**Assessment of Effectiveness of Geologic
Isolation Systems**

The Potential Influence of Organic Compounds on the Transport of Radionuclides from a Geologic Repository

March 1981

**Prepared for
the Office of Nuclear Waste Isolation
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
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by Battelle Memorial Institute**

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THE POTENTIAL INFLUENCE
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FROM A GEOLOGIC REPOSITORY

D. J. Silviera

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SUMMARY

The purpose of this study was to review the literature and to qualitatively evaluate the potential for organic compounds to influence the solubility and transport behavior of radionuclides in the event of a breach of a deep geologic repository containing nuclear waste.

This study identifies organic compounds that may be present in a repository and outlines plausible interactions and mechanisms that may influence the forms and chemical behavior of these compounds. A review of the literature, which is presented in this status report, indicates that large quantities of organic radioactive wastes are generated by the nuclear industry and if placed in a repository could increase or decrease the leach rate and sorption characteristics of waste radionuclides. The association of radionuclides with organic matter can render the nuclides soluble or insoluble depending on the particular nuclide and such parameters as the pH, Eh, and temperature of the hydrogeologic system as well as the properties of the organic compounds themselves.

Waste acceptance criteria which are being developed at the Office of Nuclear Waste Isolation (ONWI) would tend to preclude any such waste being placed in a repository that could decrease the sorption of radionuclides by the geologic media. Therefore, further experimental work is necessary to establish limits on the influence of various organic materials that may contact the radionuclides. This can only be accomplished by continuing the laboratory studies at the various institutions identified in this report. The information obtained from these research efforts can be used as input into computer chemical models being developed at PNL to estimate future geochemical conditions of the repository.

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INTRODUCTION

The placement of selected radioactive wastes in deep geologic repositories is being considered as a permanent disposal method that could alleviate the potential for detrimental impacts on the environment. However, because of the high concentration and long half-life of several waste isotopes, isolation of the radionuclides from the accessible environment will be required for extended periods. Therefore, parameters that may influence the long-term isolation of these waste materials should be studied to determine potential effects on the performance of the repository and to guide those involved with the repository siting, waste form and engineered barrier development, and repository construction.

One area of concern that has received limited attention involves the potential for organic materials to influence the mobilization and transport behavior of waste radionuclides following a breach. This concern exists because organic ligands are known to influence the solubility and mobility of metal cations in soils. Studies involving the migration of waste radionuclides from shallow land burial sites have reported that organic complexing agents can reduce K_d values for specific isotopes in bedrock by several orders of magnitude (Means et al. 1978). In contrast, other studies indicated that humic and fulvic acids found in soils and organic coatings present on clay minerals may be able to decrease the valence state of certain nuclides and reduce solubility (Bondietti et al. 1976). However, very little information is available concerning potential sources of organics which could complex with the nuclides in a deep geologic repository.

Present thinking on the contents of waste packages for a repository is that any material that can decrease the sorption of radionuclides by the geologic media shall be excluded. As a result, the objectives of this study are: 1) to identify the potential sources and forms of organic compounds that could complex with waste radionuclides before, during, or subsequent to a breach, 2) to discuss chemical, physical, and biological processes that can occur in the repository and influence the organic forms that may be present.

This information will aid the development of computer chemical models that will be used to study the behavior of waste radionuclides in the event of a breach of a deep geologic repository.

CONCLUSIONS

Large quantities of organic radioactive waste are generated by the nuclear industry (Appendix A) and if placed in a deep geologic repository these materials could increase or decrease the leach rate and sorption characteristics of the waste radionuclides. For example, organic materials that may be disposed of directly in the repository include compounds such as urea-formaldehyde or bitumen that have been used to solidify various waste forms. Organic waste forms may also include materials used for various isotope separation and purification processes such as the Purex process. These materials, which are known to accumulate as waste materials and must be disposed of, include tributyl phosphate (TBP), kerosene, n-paraffins, exchange resins, and chelating agents such as ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA). In addition, many organic waste materials from nuclear power plants, spent fuel storage basins, and fuel reprocessing plants are grouped in a category known as compactable and combustible wastes. These wastes are composed of many types of materials that contain a variety of organic compounds. These materials include air filters, ion exchange resins, plastic bags, rubber gloves, disposable protective clothing, and paper products. Present thinking indicates that no materials be placed in a repository that could adversely affect the retardation of radionuclides and strengthens the need for evaluating the ability of the various organic waste forms to complex radionuclides.

In addition to waste products, a second source of organic compounds may be soluble organic forms that are present in the surface water or ground water that could enter the repository following a breach. These compounds include proteins, lipids, carbohydrates and their decomposition products, such as amino acids, fatty acids, and mono- and poly-saccharides. Humic and fulvic acids which do not have a specific structure, but do contain functional groups, may also be present in the water and influence radionuclide solubility.

A third source of organic compounds may be organic components of the rock media that lie in the path of the ground water after it contacts the repository.

Organic compounds have been identified in trench water samples taken from low-level waste disposal sites. The types of organic compounds included several straight and branch chain aliphatic acids, aromatic acids, alcohols, aldehydes, ketones, amines, aromatic hydrocarbons, ethers and phenols. At one site, EDTA was proposed as the dominant mobilizing agent for ^{60}Co . Since many of the organic compounds previously mentioned or their decomposition products could increase the migration of radionuclides, a similar effect might occur if these waste forms were placed in a deep geologic repository, and therefore should be excluded.

If organic wastes are placed in a repository, microbial decomposition as well as thermal and radiolytic effects, could influence the forms of organic compounds presents in the repository. In recent studies, a microbial population composed of aerobes, anaerobes, and facultative anaerobes was identified in trench waters taken from shallow land burial sites. The majority of the organisms were facultative anaerobes and able to grow under anaerobic conditions using the nutrients present in the trench water. Many types of microorganisms will likely be added to the repository during repository construction and disposal operations. Therefore, it appears that microbial activity may also play a role in determining the forms of organic compounds present in a geologic repository.

In general, the results from this study to date indicate that organic compounds can increase or decrease the solubility of radionuclides by several orders of magnitude. The association of radionuclides with organic matter appears to render the nuclides soluble or insoluble depending on the particular nuclide and such parameters as the pH, Eh, and temperature of the system as well as the properties of the organic compounds. Therefore, this study will continue to monitor the current research at various institutions identified in this report and the information will be used for input into computer chemical models being used at PNL to estimate future geochemical conditions of the repository environment.

SOURCES OF ORGANIC COMPOUNDS

The three general sources of organic compounds that may interact with radioactive wastes in a repository are: 1) organic materials disposed of in the repository, 2) organic compounds transported to the repository by ground water, and 3) organic constituents of geologic media that may lie in the path of contaminated ground water.

The organic materials placed in the repository may include a wide variety of compound types. For example, they may include materials such as urea-formaldehyde or bitumen that have been used to solidify various waste forms (Hoech and Rhodes 1979, ZoBell and Molecke 1978, DOE 1979, Colombo and Neilson 1979). They may also include materials used for various isotope separation and purification processes such as the Purex process. Examples of these materials, which are known to accumulate as waste materials and must be disposed, include tributyl phosphate (TBP), kerosene, n-paraffins, exchange resins, and chelating agents such as ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA). In addition, many organic waste materials from nuclear power plants, storage basins for spent fuel, and fuel reprocessing plants are grouped in a category known as compactable and combustible wastes (DOE 1979). These wastes are composed of many types of materials which contain a variety of organic compounds. Examples of these materials include air filters, ion exchange resins, plastic bags, rubber gloves, disposable protective clothing, and paper products.

A more complete description of the variety of wastes known to accumulate from various sources of the nuclear industry is presented in Tables A.1 through A.8. Tables A.1 and A.2 identify materials currently present in shallow land burial sites with their corresponding volume and weight. A similar identification of waste forms is presented in Tables A.3 through A.8 for materials originating from representative power plants, spent-fuel storage basins, and fuel reprocessing plants.

A simple calculation based on the information contained in Table A.3 indicates that if the compactable and combustible waste from a nuclear power plant is placed in the repository, it would amount to approximately 0.6 metric tons of material for each metric ton of spent fuel.

The methods that have been used by the nuclear industry to prepare these wastes for disposal include: 1) packaging without treatment, 2) compaction, 3) sorting and shredding of the waste followed by immobilization in cement, bitumen, urea-formaldehyde, or other solid matrix, and 4) sorting and shredding followed by incineration (DOE 1979). The effect of these compactable and combustible waste forms on the solubility of the waste radionuclides is not well known and should be studied if these wastes are to be placed in a repository.

A second possible source of organic compounds is the surface water or ground water that could enter the repository during a breach. The ground waters from the specific site location of a repository should be analyzed for organic carbon. The concentration of dissolved organic carbon (DOC), has been overshadowed during the monitoring of ground water at many of the waste disposal sites in the country by an overriding concern with radionuclide contamination and the concentration of inorganic ions.

A survey of the concentration of DOC in ground water was conducted by Leenheer et al. 1974. Samples of ground water were obtained from 100 sites in 27 states and the reported values for DOC from these samples ranged from 0.1 mg/l to 15 mg/l; however, 85% of all the values were below 2 mg/l. These concentrations of DOC correlated directly with specific conductance and alkalinity, but did not correlate with pH. No difference was detected in the median DOC concentration between shallow (<61 m) and deep (>61 m) sand and gravel aquifers. Only small differences in DOC concentrations occurred for various types of consolidated rock aquifers. For example, the median DOC values for sandstone, limestone, and other rock aquifer types ranged from 0.5 to 0.7 mg/l. In related studies, Means and Hastings (1979) reported a value of 3 mg/l DOC from water collected from an aquifer 1000-m deep in the Grande Ronde Formation of the Columbia River basalt group, and Stumm and Morgan

(1970) report that concentrations of dissolved organic matter in natural waters usually range from 0.1 to 10 mg/l with the upper concentration reached in polluted lakes, streams, and estuaries. Based on these results, water from aquifers which may potentially contact a repository at a depth of approximately 600 m would probably contain nonvolatile DOC at concentrations less than 10 ppm.

The third source of organic compounds may include materials that are part of the rock media and which may lie in the path of the ground water after it has contacted the repository. The average concentration of organic compounds in various rock forms have been reported to range from 0.5 wt% to 2.1 wt% in shales to 0.19% to 0.62% in carbonates, and 0.05% to 0.52% in sandstones (Wedepohl 1978). Brownlow (1979) reported that shales tend to have two or more times the organic matter content of associated sandstones and carbonate rocks. Organic compounds at these concentrations would be capable of influencing the solubility and migration potential of radionuclides. Therefore, the potential sources and forms of organics in rock media, which may increase or decrease the solubility of radionuclides need to be identified for the specific site location of a repository. The next section will discuss various ways organic carbon complexes can influence radionuclide solubility.

MECHANISMS OF ORGANIC CARBON INFLUENCE ON THE SOLUBILITY OF RADIONUCLIDES

Basically, organic compounds can influence the solubility of radionuclides in four ways:

1. Complexing - Soluble organic materials, such as fulvic acids, soluble organic chelates, and products of microbial and chemical decomposition, may complex the nuclides in a water-soluble form preventing resorption or precipitation as they move through the rock media.
2. Sorption - Materials, such as insoluble humic compounds, are capable of sorbing the isotopes rendering the nuclides insoluble.
3. Reduction - Organic compounds may act as electron donors in chemical and biological reactions and reduce the valence of certain radionuclides (this could change the chemical behavior of nuclides such as Pu^{+5} or $+6$ to Pu^{+4} , making it less soluble.
4. Physical Effects - Physical effects should also be considered, such as the possibility of nonpolar organics coating sorbed nuclides and preventing contact with water soluble forms.

These effects will depend on the form of organic carbon, the functional groups associated, as well as pH, Eh, and the concentration of competing ions for the charged sites on the organic molecule. For example, Means et al. (1978) showed in field studies that ^{60}Co is transported in ground water as organic complexes and provided evidence that uranium is also migrating by the same mechanism. In the presence of 10^{-5}M EDTA, the K_d values for ^{60}Co in weathered Conasauga shale decreased from 7.0×10^4 to 2.9 at pH 6.7, and from 0.12×10^4 to 0.8 at pH 12. Similar field K_d values were calculated from ^{60}Co concentrations in soil and water from various wells in the ORNL burial grounds. These changes in K_d values suggest that EDTA, reported to be present at approximately $3.4 \times 10^{-7}\text{M}$ in these ground waters, is the dominant mobilizing agent in these samples. However, a minor portion of the migrating ^{60}Co and uranium was reported to be associated with natural humic substances.

In addition, complexing agents such as phthalic, palmitic, and other carboxylic acids were also detected and may be contributing to ^{60}Co and uranium mobilization.

In related studies, Relyea and Brown (1978) report that Pu can be expected to diffuse fastest as a chelated complex. They also reported that DTPA reduced the K_d of Pu in three soils more than EDTA. Likewise, the movement of ^{89}Sr in a Mohave sandy loam soil was enhanced by DTPA and other chelating agents (L'Annunziata and Fuller 1967). Wiggins and Franz (1978) provide detailed discussion of organic complexes in soil systems with ^{93}Zr , ^{63}Ni , ^{99}Tc , and $^{93\text{m}}\text{Nb}$, and report that ^{93}Zr , ^{63}Ni , and ^{93}Nb are mobile in the presence of aqueous organic complexing agents, and ^{99}Tc complexes with organic ligands in a reducing environment. Himes and Shufeldt (1970) report data that support the hypothesis that soluble organic compounds may increase the rate of ^{90}Sr leaching through soil. Of the compounds studied, glucuronic acid was the most effective in extracting ^{90}Sr from mineral soils, followed by phytic acid = citric acid > pectic acid > glycine > pyrocatechol > dextrose. The order for an organic soil containing 40% organic carbon was phytic acid > citric acid > pyrocatechol > glycine = dextrose $\approx$ glucuronic acid = pectic acid.

Nishita et al. (1977) examined the extractability of ^{239}Pu from an artificially contaminated kaolinitic soil with a number of inorganic and organic compounds. Among the organic compounds evaluated, the order of ^{239}Pu extractability was Na acetate < Na formate < Na oxalate < Na tartrate Na citrate, all 0.08M. A 0.004M DTPA solution was more effective than a 0.08M citric acid solution. Of the inorganic compounds studied, NaF, $\text{Na}_2\text{B}_4\text{O}_7$, $\text{Na}_4\text{P}_2\text{O}_7$, Na_2CO_3 , Na_2O_2 , NaOH, and NH_4OH showed the greatest extractability ranging from 8% to 29% of the applied ^{239}Pu . These were also the compounds that produced a soil extract with a pH above 9. When soil organic matter was removed with H_2O_2 , except in the case of $\text{Na}_4\text{P}_2\text{O}_7$, <2% of applied dose was extracted; thus, the ^{239}Pu extracted from the untreated soil appeared to have been associated with the alkali-soluble organic matter. The organic compounds were generally more effective extractants. The reason suggested was

a combination of the: 1) presence of a greater number of complexing ligands, 2) formation of more stable complexes, and 3) ability to extract greater amounts of soil organic matter than the inorganic compounds.

However, the effect of organic compounds on radionuclide solubility is complicated by the fact that many of the long-lived radioisotopes can exist in several valence states, and each valence state can behave differently in the environment (McFadden 1980). Plutonium, for example, can exist simultaneously in four valence states in solution. Therefore, an understanding of the oxidation states is necessary to understand its environmental behavior. Bondietti et al. (1976) showed that humic and fulvic acids found in soils are able to reduce Pu from the more soluble Pu^{+5} and Pu^{+6} valence states to Pu^{+4} . They suggest that reduction by many natural occurring organics could readily occur and also prevent oxidation of reduced forms to the more soluble higher oxidation states. Evidence was also presented that organic coatings on clay minerals may cause reduction of Pu^{+6} to the more insoluble Pu^{+4} . Likewise, Cleveland and Rees (1976) report that soils contaminated with plutonium and americium showed very low solubilization of Pu and Am with 100 ppm fulvic acid solutions in a pH range of 5 to 9, and conclude that in the soil studied, humic compounds were not a major factor in the solubilization of Pu and Am.

Nishita and Hamilton (1978) suggest that soil organic matter has an appreciable effect on ^{239}Pu extractability, depending on the pH. They suggest that ^{239}Pu movement at alkaline pH levels is likely to be relatively high in soil containing organic matter, but very low in soil containing practically no organic matter. If pH is high enough to dissolve organic matter then ^{239}Pu could become mobile. Among ^{242}Cm , ^{237}Np , ^{241}Am , and ^{239}Pu , the extractability of ^{239}Pu between pH 7 and pH 11.5 was the greatest; again indicating relatively strong association of this radionuclide with alkali-soluble organic matter. In a related study, Nishita et al. (1978) also suggest that in an alkaline condition above pH 7 a kaolinitic soil high in organic matter is likely to allow relatively high movement of ^{238}Pu and ^{242}Cm under the leaching action of water. However, in a kaolinitic soil depleted of organic matter, the movement of both radionuclides is likely to be very low at higher pH.

An excellent review on organic complexation of radionuclides, with an emphasis on the effects of microbial processes, was written by Wildung and Garland (1977). In this review they discuss organic complexation reactions with humic and nonhumic substances. Also discussed are potential mechanisms of microbial transformations of transuranic elements in soils. Studies were described that indicated microbial activity increased the solubility of Pu in soil by a factor of 2 over sterile soil. The mechanisms proposed that may have increased the solubility include: 1) the production of organic acids, 2) alteration of soil pH or Eh near the soil colloid (or the polymer) without measurable effects on overall soil pH, and 3) direct transformation of Pu by alteration of the valence state.

Organic compounds have also been postulated to influence the oxidation of Uraninite (UO_2) in the natural environment and, thereby, affecting the mobility of uranium in natural waters (Grandstaff 1976). This effect may be the result of organic molecules blocking surface oxidation sites and decreasing the effective surface area exposed to oxidation.

Evidence from the studies cited above suggest that the association of radionuclides with organic matter can result in the nuclides being rendered soluble or insoluble depending on the particular nuclide and such parameters as the pH, Eh and temperature of the system as well as the properties of the organic compounds.

DISSOLVED ORGANIC COMPOUNDS IDENTIFIED
FROM LOW LEVEL WASTE DISPOSAL SITES

Water samples from shallow land disposal sites for low-level radioactive waste at Maxey Flats, KY, West Valley, NY, Scheffield, IL, and Barnwell, SC, were studied to determine the composition of the leachates that have accumulated in the trenches (Colombo et al. 1978a,b). A summary of the range of pH and DOC concentration from these samples is presented in Table 1.

TABLE 1. Range of pH and DOC Concentrations in Trench Water Samples Taken from Shallow Land Burial Sites (Colombo et al. 1978)

	<u>pH</u>	<u>DOC mg/l</u>
Maxey Flats	2.2 - 12.4	1 - 5,800
West Valley	6.5 - 9.4	270 - 4,900
Scheffield	6.2 - 12.1	12 - 6,600
Barnwell	5.9 - 6.7	1 - 280

Some of the specific organic compounds identified are listed in Table 2. The organic compounds included several straight and branch chain aliphatic acids, aromatic acids, alcohols, aldehydes, ketones, amines, aromatic hydrocarbons, ethers and phenols. These compounds represent the organic wastes buried in the trenches as well as decomposition products of buried materials such as cardboard boxes, plastics, scintillation liquids, solvents, and decontamination fluids.

Organic compounds have also been detected in trench leachates at Oak Ridge National Laboratory. Among them were EDTA, palmitic acid, phthalic acid, and other mono- and dicarboxylic acids (Means et al. 1978). The chelating agent, EDTA, has been suggested as the dominant mobilizing agent for ⁶⁰Co, which has been detected in trench leachates. Since similar effects could occur if these waste forms were placed in a deep geologic repository, these materials should be excluded.

TABLE 2. Organic Compounds in Water Samples from Trenches
at Maxey Flats, KY or West Valley, NY
(Colombo et al. 1977b, 1979)

Acetic acid	Pentanoic acid
Benzoic acid	Phenylacetic acid
Butyric acid	Phenylhexanoic acid
Cyclohexanol	Phenylpropionic acid
Hexanoic acid	Stearic acid
Naphthalene	Tributyl phosphate
Octanoic acid	Tetrahydrofuran
Octanol	Toluene
Oleic acid	Vanillin
Palmitic acid	

CHEMICAL AND PHYSICAL PROCESSES WHICH COULD CHANGE THE FORM OF ORGANIC COMPOUNDS

The variety of organic forms that may be present in a repository could be influenced by various chemical, physical, and biological processes that may occur in the repository before, during, or subsequent to the action creating a breach. These processes may include the following:

- thermal decomposition
- radiolytic alteration of the organic molecules
- microbial decomposition
- chemical decomposition.

The thermal and radiolytic effects on organic wastes will depend on the proximity of the organic compounds to the high-level waste forms. If the organic transuranic and low level waste form packages are placed among high-level waste packages then a considerable influence could be expected. However if they are placed on different levels of the repository, the influence would be much less. The thermal and radiolytic effects on the gas-generating potential of organic compounds have been performed as part of the WIPP program (Sandia 1979). The major gases produced from organic waste degradation, in the approximate order of abundance were, H_2 , CO_2 , CO , H_2O , CH_4 , O_2 , NO_x and He. However, the study did not contain any information on the changes from one solid form to another.

Thermal and radiation stabilities of several types of organics that may be present in a repository were found in a study of decontamination processes for nuclear reactors (Choppin et al. 1979). This study examines the effectiveness of organic acids and chelating agents for the removal of corrosion products in applications involving high temperature and radiation fields.

In one of the sources Choppin cites (Margulova et al. 1972), the combination of thermal and radiolytic decomposition of the iron EDTA complex was studied. The temperatures examined were 100° , 160° , and $200^\circ C$, at radiation fields of $0.3 \text{ MR}^{(a)}/\text{hr}$ and 0.4 MR/hr . The complex decomposed only slightly

(a) Mega rads

at 100°C without radiation over 5 hr. However, with the addition of 0.3 MR/hr, the concentration of complex decreased to approximately half the initial concentration after 5 hr. At 160° and 200°C the initial complex concentration was decreased by 25% and 50%, respectively, after 2 hr. However, with the addition of radiation of 0.4 MR/hr the initial concentration of the complex decreased by 75% at both 160° and 200°C after 1 hr. The products of decomposition were not mentioned; however, metal complexes of EDTA and other ligands are generally more thermally stable in solution than the metal free ligand.

In a similar study, temperature was found to have a synergistic effect on radiolytic gas generation from organic materials (Sandia 1979). An increase in temperature from 20° to 50°C resulted in a 43% increase in the rate of gas generation and an increase from 20° to 70°C produced a 70% increase.

As previously mentioned, microorganisms can act upon organic wastes and organic-radionuclide complexes and change the form of the nuclides and organic compounds. Colombo et al. (1978) studied the population distribution and growth of microorganisms present in trench water samples at commercial disposal sites for low-level radioactive waste. (1978). They identified aerobes, anaerobes, and facultative anaerobes in the trench waters, with the majority identified as facultative anaerobes, and showed that they are able to grow under anaerobic conditions using the nutrients present in the trench water. Therefore, microbial activity also appears to play a role on the forms of organic compounds present in a geologic repository.

Microbial activity is also reported to have great potential to generate significant quantities of gas from radionuclide contaminated wastes and waste packaging materials (Sandia 1979). However, the amount of microbial activity and gas production will depend on many variables such as temperature, pH, radiation field, carbon source and essential nutrients.

The potential for a microbial population to use the organic wastes as carbon and energy sources depends on the chemical structure of the various organic compounds. There have been many studies which have examined the relationship between chemical structure and biodegradation (Howard et al. 1975, Alexander and Aleem 1961, Dias and Alexander 1971, Hammond and Alexander 1972).

From these studies, some generalizations were made by Howard et al. 1975, on the resistance of a particular compound to biodegradation. In particular, highly branched compounds are frequently resistant to biodegradation. The suggestion was also made that alcohols, aldehydes, acids, esters, amides, and amino acids are generally more susceptible to microbial attack than the corresponding alkane, olefins, ketones, dicarboxylic acids, nitriles, amines, and chloroalkanes. Substitution on aromatic rings was reported to have varying effects. Groups such as carboxyl or hydroxyl have a tendency to increase biodegradability while halogens and nitro groups reduce microbial attack. In addition, metadisubstituted phenols and phenoxy compounds were reported to be usually more resistant than ortho or para-isomers. However, these results are dependent upon the test methods and the criteria used to define biodegradation.

SELECTED STUDIES DURING FY 1980

At the Battelle-Columbus Laboratory, studies are in progress to evaluate the form and amount of organic compounds that may be present in a repository environment and to analyze the effects that these organics may have on radionuclide solubility (Means and Hastings 1980). This work is being conducted as five tasks. The first task involves analyzing ground water from the Columbia River basalt group in the Pasco Basin of Washington and from the Finnsjo and Sterno areas in Sweden. The organic compounds are being analyzed by gas chromatography-mass spectrometry (GC-MS) and by liquid chromatographic procedures.

A second task is to determine the effect of organic complexing agents on radionuclide sorption by various geologic media. These analyses are being conducted at temperatures up to 200°C.

A third task involves a study of the organic compounds present in leachates from the Maxey Flats, Kentucky disposal site for radioactive waste. EDTA has been identified as a radionuclide mobilizing agent in these samples. Natural organic compounds such as humic and fulvic acids will also be evaluated for their role in mobilizing plutonium in the Maxey Flats samples.

In a fourth task, radionuclides are being added to ground waters of varying chemical composition and the identity of the radionuclide solution species formed is being studied using liquid chromatography. This procedure separates the small inorganic chemical species from the high molecular weight organic compounds.

In a fifth task, the dissolution rates of U_3O_8 in the Hanford and Swedish ground waters and in simulated ground waters containing no organic matter are being measured. The objective of this experiment is to determine the effect of natural organic compounds on uranium solubility. Other radionuclides may be considered at a later date.

The overall goal of this program is to fully evaluate the possibility that organics from a variety of sources, including the ground water, repository

rock, or the waste itself, may form strong complexes with certain radionuclides and significantly increase transport rates from the repository. The results from these studies will be monitored and the information will be incorporated into the AEGIS modeling efforts.

Related studies are also in progress to support waste acceptance criteria for the Waste Isolation Pilot Plant (WIPP) (Sandia 1979). These studies were designed to identify organic waste forms most susceptible to degradation and the production of soluble organic compounds. Samples of various organic waste such as plywood, rubber gloves, and paper products were refluxed in a synthetic salt brine solution at 70°C. Samples of Culebra dolomite were then placed in contact with the refluxed solutions which had been spiked with either $^{243}\text{Am}(\text{III})$ or $^{239}\text{Pu}(\text{IV})$, and the Kd values were determined. The plywood extract reduced the Kd values for both Am and Pu by an order of magnitude over extracts of the other organic compounds. Also studied were Kd values for Pu present in salt brine solutions containing EDTA, oxalate, citrate, and tartrate. These studies also indicated a potential for some ligands to reduce Kd values by as much as an order of magnitude.

Brookhaven National Laboratory (BNL) is investigating the properties of solidified radioactive wastes and containers (Colombo and Neilson 1979). Analyses for organic carbon removed from the waste forms by leaching with distilled water are included in these studies. The solidified waste forms that are being studied include Portland cement, urea-formaldehyde, bitumen, and vinyl ester-styrene. Table 3 shows the experimental parameters of the leach test. The urea-formaldehyde, bitumen and vinyl ester-styrene all release organic carbon; however, the form of the soluble compounds and their ability to support microbial growth have not been determined. This experiment investigated the potential solubility of organic carbon from selected solidification matrix materials but did not consider the effect of incorporated waste. Constituents of the waste itself, such as cellulosic materials, may enhance the concentration of organic carbon in the leachate. The potential also exists for microbial decomposition of the solidified waste package, which may also influence the solubility of the organic components. Additional studies are in

TABLE 3. Organic Carbon Removed from Solidification Matrix Materials by Leaching in 300 ml of Distilled Water for 10 Days (Colombo and Neilson 1979)

	<u>Portland Type II Cement</u>	<u>Urea- formaldehyde</u>	<u>Pioneer 221 bitumen</u>	<u>Vinyl ester-styrene</u>
Specimen mass, g	296.0	218.3	103.1	198.2
Ratio of specimen vol to geometric surface area, cm	0.98	1.1	0.75	1.1
Leachant content				
a. Total C, ppm	14.8	9540	3.4	34.2
b. Org. C, ppm	0.0	9500	3.4	34.2

progress at BNL to study sorption of selected radionuclides when organic compounds are added to trench waters and soils from the Maxey Flats, KY, and West Valley, NY, disposal sites.

Pacific Northwest Laboratory (PNL) is evaluating the important mobile or volatile complexes of fission and activation products formed in the storage of low-level waste in shallow land burial. Experiments examining the behavior in soils of ^{99}Tc complexed with EDTA and DTPA have been completed and the results are being analyzed.

Studies are in progress at Temple University to determine the influence of organic ligands on the dissolution rate of mineral grains. Results of this study may have implications for interpreting dissolution rates of nuclear waste forms including solidified high level waste glass. Preliminary results from a variety of organic ligands at pH 4.5, 10^{-3}M ligand concentration and 25°C on grains of forsteritic olivine from Hawaiian beach sand indicate the relative effect on dissolution rate is: EDTA $\approx$ citrate > oxalate > tannic acid >> succinate > phthalate > acetate. The results of this study also indicate that the influence of the organic ligands on dissolution rate is due only to free ligand and not to total ligand concentration.

REFERENCES

- Alexander, M., and M. I. H. Aleem. 1961. "Effect of Chemical Structure on Microbial Decomposition of Aromatic Herbicides." Agric. and Food Chem., 9(1):44-47.
- Barnhart, B. J., E. W. Campbell, J. M. Hardin, E. Martinez, D. E. Caldwell, and R. Hallett. 1979a. Potential Microbial Impact on Transuranic Wastes Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP). Progress Report, December 15, 1978-March 15, 1979. LA-7839-PR. Los Alamos Scientific Laboratory, Los Alamos, NM.
- Barnhart, B. J., E. W. Campbell, E. Martinez, D. E. Caldwell, and R. Hallett. 1979b. Potential Microbial Impact on Transuranic Wastes Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP). Progress Report, March 15, 1979-June 15, 1979. LA-7918-PR. Los Alamos Scientific Laboratory, Los Alamos, NM.
- Bondietti, E. A., S. A. Reynolds, and M. W. Shanks. 1976. "Interaction of Plutonium with Complexing Substances in Soils and Natural Waters." In Transuranium Nuclides in the Environment, IAEA-SM-199/51. Proceedings of the Symposium, International Atomic Energy Agency, San Francisco, CA, November 17-21, 1975.
- Brownlow, A. H. 1979. Geochemistry. Prentice-Hall, Inc., Englewood Cliffs, NJ.
- Choppin, G. R., R. L. Dillon, B. Griggs, H. B. Johnson, Jr., J. F. Remark, and A. E. Martell. 1979. Literature Review of Dilute Chemical Decontamination Processes for Water-Cooled Nuclear Reactors. EPRI NP-1033. Electric Power Research Institute, Palo Alto, CA.
- Cleveland, J. M. and T. F. Rees. 1976. "Investigation of Solubilization of Plutonium and Americium in Soil by Natural Humic Compounds." Environ. Science and Tech., 10(8):802-806.
- Colombo, P. and R. M. Neilson. 1979. Properties of Radioactive Waste Containers. First Topical Report. NUREG/CR-0619, BNW-NUREG-50957. Nuclear Waste Management Research Group, Department of Nuclear Energy, Brookhaven National Laboratory, Upton, NY.
- Colombo, P., A. J. Weiss, and A. J. Francis. 1977a. Evaluation of Isotope Migration - Land Burial, Water Chemistry at Commercially Operated Low-Level Radioactive Waste Disposal Sites. Progress Report, April-June 1976. BNL-NUREG-50623. Brookhaven National Laboratory, Associated Universities, Inc., Upton, NY.

- Colombo, P., A. J. Weiss, and A. J. Francis. 1977b. Evaluation of Isotope Migration - Land Burial, Water Chemistry at Commercially Operated Low-Level Radioactive Waste Disposal Sites. Progress Report, July-September 1976. BNL-NUREG-50666. Brookhaven National Laboratory, Associated Universities, Inc., Upton, NY.
- Colombo, P., A. J. Weiss, and A. J. Francis. 1978a. Evaluation of Isotope Migration - Land Burial, Water Chemistry at Commercially Operated Low-Level Radioactive Waste Disposal Sites. Progress Report, October-December 1977. BNL-NUREG-50861. Brookhaven National Laboratory, Associated Universities, Inc., Upton, NY.
- Colombo, P., A. J. Weiss, and A. J. Francis. 1978b. Evaluation of Isotope Migration - Land Burial, Water Chemistry at Commercially Operated Low-Level Radioactive Waste Disposal Sites. Progress Report, January-March 1978. BNL-NUREG-50937. Brookhaven National Laboratory, Associated Universities, Inc., Upton, NY.
- Dias, F. F., and M. Alexander. 1971. "Effect of Chemical Structure on the Biodegradability of aliphatic Acids and Alcohols." Appl. Microbiol., 22(6):1114-1118.
- DOE. 1979. Technology for Commercial Radioactive Waste Management. DOE/ET-0028. Department of Energy, Washington, DC.
- Dosch, R. G. and A. W. Lynch. 1978. Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico. SAND 78-0297. Sandia Laboratories, Albuquerque, NM.
- Grandstaff, D. E. 1976. "A Kinetic Study of the Dissolution of Uranite." Econ. Geol., 71(8):1493-1506.
- Grigoropoulos, S. G. and J. W. Smith. 1971. "Trace Organics in Subsurface Waters." Organic Compounds in Aquatic Environments. Ed., S. D. Faust and J. F. Hunter, Marcell Dekker, Inc., New York, NY.
- Griswold, G. B. 1979. Solution Mining in Salt Domes of the Gulf Coast Embayment. PNL-3190, Pacific Northwest Laboratory, Richland, WA.
- Hammond, M. W., and M. Alexander. 1972. "Effect of Chemical Structure on Microbial Degradation of Methyl-substituted Aliphatic Acids." Environ. Science and Tech., 6(8):732-735.
- Himes, F. L. and R. Shufeldt. 1970. Influence of Some Organic Compounds on the Movement of ⁹⁰Sr in Soils. Ohio Agricultural Research and Development Center, Columbus, OH.
- Hoeck, G. W. and D. W. Rhodes. 1979. Removal and Disposal of Radioactive Sludge from the Fuel Storage Basin at the Idaho Chemical Processing Plant. ICP-1195. Idaho National Engineering Laboratory, Idaho Falls, ID.

- Holcombb, H. P., J. H. Horton, and E. L. Wilhite. 1976. Actinide-Soil Interactions in Waste Management at the Savannah River Plant. DP-MS-75-118. (For presentation at the Actinide-Sediment Reaction Conference, Richland, Washington, February 10-11, 1976.
- Howard, P. H., J. Saxena, P. R. Durkin, and L. T. Ou. 1975. Review and Evaluation of Available Techniques for Determining Persistence and Routes of Degradation of Chemical Substances in the Environment. EPA-560/7-75-006. Prepared for EPA by Syracuse University Research Corporation. PB-243.825.NTIS. Available from National Technical Information Service, Springfield, VA.
- Kosiewicz, S. T., B. L. Barraclough, and A. Zerwekh. 1978. Studies of Transuranic Waste Storage Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP): Progress Report, October 1 - December 15, 1978. LA-7649-PR. Los Alamos Scientific Laboratory, Los Alamos, NM.
- Kosiewicz, S. T., B. L. Barraclough, and A. Zerwekh. 1979. Studies of Transuranic Waste Storage Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP). Progress Report, December 15, 1978-March 15, 1979. LA-7775-PR. Los Alamos Scientific Laboratory, Los Alamos, NM.
- L'Annunziata, M. F. and W. H. Fuller. 1967. "The Chelation and Movement of $^{89-90}\text{Sr}$ (^{90}Y) in a Calcerous Soil." Soil Science, 105(5):311-319.
- Leenheer, J. A., R. L. Malcolm, P. W. McKinley and L. A. Eocles. 1974. "Occurrence of Dissolved Organic Carbon in Selected Ground-water Samples in the United States." Jour. Research U.S. Geol. Survey, 2(3):361-369.
- Margulova, T. Kh., S. A. Tevlin, Yu. E. Lebedev, and A. I. Mileav. 1972. "Influence of Radiation on the Behavior of Iron Chelate." Thermal Eng., 19(3):15-16.
- McFadden, K. M. 1980. Organic Components of Nuclear Wastes and Their Potential for Altering Radionuclide Distribution when Released to Soil. PNL-2563, Pacific Northwest Laboratory, Richland, WA.
- Means, J. L., D. A. Crerar, and J. O. Duguid. 1978. "Migration of Radioactive Wastes: Radionuclide Mobilization by Complexing Agents." Science, 200(30):1477-1481.
- Means, J. L., and D. W. Hastings. 1980. Organics Study. Quarterly Technical Progress Report to ONWI for the Period Jan. 1, 1980 through March 31, 1980. Battelle, Columbus Laboratories, Columbus, OH.
- Means, J. L., and D. W. Hastings. 1979. Status Report on the Importance of Natural Organic Compounds in Ground Water as Radionuclide-Mobilizing Agents. ONWI-84, Battelle Columbus Laboratories, Columbus, OH 43201.
- Nishita, H., R. M. Haug, and T. Rutherford. 1977. "Effect of Inorganic and Organic Compounds on the Extractability of ^{239}Pu From an Artificially Contaminated Soil." J. Environ. Qual., 6(4):451-455.

- Nishita, H. and M. Hamilton. 1977. "Factors Influencing the Chemical Extractability of ^{241}Am From a Contaminated Soil." In M. G. White and P. B. Dunaway, ed. Symposium on the Dynamics of Transuranic in Terrestrial and Aquatic Environments, Gatlinburg, TN, October 5-7, 1976. U.S. Energy Res. and Dev. Admin., Nevada Operations Office, Las Vegas, NV.
- Nishita, H. and M. Hamilton. 1978. Soil Components That Influence the Chemical Behavior of ^{239}Pu . UCLA 12/1159. Laboratory of Nuclear Medicine and Radiation Biology. University of California, Los Angeles, CA.
- Nishita, H., M. Hamilton, and A. J. Stern. 1978. "Extractability of ^{238}Pu and ^{242}Cm From a Contaminated Soil as a Function of pH and Certain Soil Components: $\text{HNO}_3\text{-NaOH}$ System." Soil Sci. Soc. Am. Proc., 42:51-56.
- Relyea, J. F. and D. A. Brown. 1978. "Adsorption and Diffusion of Plutonium in Soil." In Environmental Chemistry and Cycling Processes. Ed. by D. C. Adriano and I. Lehr Brisbin, Jr. CONF-760429. Technical Information Center, U.S. Department of Energy.
- Sandia Laboratories. 1979. Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP. SAND 79-1305, Sandia Laboratories, Albuquerque, NM.
- Shelfbine, H. C. 1978. Preliminary Evaluation of the Characteristics of Defense Transuranic Wastes. SAND 78-1850. Sandia Laboratories, Albuquerque, NM.
- Stumm, W. and J. J. Morgan. 1970. Aquatic Chemistry, An Introduction Emphasizing Chemical Equilibria in Natural Waters. Wiley-Interscience, NY, p 583.
- Wedepohl, K. H. (ed). 1978. Handbook of Geochemistry. Volume II-1. Springer-Verlag, Berlin, Heidelberg, and New York.
- Wiggins, D. J. and J. A. Franz. 1978. Mobility of Organic Complexes of Some Non-TRU Fission and Activation Products: A Selective Review. PNL-2607. Pacific Northwest Laboratory, Richland, WA.
- Wildung, R. E. and T. R. Garland. 1977. The Relationship of Microbial Processes to the Fate and Behavior of Transuranic Elements in Soils and Plants. PNL-2416. Pacific Northwest Laboratory, Richland, WA.
- Wilhite, E. L. 1976. "Movement of Organically Bound Plutonium in Soil." In Proceedings of Actinide-Sediment Reactions Working Meeting, Seattle, Washington, February 10-11, 1976. BNWL-2117. L. L. Ames, ed., Pacific Northwest Laboratory, Richland, WA.
- ZoBell, C. E. and M. A. Molecke. 1978. Survey of Microbial Degradation of Asphalts with Notes on Relationship to Nuclear Waste Management. SAND 78-1371. Sandia Laboratories, Albuquerque, NM.

APPENDIX A

TABLE A.1. Materials Present in LASL Retrievably-Stored TRU Waste
(Kosiewicz et al. 1979)

Description	Gross Volume, m ³	Net(a) Volume, m ³	Gross Weight, kg	Net(b) Weight, kg	Gross(c) Density, kg/m ³	Net(d) Density, kg/m ³
Graphite	0.21	0.21	70	56	333	267
Mixed cellulose	70.96	62.26	27,413	7,873	258	126
Plastic materials	7.18	5.44	3,657	673	255	124
Rubber materials	16.50	3.45	18,374	929	391	269
Mixed paper, plastic, rubber, etc.	77.58	36.69	64,535	6,430	305	175
Mixed combustible/noncombustible	57.90	25.71	49,374	4,075	287	158
Hydrocarbon oils	1.47	1.47	1,209	1,013	822	689
Silicon-based oils	0.74	0.74	800	702	1,081	949
Leached process residues	52.82	52.82	18,540	11,652	351	221
Property-numbered equipment	110.50	100.49	51,304	28,862	375	287
Nonproperty-numbered equipment	380.42	377.82	166,623	139,992	432	371
Noncombustible building debris	31.70	31.70	12,680	10,880	400	343
Combustible hot-cell waste	2.94	2.94	809	417	275	142
Noncombustible hot-cell waste	4.06	3.19	1,821	266	215	83
Skull and oxide	0.11	0.11	28	14	250	127
Metal crucibles, scrap, dies	36.18	33.57	14,685	6,842	336	204
Other scrap metals	34.11	11.49	34,095	2,899	399	252
Filter media	94.97	88.02	32,409	15,531	265	176
Filter media residue	0.63	0.63	173	89	275	141
Other combustibles	96.03	95.16	26,257	12,438	264	131
Other noncombustibles	167.84	96.50	122,406	16,708	304	173
Chemical wastes	1.06	1.06	332	192	313	181
Chemical treatment sludge	9.66	9.66	9,728	8,440	1,007	874
Cement paste	334.19	334.19	577,848	548,492	1,600	1,594
Contaminated soil	1.47	1.47	650	454	442	309
Glass	3.53	2.66	1,989	504	321	189
Unidentified material	4.90	4.90	1,273	805	260	164
	1610	1394	1,239,078	827,228		

(a) Internal volume of waste containers.

(b) Gross weight minus container weights.

(c) Gross density is for waste plus primary container (neglects cement casks).

(d) Net density is for waste without container.

TABLE A.2. Waste Forms Ranked by Volume for Wastes Stored at Idaho from 9/1/71 to 12/21/76 (Shefelbine 1978)

<u>Waste Form</u>	<u>% of Total Volume</u>
Metal scrap	36
Paper and rags - dry	9
Paper and rags - wet	7
Filters - CWS	7
Second stage sludge	6
LSA metal, glass, etc.	5
First stage sludge	5
Organic setups (solidified oils)	3
Unknown	3
Concrete, asphalt, etc.	2

TABLE A.3. Compactable and Combustible Wastes from a Reference Nuclear Power Plant (DOE 1979)

<u>Source</u>	<u>Components, wt%</u>		<u>Density, kg/m³</u>	<u>Volume, m³/GWe-yr (a)</u>
HEPA filters	Glass	40	1.6×10^2	5
	Wood	60		
Combustible trash	Paper	23	1.2×10^2	2×10^2
	Plastic	67		
	Rubber	6		
	Wood	3		
	Cloth	1		

(a) 38 metric tons of heavy metal (MTHM) = 1 GWe-yr

TABLE A.4. Concentrated Liquids, Wet Wastes, and Particulate Solids from a Reference Nuclear Power Plant (DOE 1979)

Source	Components, wt%		Density, kg/m ³	Volume, m ³ /GWe-yr ^(a)
Bead resins	Polystyrene	50	7.2 x 10 ²	2.9 x 10 ¹
	H ₂ O	50		
Powdered resins	Polystyrene	50	6.7 x 10 ²	2.9 x 10 ¹
	H ₂ O	50		
Filter precoat sludge	Filter aids	40	4.3 x 10 ²	3.4 x 10 ¹
	H ₂ O	60		
Cartridge filters	Filter media	80	5 x 10 ²	5
	H ₂ O	20		
Sulfate concentrate	Na ₂ SO ₄	10	1.2 x 10 ³	2.6 x 10 ²
	H ₂ O	75		
Borate concentrate	Na ₂ B ₄ O ₇	10	1.04 x 10 ³	4
	H ₂ O	90		

(a) 38 metric tons of heavy metal (MTHM) = 1 GWe-yr

TABLE A.5. Compactable and Combustible Wastes from A Reference Spent Fuel Storage Basin (DOE 1979)

<u>Source</u>	<u>Components, wt%</u>		<u>Density, kg/m³</u>	<u>Operation</u>	<u>Volume</u>
Combustible Trash	Cellulosic	50	1.2×10^2	Receiving	$6 \times 10^{-1} \text{ m}^3/\text{MTHM}$
	PVC	15		Storing	$8 \times 10^{-2} \text{ m}^3/\text{MTHM-yr}$
	Polystyrene	15		Shipping	$1.6 \times 10^{-1} \text{ m}^3/\text{MTHM-yr}$
	Latex	10		Composite(a)	$2.1 \times 10^{-1} \text{ m}^3/\text{MTHM-yr}$
	Necorene	10			
Ventilation Filters	Glass	40	1.6×10^2	Receiving	$8.5 \times 10^{-3} \text{ m}^3/\text{MTHM}$
	Wood	60		Storing	$5.3 \times 10^{-3} \text{ m}^3/\text{MTHM-yr}$
				Shipping	$5.3 \times 10^{-3} \text{ m}^3/\text{MTHM}$
				Composite(a)	$7.6 \times 10^{-3} \text{ m}^3/\text{MTHM-yr}$

(a) Composite based on operating mode in which one-sixth of storage inventory is shipped out and replaced each year.

TABLE A.6. Concentrated Liquids, Wet Wastes and Particulate Solids from a Reference Spent Fuel Storage Basin (DOE 1979)

Source	Components, wt%		Density, kg/m ³	Operation	Volume
Bead resins	Polystyrene	50	7.2×10^2	Receiving	2×10^{-3} m ³ /MTHM
	Water	50		Storing	3×10^{-4} m ³ /MTHM-yr
				Shipping	6×10^{-4} m ³ /MTHM
				Composite(a)	7.3×10^{-4} m ³ /MTHM-yr
Filter precoat sludge	Cellulosic	20	4.3×10^2	Receiving	7×10^{-3} m ³ /MTHM
	Diatomaceous earth	20		Storing	1×10^{-3} m ³ /MTHM-yr
				Shipping	2×10^{-3} m ³ /MTHM
	Water	60		Composite(a)	2.5×10^{-3} m ³ /MTHM-yr
Sulfate concentrate	Na ₂ SO ₄	25	1.2×10^3	Receiving	5×10^{-3} m ³ /MTHM
	Water	75		Storing	1×10^{-3} m ³ /MTHM-yr
				Shipping	3×10^{-3} m ³ /MTHM
				Composite(a)	2.3×10^{-3} m ³ /MTHM-yr
Miscellaneous solution concentrates	Decontami- nation agents and corrosion products	25	1.2×10^3	Receiving	1×10^{-2} m ³ /MTHM
				Storing	1×10^{-3} m ³ /MTHM-yr
				Shipping	3×10^{-3} m ³ /MTHM
	Water	75		Composite(a)	3.2×10^{-3} m ³ /MTHM-yr

(a) Composite based on operating mode in which one-sixth of storage inventory is shipped out and replaced each year.

TABLE A.7. Intermediate-Level Compactable and Combustible Wastes from a Reference Fuel Reprocessing Plant (DOE 1979)

Source	Components, wt%		Density, kg/m ³	Volume, m ³ /MTHM
Storage basin combustible trash (non-TRU)	Paper/rags	40	1.2×10^2	6×10^{-1}
	PVC	20		
	Neoprene	11		
	Polyethylene	14		
	Latex	11		
	Wood	4		
Main plant com- bustible trash (TRU)	Same as above		1.2×10^2	4×10^{-1}
PuO ₂ conversion combustible trash (TRU)	Same as above		1.2×10^2	3×10^{-2}
UF ₆ plant com- bustible trash (non-TRU)	Same as above		1.2×10^2	5×10^{-2}
Storage basin ventilation fil- ters (non-TRU)	Wood	60	1.6×10^2	1×10^{-2}
	Glass	40		
Main plant venti- lation filter (TRU)	Same as above		1.6×10^2	1.4×10^{-1}
UF ₆ plant venti- lation filters (non-TRU)	Same as above		1.6×10^2	5×10^{-3}
PuO ₂ conversion ventilation fil- ters (TRU)	Metal	60	1.6×10^2	2×10^{-2}
	Glass	40		
IX bead resins (TRU)	Polystyrene	50	7.2×10^2	5×10^{-3}
	H ₂ O	50		
Degraded extrac- tant (TRU)	TBP (vol)	30	8×10^2	8×10^{-3}
	Dodecane (vol)	70		

TABLE A.8. Low-Level Compactable and Combustible Wastes from
a Reference Fuel Reprocessing Plant (DOE 1979)

<u>Source</u>	<u>Components, wt%</u>		<u>Density, kg/m³</u>	<u>Volume, m³/MTHM</u>
Main plant combustible trash (TRU)	Paper/rags	40	1.2×10^2	1.2
	PVC	20		
	Neoprene	11		
	Polyethylene	14		
	Latex	11		
	Wood	4		

TABLE A.9. Compactable and Combustible Wastes from a Reference
Mixed Oxide Fuel Fabrication Plant (DOE 1979)

<u>Source</u>	<u>Components, wt%</u>		<u>Density, kg/m³</u>	<u>Volume, m³/MTHM</u>
HEPA filters	Metal	60	1.6×10^2	1×10^{-1}
	Glass	40		
Combustible trash	PVC	33	1.2×10^2	5×10^{-1}
	Cellulosics	30		
	Polyethylene	18		
	Latex	9		
	Neoprene	9		
	Styrene	1		

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