HEALTH-RELATED CRITERIA FOR NUCLEAR-WASTE SORTING

Why is it appropriate to sort nuclear waste from the health point of view? This is required to create for each category of waste the conditions most likely to prevent, restrict or delay the migration of waste into the environment until its radioactivity disappears, with the view of safeguarding human health. Doing this helps to avoid both the deterministic effects (i.e. effects with definite threshold doses occurring soon after exposure) and the delayed, random (or stochastic) effects of radiation. Whatever the case, human beings may only incorporate radionuclides or be irradiated at very low doses and very low dose rates. The corresponding calculated doses are more than an order of magnitude lower than natural irradiation (2.5 millisieverts per annum), and several orders of magnitude lower than doses seen to have an effect on health after chronic irradiation (several hundred millisieverts).

Sorting, conditioning, and management methods used in the field of radioactive waste all depend on the origin of the waste (hospitals, industry, **fuel** cycle, etc.) and on health-related criteria. From the health point of view, the objective is to avoid exposure liable to lead to deterministic effects, and limit the risk of delayed random (or stochastic) effects.

Deterministic and random effects, and health objectives

In order to prevent the occurrence of deterministic effects, which are observed above an **absorbed dose** of 0.5 to 1 Gy (**gray**), acute irradiation must be avoided by reducing the concentration of **radionuclides** in the environment. Theoretically, this can be done in one of two ways: *diluting* the radionuclides with stable **isotopes** found in the environment, or *concentrating* and conditioning them (see box A, ***What is radioactive waste? The various types of waste***) to limit and delay their migration to the environment until they have undergone sufficient radioactive decay.

The biological behavior of radionuclides in the organism is similar to that of the corresponding stable isotopes (e.g. iodine, tritium) or of elements considered chemically comparable (e.g. strontium and calcium). They spread throughout the body (like tritium or carbon), or are deposited in certain organs (iodine in the thyroid, strontium in the skeleton). **Actinides** are deposited principally in the liver and skeleton.

The increased frequency of the carcinogenic effects of ionizing radiation has not been proved for **equivalent doses** below 100 mSv (millisievert) after acute irradiation, or below 0.5–1 **Sv** after prolonged irradiation at low **dose rates**. No increase in hereditary effects has been observed, even at high doses. The risk of occurrence of delayed effects is therefore estimated on the basis of carcinogenic risk by calculating the **effective dose** (in mSv), for which there is no threshold according to radiobiologists. The effective dose is calculated for each radionuclide from the incorporated **activity** (in Bq).

Epidemiological and experimental studies of radionuclide effects show that radionuclides preferentially deposited in the skeleton (known as osteotropic or bone-seeking radionuclides) and **alpha** emitters induce bone cancer (or osteosarcoma) as a non-linear dose–response relationship. Cancers only occur above a certain dose, equivalent to an activity of 37 MBq (= 1 mCi, or the activity of one gram of radium-226), beyond which their frequency increases exponentially.

In view of these biological results, health objectives can be summed up as follows: avoid acute exposure (> 0.5 Gy) to prevent deterministic effects, limit chronic exposure to reduce the risk of cancer (low dose rate, equivalent dose well below 100 mSv, limit exposure to alpha emitters to remain below the bone-cancer threshold), and take into consideration possible exposure times and the quantity (by mass) that may be absorbed.

Partitioning and transfer criteria to the environment

Radionuclides are partitioned according to several criteria:

- **Specific activity**. Conditioning and management methods must be adapted to minimize the dose rate of radionuclides transferred to the environment, water in particular.
- Radioactive **half-life**. The initial activity decays by a factor of more than 1,000 in 10 radioactive half-lives. In the case of decay chains, it is essential to take into account the half-lives of **daughter products**. The process by which the organism eliminates the radionuclide must also be considered here. This implies the notion of biological half-life(1).
- Concentration of **alpha emitters**. Conditioning and management methods must be adapted to avoid the transfer of high concentrations of osteotropic alpha emitters to human beings.

Possible effects depend on the ability of each radionuclide to migrate to the environment and enter the human body through the respiratory or digestive tract, as well as on its own specific **radiotoxicity**. Migration itself depends on the solubility of the radionuclide in the surrounding medium. Broadly speaking, a soluble radionuclide migrates easily, but at the same time is diluted as it mixes with homologous stable elements. Radionuclides that are not very soluble only migrate very slowly. In both cases, dilution or slow migration in the environment mean that radionuclide intake by human beings will always occur at very low concentrations, and therefore at a very low dose and very low dose rate.

The chemical risk has not been taken into direct consideration, although a radionuclide can liberate chemical toxicity affecting one or more target organs at concentrations for which no radiotoxic effects are observed.

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(1) After human incorporation, time required for a given quantity of molecules containing a radionuclide to be halved.