IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Context and statuts of pamphlets

Contents

Context and status of pamphlets

The Department of Research and Expertise on Environmental Risks (IRSN/PRP-ENV/SERIS) took the initiative, in 2000, to compile a series of informational pamphlets on the radioecological behaviour of radionuclides in the environment. The pamphlets summarize the essential characteristics that govern the behaviour of radionuclides, with an emphasis on transfers to humans *via* the food chain. The intention is to provide information in an easily accessible and understandable format. For each radionuclide, the ecotoxicity is presented relatively to the chemical toxicity of the stable element when information is available and to the radiological toxicity of the radioactive isotope of interest. The pamphlets are a synthesis of generalized knowledge, without providing information on the nuances, exceptions, contradictions, and data gaps that commonly exist within the scientific literature relative to the environmental behaviour of radionuclides.

The information contained in the pamphlets present, as a rough order-of-magnitude guide, the default values for the main radioecological parameters. Consequently, these values do not represent recommendations of the IRSN. The choice and use of these values is the sole responsibility of the reader, and it is the reader that must justify their application. However, when possible, we present the values for which exists a scientific consensus, in particular by international bodies such as, the International Atomic Energy Agency (IAEA).

Contents and domain of validity

We tried to standardize the pamphlets so that they contain the necessary information about each radionuclide's environmental mobility and biological availability. However, the quantity of data presented within each pamphlet varies because of the heterogeneousness of knowledge. This leads to a plentiful bibliography in certain cases, such as for caesium, or very brief, as for example, with niobium. When data were missing for a radionuclide, we widened, as possible, the observations by adding data relative to the stable isotopes of the element (if they exist) or to its chemical analogues. Additionally, the importance of various pathways or mechanisms differs according to the specifics of each element, and the quantity of data presented varied accordingly. Thus, a particular pathway or mechanism may be described in detail for some radionuclides (*e.g.*, the process dominates the behaviour of the element) or may not be indicated at all if it is a minor process.

Each pamphlet contains certain fundamental sections, of which the contents and domain are detailed below.

CHARACTERISTICS

- **Chemical:** a simple description of the element (family, main properties, main oxidation states and dominant chemical species in the environment). The main chemical analogues are mentioned if important. The data generally come from the Handbook of Chemistry and Physics (Lide 1999. 79th. edition, Chemical Rubber Company CRC press, Florida, USA).

- **Nuclear:** a presentation of the key nuclear data (period, main energies, mother and daughter products, etc.) is given for the primary radioisotopes of the element; for some nuclides a decay schema is also given. We define primary radioisotopes as having the following characteristics: presence or persistence in the environment; a significant contribution to the global radiological impact in case of discharge; or one that is prominent in the news media for some reasons and for which information is welcome. The data arise from the website Nucleonica, developed at the Institute for Transuranium Elements (ITU) (http://www.nucleonica.net/) and owned by the European Atomic Energy Community.

ORIGINS

- **Natural** or **artificial:** the origin of radioisotopes are briefly described as natural (lithosphere, atmosphere) or artificial (fission or activation product); their historic source term (accidents, localized discharges, atmospheric fallout); and current discharges (from nuclear installations, conventional industries, laboratories, hospitals, or hypothetical situations such as future nuclear waste) are exposed. Any existing stable isotopes are also mentioned when their presence influences the behaviour of the radioisotopes, or when the radioecological data are limited.

CONCENTRATIONS IN THE ENVIRONMENT

This paragraph gives the mean concentration of the radioisotope (or of the stable element) measured in a natural environment (*i.e.*, not subjected to anthropological disturbances), and possibly extreme values measured in certain specific cases.

METROLOGY, ANALYTICAL TECHNICS AND DETECTION LIMITS

The various methods for quantifying the radioisotopes are described, as well as the specific equipments required. The minimal sample sizes are stated, in connection with the nature of samples and the limits of detection/quantification.

MOBILITY AND BIOAVAILABILITY IN TERRESTRIAL ECOSYSTEM

- **Soils:** an outline of the radionuclide mobility is given for the superficial soil horizon, based on average conditions (*i.e.*, generally an aerated soil with a redox potential E_H between 0 and 500 mV and a pH between 5 and 8.5). We describe the main carrier phases known to influence the element's retention (clay minerals, organic compounds, oxides and metallic hydroxides, carbonates), the major mechanisms of its sorption-desorption, as well as the parameters (mainly pH, E_H and major constituents of the soil) able to influence its mobility. The expression *"low…high…average…mobility"* is related to comparisons between elements, *e.g.*, plutonium is considered to have low mobility, while chlorine is considered very mobile in soil.

- **Plants:** data relative to the foliar or root transfer in plants are highlighted: intensity of the transfer, main parameters governing bioavailability, translocation to the edible parts of plants.

- **Animals:** transfers from food or other pathways (inhalation, water intake) *via* breeding animals to animal products (milk, meats) are briefly described. The biological periods are given when available.

- **Food products:** when the effect of food-processing transformations was studied (what is rarely the case), a dedicated paragraph gives the main results.

MOBILITY AND BIOAVAILABILITY IN FRESHWATERS

- **Water:** variation of surface waters has a large impact on the physico-chemical characteristics of the associated radionuclides; in particular, the nature of the watersheds, climatic seasons and precipitation. However, we generalize the mobility of the radionuclides in superficial continental waters (rivers and lakes) by describing nominal conditions, (*i.e.*, pH between 7 and 8,5; an average conductivity of 500 $\mu S.cm^{-1}$; annual average temperature between 9 and 18 °C, and oxidizing conditions). The speciation of the element is specified, as well as, the solubility of some of its compounds. The possibility of complex formation is given, with the potential for colloid formation. The peculiarities of dissolved and particle phases are specified as much as possible through a distribution coefficient between water and suspended matter.

- **Sediment:** this compartment constitutes a storage zone for pollutants in the aquatic environment. It is thus particularly important to characterize their mobility within sediments, estimated through the water-sediments distribution coefficient. Based on the soils, the nature of the watershed contributions and the conditions of water flow and deposition, sediments vary largely in their physico-chemical characteristics. We describe the mobility of the radionuclides for nominal conditions of sediments (pH between 6 and 8; a redox potential from 0,5 to 1 V). Processes and conditions determining the evolution of the binding of the contaminant to the sediments are presented when known.

- **Plants:** data relative to radionuclide transfer in the main categories of plants are presented (microscopic algae -phytoplankton-; mosses and higher plants). When possible, transfer pathways are specified, as well as the processes involved. However, in the aquatic environment, the transfer of radionuclides to plants is generally treated through a concentration ratio between water and plants.

- **Animals:** the biological role of the element, if known, is specified within the information available on its mobility and its bioavailability. For transfers to organisms, the kinetics of exchange are indicated, if known. The concentration factor between water and animals is given by trophic level (primary producers, first order consumers and consumers of higher orders). The distinction between various organs can be made, in particular relative to the possibility of trophic transfer (soft parts of molluscs, muscles of fish). This second pathway is described through a trophic transfer factor between prey and predator.

MOBILITY AND BIOAVAILABILITY IN MARINE ECOSYSTEM

- **Water:** the behaviour of some radionuclides in waters exhibiting large variability in their physical and chemical characteristics (*i.e.*, turbidity, salinity), such as estuaries, may be explained through these properties. Oxidation states and physico-chemical forms are specified, as well as the distribution between the soluble and particle phases. The concentrations of stable isotopes, if they exist, are generally mentioned.

- **Sediment:** this compartment is a storage zone for numerous pollutants in the marine and estuarine aquatic environments. It is thus particularly important to characterize the sediment's capacity for binding radionuclides. This is done by using the water-sediment distribution coefficient, or by identifying the carrier sedimentary phases of the pollutants. Processes and conditions determining the evolution of

contaminant binding on particles, or its immobilization in the sedimentary column, are presented when known.

- **Plants:** in the aquatic environment, radionuclide transfer to plants is generally described through a concentration factor between water and the whole plant. Data on the radionuclide uptake by seaweed are generally presented; information on higher plants is rare.

- **Animals:** the transfer pathways (water, sediment, food) are specified and the corresponding parameters are supplied, mainly as transfer factors between water and animals. The differences between species are highlighted, and distinction between various organs can be made. The kinetics of accumulation and elimination are sometimes indicated, as well as the biological role of the element. Information on the mobility or the bioavailability is given.

MOBILITY AND BIOAVAILABILITY IN SEMI-NATURAL ECOSYSTEMS

In radioprotection, the consideration of the three main ecosystems (terrestrial, freshwater and marine) does not adequately represent the variety of media potentially contaminated by radioactive substances and\or used by the man. Thus, three additional environments are described as semi-natural ecosystems: forests, arctic and alpine ecosystems.

- **Forests:** forests are used by humans for many reasons, whether for wood exploitation, hunting, harvesting of products, recreation, or as protected areas for plant and animal life. Data relative to the transfer in wood, berries, mushrooms and game are therefore presented when available. They are, however, rare and relate essentially for three radionuclides, Cs, Sr and Pu.

- **Arctic ecosystems:** the arctic ecosystem, similar to forests, is a zone where agriculture in the traditional sense is very restricted, but whose productions are widely exploited by humans. Data relative to typical species of these ecosystems and of interest for humans are presented when available.

- **Alpine ecosystems:** the third semi-natural ecosystem presents the same problems as both previous ones, and is approached in the same manner. Specific data on radionuclide transfer in this environment are given when available.

ENVIRONMENTAL TOXICITY

The previous sections characterize radionuclide mobility and bioavailability in the environment. To evaluate risks connected to the discharge or to the presence of these radioactive substances in the natural environment it is necessary to describe the exposure of living organisms. In addition to being radioactive, radionuclides are chemical elements and can also be toxic from this perspective. Both aspects, chemotoxicity and radiotoxicity, are examined in the pamphlets.

- **Chemotoxicity:** knowledge related to the element's chemotoxicity is presented, including ecotoxicological data and pertinent environmental protection criteria found in the literature.

- **Radiotoxicity:** when available, data on radiotoxicity are exposed. Information about dosimetry completes the section, given an indication of the relative importance of internal *versus* external exposure on the base of Dose Conversion Coefficients (DCC) for a set of model species (reference organisms). A complementary pamphlet, called "environmental dosimetry", presents the main principles from environmental radioprotection.

SUMMARY OF MEASUREMENT METHODS

A summary table presents the main characteristics of the many different analytical methods used in quantifying radionuclides, since the type of analysis, detection limits, associated uncertainties, and measurement times need to be considered.

USUAL RADIOECOLOGIC PARAMETERS

For each element, the main radioecological parameters used as default values by international bodies (mainly the IAEA, but also the National Radiological Protection Board, and the United States Department of Energy) are presented in tables. The definitions given below are used in the tables. However, in certain cases, an indication is given when the radioecological factors are presented differently.

Definitions for terrestrial environment

- **The distribution coefficient Kd** of the element is defined as the ratio, at equilibrium, between the mass activity of the solid phase to the volume activity of the liquid phase in the soil - solution system. It is expressed in mol.g^{-1} dry by mol.cm^{-3}. For soils, the ratio most commonly used is reduced to L.kg^{-1} and is the one used in the pamphlets. *It is always expressed with regard to the mass of the dry soil, sieved to 2 mm*.

- **The foliar transfer factor** represents the entire phenomenon of transfer from the said foliar deposition. Indeed, the characterization of the transfer following a deposit by atmospheric way *via* the foliar surfaces only is a wager even in controlled experiments, the deposited radionuclides reaching in particular always in a way or in the other one the ground.

It integrates the transfer by the foliar pathway, the possible transfer by roots (in particular for a deposit on young plantations), as well as translocation when it is concerning a part of the vegetable. It represents, generally, the ratio of the mass activity of the fresh) vegetable (or of a part of the vegetable) at its harvest time to the density of deposit on the set soil-vegetable; it is expressed in Bq.kg^{-1} of dry or fresh vegetable by Bq.m^{-2}.

- **The root transfer factor** is defined as the ratio between the mass activity of the harvested vegetable, or the part of the vegetable, to that of dry soil. The soil contamination is considered constant and homogeneous in the ploughed layer (or for the permanent meadows in the first ten centimetres), during the growth of the vegetable. The activity concentration relative to vegetables can be expressed relative to the dry or fresh weight, while the activity concentration in the soil is always relative to the soil's dry weight. The root transfer factor is thus expressed in kg of dry soil per kg of dry or fresh vegetable. The implicit hypothesis contained in this definition is that the concentration of the soil solution is connected in a linear way to the average soil mass activity in the cultivated layer. The root transfer factors of the element are given in tables and include default values.

- **The food-processing transformation** factors are quantified by the ratio of the mass activities of the radionuclide in the final product (transformed food) and the initial product (harvested farm product). It is expressed in Bq.kg^{-1} of product transformed per Bq.kg^{-1} of harvested product.

Freshwaters

- **The distribution coefficient Kd** of the element is defined as the ratio, at equilibrium, between the mass activity of the solid phase to the volume activity of the liquid phase in the water system. Rigorously expressed in mol.g^{-1} dry by mol.cm^{-3}; it is usual expressed as L.kg^{-1}. As all data related to sediment, the solid phase activity is always expressed regarding the dry mass of sediment, sieved at 2 mm if necessary. The state of the water phase varies within the literature and can be unfiltered or filtered with a 0.45 µm filter.

- **The concentration factor** is defined as the ratio at the equilibrium between the mass activity in the organism and the mass activity in water. It is expressed by L.kg^{-1} wet weight of organs or organisms. For plants, it represents the whole transfer pathways (foliar and root transfers as well as translocation). For animals, it represents rigorously the transfer linked to water exchanges (filtration, ingestion). Implicitly, other pathways (from sediments or by trophic way) may be integrated, by cumulating the transfer factors related to all the pathways.

- **The trophic transfer factor** is defined as the ratio at the equilibrium between the mass activity of the predator to the mass activity of its prey. It is usually expressed in kg wet weight of prey by kg wet weight of predator.

Marine Environment

- **The distribution coefficient Kd** of the element is defined as the ratio at the equilibrium between the mass activity of the solid phase to the volume activity of the liquid phase in the suspended matter – water system or the sediment –interstitial water system. Rigorously expressed in mol.g^{-1} dry by mol.cm^{-3}; its usual unit L.kg^{-1} is the one used in the sheets for sediments or suspend matter. As all data related to sediment, *the solid phase activity is always expressed regarding the dry mass of sediment*, sieved at 2 mm if necessary.

- **The concentration factor** is defined as the ratio at the equilibrium between the mass activity in the organism and the volume activity in water. It is expressed by L.kg^{-1} fresh weight of organs or organisms. This factor corresponds indeed to a comparison expressed through a ratio between the radioactivity levels in the organisms and those in the sea water; it does not express a transfer due only to the seawater vector, the radionuclide levels in organisms being the results of all the possible transfer pathways.

DOSIMETRIC PARAMETERS

For each radionuclide, tables contain the Dose Conversion Coefficients (DCC) calculated for a set of reference organisms represented by model species typical of the structure and the functioning of each of the three main ecosystems of interest.

Constitution of the bibliography

The reference list which appears at the end of each pamphlet is not exhaustive. The number of bibliographical references was restricted, with a preference given to citations of books, reports and publications that present syntheses. However, recent articles or articles of special interest may have been included in the reference list. In addition, Internet searches were made and the sites are cited with the date of consultation.

Writing and checking principles

The pamphlets were initially largely drafted by two specialists at Research and Expertise on Environmental Risks Department (SERIS), whose expertise were in the terrestrial environment and the continental aquatic environment. These drafts were then checked by one or two additional experts.

A first revision of the pamphlets began in 2004 and included a specialist in the marine environment. Drafts were reviewed by at least three persons belonging to the SERIS, or to the Environmental Radioactivity Study and Monitoring Department (SESURE), with skills in the terrestrial, continental aquatic and marine environments. The completeness of the pamphlets was verified by a fourth participant of the SERIS or the SESURE.

A second revision of the pamphlets began in 2010, to enrich their metrological sections, add semi-natural ecosystems and environmental toxicity data, and to include the most recently published syntheses. At least five experts within the diverse units raising from the theme Environment within the pole Radioprotection, environment, waste and crisis have contributed to the new versions of pamphlets in the following domains:

- terrestrial radioecology;
- continental aquatic radioecology;
- marine radioecology;
- metrology of ionizing radiations;
- concentrations of radionuclides in the environment.

An internal validation within SERIS is made, and after translation into English, the pamphlets are posted on the IRSN website.

Authors and verifiers are quoted on every sheet.