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Review of EPA, DOE, and NRC Regulations on Establishing Solid Waste Performance Criteria

A. J. Mattus
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WASTE MANAGEMENT TECHNOLOGY CENTER

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Chemical Technology Division

REVIEW OF EPA, DOE, AND NRC REGULATIONS ON ESTABLISHING SOLID WASTE PERFORMANCE CRITERIA

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ABSTRACT

This report provides a comprehensive review of the regulations concerning hazardous and radioactive waste disposal that have been issued by three government agencies: (1) The U.S. Department of Energy; (2) The U.S. Environmental Protection Agency; and (3) The U.S. Nuclear Regulatory Commission. The primary foci of this document are those regulations pertaining to performance and testing requirements for solid waste forms. In cases where performance and testing requirements are tied to classification of waste forms or setting of minimum standards for groundwater, these latter topics were also reviewed. The purposes of this report are to summarize and compare the various regulations regarding waste disposal, and to present those regulations in an easily understandable fashion. The primary uses of this document should be to become familiar with the regulations and to compare the requirements of the various agencies. Because this is a general, summary document, it is imperative that references be made to the original regulatory documents when decisions concerning testing or waste disposal are made which are affected by the regulations concerned herein. Also new regulations and updates are continuously being issued and should be reviewed frequently in order to stay abreast of possible regulatory changes.

1. INTRODUCTIONS

The establishment of processing methods for solidifying low-level radioactive and mixed hazardous wastes requires a knowledge not only of fixation technology and its associated chemistry, but also of relevant regulations. The regulations of concern are those which apply specifically to the processing of low-level radioactive and mixed hazardous wastes and to the desired performance characteristics of these wastes. Such regulations arise principally from three agencies: (1) the U.S. Environmental Protection Agency (EPA), (2) the U.S. Department of Energy (DOE), and (3) the U.S. Nuclear Regulatory Commission (NRC).

This report reviews those agency regulations which pertain to the desired waste performance criteria established by the EPA, DOE, and the NRC. Only those regulations which have some bearing on the performance of the waste following disposal and its potential impact on the environment have been addressed. Areas of concern that are germane to such performance are (1) waste form structural stability, (2) laboratory leach testing, (3) groundwater environmental contamination limits, and (4) waste classification when it establishes differences in desired waste form performance objectives.

The content of this report represents a summary of the pertinent regulations that were applicable at the time of writing. Since the regulatory environment is a constantly changing one, it is incumbent upon the user of this document to periodically review those publications which contain the revisions and amendments to the respective regulations.

This report is a summary of applicable regulations and is not meant to imply or delineate regulatory agency jurisdiction or applicability. It does, however, strive to present the distillation of our review of the

differences between the three agencies' requirements regarding the development of a viable waste fixation process. It is hoped that, in addition to providing direction for a viable waste fixation development program, this report will also act as a seed to promote similar reviews of other areas of regulatory requirements.

2. EPA REGULATIONS RELEVANT TO LABORATORY TESTING AND WASTE FORM PERFORMANCE CRITERIA

2.1 REGULATORY BACKGROUND

The EPA was charged by Congress with the responsibility of developing criteria for categorizing hazardous wastes. Currently, the bulk of pertinent EPA regulations is built on the Resource Conservation and Recovery Act (RCRA)[1] of 1976, which was enacted into law by Congress in an attempt to deal with solid waste disposal. The EPA has been given the jurisdiction to control the identification and listing of solid hazardous wastes under RCRA and to implement its control under 40 CFR 261.[2] Contained in the sections of 40 CFR 261 are lists of hazardous wastes and the tests necessary to establish hazardous waste characteristics.

Current RCRA regulations classify solid wastes as "hazardous" on the basis of one or more of the following criteria:

1. The waste exhibits <u>any</u> of four hazardous waste characteristics identified in 40 CFR Part 261, Subpart C[3] [i.e., the four standard EPA tests for ignitability, corrosivity, reactivity, and Extraction Procedure (EP) Toxicity].

2. Low doses of the waste have been found to be fatal to humans.
3. The waste contains one or more substances from nearly 400 toxic chemicals or classes of such chemicals listed in Appendix VIII of 40 CFR 261.[2]

Section 3001 of RCRA[4] mandates that EPA must identify hazardous wastes by one of two mechanisms. The EPA may either "list" wastes that are known to be hazardous (referred to as "listed" wastes) or may identify wastes as hazardous by virture of their characteristics (referred to as "characteristically hazardous" wastes). The definition of solid waste can be misleading since it is defined to include solid, liquid, semisolid, or even gases.

For the most part, listed wastes will likely also exhibit one or more of the above-mentioned hazardous characteristics (i.e., ignitability, corrosivity, reactivity, and EP Toxicity). When this is the case, the waste must be managed as if it were a listed waste. A waste that does not contain one of the substances listed in 40 CFR 261, Appendix VIII[5] may still be classed as "hazardous" based on characteristics alone. Note that these characteristics apply not only to the untreated waste but also to the waste form containing the waste.

2.2 CHARACTERISTICALLY HAZARDOUS WASTES

Characteristically hazardous wastes exhibit one or more of the four hazardous characteristics identified in criterion 1 above, namely, ignitability, corrosivity, reactivity, or EP Toxicity. These

characteristics are clearly defined in 40 CFR 261, Subpart C,[3] which also specifies testing methodologies to be used by the waste generator to determine whether a waste exhibits these characteristics.

The EPA addresses desired solid waste form characteristics indirectly in the process of establishing whether a waste can be deemed a hazardous waste. If a waste is not a listed waste, it still must be proven that it does not possess any of the four hazardous waste characteristics. The following is a summary of these characteristics, together with the regulatory definition of each as outlined in 40 CFR 261.[2]

1. Ignitability

   A. If a representative sample of the waste is a liquid other than an aqueous solution, the liquid should not have a flash point lower than 60°C as determined by the Pensky-Martens Closed-Cup Test or an approved equivalent test.

   B. If a representative sample of the waste is not a liquid, it must not be capable of causing a fire through friction or ignition or as a result of a spontaneous chemical change at standard temperature and pressure.

   C. If a representative sample of the waste is gaseous, it must not be ignitable.

   D. The waste must not be an oxidizer.

2. Corrosivity

   A. A representative sample of waste that is or contains an aqueous phase must exhibit a pH between 2 and 12.5 (inclusive) so as not to be considered corrosive.

B. A representative sample of waste that is or contains an aqueous phase must not corrode steel (SAE 1020) at a rate greater than 6.35 mm/year at a temperature of 55°C.

3. Reactivity

A. A representative sample of waste must not be so unstable as to undergo violent change without detonation.

B. A representative sample of waste must not react violently with water, resulting in potentially explosive mixtures, or release toxic gases, vapors, or fumes.

C. A representative sample of waste must not be capable of detonation or explosive reaction if subjected to an initiating force or heat source, and no explosives must be present in the waste.

D. A representative sample of waste must not release toxic gases when it is known to contain sulfide or cyanide over the pH range of 2 to 12.5.

4. EP Toxicity - When a representative sample of waste is leached in accordance with the test method presented in Appendix II of 40 CFR 261,[6] or some other approved method, the leachate must not contain contaminant concentrations equal to or greater than the limits presented in Table 1 of 40 CFR 261.24.[7]

2.3 LISTED WASTES

As the word "listed" implies, these wastes are identified in EPA-established lists of chemicals or chemical sources typically known to contain substances harmful to man or his environment. Wastes that meet

either criterion 2 or 3 in Sect. 2.1 have been listed as hazardous waste by the EPA.

This concept of "listed" waste has been responsible for a massive amount of confusion, even above that normally associated with regulatory verbiage. Recent indications from the EPA point to a future method for the determination of "hazardousness" based on concentrations of hazardous constituents rather than on the concept of listing.

Most confusion regarding the question as to whether a waste is hazardous has arisen over Appendix VIII of 40 CFR 261.[5] That is, criterion 3 as presented in Sect. 2.1 needs an important qualifier added, yet it is often quoted solely as written. A waste is not automatically listed, and therefore hazardous by definition, simply because it contains one or more of the constituents listed in Appendix VIII. Rather, the EPA may "list" a specific waste as hazardous because it contains Appendix VIII constituents. A waste that contains an Appendix VIII constituent is not hazardous unless it also is on one of EPA's waste lists or exhibits one of the RCRA hazardous waste characteristics.

The EPA has subdivided listed wastes into three categories, which are, in turn, collectively composed of four lists. The categories and their respective sublists, which are presented in 40 CFR 261, Subpart D,[8] are as follows:

1. Hazardous waste from nonspecific sources as outlined in the F list [40 CFR 261.31 (ref. 9)]. It is believed that most of the listed hazardous wastes at DOE's Oak Ridge facilities will be F list wastes.

2. Hazardous waste from specific sources as outlined in the K list [40 CFR 261.32 (ref. 10)].
3. Discarded commercial chemical products, off-specification species, container residues, and spill residues from any of these sources. These are outlined in two lists: (1) acutely hazardous waste, the P list [40 CFR 261.33(e) (ref. 11)] and (2) toxic wastes, the U list [40 CFR 261.33(f) (ref. 12)].

Because of the length of the F, K, P, and U lists and the appendices, they are not included in this report. They are, of course, presented in the Code of Federal Regulations which should regularly be reviewed for changes as they occur by reviewing either the Federal Register or the Environmental Reporter.

2.4 LISTS OF HAZARDOUS WASTES

When considering waste lists, the source lists, F and K, and the discarded chemicals lists, U and P, should be considered first when determining whether a waste is hazardous. Process information alone may quickly provide an answer when these four lists are consulted. "Delisting" of a waste will not be necessary if it is not on one of these waste lists, as specified in 40 CFR 260.20.[13]

The source lists, F and K, have been established on the basis of the specific identity of chemicals listed in Appendix VII of 40 CFR 261.[14] Appendix VII lists the hazardous chemical species of concern in wastes on these lists.

Because of an increasingly greater concern about the toxic, carcinogenic, mutagenic, or teratogenic effects on man of U- and P-listed wastes, greater difficulty can be expected when attempting to delist these wastes. In order for U- or P-listed wastes to be subject to RCRA regulation, the chemicals discarded must be pure and not a constituent of a manufacturing process waste.

In the process of determining whether a waste is hazardous, even if it is not on one of the four lists, the presence of hazardous wastes outlined in Appendix VIII should be ascertained because this is one of the criteria upon which hazardous waste is defined. A complete analysis for all Appendix VIII species is not necessary if an accounting for all raw materials through final product can be made. A prudent oganization would want to know if any constituents listed in Appendix VIII were in the waste because potentially larger liabilities could stem from mismanagement of the waste. This approach could justify selecting only part of Appendix VIII for analysis in a delisting process, as is discussed in 40 CFR 262.11(c).[15]

The EPA is currently reviewing a test protocol, referred to as the Hierarchical Analysis Protocol, for use in analyzing contaminated groundwater. This protocol is designed to screen samples to determine which types of compounds are not present, and, on this basis, to reduce the number of analyses that must be performed for Appendix VIII

constituents. In a proposed ruling dated October 1, 1984, in the Federal Register,[16] method 8600 for the test protocol is suggested for addition to the EPA test manual EPA/SW-846.[17]

Again, it is important to note that the presence of a constituent listed in Appendix VIII does not automatically classify a waste as hazardous but rather indicates that the waste is a candidate to be listed as a hazardous waste. The EPA has allowed room for consideration of other factors in this regard such as the resistance of the waste form to the leaching of the constituents that caused it to be listed, in addition to other hazardous waste characteristics. In effect, the opportunity exists to prove that the waste form is not capable of imposing a present or future risk to health or environment on the assumption that the waste may be mismanaged following disposal.

2.5 DELISTING OF HAZARDOUS WASTES

A waste generated at a particular site may be excluded as a hazardous waste by successfully petitioning the EPA to "delist" the waste. In a delisting petition, the waste generator should provide proof that the waste is not hazardous as a result of the specific manufacturing process used prior to disposal or storage. The EPA has published a guidance manual entitled Petitions to Delist Hazardous Wastes - A Guidance Manual,[18] which is meant to assist in the delisting process; the manual also presents examples of delisting petitions. More specifically, as mandated in 40 CFR 260.22(d):[19]

> A petition to delist a waste deemed hazardous because it contains one of the toxic hazardous waste constituents listed in Appendix VIII must demonstrate: that representative samples of the facility's waste do not contain the toxic constituent identified with that waste or, that consideration of relevant mitigating factors results in a determination that the facility's waste does not pose a substantial present or potential hazard to human health or the environment when improperly managed. The testing protocols outlined in Appendix III to 40 CFR Part 261 must be used to demonstrate absence of a hazardous waste constituent.

A critical and necessary part of any attempt to alter the original nature of a waste such that it can be delisted and rendered nonhazardous may involve immobilizing its potentially hazardous constituents, for example, in a cementitious-type medium. As such, treatment and temporary storage of the waste will be necessary. The topic of solidification and stabilization of waste is discussed in detail in an EPA guidance manual entitled Guide to the Disposal of Chemically Stabilized and Solidified Waste.[20]

The exact regulatory definition of the word "treatment" may pose additional restraints on such an approach to delisting. The addition of a substance such as cement to the waste, if defined as "treatment," may cause the product to be subject to full regulation under RCRA's Treatment, Storage, and Disposal (T/S/D) Facility Regulations.[21] This point requires further clarification by the EPA because, in the preamble to 40 CFR 261 (ref. 2), the EPA suggests that such a process can render nonlisted hazardous wastes that may exhibit EP Toxicity nonhazardous and therefore exempt from hazardous waste regulation. However, wastes that are reclaimed in order to render them less hazardous are exempted from T/S/D regulation. The EPA has not yet clarified the differences between the two terms.

Delisting a waste that may exhibit a hazardous waste characteristic as defined in RCRA Subtitle C[22] requires proof that representative samples do not exhibit this characteristic, as demonstrated by following an EPA-acceptable test protocol, such as detailed in 40 CFR 261, Appendix II (EP Toxicity Test[6]). An alternative test protocol may be used in place of the Appendix II test if, as stated in 40 CFR 261.24,[23] the method is approved by the EPA Regional Administrator.

The EP Toxicity test, outlined in detail in EPA/SW-846,[17] can be used to accomplish two objectives under Subtitle C of RCRA:[22]

1. Test results may serve to prove that a waste host such as a cementitious material is capable of preventing or impeding the leaching of an Appendix VIII constituent that caused it to be hazardous; as such, the waste may be exempted from RCRA regulation if deemed nonhazardous.

2. Results may show that the waste form does not possess the hazardous waste characteristic referred to as EP Toxicity.

The EP Toxicity test procedure is predicated on the assumption that waste will be disposed of in a landfill, together with domestic waste. Such a scenario will include biologically active decomposition of organic matter, resulting in a mildly acidic (pH 5) environment. A major decomposition product of the degradation will be acetic acid. For this reason, acetic acid is used in the laboratory to leach waste forms over a

24-h period at pH 5. The EPA considers it irrelevant that waste is not, in fact, disposed of in a municipal landfill. It is said that the established purpose of the test is to determine whether a solid waste is hazardous.

Because the current regulatory EP Toxicity test does not address the leachability of organics, a new leach test was proposed in the January 14, 1986, Federal Register.[24] The new test, developed for the EPA at ORNL,[25,26] is referred to as the Toxicity Characteristic Leaching Procedure (TCLP) and addresses both inorganic and organic waste constituents.

The proposed TCLP method is different in that the waste form must be crushed prior to leaching. In this test, two different leachants are involved: a pH-5 sodium acetate buffer and a pH-2.9 glacial acetic acid solution. Alkaline waste forms are penalized in that they must be leached in the lower-pH acid solution, depending on the outcome of a preliminary acid consumption test. The TCLP test is much harsher in the authors' opinion, and, as a result, is now highly controversial.

In addition to problems associated with the use of more acid in the TCLP procedure, a grinding step is required prior to testing. The lack of reproducibility from one laboratory to another caused by grinding has resulted in unreliable test results and may be the vulnerable part of this proposed procedure. A final decision as to when the new TCLP will replace the existing EP Toxicity test, and in what form, is expected soon.

In June 1987, EPA representatives from Region IV stated that, because of reproducibility problems with the TCLP, the grinding requirement for

this test will be made more flexible. It is believed that the requirement will be tied to other tests, such as the freeze-thaw or permeability tests, such that grinding would be required if one of these tests is failed.

The leachate solution containing possible contaminants should be analyzed using only EPA-approved methods as outlined in EPA/SW-846.[17] The concentration limits of those constituents identified in the National Primary Drinking Water Standards[27] are referenced, in addition to those in 40 CFR 261, Appendix VIII. Because some degree of groundwater dilution of a leachate would be expected in a disposal site, a dilution factor of 100 has been established so that laboratory test results may more closely simulate site conditions. This means that if a leachate contains 100 times or more than the concentration limits established by the EPA, the waste will be considered to exhibit the characteristic of EP Toxicity and therefore must be handled as a characteristically hazardous material.

For those wastes that are known listed wastes, the delisting process will require that leachates be analyzed for those components on the list (or lists). It is important to note that, for wastes such as these, other hazardous constituents must be identified, and not just those from the waste lists. For example, Appendix VIII components that are also present are deemed cohort hazards and therefore must be addressed in any attempt to delist.

For those wastes that do not contain components from any of the EPA lists mentioned, tests must still be performed for reactivity, corrosivity, ignitability, and EP Toxicity. If, in addition to not being

listed, the wastes do not exhibit any of these four characteristics, the waste is nonhazardous and is therefore not subject to RCRA regulation. In addition, characteristically hazardous waste that has been rendered nonhazardous need not go through any delisting process; however, the treatment process is subject to RCRA permitting.

In addition to pollutants outlined in 40 CFR 261, Appendix VIII, another list exists as a subset of Appendix VIII. This list, referred to as the 129 "priority" pollutants, is geared toward complex industrial effluents.

In 1976, a court decree was entered into by the District Court of the District of Columbia and the EPA and was modified in July 1984. This decree requires the EPA to study the occurrence of 65 categories of pollutants in industrial waste and to issue effluent guidelines based on best-available control technology.

Within these categories, 114 specific organics and 15 inorganic pollutants were identified, for a total of 129 priority pollutants. Recently, three organic pollutants were removed from the list, leaving 126 pollutants. These pollutants, in addition to test procedures for complex industrial wastewaters, were outlined in the Federal Register on October 26, 1984.[28]

2.6 POTENTIAL BENEFITS OF DELISTING

Reliance on the use of engineered barriers, such as synthetic liners, is a basic underlying requirement of the EPA disposal scenario. The sole objective of the use of engineered barriers is to ensure that

waste does not escape the confines of the disposal site. This objective can also be met or enhanced by using another type of engineered barrier such as a specially engineered, solidified waste mass.

The use of a waste solidification process to immobilize various types of waste constituents is not a new concept. Its value is alluded to in various places throughout many regulatory documents governing the disposal of waste. A few of the potential legal and economic benefits resulting from the use of such an immobilization process, as specifically referenced in the regulations and other documents, will now be considered.

Waste that has been delisted and rendered nonhazardous falls under the control of RCRA Subtitle D,[29] regulation for nonhazardous waste, as outlined in 40 CFR 256,[30] and 40 CFR 257,[31] and may also be subject to state regulation. The attainment of the delisted, nonhazardous waste classification may be achieved as a result of using an engineered, solidified waste form. Waste classified as nonhazardous under Subtitle D may be disposed of without using liners or leachate collection systems, as stated in 40 CFR 264.301(b).[32] Some states, however, are said to require various kinds of liners by state law.

Basically, the EPA states that a liner and leachate collection system are not required for existing portions of landfills or if operators can demonstrate that waste constituents will never migrate out of the landfill into surface water or groundwater. The exact wording used by the EPA in 40 CFR 264.301(b) (ref. 32) regarding this exemption is as follows:

> The owner or operator will be exempted from the requirements of paragraph (b) of this section if the Regional Administrator finds, based on a demonstration by the owner or operator, that

> alternative design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituents into the ground water or surface water at any future time. In deciding whether to grant an exemption, the Regional Administrator will consider:
>
> (1) The nature and quantity of the wastes;
>
> (2) All other factors which would influence the quality and mobility of the leachate produced and the potential for it to migrate to ground water or surface water.

Although engineered barriers such as synthetic liners are meant to control the release of radionuclides or other hazardous constituents over a long period of time, a draft technical position report[33] written for the NRC by Brookhaven National Laboratory researchers clearly adds, "the applicant will need to demonstrate substantial contributions by the waste package unless it can be shown that the underground facility alone can meet the controlled release requirement."

In addition to possible exemption from the use of liners, nonhazardous Subtitle D waste also is not subject to U.S. Department of Transportation (DOT) regulations as outlined in 40 CFR 4,[34] unless any radioactivity associated with a chemical waste exceeds DOT limits.

The DOT defines hazardous waste in the same way as the EPA does in 40 CFR 261.3;[35] it similarly defines hazardous waste in 49 CFR 171.8.[36] In addition, RCRA requires that the EPA's regulations must be consistent with the DOT regulations under the Hazardous Materials Transportation Act.

Waste that has been solidified and proved not to be hazardous according to EPA's RCRA Subtitle C[22] regulations can therefore be transported between sites at a much lower cost. Additionally, EPA

requires that hazardous waste cannot be stored on-site beyond 90 days without obtaining a T/S/D permit; this requirement would not apply if a waste were rendered nonhazardous.

The radioactivity associated with such waste must meet two general limits as set forth in 40 CFR 173.44 (ref. 37) in order to be exempted by DOT, even if EPA tests prove it to be nonhazardous:

1. The waste must contain <0.002 μCi of radioactivity per gram of material transported.
2. The surface activity must not exceed 200 mrem/h at the external surface of the waste package and must be no greater than 10 mrem/h at 2 m from the surface of the transport vehicle.

In addition to exemptions from transportation regulations, with nonhazardous waste there is an opportunity to have the initially established point of compliance for groundwater monitoring further from the waste. This potential change is addressed by the EPA in 40 CFR 257.3-4 (ref. 38) for nonhazardous waste in reference to possible violations of established compliance points. The EPA has stated that an alternative boundary shall be established if it can be demonstrated that such a change will not result in contamination of groundwater used for human consumption.

Other regulatory agencies, such as the NRC, recognize and place a greater emphasis on the physical characteristics of the waste form and

desired performance objectives germane to these characteristics (see Sect. 4). With this recognition, perhaps a fundamental axiom will evolve which requires that waste package reliability be compatible with the perceived or known reliability of the repository system as a whole.

2.7 GROUNDWATER PERFORMANCE OBJECTIVES

Maximum concentrations of inorganic and organic constituents present in either drinking water or, to a more limited extent, a potential addition to this water, such as a disposal waste leachate, are specified by the EPA. Relating drinking water standards to concentrations of chemical constituents in leachate is highly problematic, for the limits of only a very few species, such as the EP Toxicity test species, are addressed. The problem is that many other species, such as nitrate sulfate or chloride, have no fixed concentration limits or dilution factor in the leachate. The National Primary Drinking Water Standards [40 CFR 141.11-14 (ref. 27)] and the Secondary Drinking Water Standards [40 CFR 143.3 (ref. 39)] promulgated under the Safe Drinking Water Act of 1974, address water standards using tabulated limits and are presented in Tables 1 and 2, respectively. The primary standards are federally enforceable limits for public water systems and for hazardous waste sites, while the secondary standards carry less weight in a regulatory sense.

The concentration limits in Tables 1 and 2 are guidelines that may actually be changed by state agencies. Establishment of alternative limits will depend on local conditions, such as the availability of alternative sources of water or other factors.

The "table limits" established by the EPA will depend, in some cases, on the established background concentrations of the constituents at

Table 1. National primary drinking water standards

Parameter	Maximum concentration (mg/L) or level
Arsenic[a]	0.05
Barium[a]	1.0
Cadmium[a]	0.01
Chromium[a]	0.05
Fluoride	4.0
Lead[a]	0.05
Mercury[a]	0.002
Nitrate[b] (as N)	10.0
Selenium[a]	0.01
Silver[a]	0.05
Endrin[a]	0.0002
Lindane[a]	0.004
Methoxychlor[a]	0.1
Toxaphene[a]	0.005
2,4-D (2,4-Dichlorophenoxyacetic acid)[a]	0.1
2,4,5-Tp Silvex (2,4,5-Trichlorophenoxypropionic acid)[a]	0.01
Radium	5 pCi/L
Gross alpha	15 pCi/L
Gross beta	4 mrem/year
Turbidity	1/turbidity unit
Coliform bacteria	1/100 mL

[a]The EP Toxicity test establishes limits for these species; the limits are 100 times the concentrations presented.

[b]At the discretion of the state, levels may be lowered to 4.5 mg/L as monatomic nitrogen or 20 mg/L as nitrate.

Source: 40 CFR 141.11-14 (July 1, 1987) and also see proposed update in Fed. Regist. 52, (130), July 8, 1987.

Table 2. National secondary drinking water standards

Parameter	Maximum concentration (mg/L) or level
Chloride	250
Color	15 color units
Copper	1
Corrosivity	Noncorrosive
Fluoride	2
Foaming agents	0.5
Iron	0.3
Manganese	0.05
Odor	3 threshold odor number
pH	6.5-8.5
Sulfate	250
Total dissolved solids	500
Zinc	5

Source: 40 CFR 143.3 (July 1, 1987).

a specific site. Generally, if the background level in the groundwater exceeds a table limit at the time a permit is issued for a facility, then the background concentration would become the upper limit; otherwise, the table limits apply, as stated in 40 CFR 264.94.[40]

Sampling wells must be used to establish water quality prior to permitting, using at least three wells installed hydraulically down-gradient at the limit of the waste management area and one upgradient. The upgradient well serves to establish the groundwater background levels on a statistical basis.

The point of compliance for the enforcement of the drinking water standards is addressed in 40 CFR 264.95 (ref. 41) and is said to be the "vertical surface located at the hydraulically down-gradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated units." The waste management area is the limit projected in the horizontal plane of the disposal area; this includes the space taken up by a liner, barrier, or dike.

When several regulated units are located in close proximity, the imaginary line circumscribing all the units describes the management area. The Regional Administrator for the EPA may establish the point of compliance for a specific site by establishing a maximum distance from the surface of the waste; such a decision will be based primarily on the water table and local hydrology. A limit on the distance to the point of compliance would apply only to hazardous chemical RCRA waste disposal sites. In the case of nonhazardous waste sites, the point of compliance may be further from the disposed waste.

In recently proposed rulings, the EPA is proposing a site-specific methodology for outlining the point of compliance and a means to back-calculate acceptable leachate concentrations. The proposed rules are in the January 14, 1986, Federal Register.[24] The methodology would take into account complex geohydrological characteristics of the waste site using various screening procedures and disposal scenarios. The proposed screening procedure is best described by the following quote from page 1623 of the referenced Federal Register:

> The groundwater and surface water screening procedures use concentration-based rate and transport models that start from a potential point of human exposure at a concentration deemed to be protective of human health or the environment and back calculate the constituent concentration in a leachate immediately beneath or adjacent to the land disposal unit that will ensure that the specified protective level is not exceeded at the point of potential exposure. In those cases where EPA specifies the treatment standard as a leach concentration, a new extraction procedure will be used to determine if an extract from a waste exceeds the specified level. Use of an extraction, or leaching, procedure provides a mechanism for accounting for the entire spectrum of physical forms of a waste. Accordingly, the use of the extraction procedure allows recognition of the fact that physical form (i.e., the waste matrix) will influence the leachability of constituents in the waste.

The EPA mandates that hazardous waste disposal sites must have a liner installed to prevent any migration of waste from the landfill site. In addition, a leachate collection system must also be provided. The design and operating requirements for such a liner-leachate collection system are outlined in 40 CFR 264.301.[42] When relying on a single liner, a continuous groundwater monitoring system must be installed to show that groundwater is not contaminated at or past the point of compliance.

An exemption from installing an expensive groundwater monitoring system is described in 40 CFR 264.302,[43] which states that the requirement to monitor groundwater will be waived when a double liner is used in conjunction with a leachate collection system and when a leak detection system is installed between the liners.

For wastes that have been processed and stabilized, thereby resulting in reclassification as nonhazardous because of their ability to retain potentially hazardous constituents, no liner or leachate collection system is required. This has been provided for by the EPA through its delisting procedures and right to petition for delisting status, as previously described.

The drinking water standards presented in Tables 1 and 2 establish limits for some organic and inorganic species in addition to limits on contained gross radioactivity. Permissible limits for concentrations of radionuclides in drinking water are addressed by the EPA in 40 CFR 141.15.[44] The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water must not produce an annual dose equivalent to a total body or any internal organ dose greater than 4 mrem/year. Except for tritium and ^{90}Sr, the concentration of radionuclides resulting in such a dose must be calculated on the basis of a 2-L/d drinking water intake, as described in the amended version of NBS Handbook 69.[45]

For other radionuclides such as long-lived alpha-emitting species, as may be found in some high-level wastes, potential releases over a period

of 10,000 years must be considered for disposal systems and engineered wastes. This period is used by the EPA to establish the basis for determining the adequacy of repository performance and may be applicable for this purpose with low-level waste, as is described in ruling 40 CFR 191,[46] finalized in 1985. In addition, 40 CFR 192,[47] dealing with uranium mill tailings, sets 200 to 1000 years as a period of compliance. Environmental radiation protection standards for low-level radioactive waste disposal are still pending and are referenced in the form of an advance notice in 40 CFR 193.[48]

Test methods designed for evaluating radioactive waste and its contained radionuclides, when considering leachability and groundwater contamination potential, are also not yet available from the EPA. Space has been reserved in Appendix IV of 40 CFR 261 (ref. 2) for these test methods. It is expected that, as a result of a recent Memorandum of Understanding[49] between the EPA and DOE, joint efforts to establish guidelines for mixed hazardous waste will delineate some of these methods.

Samples of waste subjected to EPA-approved test methods must be representative in order to be considered "demonstration samples" and must consist of a minimum of four samples taken over a period of time indicative of waste or process variability. Originally, the EPA mandated that samples must represent statistical equivalence, but EPA now requires that a representative sample exhibit the average properties of the universe, or whole.

A specific sampling method has been outlined in EPA/SW-846.[17] The method, called "Pond Sampler," is designed for use when sampling ponds,

tanks, lagoons, and pits and may be extended to sampling process streams. The EPA has made it clear that samples obtained using these methods will be considered representative of the waste.

Special requirements have been established in 40 CFR 264.314 (ref. 50) for bulk or noncontainerized liquid waste or solid waste containing free liquid. This waste is not considered acceptable for placement in a landfill unless either of two conditions are met:

1. the landfill must have an approved liner, leachate collection system, and removal system in place, or
2. the liquid waste or the associated liquid is treated or stabilized using either a chemical or physical method such that no free liquid is present (in the latter case, absorbents may be used).

Similarly, in the case of containerized waste, no liquid can be present; it must be decanted, absorbed, or solidified so that it is no longer observed in the container. Exemptions exist for such items as small samples, lab packs, or battery-type equipment.

Unlike the NRC and DOE, the EPA has not specified limits for such parameters as minimum compressive strength or the maximum quantity of chelating agents permitted in a waste form. They have instead addressed these topics in an indirect manner, with the intent that results of tests already discussed will reflect these concerns.

This approach is exemplified in the impact test used to precede the EP Toxicity leach test. The impact test described in EPA/SW-846 (ref. 17) has no established criterion for pass or fail; however, the resulting enhanced leachability of the solid waste due to excessive breakage and surface area increase may reflect the physical durability of the waste. The newly proposed TCLP leaching procedure would eliminate the impact test and require that the waste form be crushed to pass a 9.5-mm screen.

Other tests are being reviewed for incorporation into delisting programs and test manual EPA/SW-846.[17] A multiple extraction procedure, referred to as method 1320, is being proposed by EPA specifically for stabilized or chemically fixed hazardous waste. This method is reportedly used by many waste treatment companies and may be incorporated into the EPA manual.

2.8 REFERENCES

1. Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901, et seg., 1976.
2. 40 CFR 261.
3. Ref. 2, Subpart C.
4. Ref. 1, Sect. 3001.
5. Ref. 2, Appendix VIII.
6. Ref. 2, Appendix II.
7. Ref. 2, Sect. 24, Table 1.

8. Ref. 2, Subpart D.

9. Ref. 2, Sect. 31.

10. Ref. 2, Sect. 32.

11. Ref. 2, Sect. 33(e).

12. Ref. 2, Sect. 33(f).

13. 40 CFR 260.20.

14. Ref. 2, Appendix VII.

15. 40 CFR 262.11(c).

16. "Method 8600," Fed. Regist. (Oct. 1, 1984).

17. U.S. Environmental Protection Agency, Test Methods for Evaluating Solid Waste - Physical/Chemical Methods, EPA/SW-846, 2nd ed., 1982.

18. U.S. Environmental Protection Agency, Petitions to Delist Hazardous Wastes - A Guidance Manual, EPA/530-SW-003, April 1985; or NTIS PB85-194488, as referenced in 50 CFR 21607.

19. 40 CFR 260.22(d).

20. U.S. Environmental Protection Agency, Guide to the Disposal of Chemically Stabilized and Solidified Waste, EPA/SW-872, rev. ed., September 1982.

21. Ref. 1, Subtitle C, Sect. 3004.

22. Ref. 1, Subtitle C.

23. Ref. 2, Section 24.

24. "Toxicity Characteristics Leaching Procedure," Proposed Rules, Fed. Regist. 51, (9), (1986).

25. M. P. Maskarinec, C.W. Francis, and J. C. Goyert, Mobility of Toxic Compounds from Hazardous Waste, ORNL/TM-6044, August 1984.

26. C. W. Francis and M. P. Maskarinec, Field and Laboratory Studies in Support of a Hazardous Waste Extraction Test, ORNL/TM-6247, February 1986.

27. 40 CFR 141.11-14.

28. 40 CFR 136.

29. Ref. 1, Subtitle D.

30. 40 CFR 256.

31. 40 CFR 257.

32. 40 CFR 264.301(b).

33. C. Sastre and C. Pescatore, Draft Technical Position on Waste Package Reliability, NUREG-0997R (Draft), prepared by Brookhaven National Laboratory, November 1983.

34. 40 CFR 4.

35. Ref. 2, Sect. 3.

36. 40 CFR 171.8.

37. 40 CFR 173.44.

38. Ref. 31, Sects. 3-4.

39. 40 CFR 143.3.

40. 40 CFR 264.94.

41. 40 CFR 264.95.

42. 40 CFR 264.301.

43. 40 CFR 264.302.

44. 40 CFR 141.15.

45. NBS Handbook 69, U.S. Department of Commerce, Amended August 1963.

46. 40 CFR 191.

47. 40 CFR 192.

48. 40 CFR 193.

49. Memorandum of Understanding, EPA-DOE.

50. 40 CFR 264.314.

3. DOE REGULATIONS RELEVANT TO LABORATORY TESTING AND WASTE FORM PERFORMANCE CRITERIA

3.1 REGULATORY BACKGROUND

DOE has established guidelines for shallow-land burial of low-level radioactive wastes generated by operation of its facilities. In doing so, DOE has adopted a site-specific approach to waste disposal and site performance requirements. All DOE operations must develop an acceptable waste disposal plan that meets the objective put forth in the DOE Order 5820 Guidance Document.[1] The stated objective of the nuclear waste disposal program is "to isolate the waste in a manner that protects the health and safety of the public and the environment."

In fulfilling this objective, DOE requires that the waste and the waste disposal site comply with all national environmental laws and resolutions. State laws and ordinances may establish additional limits of compliance which also must be met by the DOE facility, assuming the legality of jurisdiction has been established. The DOE has taken the position outlined in DOE Order 5480.2,[2] that its operations conducted under authority other than the Atomic Energy Act of 1954 (ref. 3) are subject to the EPA or state regulation pursuant to RCRA.[4]

Because some hazardous and radioactive wastes may contain material deemed classified, for the sake of national security, a Memorandum of Understanding[5] between DOE and the EPA has been issued. In this document, the regulatory standards, definitions, and areas of compliance have been outlined to protect both the public health and information that could possibly compromise national security.

The DOE embraces the concept of maintaining doses of radioactivity for the maximum exposed member of the public "as low as reasonably achievable" (ALARA) in accordance with DOE Order 5480.1A.[6] The concept of ALARA is applicable at all sites, regardless of future regulatory changes. In addition, DOE requires the operator of a disposal site to maintain the quality of existing operations through a comprehensive quality assurance program and an ongoing awareness of developing technology regarding technical and economical improvements, in compliance with the ALARA concept.

The overall focus of waste disposal guidance by DOE, EPA, and NRC seems to be converging on equivalent regulations; this has become evident most recently with the passage of the NRC 10 CFR Part 61,[7] DOE Order 5820,[8] and EPA 40 CFR 193;[9] the latter is still in rulemaking. With the advent of EPA and RCRA control being relinquished to state judicial bodies, equivalent requirements from federal agencies are becoming a necessity.

3.2 WASTE CLASSIFICATION

When classifying low-level radioactive waste, DOE recognizes the established NRC approach of classifying waste as either Class A, B, or C

as an acceptable method. Although the NRC classification method is not binding on DOE, it is recognized that established site performance objectives can be met utilizing this method.

DOE has a proposed methodology of its own for classification [DOE/LLW-14T, Dec. 1982 (ref. 10)] based on a waste's total hazard, as opposed to the NRC method of classifying only the relative concentrations of long- and short-lived radionuclides. The proposed DOE classification method considers both hazardous chemicals and radiotoxic constituents in low-level radioactive waste.

In the proposed method, a unitless number, referred to as the waste classification index (WCI), is used to classify low-level mixed wastes. The method considers the ratio of potential whole-body radiation or chemical exposure to some selected limit; the nature, amount of toxic material present, availability to humans, and decay products are considered in the analysis. Based on these considerations, the calculated waste classification index is part of a relative scale comparing the hazards of mixed hazardous and radiological wastes to man and the environment.

A hazard index is assigned to each toxic species, with the sum over all species considered equal to the waste classification index. The hazard index is computed from the concentrations of the toxic material and three unitless factors: persistence through time, a waste container factor, and a waste form factor. These unitless factors are used to calculate what is called the effective concentration for each potentially toxic material.

Considering the availability of each species to man in the biosphere and all the relevant pathways resulting in exposure, the hazard index for each species is then calculated.

It is the waste form factor which laboratory leach test work endeavors to establish; this factor expresses the maximum quantity of a radionuclide or chemical that can be expected to leach from a waste form. The factor is expressed as a percentage of the total amount of a species available to leach on a yearly basis. The factor represents the fractional release resulting from ideally assumed diffusional mass transport in a semi-infinite medium, with a uniform initial concentration and no solution concentration gradients.

This method of classification of low-level radioactive, mixed hazardous waste is a first attempt at considering the total hazard of waste to establish a more comprehensive waste disposal program. This method has been established as a tool to aid in managerial decisions as to how to group and classify such waste.

3.3 GROUNDWATER PERFORMANCE OBJECTIVES

The discharge of radionuclides to the environment must be maintained according to the ALARA concept as stated in DOE Order 5480.1A.[6] In this document, DOE requires that a dose limit of 500 mR/year be considered the maximum limit of exposure for a member of the public while at the same time enforcing the ALARA concept.

Because 90% of low-level radioactive waste considered for shallow-land disposal will decay within 100 years to levels that are considered safe in the environment, DOE anticipates that active control to prevent

human intrusion at a site should be maintained for at least 100 years. During the active control period, concentrations of radionuclides released to the environment must not exceed the limits established for gross radioactivity established by EPA in the National Interim Primary Drinking Water Standards[11] (see Table 1), as well as those for a lengthy list of radionuclides tabulated in the DOE Order 5480.1A Chapter XI attachment.[12]

Specific concentration limits for radionuclides in both air and water are presented in the DOE Order 5480.1A Chapter XI attachment.[12] In these tables, nuclides for both controlled and uncontrolled areas, as well as soluble and insoluble species, are presented. This comprehensive table of concentration limits, which was established under the U.S. Atomic Energy Commission and adopted by DOE, was revised in 1986.

For groundwater contaminated by a mixture of radionuclides, it is required that the concentration of the individual species be divided by their respective table limits and that the sum of all the resulting fractions be less than or equal to unity. The use of this sum-of-fractions calculation is explained at the end of the Chapter XI table attached to DOE Order 5480.1A.[12]

For those radionuclides which may be present in extremely low concentrations, DOE has established a "not present" clause. For this special case, a radionuclide may be considered "not present" if its ratio, based on its limit, is less than or equal to one-tenth; this applies only when the sum of all the ratios of the "not present" nuclides is less than or equal to one-fourth. When neither the concentration nor the identity of a radionuclide is known, guide values of 3×10^{-8} μCi/mL

for uncontrolled areas and 4×10^{-7} μCi/mL for controlled areas are used.

The point of compliance for the uncontrolled area limits is considered the site boundary. Radionuclides are required to have a sufficient amount of time to attenuate to regulatory limits before reaching the boundary.

The site boundary is to be established in accordance with a pathways analysis wherein all potential means of transport of radionuclides from the waste source are considered. DOE suggests that a three-dimensional buffer zone be established, with its smallest dimension capable of allowing enough time for attenuation of radioactivity to acceptable levels if migration occurs.

The site boundary is therefore established on a site-specific basis, with the pathway having the smallest dimension establishing the outer site boundary. This site-specific approach considers the possible pathways (e.g., groundwater, surface water, wind, as well as the activities of man) through which radionuclides can migrate through the environment. Such an approach allows greater flexibility to accept a broader range of waste at those sites with superior natural site characteristics, while also considering the advantages provided by stabilized waste forms.

This point of compliance criterion established for the site boundary also applies to the enforcement of all EPA drinking water quality standards, although recently the EPA was reported to be considering a numerical limit for the maximum-distance limit from the surface of the waste to the site boundary, particularly if the waste is deemed hazardous.

Such a numerical limit for the point of compliance, if enforced, will diminish, and in some cases eliminate, the value of a site-specific approach to establishing site boundaries.

DOE has addressed drinking water quality by stating that all applicable EPA, NRC, and other national air and water regulations must be complied with in accordance with Executive Order 12088,[13] a presidential order requiring federal compliance with pollution control standards. In addition, compliance with both state and local pollution control standards is also required.

3.4 WASTE FORM REQUIREMENTS AND CHARACTERISTICS

Requirements and desired waste form characteristics are generally discussed in Chapter III of DOE Order 5820 (ref. 14) and more specifically in the Draft Guidance Document[1] for this order and chapter. The waste acceptance criteria outlined in the guidance document for waste forms are as follows:

1. The maximum permissible concentrations of radionuclides must not exceed the limits of the DOE-approved classification system. Assessment of the retention characteristics of the waste form may be used to aid in establishing the maximum limits.
2. The geometry of the waste form should be such that criticality safety is maintained, especially when ^{235}U is a major component of the low-level waste.
3. Radiative or thermal energy output from the waste form should not jeopardize site performance objectives.

4. The waste form should not be capable of generating quantities of gases, vapors, or liquids which could jeopardize site performance objectives.
5. For radioactive waste containing potentially hazardous chemicals, the following objectives should be met:

   A. Contained pyrophoric material should be treated and/or packaged so as to be rendered nonpyrophoric.

   B. Contained flammable material should be treated and/or packaged so as to be rendered nonflammable.

   C. Contained corrosive materials should be neutralized and/or packaged so as to be rendered noncorrosive.
6. The waste form and/or package should be structurally stable enough not to jeopardize site performance objectives by withstanding normal compressive loads encountered during handling, shipping, and stacking of waste packages.
7. Standardized, reproducible tests that simulate expected disposal site conditions should be used to assess waste form and/or package performance.
8. Low-level gaseous waste should be packaged at a pressure that will not jeopardize container integrity or performance objectives.
9. Waste containing chelating agents, organic liquids, or metabolic products from microbial activity should be stabilized prior to disposal. Additionally, wastes containing quantities of these agents that could jeopardize site performance objectives should not be accepted unless their concentrations can be reduced.

10. Low-level waste should be in a dry, solid form and should contain no more than 0.5% by volume or 1 gal of free liquid per container, whichever is less, of noncorrosive liquid. Locally, however, DOE has mandated that no free-standing liquid is permitted with such waste at the ORNL site.

The above guidance for waste form acceptance is similar to many of the NRC's waste form requirements but is much less specific regarding numerical limits for such parameters as waste form compressive strength. Instead, DOE refers to expected performance objectives in the context of compliance with the ALARA concept and site performance objectives.

DOE recognizes the advantages of incorporating a waste into an improved waste form to decrease leachability. This is especially applicable to waste referred to as "greater confinement waste," which is composed of powders or particulates that may pose a greater risk of exposure during staging, transport, handling, and disposal.

As stated in Chapter 3.1 of the draft guidance document for DOE Order 5820,[15] "a waste form with superior retention characteristics will permit the acceptance of stabilized packages with higher concentrations of radionuclides compared with unstabilized waste." The retention characteristics are to be determined by fractional release rates and/or container lifetime according to the requirement of performing standardized, reproducible tests on the waste form or package. DOE has not ordered use of a specific leach test for this purpose; however, the MCC-1P static leach test method[16] developed by the Material Characterization Center is expected to be its future choice.

3.5 REFERENCES

1. "Management of Low-Level Waste," Chap. III in Draft Guidance Document for DOE Order 5820, March 1984.
2. "Hazardous and Radioactive Mixed Waste Management," DOE Order 5480.2, Dec. 13, 1982.
3. Atomic Energy Act of 1954, 42 U.S.C. 2011, et seq., 1954.
4. Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901, et seq., 1976.
5. Memorandum of Understanding Between the U.S. Department of Energy and the U.S. Environmental Protection Agency for Hazardous Waste and Radioactive Mixed Waste Management, Feb. 22, 1984.
6. "Environmental Protection, Safety, and Health Protection Program for DOE Operations," DOE Order 5480.1A, Aug. 13, 1981.
7. 10 CFR 61.
8. "Final Version of DOE Order 5820, Radioactive Waste Management," DOE Order 5820, Dec. 1983.
9. 40 CFR 193.
10. Waste Classification, A Proposed Methodology for Classifying Low-Level Radioactive Waste, DOE/LLW-14T, Dec. 1982.
11. 40 CFR 141.11.
12. Ref. 6, Chap. XI.
13. "Federal Compliance With Pollution Control Standards," Executive Order 12088, Fed. Regist. 43 (201), Oct. 17, 1978.
14. Ref. 8, Chap. III.

15. Ref. 1, Chap. 3.1.

16. MCC-1P Static Leach Test Method, Draft, MRB-0326, Materials Characterization Center, Richland, Wash., May 1984.

4. NRC REGULATIONS RELEVANT TO LABORATORY TESTING AND WASTE FORM PERFORMANCE CRITERIA

4.1 REGULATORY BACKGROUND

The NRC has issued regulations pertaining to the land disposal and licensing of low-level radioactive waste and disposal facilities. These regulations were published in the Federal Register dated December 27, 1982, and coded as 10 CFR 61.[1] In addition, a technical position paper on waste forms, 10 CFR 61.56,[2] dated May 1983 provides guidance regarding test methods and acceptable results for implementing the 10 CFR 61 waste form requirements. Although these regulations are very broad, covering topics such as siting, design, operations, and closure activities, only those regulations pertaining to the waste form itself are reviewed here.

4.2 WASTE CLASSIFICATION

Low-level radioactive wastes are classified by the NRC on the basis of the concentration of either long- or short-lived radionuclides or a combination of both when present as mixtures. For this purpose, the NRC has provided two tables in 10 CFR 61.55:[3] Table 1 for long-lived radionuclides of concern and Table 2 for short-lived nuclides.

The NRC has mandated that, when measuring the concentrations of radionuclides, their activity should be averaged over the volume of the waste form or the weight if the units are expressed on an activity-per-

unit-weight basis as nanocuries per gram. The NRC believes that trace radionuclides contained in most solidified waste forms should be homogeneously distributed and incidental to the total activity and, therefore, that averaging over the waste form volume or mass will be representative.

For this reason, the NRC considers most waste streams to be homogeneous for the purpose of classification. For containerized waste, the volume used for waste classification will be the volume of the container itself, that is, only if the volume of the container is not >10% larger than the waste volume itself.

When considering containerized-absorbed liquids, classification is based on the volume and mass of the liquids prior to absorption. Absorbed liquid is not, however, classified in the same way as is solidified liquid when using, for example, cement or bitumen as a binder. For a liquid, slurry, or even a solid part such as a filter, once fixed in such a medium, the volume of the resulting solidified waste mass is used in the calculation of the activity per unit volume for the purpose of classification.

The NRC classifies low-level radioactive wastes as either Class A, B, or C on the basis of the content of specific radionuclides and their measured concentrations in the waste. Two tables of radionuclides are presented in 10 CFR 61.55 (ref. 3) for this purpose (see Tables 3 and 4). These classes are not related in any way to the Department of Transportation designations of Class A, B, and C assigned to different types of materials during transport.

Table 3. NRC radionuclide concentrations used to classify low-level radioactive wastes: long-lived radionuclides

Long-lived radionuclides	Concentration (Ci/m^3)
^{14}C	8
^{14}C in activated metal	80
^{59}Ni in activated metal	220
^{94}Nb in activated metal	0.2
^{99}Tc	3
^{129}I	0.08
Alpha-emitting transuranic nuclides with a half-life greater than five years	100[a]
^{241}Pu	3,500[a]
^{242}Cm	20,000[a]

[a]Units are nanocuries per gram.
Source: 10 CFR 61.55, Table 1.[4]

Table 4. NRC radionuclide concentrations used to classify low-level radioactive wastes: short-lived radionuclides

Short-lived radionuclides	Concentration (Ci/m^3) Col. 1	Col. 2	Col. 3
Total of all nuclides with <5-year half-life	700	a	a
^{3}H	40	a	a
^{60}Co	700	a	a
^{63}Ni	3.5	70	700
^{63}Ni in activated metal	35	700	7000
^{90}Sr	0.04	150	7000
^{137}Cs	1	44	4600

[a]There are no limits established for these radionuclides in Class B or C. Practical considerations, such as the effects of external radiation and internal heat generation on transportation, handling, and disposal, will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 4 determine the waste to be Class C independent of these nuclides.

Source: 10 CFR 61.55, Table 2.[5]

For the purpose of classification, the long-lived radionuclides are considered first, for they pose the greatest potential hazard because of their lengthy persistence in the environment following disposal. Short-lived radionuclides are considered only if the long-lived nuclides fail to resolve the waste class based solely on their presence, in accordance with the tabulated limits in Tables 3 and 4 for long- and short-lived radionuclides, respectively.

The columns in each table are considered separately and independently of each other when determining the waste class. Table 3 contains only one column of limits for long-lived nuclides but can be considered also to include a second column equal to one-tenth of the listed limits in this table. In general, classification is determined by considering the concentration of radionuclides in each column and then moving to the next as the total column concentration limit is exceeded.

When a mixture of radionuclides from either table alone or from both tables is present, a sum-of-the-fractions rule is applied separately from column to column within the tables to determine the total concentration. This is applied by dividing each radionuclide's concentration by the appropriate table limit and then adding the resulting fractions. Only one column in each table can be used during this determination. The waste class will be determined by the column that yields a sum that is less than or equal to 1.0; otherwise, the next column must be considered.

A description of the use of the Tables 3 and 4 for waste classification, when considering waste containing radioelements from

Table 3, Table 4, or a mixture from both tables, will now be considered. Waste containing only radionuclides that are not listed in either table is automatically Class A.

4.2.1 Table 3--Waste Containing Long-Lived Radionuclides Only

If, for a single radionuclide, the concentration does not exceed 0.1 times the listed value in Table 3, the waste is Class A. If the concentration exceeds 0.1 times the value in Table 3 but does not exceed the Table 3 limit, the waste is Class C. When the concentration exceeds the Table 3 value, the waste is not suitable for shallow-land disposal. If more than one Table 3 radionuclide is present, the total concentration shall be determined by the sum-of-fraction rule previously described, with the resulting sum used to judge whether to proceed to the next column or table or to render the waste unsuitable for shallow-land burial.

4.2.2 Table 4--Waste Containing Short-Lived Radionuclides Only

For those wastes that contain only Table 4 radionuclides, this table is used to determine the waste class. If, for a single radionuclide from Table 4, the concentration does not exceed the value in Column 1, the waste is Class A. If, however, the concentration exceeds the Column 1 limit but does not exceed the limiting value in Column 2, the waste is Class B.

Using this same reasoning, when the concentration exceeds the Column 2 limit but does not exceed the Column 3 limit, the waste would be Class C. Exceeding the Column 3 limit automatically causes a waste to be classed as unsuitable for shallow-land burial.

For wastes containing mixtures of Table 4 radionuclides only, the sum-of-fractions rule must again be applied within a column to determine the total concentration. In addition to the tables' limits, the application of this rule becomes a second necessary qualifier for each column when more than one radionuclide is considered.

4.2.3 Mixture of Long- and Short-Lived Radionuclides

When radionuclides are present in a waste from both tables, the Table 3 nuclides must be considered first because of their greater potential hazard. If the concentration of a nuclide listed in Table 3 does not exceed 0.1 times the value listed in this table, the class shall be determined by the Table 4 radionuclides.

When the concentration of a nuclide listed in Table 3 exceeds 0.1 times the table limit but does not exceed the Table 3 limit, the waste is Class C, that is, provided the concentration of any nuclide present from Table 4 does not exceed the Column 3 limit.

4.3 MIXED CHEMICAL AND RADIOLOGICAL WASTE

Classification of waste based on both its chemical and radiological composition is not directly addressed by the NRC. The NRC does state that classification by total hazard would make good sense but is not currently technically feasible. The Commission instead attempts to identify licensees who generate these mixed hazardous wastes according to EPA regulations on a case-by-case basis. In this regard, the NRC explicitly defines "hazardous waste" to mean waste deemed as such by the EPA according to 40 CFR 261.[6]

4.4 RADIOLOGICAL DESCRIPTION OF LOW-LEVEL RADIOACTIVE WASTE

The NRC requires in 10 CFR 20.311 (ref. 7) that waste possess a radiological description for both manifesting and classification. Two general requirements have been established: (1) the radionuclide identities and quantities should be listed and (2) the total radioactivity must be known.

A specific requirement of the description is that the isotopes ^{3}H, ^{14}C, ^{99}Tc, and ^{129}I be quantified and listed because of their known high degree of mobility. These specific isotopes, in addition to others, need not be identified if, as a result of knowledge or control of the waste source, they can be shown to be absent from a given waste stream.

Three criteria have been established to aid in determining which specific radionuclide concentrations in low-level radioactive waste should be considered:

1. any radionuclide specifically required to be listed by 10 CFR 20.311 (ref. 7) [specific isotopes listed above] or by license conditions,

2. any radionuclide which is listed in 10 CFR 61.55 (ref. 3) [i.e., Tables 1 (ref. 4) and 2 (ref. 5) for long- and short-lived radionuclides] and which forms a significant part of the total activity that determines the waste class, and
3. radionuclides that are contained in "significant" quantities.

Radionuclides listed in Tables 1 (ref. 4) and 2 (ref. 5) of 10 CFR 61.55 (ref. 3) are considered "significant" for purposes of classification if their concentration is >0.01 times the concentration of that nuclide listed

in Table 1 or 0.01 times the smallest concentration of that nuclide listed in Table 2, provided the isotope has a half-life of >5 years.

For isotopes having half-lives of <5 years, the concentration is considered "significant" for the purpose of classification if its concentration is >7 $\mu Ci/cm^3$ (0.01 times the value in 10 CFR 61.55, Table 2, Column 1). Isotopes not listed in either Table 1 or Table 2 of 10 CFR 61.55 should also be identified and quantified if present in a concentration of >7 $\mu Ci/cm^3$. In addition to isotopes, the presence of source or special nuclear material in the waste must also be established and reported.

The NRC has taken a flexible position when considering the inherent difficulties associated with the measurement of radionuclides contained in waste for the purpose of proper classification. The NRC considers concentrations within a factor of 10 a reasonable target for accuracy when it can be demonstrated that a reasonable effort has been made to ascertain such concentrations in a consistent and realistic manner.

Although licensees are required by the NRC to comply with the requirement for a valid and acceptable classification procedure, four basic methods may be used individually or in combination. The method or methods chosen will be specific to each particular facility and must be acceptable to the NRC regulatory staff. The four basic methods that may be considered for use are as follows:

1. classification by materials accountability,
2. classification by source,
3. classification by gross radioactivity, or
4. classification by direct measurement of individual radionuclides.

4.5 WASTE FORM REQUIREMENTS AND CHARACTERISTICS

The NRC has specified minimum waste characteristic requirements for all classes of waste in 10 CFR 61.56 (ref. 2) and in the NRC technical position paper on waste form entitled "Final Waste Classification and Waste Form Technical Position Paper,"[8] dated May 11, 1983. The waste form characteristics outlined in this document have been established to facilitate handling and safety of personnel at the disposal site and to ensure that the waste maintains its stability following disposal.

The NRC had previously required that the physical dimensions of waste forms be maintained within 5%, but this requirement has been revised to eliminate any numerical limit for deformation. Instead, current requirements include a minimum compressive strength of 50 psi and the minimization of voids in or between waste masses to lower the likelihood of deformation or cracking following disposal. Such a condition could result in water infiltration, and subsequently the leachability of the waste could be enhanced.

The requirement of a minimum compressive strength for a solidified waste form is, as stated, a minimum because the waste fixation process must strive to achieve the maximum strength possible at all times. Standard tests recommended by the NRC to establish compressive strength as well as other parameters of concern are presented in Table 5.

In addition to solid waste, liquid waste must also be stabilized, either by solidification or by packaging with absorbent material capable of absorbing twice the contained volume of liquid. Just as with a

Table 5. NRC-recommended test methods

Stability guidance tests	Recommended test methods[a]
Compressive strength	ASTM C 39[9] or D 1074[10]
Biodegradation	ASTM G 21[11] and G 22[12]
Leachability	ANS 16.1[13]
Thermal degradation	ASTM B 553[14], Sects. 3, 5.4.1, and 5.4.4
Free-standing liquid	ANS 55.1[15]

[a]For some tests, other comparable methods may be considered.

solid waste form, the final absorbed processed waste must also conform to other common requirements such as the free-standing liquid limit, which will be discussed below.

Because it has been established that the presence of chelating agents in waste may mobilize and enhance the migration of certain radionuclides, wastes containing more than 0.1% by weight must be identified and segregated from other wastes when possible. As a result, waste containing such chelating agents in sufficiently high quantities may require special disposal methods. It is therefore required that waste generators identify such wastes containing chelating agents, defined by the NRC as any amine, hydroxy, or polycarboxylic acids, and estimate the approximate total concentration present.

Waste form requirements and desired characteristics are classification specific. The requirements for Class A waste are considerably fewer than those for Classes B and C because Class A waste is the most innocuous. As a result, Class A waste is not required to maintain its gross physical properties and identity over 300 years as Class B and C must and, as such, is not subject to all the test requirements specified by the NRC for Class B and C wastes.

Class A waste is exempt from Class B and C requirements only when it is segregated during disposal from these other classes; otherwise, it must be stabilized and meet all the Class B and C waste form requirements. On this basis, disposal strategy can sometimes eliminate the need for implementing generic testing and the requirement to engineer the desired waste-form characteristics into a processed waste product.

The maintenance of gross physical properties and identity for Class B and C waste applies to containerized and noncontainerized waste. Structural stability is the key to desired waste form integrity; the unconfined solidified waste form can provide the required stability, or a high-integrity container may be used. One or both of these means of achieving stability for Class B and C waste must be relied on to ensure the maintenance of what the NRC refers to as gross physical properties and identity for 300 years. In contrast, segregated Class A waste need not meet such requirements or be stabilized.

Minimum requirements for unconfined, solidified Class B and C waste or its container, if present, have been outlined by the NRC in their

technical position paper. These minimum requirements are as follows:

1. The waste should be in a solid form or in a container that provides stability following disposal.
2. No free-standing corrosive liquid should be associated with the waste, if possible; limits of 0.5 and 1 vol % have been established for noncontainerized and containerized waste, respectively.
3. Radiation effects must not result in the degradation of the waste container.
4. Biodegradation must not enhance degradation of the waste container.
5. The compressive loads expected on the waste or its container should not contribute to waste instability.
6. The presence of water should not result in waste or container instability following disposal.
7. If the waste is solidified, the solidification medium should be compatible with the untreated waste.

In addition to the above general requirements for Class B and C waste or its containers, there are other general requirements that apply to all waste classes. These general requirements have some commonality with specific Class B and C waste requirements previously listed and are as follows:

1. Cardboard or fiberboard boxes must not be used as containers.
2. Liquid waste must be solidified or packaged in absorbent material.

3. The volume of free-standing liquid associated with waste should be minimized and is subject to limits.
4. The waste must not be capable of detonation or explosion.
5. The waste must not generate toxic gases or vapors.
6. The waste must not be pyrophoric.
7. Gaseous wastes must not exhibit pressures greater than 1.5 atm at 20°C and must not contain more than 100 Ci per container.
8. Wastes must not contain pathogenic or bioinfectious materials.

If a solidification waste program is chosen for Class B and C waste and if codisposal of Class A waste is the policy, a process control program that relies upon generic test data to qualify a licensee's program and product is necessary. The test program must be able to ensure that the product waste form produced will consistently comply with the required structural stability outlined in the technical position paper.

The NRC takes a regulatory position on solidified waste by establishing stability guidance for implementation into a quality assurance program. This guidance will now be described, with the interrelationship between the guidance criteria and the waste class presented in Fig. 1, as follows:

1. Generic testing should include the use of samples based on the proposed waste streams and should be representative of the range of chemistries expected.
2. Compressive strengths of at least 50 psi should be obtainable for all waste specimens, with the objective of obtaining the maximum strength, not just the minimum.

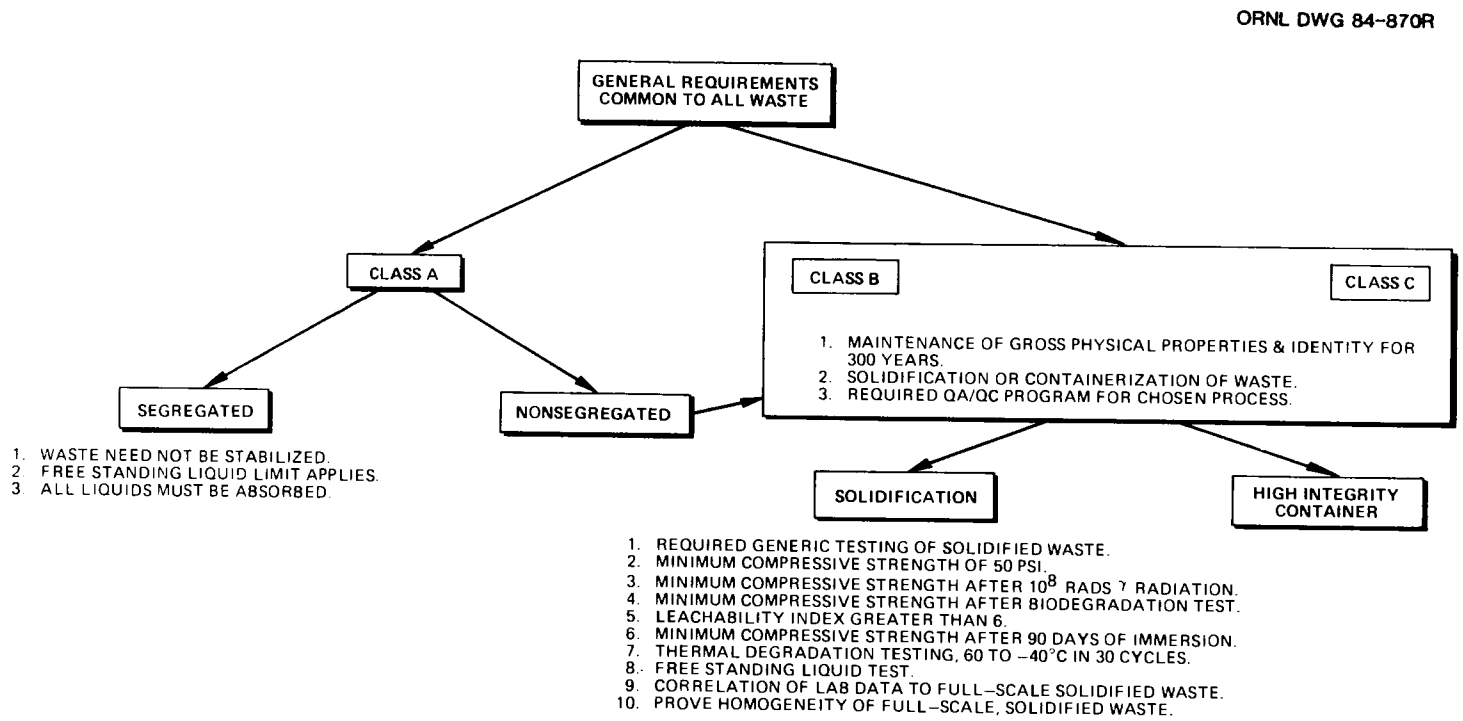

Fig. 1. Schematic of the NRC regulatory technical position on waste form requirements.

3. The waste specimens should possess at least the minimum compressive strength when exposed to a radiation field of 10^8 rads of gamma radiation or the expected level, if higher.
4. Specimens prepared from various waste streams should be resistent to biodegradation and should show no visible sign of culture growth. Following the biodegradation tests, the specimens again must possess a compressive strength of at least 50 psi. In addition, associated biodegradation results must be extrapolated for full-scale waste forms to 300 years and must result in <10% loss of the total carbon from the waste form.
5. Upon leaching for a minimum of 90 days, a calculated leachability index greater than 6 must be obtained for all radiochemical species of concern (see also Sect. 4.6).
6. Following immersion in water for 90 days, waste specimens must maintain at least the minimum compressive strength of 50 psi.
7. Waste specimens must be resistent to thermal degradation. Following 30 thermal cycles between 60 and -40°C, the waste specimen must pass the minimum compressive strength requirement.
8. Specimens should have <0.5 vol % of free-standing liquid, and this liquid should exhibit a pH between 4 and 11.
9. Test data from cores or sections of full-scale waste forms should be evaluated using the above tests to correlate laboratory results with full-scale products. This testing may be performed on nonradioactive specimens prepared using actual or comparable solidification equipment.

10. To ensure that full-scale products are homogeneous to the extent that all regions can be expected to have a minimum compressive strength of at least 50 psi, broken pieces from throughout the specimen should be tested. Again, full-scale specimens for this test may be simulated, nonradioactive products prepared using actual or comparable solidification equipment.

4.6 PROPOSED CHANGES TO WASTE FORM REQUIREMENTS AND CHARACTERISTICS

In October of 1986, the NRC published a new draft technical position on waste form requirements and characteristics which is referred to as Revision 4.[16] The requirements outlined in this regulatory guide are meant to replace those discussed above.

Because this is a draft of proposed changes, all the specific requirements will not be addressed here. The most notable change proposed in this document includes increasing the minimum unconfined compressive strength from 50 to 60 psi, with the minimum leach index remaining unchanged at 6.

It is suggested that this proposed draft be reviewed by those involved with the NRC regulatory performance guidelines or waste form testing. It is expected that the proposed changes will be adopted by the NRC sometime in 1988.

4.7 GROUNDWATER PERFORMANCE OBJECTIVES

The NRC cites the only existing comprehensive list of standards for groundwater and air contamination by radionuclides as an attachment to DOE Order 5480.1A (ref. 17) and referenced as Chapter XI. This list was originally developed under the auspices of the U.S. Atomic Energy Commission.

The EPA Primary Drinking Water Standards[18] list the gross alpha, beta, and gamma activity limits for drinking water without regard for the specific identity of the species contributing to the activity. These gross activity limits should be used in conjunction with the NRC table of specific radionuclides when evaluating groundwater or laboratory leachate solutions.

A question exists regarding an acceptable concentration factor for both the NRC limits and the EPA Primary Drinking Water limits for gross radioactivity when evaluating laboratory leach test results. The EPA has applied a conservative factor of 100 for those specific inorganic and organic species of concern in the EP Toxicity test. This conservative factor takes into consideration the expected effect of groundwater dilution and relates this to the concentrations of chemical species obtained in a laboratory leach vessel. As a result, leachate concentration limits have been established at 100 times the drinking water standards for evaluating laboratory leach tests. Although it seems reasonable that a similar concentration factor should apply when considering radionuclides, neither the NRC nor the EPA has addressed this issue regarding mandatory leach testing.

The NRC recognizes and requires compliance with both the EPA Primary Drinking Water Standards [40 CFR 141 (ref. 18)] and the National Secondary Drinking Water Regulations [40 CFR 143 (ref. 19)]. There is a noticeable difference, however, regarding the point at which the EPA and NRC water quality regulations are enforced. Currently, the NRC addresses groundwater quality at the nearest groundwater user's supply, whereas the EPA prefers the boundary of the waste emplacement.

Groundwater effluent control is tied to radioactive exposure received by an inadvertent intrusion into the disposal site. In short, the NRC requires that movement of radioactivity should not result in a whole-body dose to an inadvertent intruder greater than 500 mrem/year at the site boundary and, in addition, should not cause the EPA drinking water standards to be exceeded at the nearest groundwater user's supply.

4.8 REFERENCES

1. 10 CFR 61.
2. Ref. 1, Sect. 56.
3. Ref. 1, Sect. 55.
4. Ref. 1, Sect. 55, Table 1.
5. Ref. 1, Sect. 55, Table 2.
6. 40 CFR 261.
7. 10 CFR 20.311.
8. Nuclear Regulatory Commission, "Final Waste Classification and Waste Form Technical Position Paper," May 11, 1983.
9. American Society for Testing and Materials, "Compressive Strengths of Cylindrical Concrete Specimens," ASTM C39, 1979.
10. American Society for Testing and Materials," Compression Strengths of Bituminous Mixtures," ASTM D1074, 1980.
11. American Society for Testing and Materials, "Determining Resistance of Synthetic Polymeric Materials to Fungi," ASTM G21, 1970.
12. American Society for Testing and Materials, "Determining Resistance of Plastics to Bacteria," ASTM G22, 1976.

13. American Nuclear Society Standards Committee, "Measurement of the Leachability of Solidified Low-Level Radioactive Wastes," (Draft), ANS 16.1, June 20, 1984.

14. American Society for Testing and Materials, "Thermal Cycling of Electroplated Plastics," ASTM B553, 1979.

15. American Nuclear Society, "American National Standard for Solid Radioactive Waste Processing System for Light Water Cooled Reactor Plants," ANS 55.1, Appendix 2, 1979.

16. Nuclear Regulatory Commission, "Draft Regulatory Guide on Low-Level Waste Form Stability," Proposed Revision to 10 CFR 61, RG LLW Form Stability, Rev. 4, October 1986.

17. "Environmental Protection, Safety, and Health Protection Program for DOE Operations," DOE 5480.1A, August 13, 1981.

18. 40 CFR 141.

19. 40 CFR 143.

SUMMARY

To summarize and interpret regulations regarding solid waste performance as established by these different agencies serves to amplify their differences and similarities. The problem, however, lies in the accuracy of interpretation as a result of the sometime vague and general regulatory vernacular used in agency documents. For this reason, important points of concern or confusion must be answered in writing by an agency representative before proceeding with an important stage in any waste disposal plan. This should be done with the realization that agency guidelines may differ from one region of the country to another and that states may also impose stricter regulations of their own.

It is important for the reader to realize that this summary of the regulations represents a specific point in time and that some effort must be made to investigate current changes when reviewing this report. During the spring of 1987, when this document was being given a final review prior to publication, a number of proposals were about to be issued by the EPA and the NRC, some of which are expected to be joint proposals for handling mixed, low-level wastes.

With the definition of hazardous waste becoming broader everyday, in the sense that a larger number of increasingly complex wastes are included, analytical and disposal technologies are pushed to their respective limits. For this reason, the application and refinement of waste disposal technology in our laboratories must serve to guide regulatory agencies in a realistic direction. Such a realistic approach would include a greater

emphasis on the ability of tailored solidified waste forms to immobilize various types of waste. More research directed at understanding the limitations associated with immobilization and realistic testing protocols are needed to aid in directing the regulatory agencies towards the establishment of coherent, effective regulations. In addition, waste generators can only hope that agencies such as the EPA, NRC, and DOE will as a result of our guidance find some commonality in the restrictions imposed upon the treatment and safe storage of wastes.

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