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0014-4754/90/080792-03$1.50 + 0.20/0

Characteristics of nuclear and fossil energy wastes

A. J. Francis

Department of Applied Science, Brookhaven National Laboratory, Upton (New York 11973, USA)

Summary. The radionuclides and toxic metals in transuranic, low-level radioactive coal combustion, and coal conversion wastes are summarized. These wastes also contain a variety of organic compounds, some of which can support indigenous microbial activity resulting in solubilization or stabilization of toxic metals and radionuclides.
Key words. Toxic metals; radionuclides; organics; low-level radioactive wastes; transuranic wastes; coal wastes.

Introduction

The wastes generated from the use of fossil and nuclear fuels contain a variety of organic and inorganic compounds, including radionuclides. Subsurface disposal of the large quantities of solid wastes seems to be the viable alternative and may occur as back-to-pit operations or in specifically constructed landfills. Disposal of these complex chemical substances in the subsurface environment can result in the contamination of ground and surface water by waste leachate containing radionuclides, toxic metals, and organic compounds, which renders regional groundwater unsuitable for domestic use or irrigation and presents a significant environmental health and ecological hazard.

The characteristics of the waste vary widely with the source and the process used. In general, the kinds of organic compounds, radionuclides and toxic metals in nuclear and fossil energy wastes are known [1–11]. However, the form in which the radionuclides and toxic metals are present in the wastes, e.g., elemental, oxide, coprecipitate, ionic, organic or inorganic complexes, is least understood, but is important from the standpoint of stability and mobility in the environment. The general characteristics of the type of wastes generated from nuclear and fossil energy are summarized in this paper.

Radioactive wastes

Radioactive wastes are generated from mining, milling, preparation of fuel for reactors, and weapon-production. The wastes containing the radioisotopes may be in the form of gases, liquids, or solids, may be soluble or insoluble, and may give off various types of radiation at many energy levels. Radioactive wastes are classified as high-level wastes, transuranic wastes, and low-level wastes [10].

High-level wastes

High-level wastes (HLW) are either intact fuel assemblies that are discarded after serving their useful life in a nucle-

ar reactor (spent fuel) or the portion of the wastes generated in the reprocessing of spent fuel that contain virtually all of the fission products and most of the actinides remaining after reprocessing. HLW require extensive radiation shielding. These wastes are being considered for disposal in geologic repositories or by other technical options designed to provide long-term isolation of the wastes from the biosphere. Because of the high levels of radioactivity, there is little concern that there will be any significant microbial activity which could affect the integrity of the waste in the near field. However, one could expect significant microbial effects in the far field, where the radiation effects on microbes will be minimal. In general, microbes are highly resistant to radiation [5].

Transuranic wastes

Transuranic (TRU) wastes are those wastes contaminated with alpha-emitting transuranium nuclides with half-lives greater than 20 years and concentrations greater than 100 nCi per gram of waste. TRU wastes result predominantly from spent fuel reprocessing, the fabrication of plutonium to produce nuclear weapons, and plutonium fuel fabrication for recycling to nuclear reactions. The wastes include adsorbed liquids, sludges, organics, and cemented materials containing the following radionuclides: ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{244}Cm, ^{252}Cf, and metals. TRU wastes will be disposed of in deep geological salt mines in a manner similar to that for high-level waste disposal [12]. Significant microbial activity is expected because of the organic constituents. This causes great concern in terms of gas generation and pressurization of containment areas in the repository.

Low-level wastes

Low-level radioactive wastes (LLW) constitute the greatest quantity and they contain low but potentially hazardous concentrations of radionuclides. They include wastes not classified as high-level waste, transuranic waste, spent nuclear fuel, or by-product materials, which require little or no shielding. An analysis of the history of low-level waste disposal at both commercial and government disposal sites and the characteristics of the wastes have been discussed in detail [2, 9]. LLW are generated in almost all activities involving radioactive materials and are presently being disposed of by shallow-land burial. The laws governing the land disposal are complex, very stringent, and increasingly ever-changing.

Low-level radioactive wastes are generated from nuclear power plants, research organizations, hospitals, universities, radiopharmaceutical manufacturers, fuel fabrication industry, and government energy research and military programs. Low-level wastes contain a variety of radionuclides, toxic metals (especially Pb, Cr, Hg), contaminated equipment, and organic materials, e.g., protective clothing, gloves, small tools, plastics, paper, scintillation liquids, organic solvents (chlorinated solvents), aqueous liquids containing radionuclides, decontamination solutions, radioactive carcasses of experimental animals, spent-ion exchange resins, and sludges.

Although records of total radioactivity buried at the shallow land disposal sites are kept, no detailed information on specific radionuclide content is available. Nevertheless, several radionuclides such as americium-241, barium-133, carbon-14, cesium-134, 137, cobalt-60, iodine-129, iron-55, manganese-54, nickel-63, plutonium-238, 239, 240, potassium-40, radon-222, ruthenium-106, sodium-22, strontium-90, thorium-232, tritium, and uranium-234, 235, 238 have been detected in the leachate samples from the commercial low-level radioactive waste disposal sites. A variety of organic compounds in leachate samples from low-level radioactive waste disposal sites have been identified [6]. Microbial transformations of low-level wastes have been discussed in detail elsewhere [5]. Migration of radionuclides from several shallow-land waste disposal sites has been reported. This is primarily due to the composition of the buried waste, as well as improper disposal and management practices employed in the past.

Uranium wastes

Uranium mine and mill tailings are the residues from uranium mining and milling operations that contain low concentrations of the naturally occurring radioactive materials uranium, radium, and thorium, and toxic metals such as arsenic, cobalt, copper, nickel, lead, and selenium. The tailings are generated in very large volumes and are currently stored at the site of mining and milling operations.

Uranium processing wastes generally contain depleted uranium, and in some cases low-level radioactive materials (primarily uranium, radium, and thorium), and a variety of toxic metals and organic compounds such as chlorinated solvents and hydraulic oils. Some of these wastes are highly reactive, e.g., pyrophoric and pyrotechnic. These wastes are generated primarily from weapon-production processes and defense-related activities.

Coal wastes

Solid wastes from coal utilization which are of concern here include coal-cleaning residuals, fly ash, bottom ash, scrubber sludge, spent fluidized-bed material from coal combustion; chars, acid gas cleanup wastes, air and water pollution control wastes, tar and oil sludges, biosludges, and spent catalyst from coal gasification and liquefaction.

Solid wastes generated from the coal industry are quite variable. They are largely dependent upon the composition of the coal which is very heterogeneous and varies widely in composition from seam to seam, within a seam, from mine to mine, and within a mine; the specific processes used, and plant design and operation. Nearly one-third of the mined coal is discarded after physical cleaning. The types of contaminants released from solid waste

piles include organic compounds, metal ions, and acidity primarily due to chemical and microbiological action.

Coal combustion waste

The largest volume of solid wastes from the energy industries currently and in the near future is produced by conventional coal combustion. The major solid wastes are fly ash, bottom ash, and flue gas desulfurization (FGD) from water treatment, such as make-up water, boiler blowdown, water from coal pile runoff, and ash-handling systems. The ash residue from coal combustion consists of inorganic mineral constituents present in coal, as well as the organic matter which is not fully burned. Two types of ash produced during combustion are fly ash and bottom ash. Fly ash consists of the fine particulates that are entrained in the flue gas stream. Bottom ash is the coarser, heavier residue which accumulates in the furnace bottom either as a loose dry ash or as a slag. The inorganic constituents of the coal ash are As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Se, S, Te, Th, Sn, U, V, and Zn[1]. Coles et al.[3] and Styron et al.[8] studied the fate of radionuclides ^{238}U, ^{235}U, ^{228}Th, ^{228}Ra, ^{226}Ra, and ^{210}Pb present in coal. All of the radionuclides studied are enriched in ash relative to the input coal and in general tend to concentrate in the finer particles. While there are some lignites that have relatively high radionuclide content, they are not being used as fuel.

Coal conversion wastes

The major waste streams produced from coal gasification and liquefaction are: 1) chars, ashes, particulates, and filter cake from the liquefaction operation and auxiliary air and water pollution control systems; 2) spent catalysts and absorbents from the conversion process; 3) inorganic solids and sludges from acid gas removal raw water treatment, and air and water pollution control; 4) sludges of coal tars and liquid products; and 5) biological treatment sludges (biosludges) from water pollution control[4].

Laboratory leaching studies of solid wastes from gasification produced basic as well as acidic leachates containing variable amounts of metals such as Ca, Pb, Al, Fe, Zn, Mn, Mo, and Sb. Acid leachates generally contain high levels of metals and sulfate which result from the oxidation of residual reduced sulfur remaining after conversion[7]. The effects of natural weathering processes, microbiological processes, and the influence of climatic conditions on the leaching of the toxic organic and inorganic constituents of the coal conversion solid wastes from the disposal environment are not clearly known.

Methods of disposal of coal wastes are: ponding in indigenous clay soil, with a flexible liner or a liner of impervious soil or asphalt or with drainage; chemical treatment and landfill; mine disposal and ocean disposal. All of these methods of disposal of solid wastes from both nuclear and non-nuclear fuel cycles would indeed require monitoring, and in the case of land disposal will require continuous management, including growth of vegetation and control measures to prevent runoff problems. Factors to be considered include structural strength, permeability, leachate potential, solid attenuations of leachate, liner life, and dewatering methods.

Other wastes

So-called hazardous waste is not radioactive but contains chemical substances which present danger to human health and the environment and must be treated to reduce or eliminate their toxicity prior to disposal.

Mixed waste is a combination of hazardous and radioactive waste and therefore both its hazardous and radioactive components must be taken into consideration in treatment and disposal.

Acknowledgments. This research was performed under the auspices of the Ecological Research Division's Subsurface Science Program, Office of Health and Environmental Research, U.S. Department of Energy, under Contract No. DE-AC02-76CH00016.

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