights law and international humanitarian law (IHL), along with nuclear-specific treaties, are among the specific legal regimes that protect civil nuclear infrastructure from malicious cyber operations.

States should consider offering specific interpretations of those rules and regimes for the cyber-nuclear context, as well as adopting additional non-binding norms or standards to complement them. States should also develop strategies to enhance the enforcement of international law in cyberspace, and to ensure accountability for unlawful cyber operations targeting civil nuclear facilities in particular.

Effective mitigation of cyberthreats to civil nuclear infrastructure, and to critical infrastructure more generally, requires a multi-tiered approach: enhancing international and regional cooperation, refining national cybersecurity frameworks and fostering public–private partnerships. Implementing these strategies will help ensure the safe and secure development of the civil nuclear sector, thereby better supporting nuclear energy's potential to provide societal and environmental gains.

https://www.gao.gov/nuclear-waste-disposal#:~:text=For%20instance%2C%20high%2Dlevel%20nuclear,a%20long%20period%20of%20time. [Accessed 8.5.2024]
[U. S.] GAO Government Accountability Office]

Nuclear Waste Disposal - Issue Summary

Radiation is used in many different industries, including as fuel for nuclear power plants and in the production of nuclear weapons for national defense. These uses generate nuclear waste, and this waste must be disposed of in safe and effective ways. There are three main types of nuclear waste—high-level, transuranic, and low-level waste—and each type must be disposed of according to its risk to human health and the environment. For instance, high-level nuclear waste remains highly radioactive for tens of thousands of years and must be disposed of in such a way that it can be securely isolated for a long period of time.

The Department of Energy (DOE) oversees the treatment and disposal of radioactive waste from the nation's nuclear weapons program; it is also responsible for siting, building, and operating a geologic repository to dispose of nuclear waste. There are a number of ways that DOE could improve how it stores, treats, and disposes of this waste.

For instance:

The nation has over 85,000 metric tons of spent nuclear fuel from commercial nuclear power plants. DOE is responsible for disposing of this high-level waste in a permanent geologic repository but has yet to build such a facility because policymakers have been at an impasse over what to do with this spent fuel since 2010. As a result, the amount of spent nuclear fuel stored at nuclear power plants across the country continues to grow by about 2,000 metric tons a year. Meanwhile, the federal government has paid billions of dollars in damages to utilities for failing to dispose of this waste and may potentially have to pay tens of billions of dollars more in coming decades. If Congress were to authorize a new consent-based process for siting a repository, it could help break the impasse over a permanent solution for commercial spent nuclear fuel.

DOE also oversees the treatment and disposal of about 90 million gallons of radioactive waste from the nation's nuclear weapons program. Most of this waste is stored in tanks at 3 DOE sites. According to federal law, certain high-level mixed waste must be vitrified—a process in which the waste is immobilized in glass—and disposed of in a deep geologic repository. However, DOE estimates that about 90% of the volume of this waste contains about 10% of the radioactivity. DOE considers this portion of the waste to be low-activity waste, which experts believe may be safely treated and disposed of with methods other than vitrification. Nevertheless, DOE plans to vitrify a portion of this low-activity waste at its Hanford Site in Washington State but may face challenges starting operations of a treatment facility to do so. In addition, DOE may be able to reduce certain risks and save tens of billions of dollars by adopting alternative approaches to treating and disposing of a portion of Hanford's low-activity radioactive waste. DOE has also faced challenges designing and building high-level waste treatment facilities at Hanford and Idaho National Laboratory. Additionally, the United States will continue to generate new high-level defense waste as a result of its ongoing weapons program and efforts to modernize the nuclear stockpile.

The Partially Constructed Hanford Pretreatment Facility in Washington State, 2013 and 2020

Transuranic nuclear waste is waste contaminated by nuclear elements heavier than uranium, such as diluted plutonium. The United States has only one deep geologic repository for the disposal of defense-related transuranic waste—the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. However, DOE has experienced challenges constructing a new ventilation system and may face delays in expanding WIPP to dispose of all defense transuranic waste.

Underground tunnel at the geologic repository for defense waste in New Mexico

Low-level waste may be generated from both civilian and defense activities. Low-level waste is generally defined as waste that is not high-level or transuranic waste. Low-level waste decays rapidly and can typically be disposed of in a near-surface disposal facility. Three gaseous diffusion plants—located near Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee—at one time enriched uranium for both defense and civilian purposes. However, these plants were rendered obsolete by newer, more efficient technologies. As DOE decontaminates and decommissions these facilities, it generates significant amounts of waste, including building materials and hazardous and radioactive waste removed from equipment and piping. Much of this waste is considered to be low-level waste and must be disposed of at a low-level waste disposal facility. However, DOE's fund to clean up these plants is likely not large enough—cleanup costs may exceed the amount in this fund by $45 billion. In addition, DOE is working to convert DUF6 (a dangerous byproduct of the uranium enrichment process) into a more stable chemical form that can be disposed of or reused. DOE estimates it could cost at least $7.2 billion to convert and dispose of the DUF6 as low-level waste. If DOE can transfer portions of its DUF6 inventory—such as by selling some to a private company—it could save billions. However, it is unclear if DOE has authority to sell depleted uranium. Moreover, DOE is responsible for disposing of certain low-level nuclear waste from medical equipment, metals in nuclear reactors, and cleanup sites—commonly referred to as greater-than-class C waste. However, no legal options currently exist to dispose of this waste.

https://www.google.com/search?q=half+life+of+fission+products&oq=half-lives+of+fissionable+&gs_lcrp=EgZjaHJvbWUqCAgBEAAYFhgeMgYIABBFGDkyCAgBEAAYFhgeMgoIAhAAGA8YFhgeMg0IAxAAGIYDGIAEGIoFMgoIBBAAGIAEGKIEMgoIBRAAGIAEGKIEMgoIBhAAGIAEGKIEMgoIBxAAGIAEGKIE0gEJNDc2MTdqMGo5qAIAsAIA&sourceid=chrome&ie=UTF-8 (Accessed 13.10.2024)

Fission products have half-lives of 90 years (samarium-151) or less, except for seven long-lived fission products that have half lives of 211,100 years (technetium-99) or more.

Iodine-129 has the longest half-life, 15.7 million years, and due to its higher half life, lower fission fraction and decay energy it produces only about 1% the intensity of radioactivity as ^{99}Tc.

N Yamano, T Inakura, C Ishizuka, S Chiba,
'Estimation of uncertainty in transmutation rates of LLFPs in a fast reactor transmutation system via an estimation of the cross-section covariances', *Journal of Nuclear Science and Technology, 2021* Abstract accessed 27.11.2024

> Long-lived fission products (LLFPs) are potential sources of radiation hazard upon long-term deep geological disposal of high-level radioactive waste due to their long half-lives, e.g., 79Se: 327,000 years, 93Zr: 1,610,000 years, 99Tc: 211,100 years, 107Pd: 6.5 million years, 129I: 15.7 million years, and 135Cs: 2.3 million years. Transmutation of minor actinides (MAs) is normally the primary goal of the separation-and-transmutation scenarios because they are considered as major elements in terms of long-term radiation hazard [1]. However, MAs are transmuted by fission reactions, which eventually produce fission products including LLFPs. Therefore, the transmutation of LLFPs is inevitably a matter to be considered seriously concerning a long-term risk in the groundwater scenario of deep geological repository [2,3].

https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html)

> **What nuclear waste has the longest half-life?**
>
> Some isotopes decay in hours or even minutes, but others decay very slowly. Strontium-90 and cesium-137 have half-lives of about 30 years (half the radioactivity will decay in 30 years). Plutonium-239 has a half-life of 24,000 years.

International Atomic Energy Agency – Waste Heat
https://www.iaea.org › newscenter › news › what-is-nucl..) 15 June 2021, accessed 18.11.2024)

> About 33% of the thermal energy produced in nuclear reactions is converted into (nuclear-powered) electricity. The remaining 67% is released, for example, into the sea, etc., as waste heat. Therefore, waste heat recovery and its use in nuclear power plants (NPPs) are important for increasing the power generation efficiency.

https://www.google.com/search?q=half+life+of+fission+products&oq=half-lives+of+fissionable+&gs_lcrp=EgZjaHJvbWUqCAgBEAAYFhgeMgYIABBFGDkyCAgBEAAYFhgeMgoIAhAAGA8YFhgeMg0IAxAAGIYDGIAEGIoFMgoIBBAAGIAEGKIEMgoIBRAAGIAEGKIEMgoIBhAAGIAEGKIEMgoIBxAAGIAEGKIE0gEJNDc2MTdqMGo5qAIAsAIA&sourceid=chrome&ie=UTF-8 (Accessed 13.10.2024)

> 'Nuclear and thermal power plants dispose large amounts of waste heat into oceans, rivers, lakes, and air. Based on the heat generated by nuclear reactors, power plants usually have a generation end efficiency of 33–35% and about 60% of waste heat. There are a few cases in which such waste heat was used for fish farming, farm cultivation, seawater desalination, etc. Large-scale nuclear power plants (NPPs) are often located far from energy-consuming areas, so the recovery and effective utilization of their waste heat is an important issue. There is also no technology for converting the waste heat of NPPs into electricity.'

Fission products have half-lives of 90 years (samarium-151) or less, except for seven long-lived fission products that have half lives of 211,100 years (technetium-99) or more.

Naoki Yamano, Tsunenori Inakura, Chikako Ishizuka, Satoshi Chiba, 'Estimation of uncertainty in transmutation rates of LLFPs in a fast reactor transmutation system via an estimation of the cross-section covariances', *Journal of Nuclear Science and Technology, 2021* (Abstract)

Long-lived fission products (LLFPs) are potential sources of radiation hazard upon long-term deep geological disposal of high-level radioactive waste due to their long half-lives, e.g., 79Se: 327,000 years, 93Zr: 1,610,000 years, 99Tc: 211,100 years, 107Pd: 6.5 million years, 129I: 15.7 million years, and 135Cs: 2.3 million years. Transmutation of minor actinides (MAs) is normally the primary goal of the separation-and-transmutation scenarios because they are considered as major elements in terms of long-term radiation hazard [1]. However, MAs are transmuted by fission reactions, which eventually produce fission products including LLFPs. Therefore, the transmutation of LLFPs is inevitably a matter to be considered seriously concerning a long-term risk in the groundwater scenario of deep geological repository [2,3].

https://en.wikipedia.org/wiki/Long-lived_fission_product

Long-lived fission products (LLFPs) are radioactive materials with a long half-life (more than 200,000 years) produced by nuclear fission of uranium and plutonium. Because of their persistent radiotoxicity, it is necessary to isolate them from humans and the biosphere and to confine them in nuclear waste repositories for geological periods of time. The focus of this article is radioisotopes (radionuclides) generated by fission reactors.

Evolution of radioactivity in nuclear waste
Nuclear fission produces fission products, as well as actinides from nuclear fuel nuclei that capture neutrons but fail to fission, and activation products from neutron activation of reactor or environmental materials.

Short-term
The high short-term radioactivity of spent nuclear fuel is primarily from fission products with short half-life. The radioactivity in the fission product mixture is mostly due to short-lived isotopes such as ^{131}I and ^{140}Ba, after about four months ^{141}Ce, ^{95}Zr/^{95}Nb and ^{89}Sr constitute the largest contributors, while after about two or three years the largest share is taken by ^{144}Ce/^{144}Pr, ^{106}Ru/^{106}Rh and ^{147}Pm. Note that in the case of a release of radioactivity from a power reactor or used fuel, only some elements are released. As a result, the isotopic signature of the radioactivity is very different from an open air nuclear detonation where all the fission products are dispersed.

After several years of cooling, most radioactivity is from the fission products caesium-137 and strontium-90, which are each produced in about 6% of fissions, and have half-lives of about 30 years. Other fission products with similar half-lives have much lower fission product yields, lower decay energy, and several (^{151}Sm, ^{155}Eu, ^{113m}Cd) are also quickly destroyed by neutron capture while still in the reactor, so are not responsible for more than a tiny fraction of the radiation

production at any time. Therefore, in the period from several years to several hundred years after use, radioactivity of spent fuel can be modeled simply as exponential decay of the ^{137}Cs and ^{90}Sr. These are sometimes known as medium-lived fission products.[1][2]

CAESIUM

https://en.wikipedia.org/wiki/Caesium-137

Caesium-137 ($^{137}_{55}Cs$), cesium-137 (US),[7] or radiocaesium, is a radioactive isotope of caesium that is formed as one of the more common fission products by the nuclear fission of uranium-235 and other fissionable isotopes in nuclear reactors and nuclear weapons. Trace quantities also originate from spontaneous fission of uranium-238. It is among the most problematic of the short-to-medium-lifetime fission products. Caesium-137 has a relatively low boiling point of 671 °C (1,240 °F) and easily becomes volatile when released suddenly at high temperature, as in the case of the Chernobyl nuclear accident and with atomic explosions, and can travel very long distances in the air. After being deposited onto the soil as radioactive fallout, it moves and spreads easily in the environment because of the high water solubility of caesium's most common chemical compounds, which are salts. Caesium-137 was discovered by Glenn T. Seaborg and Margaret Melhase.

Caesium-137, along with other radioactive isotopes caesium-134, iodine-131, xenon-133, and strontium-90, were released into the environment during nearly all nuclear weapon tests and some nuclear accidents, most notably the Chernobyl disaster and the Fukushima Daiichi disaster.

Caesium-137 in the environment is substantially anthropogenic (human-made). Caesium-137 is produced from the nuclear fission of plutonium and uranium, and decays into barium-137.[26]

P. BJERREGAARD, O. ANDERSEN, in **Handbook on the Toxicology of Metals (Third Edition)**, 2007. Abstract accessed 27.10.2024 and cited in part:

^{134}Cs and ^{137}Cs are major fission products in nuclear processes, and with their half-lives of 2.1 and 30 years, respectively, they constitute an important source of contamination of the environment with radioactivity.

Major releases have come from nuclear weapons testing, from the nuclear fuel reprocessing plant at Windscale, UK, and from the Chernobyl accident at which 85 and 46 × 10^{15} Bq of ^{137}Cs and ^{134}Cs, respectively, were emitted (EEA, 2003)."

Further, [d]ischarges of ^{137}Cs from Windscale could be traced in seawater in the Irish Sea, north of Scotland, along the Norwegian coast around Svalbard. "Background concentrations" (originating from global fallout from nuclear weapons testing) were found only after 6-8 years at 5000-7000 km along north-east Greenland (citing Hallstadius *et a.,* 1986).

Cesium has a low tendency to adsorb to particles in water, and discharges of ^{137}Cs from Windscale could be traced in seawater in the Irish Sea, north of Scotland,

along the Norwegian coast around Svalbard, not reaching “background concentrations”.

Following the Chernobyl accident in 1986, levels of ^{137}Cs content in fish exceeded the limits (1500 Bq/kg) for human consumption (Hakanson *et al.,* 1992).

Furthermore, deposited ^{137}Cs became concentrated in lichens, which are an important food source for reindeer during autumn and winter. Fallout from nuclear weapons testing and, more particularly, the Chernobyl reactor accident, have seen ^{137}Cs levels in reindeer in some areas of Scandinavia far exceed the limits for human consumption (Ahman and Ahman, 1994).

Atmospheric transport of ^{137}Cs and fallout may create problems in especially sensitive ecosystems far away from the sites of emission.

Oligotrophic freshwater systems are among such sensitive ecosystems. ^{137}Cs is taken up into organisms through the same routes as potassium, and the ability of cells to transport potassium against concentration gradients to high intercellular concentrations also leads to a fairly high bioconcentration of radioactive caesium. After the Chernobyl accident in 1986, a considerable amount of ^{137}Cs was deposited in the northern and central parts of Scandinavia and in a large number of Swedish lakes, the ^{137}Cs content of the fish exceeded the limits (1500 Bq/kg) for human consumption (Hakanson *et al.,* 1992).

On deposition from the atmosphere, ^{137}Cs is concentrated in lichens that constitute an important fraction of the food of reindeers during the autumn and winter seasons. Fallout from nuclear weapons testing, and especially the Chernobyl accident, resulted in ^{137}Cs activities in reindeer in certain Scandinavian areas that vastly exceeded the limits for human consumption (Ahman and Ahman, 1994). Fungal mycelia assimilate ^{137}Cs very efficiently from the soil, and mushrooms may be an important source for ^{137}Cs uptake in ruminants such as roe deers (Zibold *et al.,* 2001) and goats (Hove *et al.,* 1990). Predators with roe deer and reindeer as their main prey, such as lynx, also accumulated ^{137}Cs to high activities after the Chernobyl accident (Ahman *et al*., 2004).