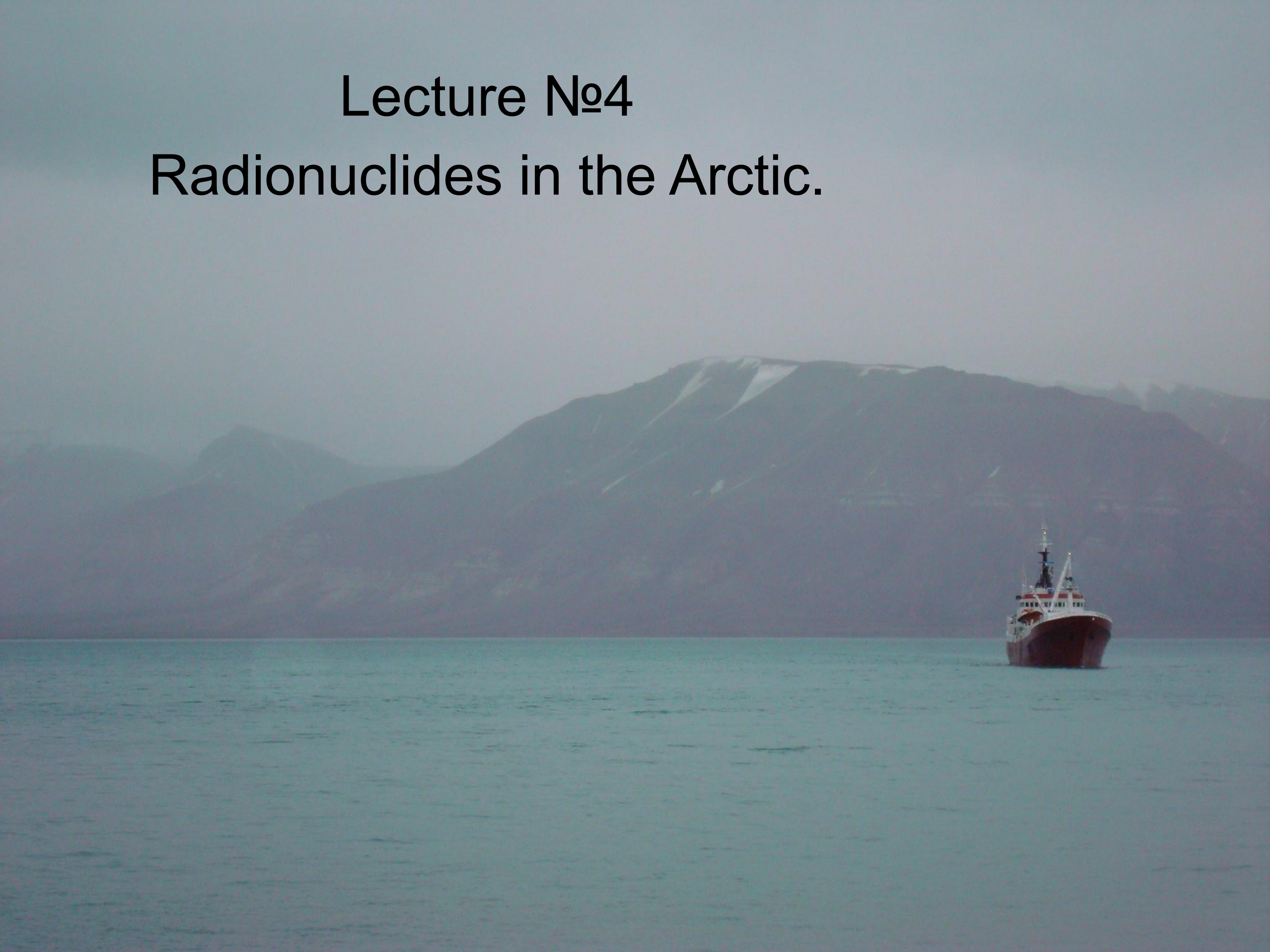
Lecture №4

Radionuclides in the Arctic.



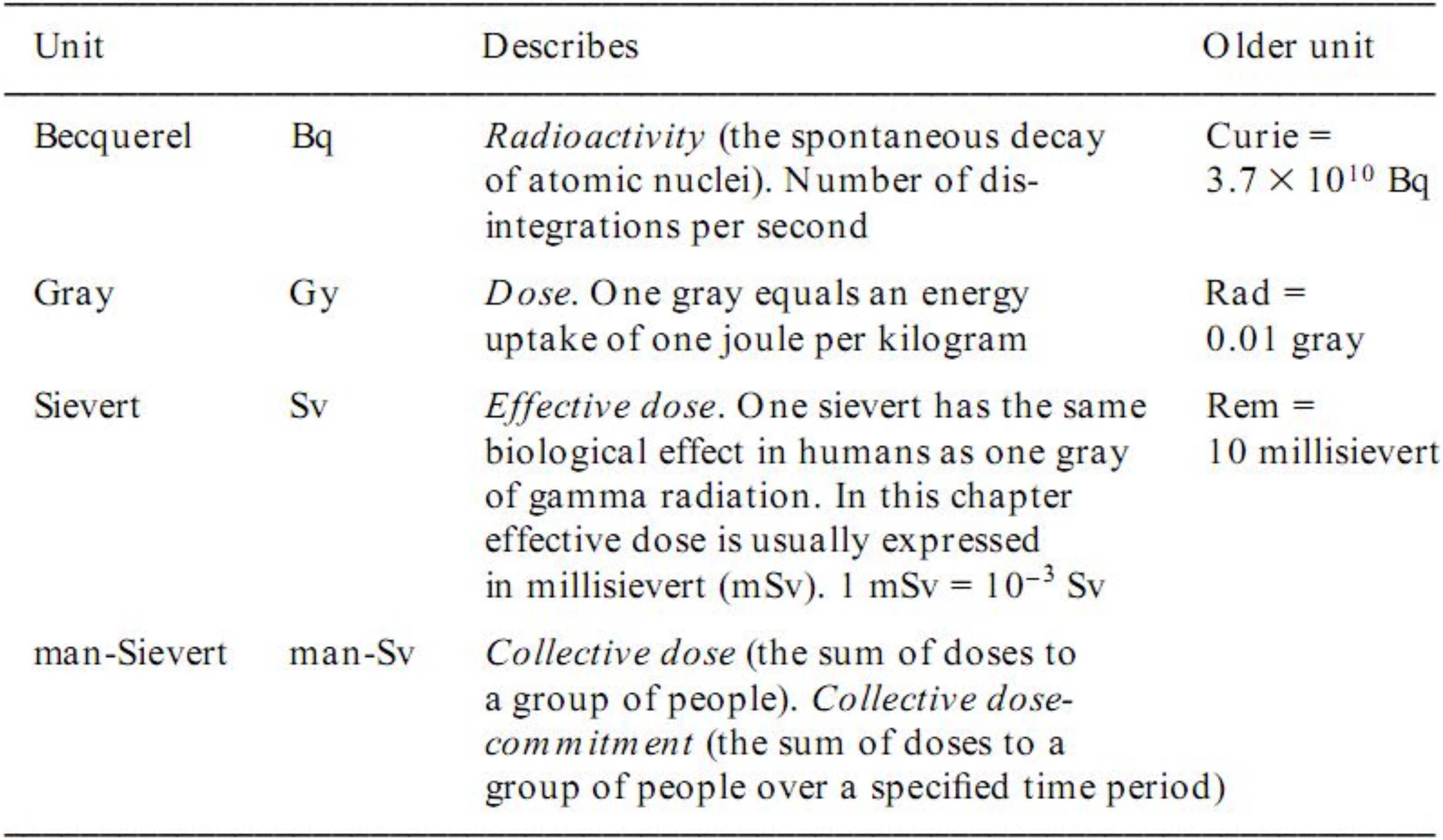
Radioactivity

Radioactivity is the property of spontaneous disintegration, or decay, of atomic nuclei accompanied by the emission of ionizing radiation. Activity corresponds to the number of disintegrations per second of an isotope (with dimensions T^{-1}).

Radioactivity

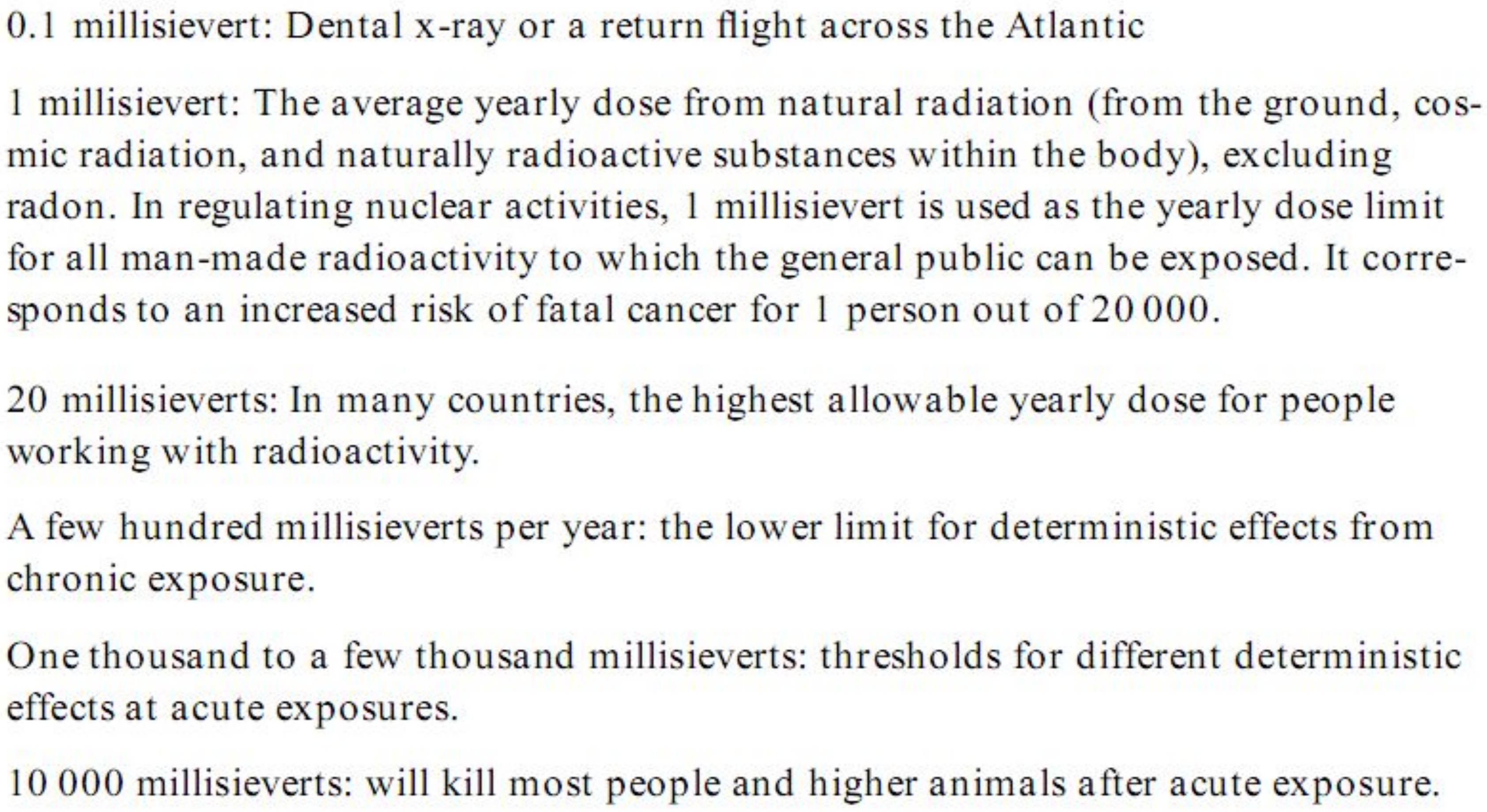
- The SI (Standards Internationaux) unit of activity is the reciprocal second (s –1) with the name **Becquerel** (Bq). The older, non-SI, unit **Curie** (Ci) that was derived from the (presumed) activity of one gram of radium and is still used in some fora, corresponds to $3.7*10^{10}$ Bq.

Units and abbreviations



Unit		Describes	Older unit
Becquerel	Bq	*Radioactivity* (the spontaneous decay of atomic nuclei). Number of disintegrations per second	Curie = 3.7×10^{10} Bq
Gray	Gy	*Dose*. One gray equals an energy uptake of one joule per kilogram	Rad = 0.01 gray
Sievert	Sv	*Effective dose*. One sievert has the same biological effect in humans as one gray of gamma radiation. In this chapter effective dose is usually expressed in millisievert (mSv). 1 mSv = 10^{-3} Sv	Rem = 10 millisievert
man-Sievert	man-Sv	*Collective dose* (the sum of doses to a group of people). *Collective dose-commitment* (the sum of doses to a group of people over a specified time period)	

Radiation doses – a comparison



0.1 millisievert: Dental x-ray or a return flight across the Atlantic

1 millisievert: The average yearly dose from natural radiation (from the ground, cosmic radiation, and naturally radioactive substances within the body), excluding radon. In regulating nuclear activities, 1 millisievert is used as the yearly dose limit for all man-made radioactivity to which the general public can be exposed. It corresponds to an increased risk of fatal cancer for 1 person out of 20 000.

20 millisieverts: In many countries, the highest allowable yearly dose for people working with radioactivity.

A few hundred millisieverts per year: the lower limit for deterministic effects from chronic exposure.

One thousand to a few thousand millisieverts: thresholds for different deterministic effects at acute exposures.

10 000 millisieverts: will kill most people and higher animals after acute exposure.

Natural radioactivity

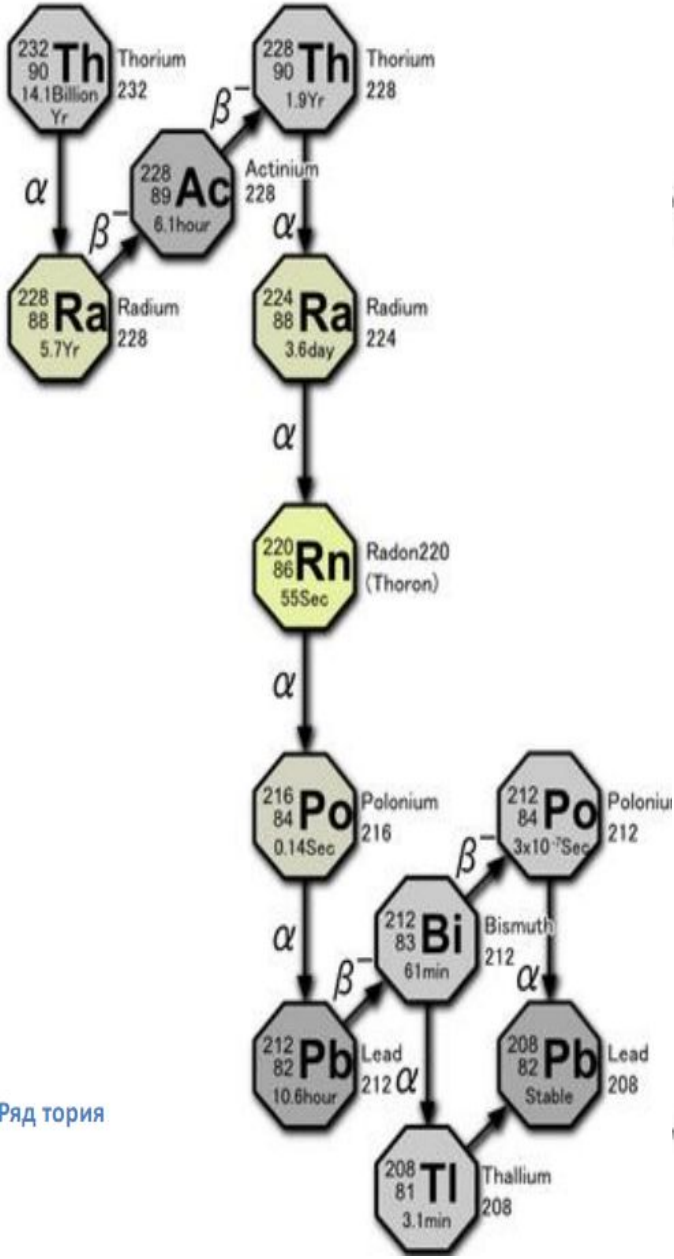
Natural radioactivity is derived from the decay of nuclei in the Earth’s crust and by the bombardment of the Earth by cosmic radiation producing radionuclides in the Earth’s atmosphere.

These natural radionuclides fall into three categories:

1. the very long-lived primordial radionuclides (^{40}K, ^{238}U, ^{232}Th, ^{235}U) formed at the time the Earth was created;
2. decay chain radionuclides (radionuclides in the uranium, thorium and actinium decay series) that are the products of decay of primordial nuclides;
3. and cosmogenic nuclides produced by the interaction of high energy cosmic radiation with the Earth’s atmosphere (e.g., ^{3}H, ^{7}Be, ^{14}C, ^{22}Na).

Artificial radioactivity.

In most situations, the most radiologically important fission products in the short term are ^{89}Sr, ^{90}Sr, ^{131}I and ^{137}Cs, and in the long term, ^{90}Sr and ^{137}Cs, because of their yields, half-lives and chemical properties. Activation products are the isotopes formed principally by the capture of neutrons by stable isotopes in high neutron flux environments.



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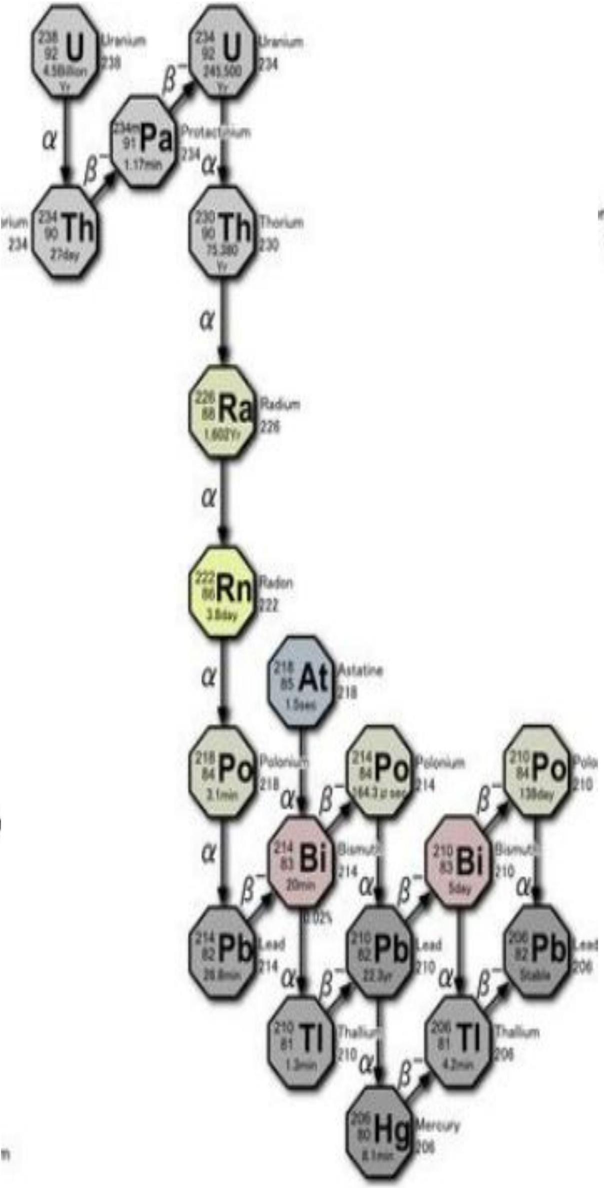

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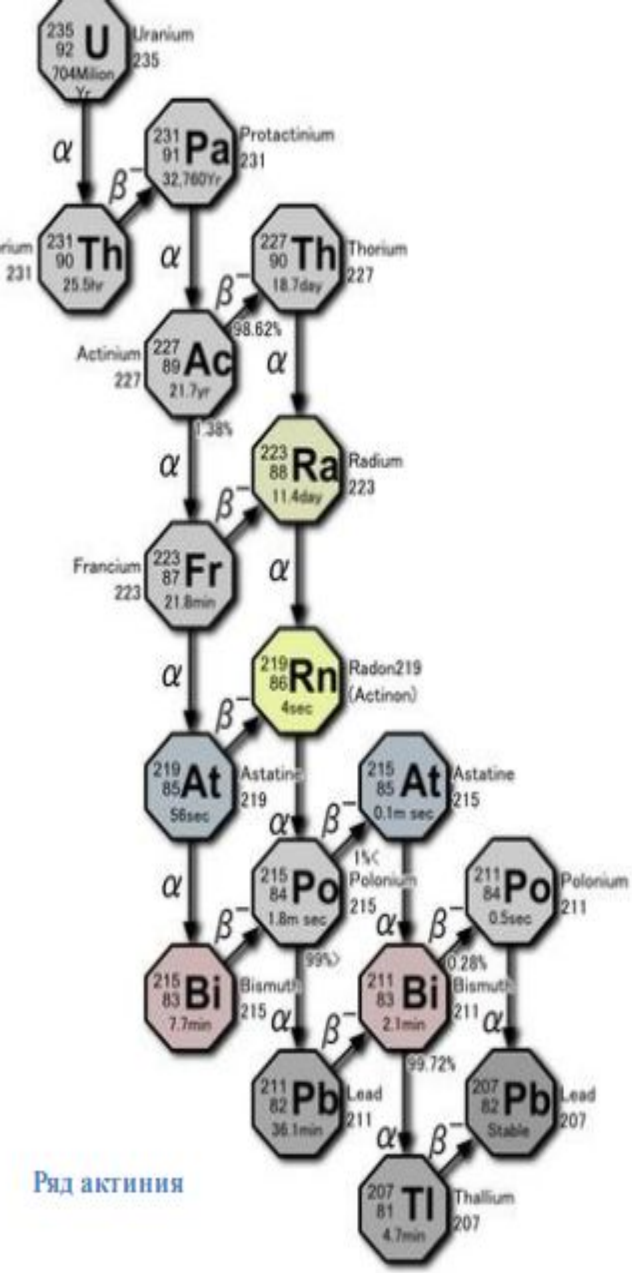


Ряд актиния

Radioactivity in the Arctic

- Radioactivity in the Arctic have highlighted that the Arctic terrestrial environment is more vulnerable to radioactive contamination than many other parts of the world. Moreover, they have shown that past sources such as fallout from nuclear testing in the 1950s and 1960s and the 1986 accident at the Chernobyl nuclear power plant still contribute to human exposure.
- Radioactivity in the Arctic is a concern because contamination can persist for long periods in soils and some plants and because pathways in the terrestrial environment can lead to high exposures of people.

Radioactivity in the Arctic

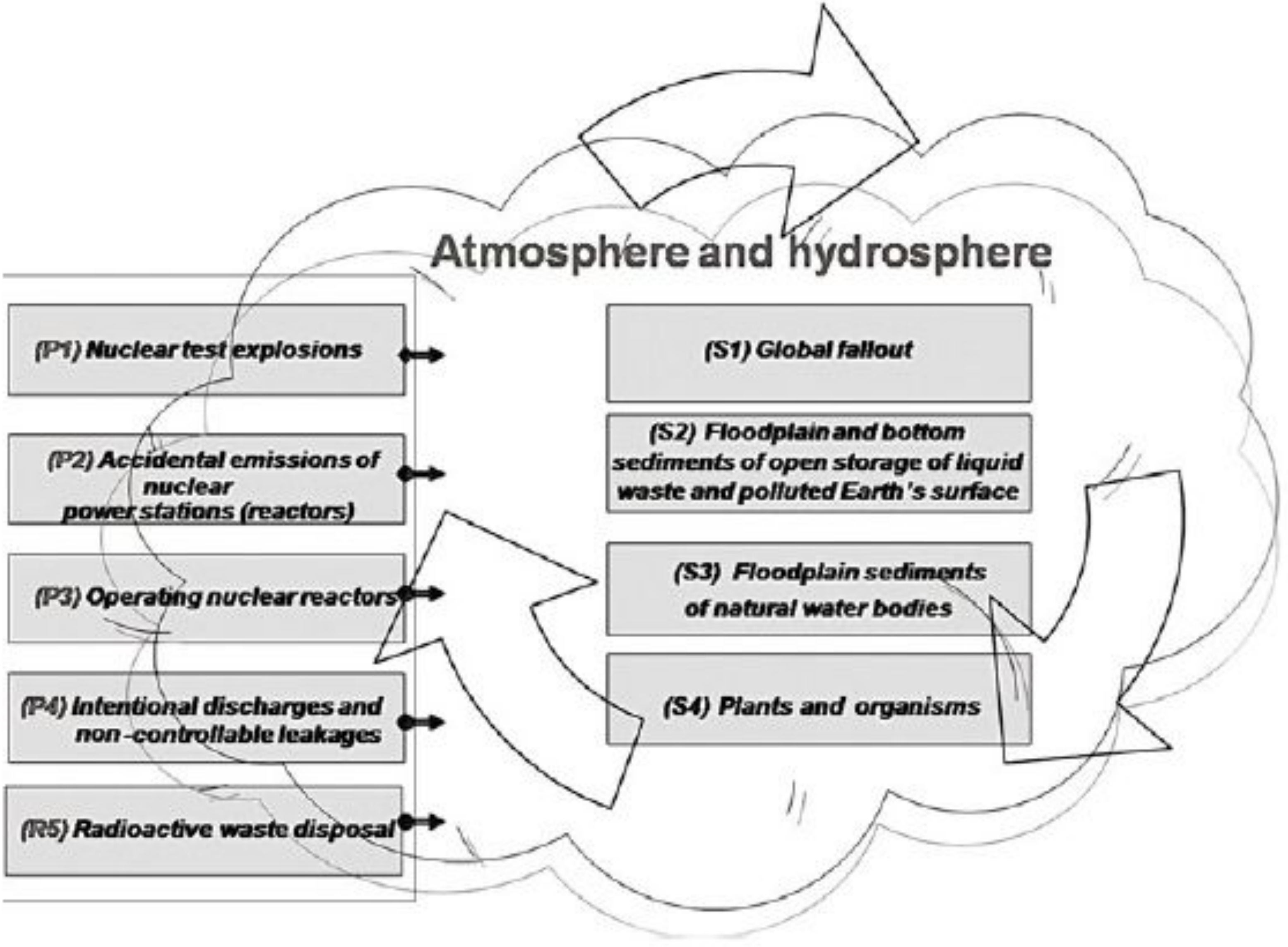
The sources of radioactive contamination in the Arctic can be divided into past contamination sources and potential future sources.

Past contamination sources

Past fallout remains in the terrestrial environment.

- From a circumpolar perspective, fallout from past nuclear weapons testing has historically been the most important source of human and environmental exposure to anthropogenic radioactive contamination. Other past significant emissions include fallout from the 1986 accident in the Chernobyl nuclear power plant, which affected the European Arctic. Although the fallout spread all over the globe, the Arctic is particularly vulnerable because Arctic vegetation has very efficient uptake of radionuclides.
- Potential sources of radioactive contamination of the Arctic include nuclear powered vessels that were poorly maintained or being decommissioned; dumped and stored radioactive wastes, including wastes stored under inadequate conditions; radioisotope thermoelectric generators (RTG s) used as energy sources in northern regions; and nuclear power plants and reprocessing facilities located close to the Arctic.

Primary (P) and secondary (S) sources of artificial radionuclide



Atmosphere and hydrosphere

(P1) Nuclear test explosions

(P2) Accidental emissions of nuclear power stations (reactors)

(P3) Operating nuclear reactors

(P4) Intentional discharges and non-controllable leakages

(R5) Radioactive waste disposal

(S1) Global fallout

(S2) Floodplain and bottom sediments of open storage of liquid waste and polluted Earth's surface

(S3) Floodplain sediments of natural water bodies

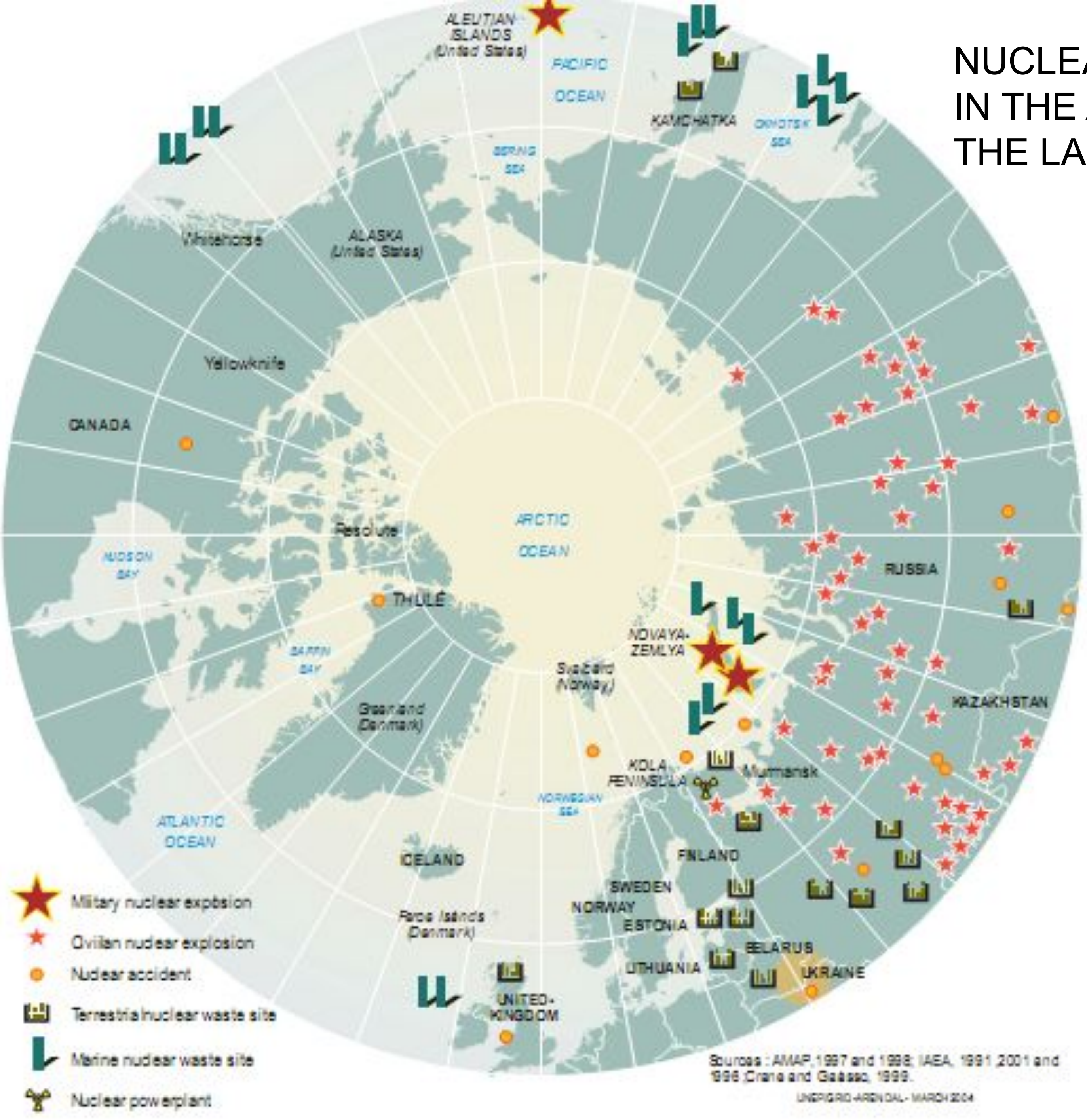
(S4) Plants and organisms

Radioactivity in the Arctic

Radioactive contamination of the Arctic has occurred at two different scales:

1. Widespread contamination, such as that associated with global nuclear weapons testing, Sellafield releases and the Chernobyl accident.
2. Localized contamination of smaller areas (e.g., resulting from the Thule nuclear weapons accident and radioactive wastes dumped at sea). The following presentation focuses on ^{137}Cs and ^{90}Sr, since these radionuclides are important for determining dose to humans, and considerable data exist on each of them.

NUCLEAR ACTIVITIES IN THE ARCTIC OVER THE LAST 50 YEARS



Sources : AMAP, 1997 and 1998; IAEA, 1991, 2001 and 1996; Crane and Galasso, 1999.

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Widespread contamination of land and sea

- Terrestrial contamination

The two major sources of fallout in the Arctic region have been nuclear weapons testing and the Chernobyl accident.

- Marine contamination

The anthropogenic sources contributing to the contamination in the marine environment are mainly nuclear weapons fallout and releases from Sellafield and the Chernobyl accident.

Localized contamination

- Short-range fallout from Novaya Zemlya tests

There have been some 130 tests at Novaya Zemlya, 88 in the atmosphere, 3 underwater and 39 underground

Sources

1. Nuclear tests 1945 - 1990

According to the UNSCEAR 2000 (UNSCEAR 2000), after 1945, 2,419 nuclear explosions were conducted with a total yield equivalent to 530 Mt.

The main overall yield (440 Mt) was primarily due to 543 atmospheric nuclear explosions, while 1,876 underground nuclear explosions produced only 17% of the total yield (90 Mt).

The most powerful atmospheric nuclear explosions (4 MW in excess of their power) are responsible for almost 66% of the total yield.

The largest nuclear test in the atmosphere was an explosion with a capacity of 50 megatons, carried out on October 30, 1961 on Novaya Zemlya.

The largest underground explosion on Novaya Zemlya (from 1.5 to 10 Mt) was carried out on October 27, 1973.

MAIN ATMOSPHERIC AND UNDERGROUND NUCLEAR EXPLOSIONS SINCE 1945

Sources: Assemblée nationale française, Christian Bataille, Henri Revol,*Incidences environnementales et sanitaires des essais nucleaires effectues par la france entre 1960 et 1996 et elements de comparaison avec les essais des autres puissances nucleaires*, rapport no. 3571, 2002;

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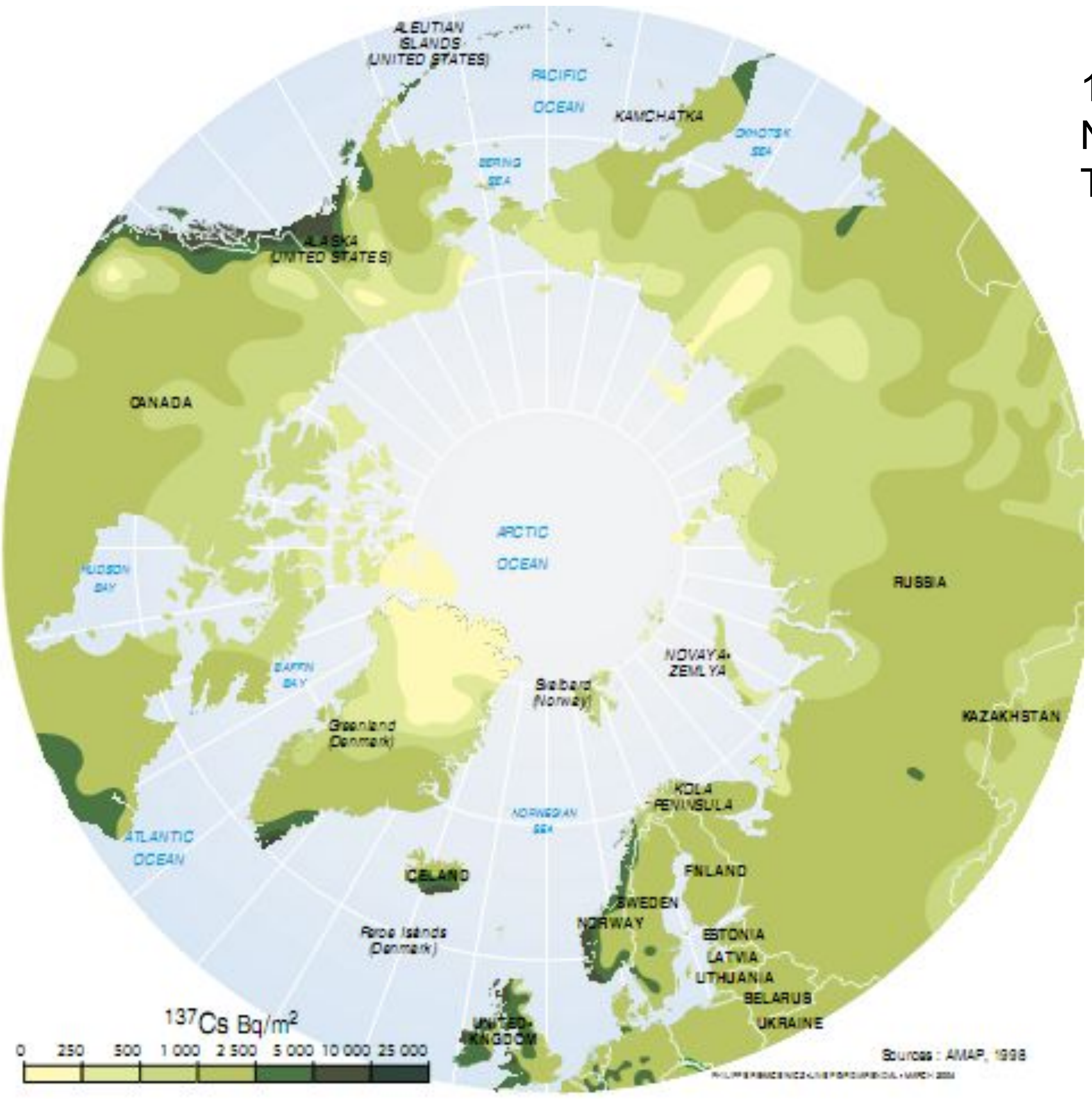
Of 130 explosions conducted on Novaya Zemlya:

- 85 were atmospheric,
- 3 - underwater,
- 2 - at the surface of water,
- 1 - on the surface of the earth,
- and 39 - underground.

Approximately 12% of the radioactive products of the explosions on Novaya Zemlya fell outside the test sites, 10% of deposition fell into the concentric circumpolar ring at the latitude of Novaya Zemlya, and 78% in the form of fine dispersed products replenished the global fund of stratospheric radionuclides, from which further radioactive fallout occurred (AMAP 1998).

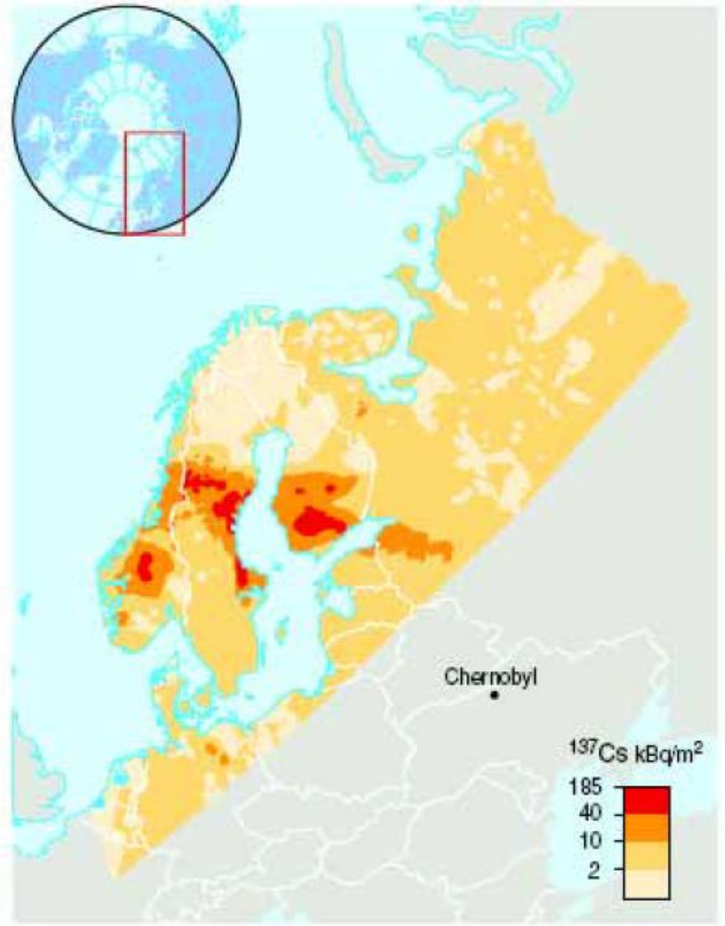
137 CESIUM FROM NUCLEAR WEAPON’S TESTING FALLOUT



Sources : AMAP, 1998

Sources

2. The Chernobyl accident of 1986



Sources

3. Western European radiochemical plants for processing nuclear fuel.

At radio chemical plants, uranium and plutonium are separated from spent nuclear fuel for reuse, which is accompanied by the formation of a large number of various radioactive waste (UNSCEAR 2000).

The most powerful and currently operating plants in Western Europe are Sellafield (Great Britain) and La Ag (France).

Discharges Sellafield through the pipes fall into the Irish Sea, and discharges RHZ on Cape La Ag in the Channel English Channel.

Sources


Mining and Chemical
Industrial Complex of Zheleznogorsk
Yenisey
Tom
Siberian Chemical Combine
Ob
Kara Sea
Barents Sea
Komsomolets
Kursk (removed)
Mayak
Dounreay
Sellafield
Chernobyl
Cap de la Hague
Nuclear accident
Reprocessing plant
Sunken nuclear submarine
Dump site of solid radioactive waste

Sources

4. Radiochemical plants of Russia

Currently, there are five Rosatom nuclear fuel cycle plants that can influence the water environment of the Arctic seas.

The main ones are Mayak complex in Chelyabinsk Oblast (Ob River basin), Siberian Chemical Plant Tomsk-7 in Tomsk Oblast (Ob River Basin), Krasnoyarsk Mining and Chemical Combine in the Krasnoyarsk Territory (Yenisei Basin) (AMAP 1998).

Sources

5. The Russian nuclear fleet (including the service infrastructure)

In total:

nuclear submarines - 248,

surface nuclear ships - 5,

nuclear icebreakers - 8,

The total number of nuclear reactors installed at these facilities exceeded 450, and their total capacity is comparable to the installed capacity of all nuclear power plants of the country (Strategic 2004).

Sources

6. Kola and Bilibino nuclear power plants,

Sources

7. Radioisotope thermoelectric generators (RTGs)

A special source of possible radiation impact on the Arctic coast is the so-called radioisotope thermoelectric generators.

RTGs are used for long-term autonomous power supply of lighthouses and luminous navigation signs. In total, about 1000 RTGs were placed in Russia, mainly along the coast of the Arctic Ocean.

The period of their production continued from 1976 to 1990. The service life of all types of RTGs is 10 years. At present, for all RTGs the service life has been completed

Sources

8. Underground nuclear explosions for economic purposes

In the period from 1965 to 1988, the USSR carried out an extensive program of surface nuclear explosions for economic purposes.

A total of 116 explosions were conducted.

In general, the tasks of mining, oil and gas and construction industry were solved.

Sources

9. Elevated levels of natural radionuclides during offshore oil and gas production

★ Civilian nuclear explosions

SOURCES OF RADIOACTIVE WASTE

The following categories:

- High-Level Waste (HLW)—
- Uranium mining and mill
- By-product material
- Low-Level Waste:
  - Class A
  - Class B
  - Class C
  - Greater Than Class C (GTCC)
- Formerly Used Sites Remedial Action Program (FUSRAP)
- Naturally Occurring Radioactive Material (NORM)

Movement of radioactive materials

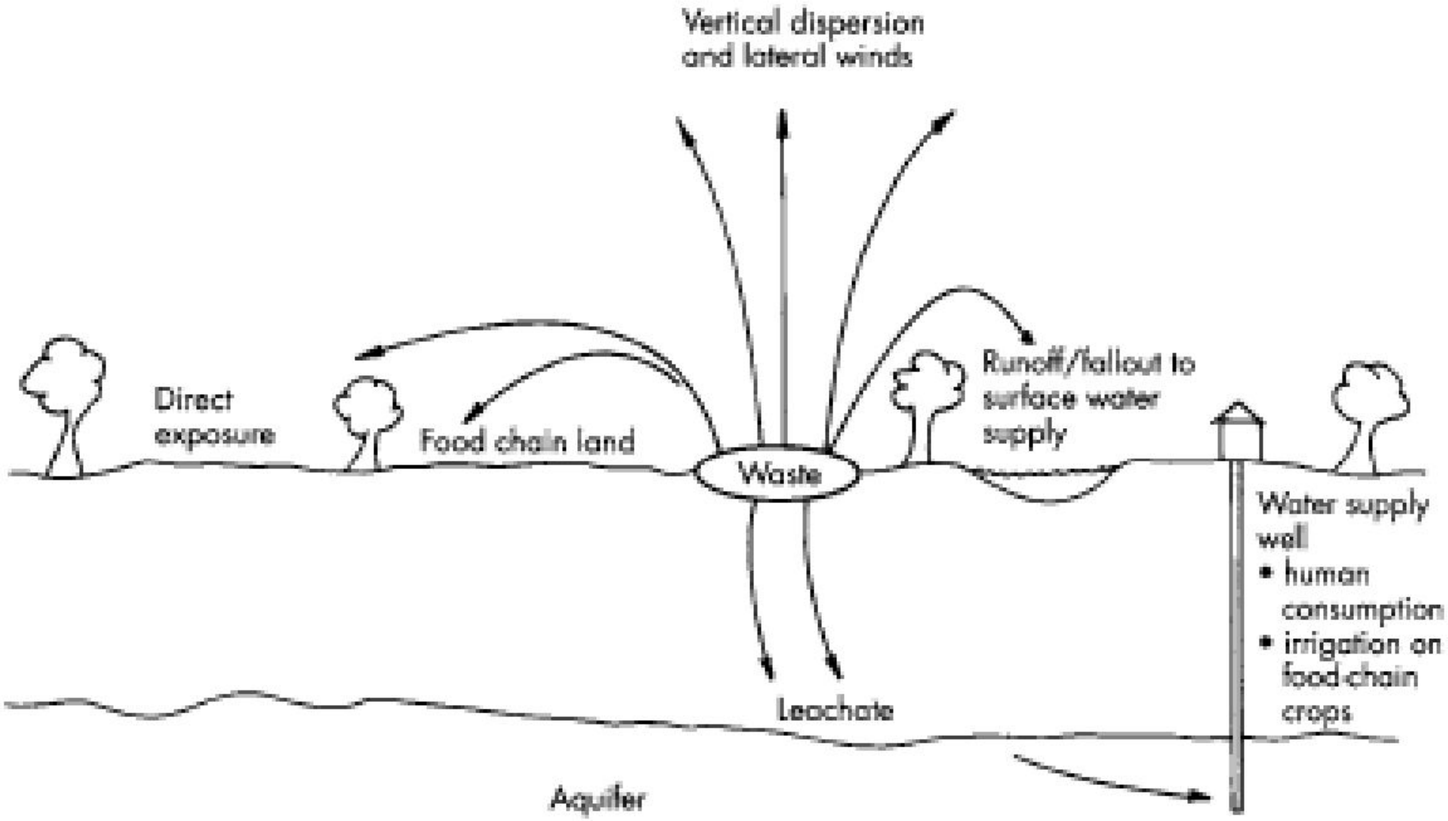


FIGURE 16–6. Potential movement of radioactive materials from waste storage and "disposal" areas to the accessible environment

Atmospheric transport

The mean residence time of radionuclides in the Arctic stratosphere is in the order of one year. The transfer of radionuclides from the stratosphere to the troposphere occurs preferentially in the spring, when the tropopause is most ‘permeable’

- The mean residence time of radionuclides in the troposphere is only a few weeks.
- Radionuclides in the troposphere are transferred to the surface of the Earth as wet or dry fallout.

Marine transport

- Releases into Arctic marine ecosystems can either occur directly, through routine releases from nuclear reactors into cooling water streams, leakage from dumped solid wastes, direct dumping of liquid wastes, or indirectly via atmospheric deposition. In addition, radionuclides released else where may be transported into Arctic marine systems.

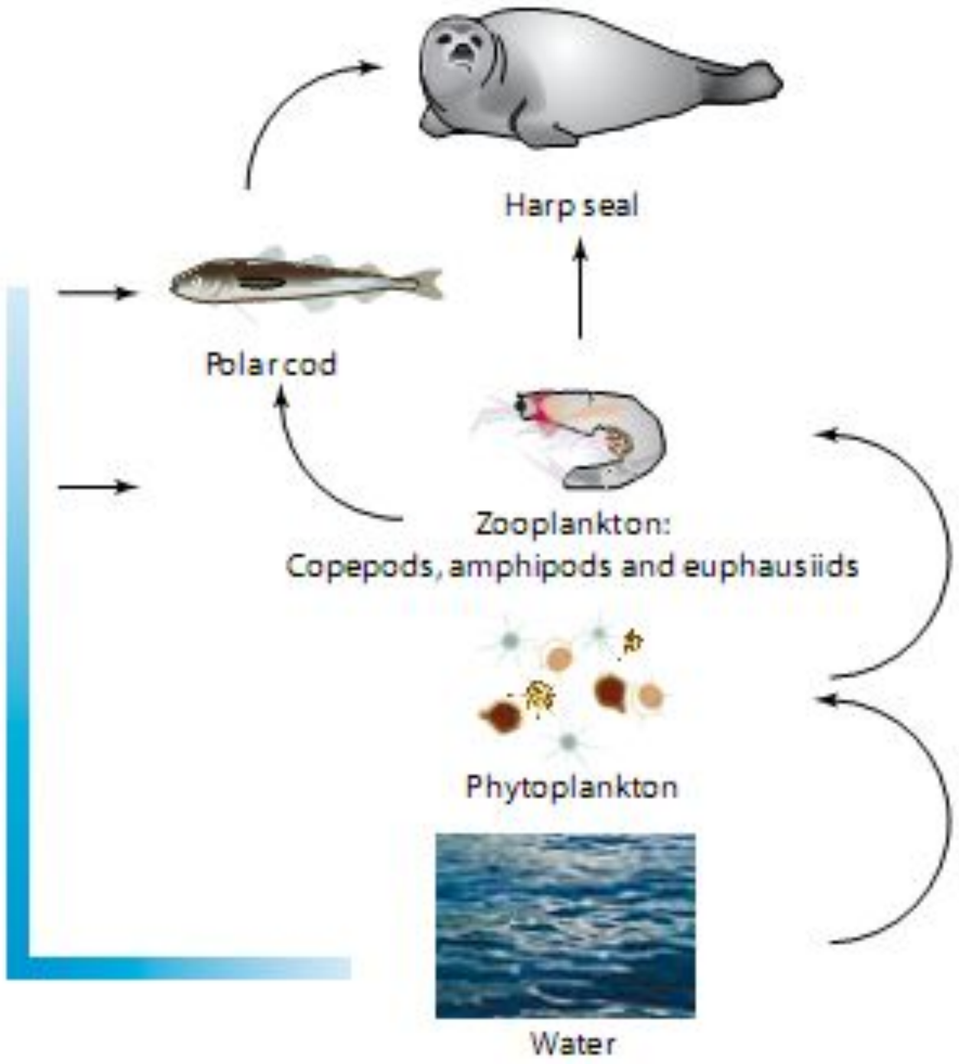
Terrestrial transport

- Once radionuclides are deposited onto the Earth’s surface, their subsequent behavior is dependent on a number of factors including their physico-chemical form and the type of environment into which they have been released.
- Terrestrial and freshwater environments generally receive most of their radioactive contamination through precipitation (wet fallout).
- Vegetation may be contaminated directly by deposition of the radionuclides onto the surface of the plants, or indirectly by uptake from the soil through the roots.
- Further transfer of radionuclides in the food chain occurs when animals, including humans, consume food, drink water or breath air.

Transfer

1. Interception
2. Soil-to-plant transfer
3. Plant-to-animal transfer

- Diet selection
- Availability for absorption in the gut
- Metabolism of the radionuclide



Food-chain model for harp seal in the Barents Sea. Source:
simplifed from Dommasnes et al. (2001).

Half-life of a radionuclide

- The effective biological half-life of a radionuclide in an organism is a function of both the biological half-life of the element in the organism and the physical half-life of the radionuclide.

$1/T\ 1/2\ eff\text{-}biol = 1/T\ 1/2\ biol + 1/T\ 1/2\ phy$

- The effective ecological half-life of a radionuclide is a function of both the half-life of the element in a component of an ecosystem and the physical half-life of the radionuclide.

$1/T\ 1/2\ eff\text{-}eco = 1/T\ 1/2\ eco + 1/T\ 1/2\ phy$

The half-life of a radionuclide

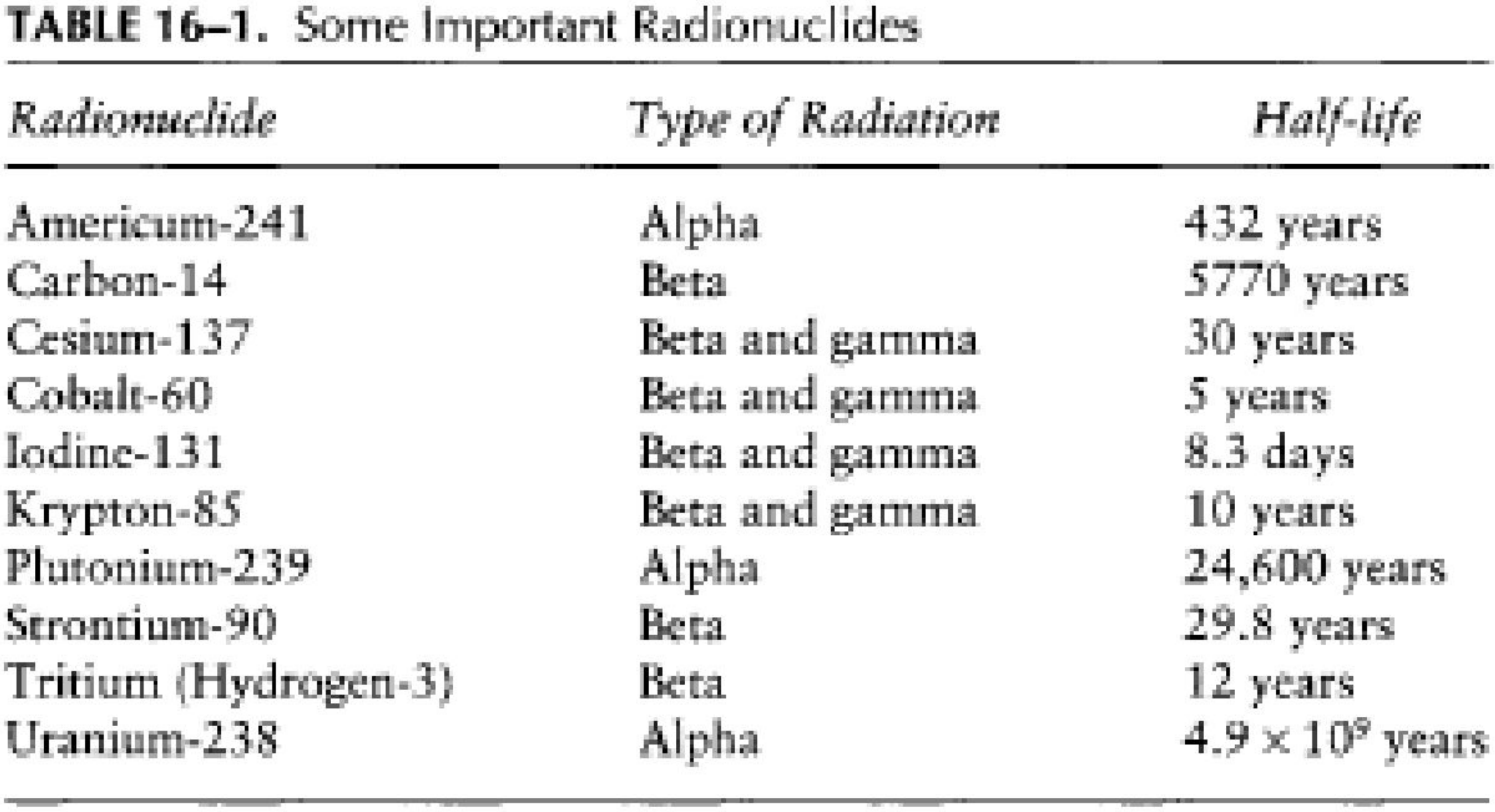


TABLE 16–1. Some Important Radionuclides

Radionuclide	*Type of Radiation*	*Half-life*
Americum-241	Alpha	432 years
Carbon-14	Beta	5770 years
Cesium-137	Beta and gamma	30 years
Cobalt-60	Beta and gamma	5 years
Iodine-131	Beta and gamma	8.3 days
Krypton-85	Beta and gamma	10 years
Plutonium-239	Alpha	24,600 years
Strontium-90	Beta	29.8 years
Tritium (Hydrogen-3)	Beta	12 years
Uranium-238	Alpha	4.9×10^9 years

Freshwater pathways

The transfer of radionuclides from such systems occurs mainly through consumption of freshwater fish and from exploitation as drinking water. The mobility of a radionuclide depends on its ability to bind to river sediments and its competitive interactions with other ions. Strontium is one of the more mobile elements in aquatic systems because it does not bind strongly to sedimentary material.

Marine pathways

- Exposure from marine pathways arises from the consumption of marine food products, including fish and shellfish, mammals such as seals and whales, and seaweed. In general, contamination of marine biota is much less than that arising from terrestrial pathways, largely because of the strong sorption of many radionuclides by aquatic sediments and also because of the enormous dilution which occurs in marine water bodies

The effects of radiation under Arctic conditions:

- Severe climatic conditions are factors of natural environmental stress, restricting the number of biological species which are able to survive in the Arctic. Low biodiversity is a negative ecological factor associated with the low capacity of Arctic ecosystems to adapt in the case of any environmental changes.
- The development of radiation effects in the Arctic poikilothermic (or hibernating) organisms is expected to occur more slowly, because of low environmental temperatures. On the other hand, repair of radiation damage in cells and tissues is not effective at very low temperatures. Lesions in the cooled (poikilothermic or hibernating) organisms are latent. However, if organisms become warm, lesions are rapidly revealed. As a result, radiation effects may not appear during the winter period, but may manifest themselves intensively during the warm season.

The effects of radiation under Arctic conditions

- Development of embryos and young poikilothermic organisms in the Arctic occurs slowly;
- High concentrations of lipids in Arctic animals may be expected to increase their radiosensitivity, because chemical products of lipidoperoxidation produced by irradiation are toxic for organisms.
- Long-distance migrations of Arctic animals, in general, are favorable for survival, because animals do not stay within any contaminated local area for long periods; thus accumulated doses to migratory animals are expected to be lower than those for sedentary organisms.

The effects of radiation

- morbidity (e.g., worsening of physiological characteristics of organisms; effects on immune system, blood system, nervous system);
- reproduction (negative changes in fertility and fecundity, resulting in reduced reproductive success);
- mortality (shortening of lifetime as a result of combined effects on different organs and tissues of the organism);
- cytogenetic effects (radiation effects at the cellular level);
- ecological effects (changes in biodiversity, ecological successions, predator-prey relationships);
- stimulation effects (radiation hormesis, low dose stimulation effects); and
- adaptation effects (responsive adjustments of organisms to the conditions of chronic irradiation).