NUCLEAR WASTE MANAGEMENT

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Summary

Almost every country is producing nuclear waste issued from industry, medicine, research and nuclear power plants. Radioactive waste are waste that generate ionizing radiation. The hazards associated with the exposure to ionizing radiation, along with the long persistence of the radiation, have led to the development of elaborated handling procedures, regulation and control.

The radioactive waste management is a concept elaborated by the international community and the nuclear energy agencies to describe a sequence of operations starting from the generation of radioactive waste to its end processing, storage and final disposal.

The objective of the regulation is to protect people and environment and to prevent any burden on the future generation. The objective of this text is to overview the origin and types of nuclear waste and to introduce some of the current regulatory principles. The different steps of the waste processing and disposal are also discussed.

1. Introduction

A radioactive waste is a waste that generates ionizing radiation. The hazards associated with the exposure to ionizing radiation, along with the long persistence of the radiation, have led to the development of elaborated handling procedures, regulation and control. The complete set of regulations on radiation exposure limit the amount of radiation that may by received. The **radioactive waste management** is a concept that is used to describe a sequence of operations starting with the generation of radioactive waste, including its storage (meaning the temporary retention of waste) and disposal (discarding of waste with no intention of retrieval).

Almost every country is producing nuclear waste, making proper management of this radioactive waste a challenging issue. Countries with electrical nuclear power plants are producing much more waste than other countries. Some national regulatory standards regulate waste containing trivial amounts of radioactive waste from nuclear activities, but the requirements do not apply to waste from industries handling naturally occurring radioactive materials (NORMs), which may contain substantial amounts of radioactivity. The general objective is to manage radioactive waste in such a way as to protect human health and the environment and to limit any burden placed on future generations. The guiding safety for nuclear waste are, rather than being diluted and dispersed into the environment, highly radioactive waste are confined, contained and isolated. There are still uncertainties surrounding the final disposal of the most highly radioactive waste, those requiring isolation for thousands of years.

2. The regulatory system: exclusion versus exemption

All substances, whether regarded as waste or not, hold some amount of radioactivity. They contain at least naturally occurring radioactive substances. Very strictly, every waste should thus be considered as radioactive waste. Because this attitude is an untenable situation, only the compounds with a radioactive level above a defined background level, which is defined as the **exemption threshold**, are considered radioactive waste that are submitted to special regulation and control. In many countries, regulations governing radioactive waste management and disposal are guided by international standards of radiation protection and safety. These were last issued by the International Atomic Energy Agency (IAEA) in 1996 as the "*International Basic Safety Standards for Protection against Ionizing radiation and for the Safety of Radiation sources (BSS)"*. The BSS establish the requirements for controlling the additional radiation exposure caused by **practices**. This is the term used to characterise human activities (medical, industrial and military uses of radiation and radioactive materials and the generation of electricity by nuclear power) including their waste, which are expected to add radiation exposure to the background radiation exposure. The BSS also establish requirements for averting radiation exposure through **interventions**, which is the term used to describe the protective activities seeking to reduce radiation exposure that is not part of a controlled practice. Thus, practices may generate radioactive waste; interventions may leave residual radioactive waste.

The concepts of exclusion and exemption have been developed in the BSS to describe situations where controls are either not feasible or not warranted. **Exclusion** simply determines what waste shall-and what shall not-be subject to radiation safety. Exposures which are excluded include uncontrollable exposures and exposures that are essentially not amenable to control regardless their magnitude. Uncontrollable exposures are those that cannot be restricted under any conceivable circumstances. Typical examples are an exposure caused by radioactive elements such as ^{40}K that is an essential constituent of our body and exposure due to cosmic rays at the ground level. In relation to the controllability of exposures from other natural sources, including waste from industries processing NORMs, the international practice is vague and the national attitudes to these materials are extremely variable. People in many countries enjoy beaches with monazite sands, which are rich in naturally occurring radioactive materials. The authorities in these countries do not restrict radiation exposure (*e.g.* by limiting access to the beaches), whereas in other countries the transport of relatively small amounts of these types of sands is under regulatory control. **Exemption** determines what waste may -and what may not- is freed a priori from some or all regulatory controls. An exemption procedure specifies that the source concentration must be sufficiently low (< 70 Bq/g) to be of no regulatory concern. The individual dose may not exceed 10 μSv/year, and the collective dose may not be greater than 1 man Sv. This is equivalent to less than 1% of the average natural background and less than one tenth of a percent of typically elevated background radiation levels in many parts of the world. These considerations support the idea that waste with radiation doses in this range can be regarded as trivial and that the radioactive waste can be treated as normal waste. The term **clearance** was introduced to denote exemption from within the system of control (exemption a posteriori). It concerns sources that for one reason or another are under regulatory control and should not continue to be so. The IAEA has developed clearance levels for the release of radioactive materials from medicine, industry and research and is also developing clearance levels for general application to any solid material. In this respect, the reader is referred to the "*Safety guide on the regulatory control of radioactive discharges to the environment"* published recently by the IAEA. Materials, for which *no future* is foreseen with *activity levels above clearance levels*, will be considered as **radioactive waste**. When the activity levels are at or below clearance levels, the wastes are not been regarded as being radioactive for regulatory purposes.

3. The origin of radioactive waste

Nature has always been a prime generator of radioactive waste. The **natural radioactive waste** generated over time and -more recently- by industries processing NORMs is simply impossible to quantify. For instance, the amount of natural radioactivity in the seas is estimated to be on the order of 10^{21} Bq. Spring waters near the Caspian Sea in Iran, rich in radium-226, emerge and deposit precipitates. In these areas the radiation exposure to residents can be up to 100 times higher than the international exposure limit. Volcanic deposits in Brazil may deliver radiation exposures that are on average 10 times higher than the limit. In Tajikistan, Residual waste tailings from past mining and milling operations have been estimated to be around 50 million tons with a total of long-lived radioactivity of up to 10^{18} EBq. Thousands of these tailings exist in other parts of the world.

Public concern mainly focuses on radioactive waste arising from human activities. A large fraction of the global radioactive waste has been generated from **military nuclear**

programs including atmospheric weapons testing. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates that, as a consequence of nuclear weapon testing, more than 10^{24} Bq was discharged in the atmosphere. While most of this waste was short-lived, a fraction of around 1% was relatively long-lived waste. Furthermore, in the second half of the 20^{th} century around 10^{20} Bq have been disposed of in the Oceans. Much more has been dumped into the world's seas as a result of accidents and losses including many sunken nuclear submarines.

The waste from **civil nuclear operations** expressed as amount of radioactivity reaches 10^{24} Bq and this inventory is growing at a rate of 10^{23} Bq/yr. Civilian radioactive waste can arise from medicine, industry and research, but this appears little compared to the waste produced by nuclear power plants. The waste may be very heterogeneous and can contain long-lived radionuclides. Worldwide production of nuclear power generates four main categories of waste. Firstly, the residues left from processing uranium ore. These contain NORMs mined with the uranium, and some chemicals used in the separation process. The radioactivity is low-level but long-lived. Secondly, the materials and equipment such as protective clothing, cleaning materials, ion-exchange resins that became contaminated during the operation of nuclear facilities. The radioactivity is mainly low-level and short-lived. Thirdly, the waste arising from nuclear fuel after it has been used in a reactor. This can be the used fuel itself (if it is not reprocessed) or the waste resulting from reprocessing of the used fuel. Used fuel that is not reprocessed can be regarded as high-level, long-lived waste. Waste from reprocessing are a mixture of high-, intermediate- and low-level waste, with the mixture depending on the treatment techniques used. Fourthly, the waste resulting from dismantling nuclear reactors after the fuel has been removed and from the fuel processing plants at the end of their operating lives. The radioactivity is low-and intermediate-level and mainly relatively short-lived but there can be also long-lived waste.

Waste types

Depending on their radionuclide content, we can consider many different radioactive waste types. There are many different radionuclides each with their specific radioactivity and specific half-life. They are emitters, in a single or combined form of alpha, beta or gamma radiation. These radiations have their specific penetrating power in the matter and require therefore different shielding. Alpha radiations have a low penetrating power and a single paper sheet can stop them all. Beta particle is somewhat more penetrating and can be stopped by a few mm thick aluminum sheet. The gamma rays have a high penetration power and only a layer of more than a meter of concrete will attenuate significantly the radiation. (Fig.1).

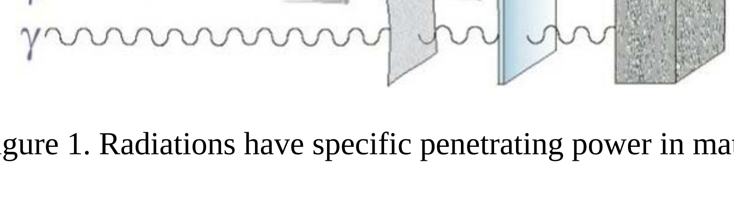

Figure 1. Radiations have specific penetrating power in matter

The classification of the radioactive waste may vary from one country to another but they are all generally based on the IAEA recommendation.

High-level waste (HLW) results mostly from treatment or conditioning of spent nuclear fuel and contains most of the fission products and actinides present in spent fuel. Typical characteristics of HLW are thermal power above about 2 kW/m^3 and significant levels long-lived radionuclide concentrations with a half-life of more than 30 years. The radiological activity is at least 10^5 times higher than the background radiation. **Low- and intermediate level waste (LILW)** come from hospitals, laboratories, industry and the nuclear fuel cycle. LILW are waste with radiological characteristics between those of exempt waste (waste that is cleared from regulatory control in accordance with the exemption principle) and high-level waste. Typical characteristics of LILW are activity levels above clearance levels and thermal power below about 2 kW/m^3. Intermediate-level waste (ILW) has a radiological activity up to 10^5 times the background level and often contains significant amounts of α-emitters, whereas low-level waste (LLW) has a radiological activity up to 1 000 times higher than the background level. This latter type of waste has a radiological concentration of less than 40 GBq/m^3. It is produced not only by nuclear power plants, but also by other facilities such as nuclear research centers and hospitals. LILW may be short-lived waste (LILW-SL) or long-lived waste (LILW-LL). Short–lived waste do not contain significant levels of radionuclides with a half-life greater than 30 years, in contrast to long-lived waste containing significant amounts of radionuclides with a half-life of more than 30 years. In short-lived waste packages, concentrations of long-lived radionuclides are limited to 4 000 Bq/g for individual waste packages and to an overall average of 400 Bq/g for the total waste volume. **Very low-level waste (VLLW)** are radioactive waste, which are considered suitable by the regulatory body for authorized disposal, subject to specified conditions, with ordinary waste in facilities not specifically designed for radioactive waste disposal.

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Biographical Sketches

Louis de Saint-Georges obtained a PhD in Biology at the University of Louvain (UCL), Belgium, were he was teaching assistant. His first research activity at the Laboratory of Embryology and Comparative anatomy was on the morphogenesis, cell-to-cell interactions in the first developmental stage of the amphibian embryo. Head of the electron microscopy laboratory of the radiobiology department at the Nuclear Energy study Center (CEN/SCK) the research efforts were on the radiation-induced pneumonitis and the murine radiation-induced leukemias. In 1988-1990, he was research associate at the Radiobiology Department of the University of Utah, USA. Senior scientist in the radioprotection department of the CEN/SCK, the current research activity concern the radiosensitivity of the organism in development with special emphasis on the developing brain. Particular attention is carried on radiation-induced apoptotic response to low level doses of ionizing radiation.

Patrick De Boever obtained a M Sc Chemistry and a PhD in Applied Biological Sciences at the Ghent University. He performed post-doctoral research at the Ghent University and the University of Antwerp. His research interest was mainly focused on the microbial ecology endogenous to the human gastrointestinal tract. and its impact on the host's health status. He has a track record of several peer-reviewed manuscripts in this domain. He recently joined the Radioactive Waste & Cleanup Division of the SCK-CEN for post-doctoral research on the potential use of microorganisms to treat radioactive waste and to study the possible impact of microorganisms on radioactive waste in geological disposals.

Guy Collard has obtained a M Sc Chemistry at the University of Liège. He is employed by the SCK-CEN for 25 years and is currently director of the Radioactive Waste & Cleanup Division. He is responsible for the management of R&D, contractual research, expertise, services, etc related to Waste, Decommissioning and Cleanup. He is author of several papers about Waste Management, Decommissioning and Decontamination, and Remediation of contaminated sites. He participates in different expert groups about decommissioning planning and cost. He is full member of the Technical Advisory Group (Co-operation on Decommissioning Nuclear Installations) of the OECD/NEA. He is member of the IAEA expert group on remediation of contaminated sites. He is president of the Board of Directors of “Ecoprogress International” (International scientific association on site remediation).