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Parametric Study of Radionuclide Characterization — Low-Level Waste

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**PARAMETRIC STUDY OF RADIONUCLIDE CHARACTERIZATION —
LOW-LEVEL WASTE**

1.0 INTRODUCTION

1.1 SCOPE

The criteria and guidance given in this addendum specifically address the classification of low-level waste into Category 1, Category 3, and Greater Than Category 3 (GTC3). These categories are developed based on the performance assessment (PA) being conducted for the Hanford Site. The radionuclides and their concentration for each category are listed in the revised Table 1-1 (Attachment 1). The information to classify the waste for U.S. Department of Transportation (DOT) and to classify Transuranic (TRU)/Non-TRU, Contact Handled (CH)/Remote Handled (RH) waste is given in WHC-EP-0063-3 (WHC 1991).

1.2 NEED FOR CHANGES

U.S. Department of Energy (DOE) Order 5820.2A (DOE 1988) requires that all DOE sites prepare a PA of their disposal facilities. The results of the Hanford Site's preliminary PA require that all low-level waste be classified into Category 1, Category 3, and GTC3. In addition, the order requires that waste be analyzed for the Nuclear Regulatory Commissions (NRC) low-level waste classification of Greater than Class C (GTCC) in accordance with Title 10, *Code of Federal Regulation* (CFR), Part 61. The isotopes and the radioactivity level for each of these categories was determined by the PA. This addendum will reflect the interim requirements for the radionuclide characterization of waste. The final version of this addendum will be issued after the PA is completed and will be included in updates to WHC-EP-0063-3 (WHC 1991). Minor changes, if any, are expected in the final version.

1.3 IMPLEMENTATION

Each generating facility has programs which may vary from small to large. In some cases it may be simple to implement this program and in others it may be complicated. The Hanford Site staff will be flexible as the generating facilities develop their programs. The acceptability of any particular program will be evaluated based on the following efforts: to ensure realistic representation of the radionuclides in the waste, to keep exposure as low as reasonably achievable (ALARA), and to maintain consistency and quality of data and documentation.

1.4 EFFECT ON HANFORD SITE WASTE ACCEPTANCE CRITERIA

Solid radioactive waste generators are required to characterize waste before it is shipped to the Hanford Site for storage and/or disposal. Waste generators must characterize the waste with sufficient accuracy to properly

document the types and quantities of radionuclides, as given in WHC-EP-0063-3 (WHC 1991). So far the characterization of the waste requires classification based on DOT type, TRU or Non-TRU, CH or RH, and a partial list of Category 3 radionuclides developed in the preliminary PA.

With the advent of the PA, the waste also has to be analyzed for Category 1, 3, GTC3, and GTCC. This addendum will add additional requirements for characterization of waste and will effect the following sections in WHC-EP-0063-3 (WHC 1991).

- Section 4.3, "Waste Characterization"
- Section 5.3, "Waste Characterization"
- Section 6.3, "Waste Characterization"
- Appendix A, Attachment A
- Appendix B, "Solid Waste Storage/Disposal Records and Instructions, Low-Level Waste Storage/Disposal Record Instructions, Item 20 and Transuranic Waste Storage/Disposal Record and Instructions: Item 36."

In case of conflict between WHC-EP-0063-3 (WHC 1991) and this addendum, this addendum will supersede.

1.5 PROPOSED ACTIONS TO MEET REGULATORY GUIDANCE

This program of characterizing waste for Categories 1, 3, and GTC3 is being developed to meet the requirements of DOE Order 5820.2A (DOE 1988). The first step in the development of this program was to conduct a PA of the Hanford Site. Although the final version is not issued, the PA has been developed to a point that few changes are expected. From the PA a list of radionuclides and the activity levels was generated that forms the basis for classifying waste as Category 1, Category 3, or GTC3.

The guidance to interpret the revised Table 1-1 (Attachment 1) and implementation of other requirements such as radiological description, averaging of radionuclide concentration, sampling, measurement techniques, fraction rule, daughter products, reportable quantities, detection limits, and reporting format, is given in Section 2.0. This guidance will be modified as input from the waste generating facilities are received.

2.0 PROCEDURAL GUIDANCE RADIONUCLIDE CHARACTERIZATION

All low-level waste must fall into one of the three categories (Category 1, Category 3, or GTC3) based on the concentration limit given in the revised Table 1-1 (Attachment 1). The technical position and acceptable procedures (for the waste generators to develop a compliance program to ensure proper classification of waste) are given in this section. To make sure that the regulatory requirements are met and at the same time unnecessary analysis costing financial resources is not done, various methods and approaches are suggested. The methods have different levels of sophistication, each suitable for a particular application depending on requirements and the associated hazard.

2.1 METHODS OF RADIOACTIVE ANALYSIS

There are various methods that can be used in the characterization of radionuclides in the waste. Each method has its area of application and level of sophistication. More than one method may have to be used to analyze the waste depending on the physical, chemical, and radioactive composition of the waste.

2.1.1 Process Data

Well documented process data can be an effective method for the radionuclide characterization of waste. Obtaining process data should be the first step in determining the class, category, and type of waste. From analyzing the process data, the general radionuclide distribution and their relative concentration can be determined. With this information individual isotopes can be targeted with specific instrumentation. For example, if the waste has only gamma emitting radionuclides and does not contain problem isotopes, then gamma spectral analysis can be done and other tests may not be required. The problem isotopes are those which have long half-lives, low energy beta and/or alpha, and are hard to detect. The process knowledge can also be used in identifying the isotopes that are not present thus eliminating those tests that are specific to them. An example of this could be a facility that handles only plutonium.

Process knowledge can help establish the general character of waste (TRU or Non-TRU, category, etc.). Documentation of such process knowledge should be kept as substantive proof.

The Hanford Site waste generators, in many cases, can use the process knowledge for characterizing waste given in the Attachment 7. Offsite generators can develop a similar approach.

2.1.2 Material Balance

In certain instances the process data that have material balance information can be used to establish isotopic content in the waste. An example of this could be a test conducted with a limited number of well

identified isotopes and the isotopic inventory is accounted for in the process such as an experiment in a university or similar laboratory with a tracer isotope.

2.1.3 Calculation Method

Theoretical calculations may be an acceptable method of establishing the radionuclide concentration in waste. An example of this could be the radionuclides formed in metals, as a result of neutron/proton activation. Large pieces of activated metal are somewhat hard to analyze using laboratory methods. Another application could be the waste generated in processing the irradiated fuel. Computer programs such as ORIGEN2 (Croff 1980) calculates the activation and fission products in the fuel. Using such a computer program, the relative concentration of various radionuclides can be determined. If the concentration of ^{137}Cs or a similar radionuclide is determined then the concentration of other radionuclides can be determined by establishing the ratios. If the fuel is processed or has been in storage then partition factors and decay constants will have to be used.

2.1.4 Gross Radiation Measurement

Gross radiation measurement (GRM) could have a wide application and can be an effective tool used to characterize the waste containing gamma or certain high energy beta. GRM, which may entail dose-to-curie scaling, are well suited for routine analysis of limited quantity (LQ), low specific activity (LSA), and Category 1 designations of waste streams. Use of GRM in characterizing the waste will require that measurements are correlated on a consistent basis with the distribution of radionuclides within the particular waste stream analyzed and that the radionuclides distributions are initially determined and periodically verified. GRM can be used in determining the curie level of other drums from a waste stream when one of the representative drums has been analyzed by direct measurement techniques such as gamma spectroscopy. Field instruments may be used in GRM.

GRMs could provide sufficient characterization for LQ, LSA, and Category 1 waste if supported by process information. Characterization is to be part of the low-level certification plan and is to be approved before issuing the appropriate waste storage/disposal request.

2.1.5 Direct Radiation Measurement

Direct radiation measurement entails laboratory analysis. It is used especially for the characterization of low energy gamma and alpha/beta containing waste. Direct radiation measurement targets specific radionuclides using laboratory equipment and chemical separation. The method is more useful in determining TRU, Category 3, GTC3, and very low-level threshold concentrations. Threshold concentration is the level of activity below which the material can be released as nonradioactive.

2.2 GENERAL GUIDANCE

Certain guidelines are given which might help the waste generator to meet the regulatory requirements for the characterization of waste. These guidelines are broad and may not apply to a specific situation. In case of any difficulty, the generator should contact the Hanford Site staff.

2.2.1 Reportable Quantities

The generator is required to report the concentrations of radionuclides which are expected to be present in the waste stream. The specific nuclides and their concentrations can be identified through process knowledge and/or analysis of representative samples.

It is required that the generator provide the concentration of all nuclides listed in Table 1-1 (Attachment 1) that are potentially present in the waste stream. Other nuclides with half-lives greater than 5 years and are not listed in Table 1-1 will also be listed. The large number of nuclides present in Table 1-1 does not dictate that the generator is required to estimate or analyze for all of them. The large list of nuclides is provided to cover nuclide inventories that potentially could be present at various waste generator sites.

The concentration limits in Table 1-1 (Attachment 1) may be used to determine the need for sampling and analysis for a particular nuclide. Frequently, the concentration of a particular nuclide in a waste stream reported by the generator is well below the limits in Table 1-1 and may be below the limits of detection. In this situation, the potential contribution to dose may be negligible. As a conservative guideline, if reliable process knowledge indicates that the concentration of a particular nuclide is less than or equal to 1% of the Category 1 concentration limit, no analysis is required. On the other hand, if uncertainty in the concentration of the nuclide dictates sampling and analysis, the limit of detection provided by standard analytical procedures can be used as the reported concentration. It will also be marked as such.

Attachment 2 includes tables giving the detection limits for the various isotopes. Except for a few nuclides the detection limits are generally equal to or less than 1% of the Category 1 concentration limit.

The following rules should be used in determining the category of waste.

- If only one radionuclide is present in the waste, use the value in Table 1-1 (Attachment 1) to determine the appropriate category.
- If more than one radionuclide listed in Table 1-1 is present in the waste, then the sum-of-the-fractions rule will be used to determine the proper waste category.
- If the waste contains unlisted radionuclides with half-lives greater than 5 years, analysis in consultation with Hanford Site staff will be required to determine the category of the waste.

- Cases may exist where a mixture of components may be below laboratory testing limits, but the sum of the fractions of the radionuclide may be greater than Category 1. Laboratory testing limits should be able to determine 1/20 of the Category 1 quantity to allow confident use of the sum-of-the-fractions rule.
- If the radionuclide is known or suspected to be contained within the waste but is in quantities less than the minimum detectable activity (MDA) in the analyzed sample, then record "Less than MDA" and add in parentheses the MDA value. The MDAs for certain isotopes are given in Attachment 2. Attachment 2 also has tables listing pertinent information that can be used by the waste generator.
- If a radionuclide with a half-life less than 5 years has a long lived daughter then the activity concentration of the parent must be provided. For example, ^{147}Pm with a half-life of 2.6 years decays to ^{147}Sm with a half-life of 1.0 E+11 years. In this case the activity concentration of ^{147}Sm must be considered in the sum-of-the-fraction calculations.

2.2.2 Accuracy of Data

There might be limitations in obtaining and measuring representative samples because of the excessive cost, ALARA considerations, or type and dimensions of a particular waste. In such cases it will be considered reasonable that the measured or inferred radionuclide concentrations are accurate to within a factor of 10.

2.2.3 Boundary Conditions

The accuracy of data is more important as the radionuclide concentration approaches the limits of Category 1 and 3 given in Table 1-1 (Attachment 1), because the waste could change its category. In case of doubt it will be advisable to use a more conservative approach. For example, if the radionuclide concentration is just below the Category 1 limit and the accuracy of data is around a factor of 10, then unless more analysis is done, the waste should be classified as Category 3.

2.2.4 Exempted Waste

Waste from naturally occurring radioactive materials whose specific activity is below 2 nCi/g will be exempt from these requirements.

If from the process knowledge and/or direct measurements the waste is analyzed to be TRU then, the categorization of the waste using this addendum may not be required. The waste generator should refer to the sections in WHC-EP-0063 (WHC 1991) dealing with the TRU waste.

2.2.5 Sum-of-the-Fractions Rule

The majority of wastes will contain a mixture of radionuclides, and; therefore the determination of classification is accomplished by the sum-of-the-fractions rule. For each nuclide given in Table 1-1 (Attachment 1), the fraction of the allowable inventory which is present in the waste stream is determined by calculating the ratio of the waste stream concentration to the allowable limit (either Category 1 or Category 3). The sum-of-the-fractions is then calculated to determine classification. For any given sum-of-fractions calculation, a mixture of Category 1 and Category 3 limits for different nuclides cannot be used.

The sum-of-the-fractions estimate determines classification in the following ways.

- If the sum of the fractions has a value of less than one using Category 1 values, the waste is Category 1 waste.
- If the sum of the fractions has a value of greater than one using Category 1 values and a value less than one using Category 3 values, the waste is Category 3 waste.
- If the sum of the fractions has a value of greater than one using Category 3 values, the waste is GTC3 waste.

2.2.6 U.S. Nuclear Regulatory Commission's Classification for Greater Than Class 3 Waste

If the waste is determined to be GTC3 waste, an additional determination of classification must be made according to the U.S. Nuclear Regulatory Commission's (NRC) classification scheme in 10 CFR 61. In particular, it must be shown whether the waste is GTCC waste. DOE Order 5820.2A (DOE 1988) mandates that GTCC waste cannot be disposed as low-level waste without going through the *National Environmental Policy Act* (NEPA) process. This would require a special PA with the waste being stored temporarily. Should the waste be unsuitable for land disposal it would be prepared for geological disposal. If this situation arises for a given waste stream, it must be evaluated on a case-by-case basis.

Some differences exist between the NRC classification system and the Category 1 and 3 limits provided in Table 1-1 (Attachment 1). First, the general approach to quantifying limits is similar. The Class C and Category 3 waste designations are similar. However, for nuclides identified specifically in both the NRC regulation and Table 1-1, different concentration limits are used. This results from the use of different intrusion scenario assumptions to quantify limits and differences in recommended dose estimate methodology provided by the International Commission on Radiological Protection (ICRP) in the last decade. Second, the NRC provides two tables rather than one, that separate long lived nuclides from short lived (5 to 30 years) nuclides. The regulation also stipulates that the sum-of-the-fractions calculation applies only to 10 CFR 61, Table 1 or Table 2, not both together. Attachment 6 reproduces NRC Tables 1 and 2 and other relevant information from 10 CFR 61 for convenience of the user.

2.2.7 Daughter Products

In the case where a nuclide has a daughter product in secular equilibrium, only the activity concentration of the parent must be provided.

Nuclides which have half-lives less than 5 years were eliminated from the list in Table 1-1 (Attachment 1) and do not have to be considered in the sum-of-the-fractions calculation. However, if a less than 5-year half-life nuclide has a long lived daughter (e.g., ^{147}Pm to ^{147}Sm), the activity of that daughter must be considered in the sum-of-the-fractions calculation.

2.2.8 Weight or Volume — Basis for Concentration

Radionuclide concentrations should be determined upon the volume or weight of the final waste form if the radionuclide within the waste is reasonably homogeneous. The weight of the container should not be included. If weight is used, an estimate of waste density should be provided. This requirement needs to be interpreted for the variety of different types and forms of low-level waste.

- For the purpose of waste categorization most streams may be considered homogeneous. Waste such as miscellaneous waste, spent ion-exchange resins, filters, filter media, contaminated dirt, and trash can be considered homogeneous. Small concentrated and check sources may be averaged over the trash volume.
- If the waste is well compacted in a container, such as in a drum, then the volume of the container can be used in the determination of concentration.
- The waste classification volume or weight of large unpackaged components such as pumps, heat exchangers, tanks, valves, machinery, and ballasts, will be the total weight or displaced volume of the component (i.e., void volume subtracted from the envelope volume).
- For the mixtures of activated or contaminated waste in a disposal container, the classification of the waste will be based on the volumetric or weighted averaged concentration of the combined components, provided that all the concentration within the individual components are within a factor of 10 of the averaged concentration (see Attachment 3).
- Categorization of absorbed liquids will be based on the volume/mass of the liquids before absorption.
- In the case of stabilized waste such as solidified liquids/sludges, filters encapsulated in binder, etc., the waste classification volume may be considered to be the solidified volume. This exception will be allowed if stabilization is not done for the purpose of dilution. For additional information see Attachment 3.

2.2.9 Required Measurements

Routine measurements (one or two per batch) should be taken for Category 3 waste which has isotopes that can be analyzed by gross radiation measurements. Routine measurements should be taken for Category 1 waste if process variation could cause an upward change in the waste classification. In the case of problem isotopes requiring direct radiation measurements, confirmatory analysis should be done periodically using gross radiation measurements. If the process has changed to alter the nuclide activity by a factor of 10 or more, confirmatory analysis should be done again using direct radiation measurements. This methodology is to limit the number of detailed analyses without sacrificing reliability.

2.2.10 Radionuclide Distribution in Waste

The isotopic distribution of the trash and similar secondary waste can be based upon the distribution determined for the main stream. Smear samples could also be used for the analysis.

2.2.11 10% Rule

If the waste is determined to be Category 1, the reportable activity should include all nuclides that contribute greater than 10% of the total activity of the waste matrix. Up to 90% of all activity will be reported irrespective of the percentage activity of any one isotope. The 10% rule can also be used for DOT types, LQ, and LSA with radionuclides having less than 5-year half-lives. The waste generator will make sure that the 10% rule does not effect the waste classification.

2.2.12 1% Rule

In some cases the wastes may have a number of radionuclides listed in Table 1-1 (Attachment 1). If it is determined that the waste is Category 3 based on the process knowledge and measurements of a few of the radionuclides, then the balance of the radionuclides need not be analyzed to 1% of the Category 1 values given in Table 1-1. Instead, the activity of individual radionuclides can be reported to within 1% of the total activity. It is important to note that the 1% rule is applicable as long as the waste category does not change (e.g., Category 3 may not change to GTC3). The 1% rule can be used effectively to save some detail direct measurements requiring chemical separation etc.

2.2.13 Activated Metals

For activated metals the isotopic distribution can be determined by the activation analysis calculation. Dose measurements coupled with a standard dose-to-curie conversion will be used to check the reliability of the calculations.

2.2.14 Suspect Radioactive Waste

In certain cases, the instruments may not detect individual radionuclides but the waste material cannot be released for nonradioactive disposal because of the potential for contamination. When this occurs, report the isotopes that would most likely be present based on the documented process knowledge. Use the detection limit of the survey equipment to report the curie content and document it as such.

2.2.15 Characterization for U.S. Department of Transportation Classification

Criteria for characterization of waste for DOT classification, TRU or Non-TRU, CH or RH, and other licensing conditions are covered in WHC-EP-0063-3 (WHC 1991), 49 CFR Parts 100 to 199 and elsewhere.

2.2.16 Approved Analytical Laboratories

The analytical analysis to characterize waste should be done in a quality assurance controlled laboratory. The laboratory must meet, as a minimum, the quality controlled program given in Attachment 4. A list of national commercial laboratories who have responded to the Hanford Site survey to establish their area of expertise and evaluate their quality controlled program is given in Attachment 5.

2.2.17 Sampling Procedures

The sampling procedures depend on the type and form of waste and therefore no specific guidance can be provided. At this time it is recommended that the waste generator have a quality controlled sampling program based on the industry's standard procedures. The program should address the following:

- The techniques or guidelines used in selecting sampling methods and sites using charts, flow diagrams, and tables; containers; reagents used for sample collection; preservation; transport; and storage
- Special conditions for the preparation of sampling equipment and containers to avoid sample contamination and sample preservation methods and holding times.

Sample custody is a part of any good laboratory or field operation. Where samples may be needed for legal purposes, chain-of-custody procedures should be used. As a minimum, the following should be described and provided:

- Field sampling operations involving documentation of procedures for preparation of reagents or supplies

- Procedures and forms for recording the location and specific considerations associated with sample acquisition
- Documentation of specific sample preservation
- Prepared sample labels
- Standardized field tracking forms to establish sample chain of custody in the field.

Laboratory operations should include the following:

- Identification of the responsible party to act as sample custodian at the laboratory
- A provision for a laboratory sample custody log
- Specifications of laboratory sample custody procedures for sample handling, storage, and dispersement for analysis.

Calibration procedures and information should be included for each major measurement parameter, including all pollutant and waste measurement systems. The frequency for recalibration, calibration standards and their sources, including traceability procedures, should be listed in the procedures or information.

The sampling program developed by the waste generators will also meet the guidance given in *DOE Methods for Evaluating Environmental Samples* DOE/EM-0089T (DOE 1992). In addition industry standards such as ASTM D4687-87, *Guide for General Planning of Waste Sampling*, could be consulted. The Hanford Site waste generators can use the services of Office of Sample Management in meeting the sampling requirements.

2.2.18 Radionuclide Concentration Reporting Format

The format for reporting radionuclides is covered in WHC-EP-0063-3 (WHC 1991). In reporting the isotopic activity, the generator must provide a nuclide quantity as a concentration, in curies per cubic meter. In the case of TRU nuclides, the concentration must be reported in curies per gram. If the concentration is reported in curies per gram, the density of the waste material must also be provided to convert curies per gram to curies per cubic meter. The generator must provide an indication of the means by which the concentration given was derived. It is particularly important to indicate if the concentration reported is the limit of detection for a given nuclide or a predicted value based on decay chain calculations.

2.2.19 Data

Tables are given in Attachment 2 that may be help waste generators implement this addendum. Some of the information given in these tables is as follows:

- Attachment 2, Table 2-1 — Lists some of the Category 3 radionuclides and the associated MDA. The testing technique, instrument, manufacturer of instrument and approximate price for the analysis is also given.
- Attachment 2, Table 2-2 — Lists the sensitivity of various instruments (proportional counter, alpha spectroscopy, liquid scintillation counter, and semiconductors) for some selected radionuclides.
- Attachment 2, Table 2-3 — Lists the common radionuclides at the Hanford Site with half-lives, DOT type limits, Hanford Site categories limits, NRC low-level waste classes limits, and International Atomic Energy Agency transport categories limits.
- Attachment 2, Table 2-4 — Selected Radionuclides with Parent to Daughter Ratios.
- Attachment 2, Table 2-5 — Gamma Dose Rates from Various Isotopic Sources.
- Attachment 2, Table 2-6 — General Methods for Selected Radionuclide Analysis.

2.2.20 Cost Benefit Analysis

There may be instances when the waste generator should consider the benefit of analysis against cost and ALARA. The cost of analysis may be more than disposing of waste as Category 3. In certain applications the ALARA considerations may override the benefits of direct measurement analysis of a waste. The waste generator should consult with the Hanford Site in such cases.

3.0 REFERENCES

- ASTM, 1987, *Guide for General Planning of Waste Sampling*, ASTM D468, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- Croff, A. G., 1980, *A User's Manual for the ORIGEN2 Computer Code*, ORNL/TM-717 5, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- DOE, 1988, *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C.
- DOE, 1992, *DOE Methods for Evaluating Environmental Samples*, DOE/EM-0089T, U.S. Department of Energy, Washington, D.C.
- National Environmental Policy Act of 1969*, 42 U.S.C. 4321 et seq.
- NRC, 1991, *Technical Position on Waste Form*, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C.
- WHC, 1992, *Hanford Solid Waste Acceptance Criteria*, WHC-EP-0063-3, Westinghouse Hanford Company, Richland, Washington.
- 10 CFR 61, 1992, "Licensing Requirements for Land Disposal of Radioactive Waste," *Code of Federal Regulations*, as amended.
- 49 CFR 100-500, Subtitle B, 1991, "Other Regulations Relating to Transportation," *Code of Federal Regulations*, as amended.

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ATTACHMENT 1

LIST OF RADIONUCLIDES AND INVENTORY LIMITS

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LIST OF RADIONUCLIDES AND INVENTORY LIMITS

The list of radionuclides and inventory limits provided in Table 1-1 of WHC-EP-0063-3 (WHC 1991) classifying low-level waste as Category 1, Category 3, or Greater Than Category 3 (GTC3) waste has been revised as given in this attachment. The isotopes and their concentration limits in Table 1-1 have been derived from the performance assessment based on the revised data. The performance assessment uses intrusion scenario analysis and meets the performance objectives in DOE Order 5820.2A (DOE 1988).

Table 1-1. Category 1 and 3 Limits (WHC 1991 Table 4.1). (2 sheets)

Nuclide	Cat 1 Conc Limit (Ci/m ³)	Cat 3 Conc Limit (Ci/m ³)	Nuclide	Cat 1 Conc Limit (Ci/m ³)	Cat 3 Conc Limit (Ci/m ³)
³ H	5.0 E+06	--	¹⁵¹ Sm	3.8 E+01	1.8 E+05
¹⁰ Be	1.0 E+00	2.2 E+02	¹⁵⁰ Eu	1.6 E-03	7.7 E+02
¹⁴ C	4.0 E-02	9.1 E+00	¹⁵² Eu	5.3 E-02	--
¹⁴ C*	4.0 E-01	9.1 E+01	¹⁵⁴ Eu	8.3 E-01	--
³⁶ Cl	4.0 E-04	8.3 E-02	¹⁵² Gd	6.3 E-03	1.3 E+00
⁴⁰ K	1.7 E-03	3.4 E-01	¹⁸⁷ Re	5.3 E+00	1.1 E+03
⁶⁰ Co	7.7 E+01	--	²¹⁰ Pb	1.0 E-02	5.6 E+05
⁵⁹ Ni	4.0 E+00	8.3 E+02	²⁰⁹ Po	2.9 E-02	7.7 E+01
⁵⁹ Ni*	4.0 E+01	8.3 E+03	²²⁶ Ra	1.4 E-04	3.6 E-02
⁶³ Ni	4.8 E+00	1.7 E+04	²²⁸ Ra	1.9 E+01	--
⁶³ Ni*	4.8 E+01	1.7 E+05	²²⁷ Ac	4.5 E-03	3.2 E+05
⁷⁹ Se	3.8 E-01	8.3 E+01	²²⁹ Th	4.8 E-04	1.1 E-01
⁹⁰ Sr	4.3 E-03	1.5 E+04	²³⁰ Th	2.1 E-03	1.3 E-01
⁹³ Zr	2.7 E+00	5.9 E+02	²³² Th	1.2 E-04	2.2 E-02
⁹⁴ Nb	2.6 E-04	5.6 E-02	²³¹ Pa	1.6 E-04	3.3 E-02
⁹⁴ Nb*	2.6 E-03	5.6 E-01	²³² U	5.3 E-04	4.0 E+00
⁹³ Mo	3.0 E-01	7.1 E+01	²³³ U**	7.7 E-03	1.1 E+00
⁹⁹ Tc	5.6 E-03	1.2 E+00	²³⁴ U	9.1 E-03	2.1 E+00
¹⁰⁷ Pd	4.8 E+00	1.0 E+03	²³⁵ U	3.2 E-03	5.9 E-01
^{113m} Cd	2.0 E-01	--	²³⁶ U	1.0 E-02	2.2 E+00
^{121m} Sn	6.3 E+00	2.0 E+05	²³⁸ U	6.3 E-03	1.4 E+00
¹²⁶ Sn	1.8 E-04	3.8 E-02	²³⁷ Np**	1.9 E-04	4.0 E-02
¹²⁹ I*	2.9 E-03	5.9 E-01	²³⁸ Pu**	9.1 E-03	4.5 E+01
¹³³ Ba	7.7 E-01	--	²³⁹ Pu**	3.6 E-03	7.7 E-01
¹³⁵ Cs	1.9 E-01	4.2 E+01	²⁴⁰ Pu**	3.6 E-03	7.7 E-01
¹³⁷ Cs	6.3 E-03	1.3 E+04	²⁴¹ Pu	7.7 E-02	3.1 E+01
¹⁴⁷ Sm	1.6 E-02	3.4 E+00	²⁴² Pu**	3.8 E-03	8.3 E-01

Table 1-1. Category 1 and 3 Limits (WHC 1991 Table 4.1). (2 sheets)

Nuclide	Cat 1 Conc. Limit (Ci/m ³)	Cat 3 Conc. Limit (Ci/m ³)	Nuclide	Cat 1 Conc. Limit (Ci/m ³)	Cat 3 Conc. Limit (Ci/m ³)
²⁴⁴ Pu**	8.3 E-04	1.7 E-01	²⁴⁴ Cm**	2.3 E-01	2.9 E+02
²⁴¹ Am**	2.6 E-03	1.1 E+00	²⁴⁵ Cm**	2.1 E-03	3.3 E-01
^{242m} Am**	2.6 E-03	2.4 E+00	²⁴⁶ Cm**	3.3 E-03	7.7 E-01
²⁴³ Am**	1.3 E-03	2.8 E-01	²⁴⁷ Cm**	7.1 E-04	1.5 E-01
²⁴³ Cm**	2.5 E-02	6.3 E+02	²⁴⁸ Cm**	9.1 E-04	2.0 E-01

*Isotope is in activated metal. Category 1 and 3 limits are 10 times that for isotope not in activated metal.

**Category 3 limit is the lower of this value and 100 nCi/g.

REFERENCES

- DOE, 1988, *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C.
- WHC, 1991, *Hanford Solid Waste Acceptance Criteria*, WHC-EP-0063-3, Westinghouse Hanford Company, Richland, Washington.

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ATTACHMENT 2

DETECTION LIMITS FOR RADIONUCLIDES

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DETECTION LIMITS FOR RADIONUCLIDES

2-1 SURVEY OF RADIATION ANALYSIS LABORATORIES

To determine the radioactivity of any waste sample, a variety of instruments and methods can be used depending on the accuracy desired. A guideline must be developed to indicate the measurement techniques for the desired minimum detectable activity (MDA) and level of accuracy for the various isotopes and categories/types of waste. Such guidelines can only be general and are provided to help the waste generator.

To develop the guidelines for the radioactive analysis of waste, a country-wide survey of the approved laboratories that service waste generators was conducted through the services of the University of Utah (Slaughter and Sandquist 1992). Information was collected as to the MDA of the instrument, testing technique, type of instrument and manufacturer, and approximate cost of analysis for some of the radionuclides listed in Table 1-1 (Attachment 1). This information is given in the tables in this attachment. The data given are only representative of the laboratories surveyed and should be used as guidance only. Other tables are added to provide relevant information to the waste generator.

The MDA as used in this document is defined as follows:

$$MDA = \frac{2.71 + 4.65S_b}{\epsilon V Y C S t e^{-\lambda T}}$$

where:

- S_b = Standard deviation of the background counts
- ϵ = Counting efficiency
- V = Sample volume (mL)
- Y = Chemical yield
- C = Dimensional conversion factor (2.22×10^6 dpm/ μ Ci)
- S = Correction factor for radiation absorption
- t = Background counting time, equivalent to the sample counting time
- $e^{-\lambda T}$ = Correction for radioactive decay (Assume this factor is 1 for this survey).

2-2 REFERENCES

Slaughter, D. M., and G. M. Sandquist, 1992, *Westinghouse Hanford Site Low-Level Waste Characterization Guidance Document*, Draft August 24, 1992, Nuclear Engineering Laboratory, University of Utah, Salt Lake City, Utah.

Table 2-1. MDA, Instruments and Cost of Analysis of Selected Category 3 Radionuclides. (4 sheets)

Radionuclide, major radiation type	Minimum detectable activity ($\mu\text{Ci/g}$)	Testing technique	Type of instrument	Cost of analysis*
^3H [B]	5.0×10^{-4} 3.0×10^{-4} 4.0×10^{-4} --	Distillation Distillation Distillation Alpha spectroscopy	LSC LSC LSC --	\$114
^{14}C [B]	5.0×10^{-6} 3.0×10^{-6} 1.0×10^{-7}	Benzene/Synthesis Combustion Chemical separation and direct	LSC LSC LSC	\$180
^{60}Co [B, γ]	2.0×10^{-8} 1.0×10^{-8} 1.0×10^{-9} -- --	Gamma counter Direct Direct Gamma spectroscopy HPGe gamma spectroscopy	Ge(Li) Ge(Li) HPGe HPGe --	\$149
^{59}Ni [γ]	2.0×10^{-6} 2.0×10^{-5} 5.0×10^{-9}	Liquid/liquid extraction Chemical separation Chemical separation and direct	LEPD NaI(Tl) HPGe	\$207
^{63}Ni [B]	5.0×10^{-6} 4.0×10^{-6} 1.2×10^{-8}	Liquid/liquid extraction Chemical separation Chemical separation and direct	LSC LSC LSC	\$207
^{79}Se [B, γ]	5.0×10^{-6}	Separation	LSC	\$300
^{90}Sr [B]	1.0×10^{-6} 5.0×10^{-7} 1.0×10^{-9}	Separation Chemical separation Chemical separation and direct	BGPC BGPC BGPC	\$133
^{94}Nb [B, γ]	2.0×10^{-8} 1.0×10^{-8} 5.0×10^{-9} --	Gamma counter Direct Direct Gamma spectroscopy	Ge(Li) Ge(Li) HPGe HPGe	\$168

Table 2-1. MDA, Instruments and Cost of Analysis of Selected Category 3 Radionuclides. (4 sheets)

Radionuclide, major radiation type	Minimum detectable activity ($\mu\text{Ci/g}$)	Testing technique	Type of instrument	Cost of analysis*
^{99}Tc [β , γ]	2.0×10^{-5} 1.0×10^{-6} 1.2×10^{-8} -- --	Ion exchange Chemical separation Chemical separation and direct Proportional beta counter GPC	LSC Proportional LSC GPC --	\$183
^{129}I [β , γ]	2.0×10^{-6} 1.0×10^{-5} 5.0×10^{-9} --	Gamma counter Chemical separation Chemical separation and direct LSC	LEPD Germanium LE HPGe --	\$181
^{137}Cs [β , γ]	2.0×10^{-8} 5.0×10^{-7} 5.0×10^{-9} -- --	Gamma counter Chemical separation Direct Gamma spectroscopy HPGe gamma spectroscopy	Ge(Li) Proportional HPGe HPGe --	\$147
^{238}Pu [α , γ]	2.0×10^{-7} 5.0×10^{-8} 5.0×10^{-10} --	Ion exchange Chemical separation Chemical separation and direct Alpha spectroscopy	Alpha spectroscopy Alpha spectroscopy Alpha spectroscopy Si(Li)	\$250
^{239}Pu [α , γ]	2.0×10^{-7} 5.0×10^{-8} 5.0×10^{-10} -- --	Ion exchange Chemical separation Chemical separation and direct Alpha spectroscopy Alpha spectroscopy	Alpha spectroscopy Alpha spectroscopy Alpha spectroscopy Si(Li) --	Not available
^{240}Pu [α , γ]	2.0×10^{-7} 5.0×10^{-8} 5.0×10^{-10} --	Ion exchange Chemical separation Chemical separation and direct Alpha spectroscopy	Alpha spectroscopy Alpha spectroscopy Alpha spectroscopy Si(Li)	Not available
^{241}Pu [β]	1.0×10^{-5} 5.0×10^{-6} 5.0×10^{-10}	Ion exchange Chemical separation Chemical separation and direct	LSC Alpha spectroscopy LSC LSC	\$250

Table 2-1. MDA, Instruments and Cost of Analysis of Selected Category 3 Radionuclides. (4 sheets)

Radionuclide, major radiation type	Minimum detectable activity ($\mu\text{Ci/g}$)	Testing technique	Type of instrument	Cost of analysis*
^{241}Am [α , γ]	5.0×10^{-8} 5.0×10^{-8} 5.0×10^{-10} --	Gamma counter Chemical separation Chemical separation and direct Alpha spectroscopy	Ge(Li) Alpha spectroscopy Alpha spectroscopy Si(Li)	\$199
^{242}Cm [α , γ]	2.0×10^{-7} 5.0×10^{-8} 5.0×10^{-10} --	Ion exchange Chemical separation Chemical separation and direct Alpha spectroscopy	Alpha spectroscopy Alpha spectroscopy Alpha spectroscopy HPGe Si(Li)	\$208
^{244}Cm [α , γ]	2.0×10^{-7} 5.0×10^{-8} 5.0×10^{-10} -- --	Ion exchange Chemical separation Chemical separation and direct Alpha spectroscopy Alpha spectroscopy	Alpha spectroscopy Alpha spectroscopy Alpha spectroscopy Si(Li) --	Not available
Gross alpha NA	1.0×10^{-5} 1.0×10^{-5} 1.0×10^{-9} --	Concentrate and count Direct Dissolution and count Alpha spectroscopy	Alpha proportional Proportional GPC Si(Li)	\$200
Gross beta NA	1.0×10^{-5} 1.0×10^{-5} 7.0×10^{-9}	Concentrate and count Direct Dissolution and count	BGPC BGPC BGPC	\$200
Gross gamma NA	2.0×10^{-8} -- --	Gamma counter Gamma spectroscopy NaI(Tl) with SCA	Ge(Li) HPGe --	\$200

Table 2-1. MDA, Instruments and Cost of Analysis of Selected Category 3 Radionuclides. (4 sheets)

Radionuclide, major radiation type	Minimum detectable activity ($\mu\text{Ci/g}$)	Testing technique	Type of instrument	Cost of analysis*
Neutrons NA	--	--	--	Not available

*Approximate cost for budgetary purposes. These numbers are given for budgetary purposes. The cost may vary considerably depending on the form of waste, accuracy required and the number of samples. The cost also varies with the lab performing the analysis. Certain labs specialize certain radionuclides and may charge less of them.

BGPC = Beta gas flow proportional counter.

Ge(Li) = Germanium (lithium drifted).

HPGe = High-purity germanium.

LE = Low energy.

LEPD = Low-energy photon detector.

LSC = Liquid scintillation counter.

Si(Li) = Silicon (lithium drifted).

SCA = Single-channel analyzer.

Table 2-2. Sensitivities of Various Instruments.

Table 2-2a. Proportional Counter.

Isotopes	Type of radiation	Average MDA (mCi/g)
⁹⁰ Sr	Beta	1 E-6
Gross counting	Beta	1 E-5
Gross counting	Alpha	1 E-5

Table 2-2b. Alpha Spectroscopy.

Isotope	Average MDA (mCi/g)
²³⁸ Pu	1 E-6
¹³⁹ Pu	1 E-8
²⁴¹ Am	1 E-8
²⁴² Cm	1 E-8
²⁴⁴ Cm	1 E-8

Table 2-2c. Liquid Scintillation Counter.

Isotope	Average MDA (mCi/g)
³ H	5 E-4
¹⁴ C	5 E-6
⁶³ Ni	5 E-6
⁷⁹ Sc	5 E-6
⁹⁹ Tc	5 E-5
⁹⁹ Pu	1 E-5

Table 2-2d. Semiconductor.

Isotopes	MDA (mCi/g)
⁶⁰ Co	2 E-8
⁹⁴ Nb	2 E-8
¹³⁷ Cs	2 E-8
²⁴¹ Am	2 E-8
¹²⁹ I	2 E-8
Gross gamma	1 E-5

MDA = Minimum detectable activity.

Table 2-3. Common Radionuclides at Hanford. (2 sheets)

Radionuclide	Half-Life	DOT Values			Hanford Categories			NRC Limits			IAEA 1985	
		LSA (mCi/g)	A1 (Ci)	A2 (Ci)	1 (Ci/m ³)	3 (Ci/m ³)	A (Ci/m ³)	C (Ci/m ³)	A1 (Ci)	A2 (Ci)		
Ag(m)-110	249.8 days	.3	7	7	unlimited	not established	< or = 700	not established	10	10		
Am-241	432.7 yr.	.0001	8	.008	10 nCi/gm	100 nCi/gm	< or = 10 (nCi/gm)	10 (nCi/gm) < and <100 (nCi/gm)	50	.005		
Ba(m)-137	2.552 m.	.3	30	30	unlimited	not established	< or = 700	not established	N/A	N/A		
C-14	5730 yr.	.3	1000	60	.0006	8	< .80	.8 < and < 8	1000	50		
Cd-109	462 days	.3	1000	70	unlimited	not established	< or = 700	not established	1000	20		
Ce-141	32.5 days	.3	300	25	unlimited	not established	< or = 700	not established	200	10		
Ce-144	284.6 days	.3	10	7	unlimited	not established	< or = 700	not established	5	5		
Cm-242	162.8 days	.005	200	.2	2E+03(nCi/gm)	2E+04(nCi/gm)	< 2000 nCi/gm	<20000 nCi/gm & >2000 nCi/gm	1000	.2		
Co(m)-58	9.15 hr.	.3	1000	1000	unlimited	not established	< or = 700	not established	1000	1000		
Co(m)-60	10.47 m.	.3	7	7	300	none	< or = 700	not established	1000	1000		
Co-58	70.88 days	.3	20	20	unlimited	not established	< or = 700	not established	20	20		
Co-60	5.27 yr.	.3	7	7	300	none	< or = 700	not established	10	10		
Cr-51	27.7 days	.3	600	600	unlimited	not established	< or = 700	not established	800	800		
Cs(m)-134	2.91 hr.	.3	1000	10	unlimited	not established	< or = 700	not established	1000	200		
Cs-134	2.065 yr.	.3	10	10	unlimited	not established	< or = 700	not established	10	10		
Cs-137	30.17 yr.	.3	30	10	.02	4.6E+03	< or = 700	not established	50	10		
Eu-152	13.48 yr.	.3	20	10	N/A	N/A	< or = 1	< 4600 or > 44	20	20		
Eu-154	46.1 m.	.3	10	5	unlimited	not established	N/A	N/A	20	10		
Eu-156	8.59 yr.	.3	10	5	N/A	N/A	< or = 700	not established	20	10		
Eu-155	4.71 yr.	.3	400	60	unlimited	not established	< or = 700	not established	500	50		
Fe-55	2.73 yr.	.3	1000	1000	unlimited	not established	< or = 700	not established	1000	1000		
Fe-59	44.51 da's	.3	10	10	unlimited	not established	< or = 700	not established	20	20		
H-3	12.3 yr	.3	1000	1000	5E+00	none	< or = 40	not established	N/A	N/A		
I-125	60.1 days	.3	1000	70	unlimited	not established	< or = 700	not established	500	50		
I-129	15700000 yr.	.3	1000	2	1E-03	8E-02	< .008	< .08 and > .008	no limit	no limit		
I-131	8.04 days	.3	40	10	unlimited	not established	< or = 700	not established	80	10		
Mn-54	312.2 days	.3	20	20	unlimited	not established	< or = 700	not established	20	20		
Na-22	2.605 yr.	.3	8	8	unlimited	not established	< or = 700	not established	10	10		
Nb(m)-94	6.26 m.	.3	77	77	.0008	.2	< .02	< .2 and > .02	10	10		
Nb(m)-95	3.61 days	.3	20	20	unlimited	not established	< or = 700	not established	20	20		
Nb-94	20400 yr.	.3	100	100	.0008	.2	< .02	< .2 and > .02	10	10		
Nb-95	34.97 days	.3	20	20	unlimited	not established	< or = 700	not established	20	20		
Ni-59	76000 yr.	.3	1000	900	3.0E+00	2.2E+02	< or = 700	< 220 and > 22	1000	1000		
Ni-63	100 yr.	.3	1000	100	2E+00	7E+02	< or = 3.5	< 700 and > 70	1000	800		
Pb-212	10.64 hr.	.3	6	5	unlimited	not established	< or = 700	not established	8	8		
Pm-147	2.623 yr.	.3	1000	25	unlimited	not established	< or = 700	not established	1000	20		
Po-210	138.38 days	.005	200	.2	unlimited	not established	< or = 700	not established	1000	.5		
Pr(m)-144	7.2 m.	.3	1000	100	unlimited	not established	< or = 700	not established	N/A	N/A		
Pu-241	17.28 m.	.3	100	.1	5E+01 (nCi/gm)	3.5E+03(nCi/gm)	< 350 nCi/gm	<3500 nCi/gm & >350 nCi/gm	1000	.2		
Pu-241	14.4 yr.	.005	30	25	unlimited	not established	< or = 700	not established	50	5		
Ru-103	39.27 days	.3	10	7	unlimited	not established	< or = 700	not established	50	5		
Ru-106	1.02 yr.	.3	40	25	unlimited	not established	< or = 700	not established	50	5		
Sb-125	2.758 yr.	.3	40	40	unlimited	not established	< or = 700	not established	80	80		
Se-75	119.78 days	.3	1000	1000	unlimited	not established	< or = 700	not established	1000	1000		
Se-79	65000 yr.	.3	1000	90	.007	.07	N/A	N/A	1000	100		
Sm-151	90 yr.	.3	30	30	N/A	N/A	< or = 700	not established	50	50		
Sm-151	64.84 days	.3	30	30	unlimited	not established	< or = 700	not established	50	50		

Table 2-3. Common Radionuclides at Hanford. (2 sheets)

Radionuclide	Half-Life	DOT Values			Hanford Categories			NRC Limits			IAEA-1985	
		LSA (mCi/g)	A1 (Ci)	A2 (Ci)	1 (Ci/m3)	3 (Ci/m3)	A (Ci/m3)	C (Ci/m3)	A1 (Ci)	A2 (Ci)		
Sr-90	29.1 yr.	.005	10	.4	5E-03	7E+03	< or = .04	<7000 or >150	5	2		
Ta-182	114.4 days	.3	20	20	unlimited	not established	< or = 700	not established	20	10		
Tc(m)-99	6.01 hr.	.3	100	100	7E-03	3E+00	< .3	< 3 and > .3	200	200		
Tc-99	213000 yr.	.3	1000	25	7E-03	3E+00	< .3	< 3 and > .3	1000	20		
Te(m)-127	109 days	.3	300	20	unlimited	not established	< or = 700	not established	500	10		
Te-127	9.4 hr.	.3	300	20	unlimited	not established	< or = 700	not established	500	10		
Te-129	1.16 hr.	.3	100	20	unlimited	not established	< or = 700	not established	10	10		
Te(m)-129	33.6 days	.3	30	10	unlimited	not established	< or = 700	not established	10	10		
Th-232	14100000000 yr.	.3	unlimited	unlimited	N/A	N/A	N/A	N/A	no limits	no limit		
U-235	7040000000 yr.	.005	100	.2	N/A	N/A	N/A	N/A	no limits	100		
U-238	4470000000 yr.	.3	unlimited	unlimited	N/A	N/A	N/A	N/A	no limits	no limit		
Y(m)-90	3.19 hr.	.3	10	10	unlimited	not established	< or = 700	not established	5	5		
Y-90	2.67 days	.3	10	10	unlimited	not established	< or = 700	not established	5	5		
Zn-65	243.8 days	.3	30	30	unlimited	not established	< or = 700	not established	50	50		
Zr-95	64.02 days	.3	20	20	unlimited	not established	< or = 700	not established	20	20		

Table 2-4. Selected Radionuclides with Parent to Daughter Ratio.
(2 sheets)

Element and atomic number	Radionuclide	Parent/daughter ratio	
Actinium (89)	^{227}Ac	^{227}Th ^{223}Fr	0.9862 0.014
Americium (95)	^{241}Am	^{237}Np	1.00
Americium (95)	^{243}Am	^{239}Np	1.00
Barium (56)	^{133}Ba	^{133}Cs	1.00
Bismuth (83)	^{207}Bi	^{207}Pb	1.00
Bismuth (83)	^{210}Bi	^{210}Po	1.00
Californium (98)	^{249}Cf	^{245}Cm	1.00
Californium (98)	^{250}Cf	^{246}Cm	0.9992
Carbon (6)	^{14}C	^{14}N	1.00
Cesium (55)	^{135}Cs	^{135}Ba	1.00
Cesium (55)	^{137}Cs	$^{137\text{m}}\text{Ba}$ ^{137}Ba	0.946 0.054
Chlorine (17)	^{36}Cl	^{36}S ^{36}Ar	0.019 0.981
Cobalt (27)	^{60}Co	^{60}Ni	1.00
Curium (96)	^{243}Cm	^{239}Pu ^{243}Am	0.998 0.0024
Curium (96)	^{244}Cm	^{240}Pu	1.00
Curium (96)	^{245}Cm	^{241}Pu	1.00
Curium (96)	^{246}Cm	^{242}Pu	0.9997
Europium (63)	^{152}Eu	^{152}Gd ^{152}Sm	0.279 0.721
Europium (63)	^{154}Eu	^{154}Sm ^{154}Gd	0.0002 0.9998
Holmium (67)	^{166}Ho	^{166}Er	1.00
Hydrogen (1)	^3H	^3He	1.00
Iodine (53)	^{129}I	^{129}Xe	1.00
Iridium (77)	^{192}Ir	^{192}Pt ^{192}Os	0.953 0.047
Krypton (36)	^{85}Kr	^{85}Rb	1.00
Lead (82)	^{210}Pb	^{210}Bi	1.00
Neptunium (93)	^{237}Np	^{233}Pa	1.00

Table 2-4. Selected Radionuclides with Parent to Daughter Ratio.
(2 sheets)

Element and atomic number	Radionuclide	Parent/daughter ratio	
Nickel (28)	^{59}Ni	^{59}Co	1.00
Nickel (28)	^{63}Ni	^{63}Cu	1.00
Niobium (41)	$^{93\text{m}}\text{Nb}$	^{93}Nb	1.00
Niobium (41)	^{94}Nb	^{94}Mo	1.00
Plutonium (94)	^{238}Pu	^{234}U	1.00
Plutonium (94)	^{239}Pu	^{235}U	1.00
Plutonium (94)	^{240}Pu	^{236}U	1.00
Plutonium (94)	^{241}Pu	^{237}U ^{241}Am	2.5E-5 0.999
Plutonium (94)	^{242}Pu	^{238}U	1.00
Protactinium (91)	^{231}Pa	^{227}Ac	1.00
Radium (88)	^{226}Ra	^{222}Rn	1.00
Radium (88)	^{228}Ra	^{228}Ac	1.00
Rhenium (75)	^{186}Re	^{186}Os ^{186}W	0.940 0.060
Rhenium (75)	^{187}Re	^{187}Os	1.00
Rubidium (37)	^{87}Rb	^{87}Sr	1.00
Samarium (62)	^{151}Sm	^{151}Eu	1.00
Selenium (34)	^{79}Se	^{79}Br	1.00
Strontium (38)	^{90}Sr	^{90}Y	1.00
Technetium (43)	^{97}Tc	^{97}Mo	1.00
Technetium (43)	^{99}Tc	^{99}Ru	1.00
Thorium (90)	^{230}Th	^{226}Ra	1.00
Thorium (90)	^{232}Th	^{228}Ra	1.00
Uranium (92)	^{232}U	^{228}Th	1.00
Uranium (92)	^{233}U	^{229}Th	1.00
Uranium (92)	^{234}U	^{230}Th	1.00
Uranium (92)	^{235}U	^{231}Th	1.00
Uranium (92)	^{238}U	^{234}Th	1.00
Zirconium (40)	^{93}Zr	$^{93\text{m}}\text{Nb}$	1.00

Table 2-5. Gamma Dose Rates From Various Isotopic Sources.

Isotope	Half-life	Roentgens per hour per curie	
		(At 1 cm)	(At 1 ft)
¹⁹⁸ Au	2.69 days	2,480	2.65
⁷⁶ As	26.5 hours	2,300	2.46
⁸² Br	35.9 hours	14,600	15.62
⁵⁸ Co	71.0 days	5,300	5.67
⁶⁰ Co	5.25 years	12,800	13.69
¹³⁷ Cs	30.0 years	3,100	3.31
⁶⁴ Cu	12.8 hours	1,140	1.22
⁵⁹ Fe	45.1 days	6,800	7.28
⁷² Ga	14.1 days	12,300	13.16
²⁰³ Hg	47 days	1,100	1.18
¹²⁸ I	25 months	450	0.48
¹³⁰ I	12.5 hours	12,000	12.84
¹³¹ I	8.04 days	2,250	2.41
¹⁹² Ir	74.4 days	5,000	5.35
⁴² K	12.5 hours	1,520	1.63
⁵² Mn	5.7 days	19,700	21.08
⁵⁴ Mn	291 days	4,700	5.03
²² Na	2.6 years	11,600	12.41
²⁴ Na	15.0 hours	18,700	20.01
²²⁶ Ra	1,590 years	8,440	9.03
¹⁸² Ta	111 days	5,690	6.13
¹⁷⁰ Tm	127 days	40	0.04
⁶⁵ Zn	245 days	2,800	1.93

Table 2-6. General Methods for Selected Radionuclide Analysis.

Nuclide	Analysis	Nuclide	Analysis
³ H	Separation+LSC	¹⁸⁷ Re	X-ray diffraction
¹⁰ Be	Separation+BGPC or LSC	²¹⁰ Pb	Separation+LSC or LEPD
¹⁴ C	Separation+LSC	²⁰⁹ Po	Separation+AEA
¹⁴ C*	Separation+LSC	²²⁶ Ra	Separation+AEA
³⁶ Cl	GSA**	²²⁸ Ra	Separation+LSC or BGPC
⁴⁰ K	GSA**	²²⁷ Ac	Separation+AEA
⁶⁰ Co	GSA**	²²⁹ Th	Separation+AEA
⁵⁹ Ni	Separation+LEPD	²³⁰ Th	Separation+AEA
⁵⁹ Ni*	Separation+LEPD	²³² Th	Separation+AEA or MS
⁶³ Ni	Separation+LSC	²³¹ Pa	Separation+AEA or GSA
⁶³ Ni*	Separation+LSC	²³² U	Separation+AEA or MS
⁷⁹ Se	Separation+LSC	²³³ U	Separation+AEA or MS
⁹⁰ Sr	Separation+BGPC	²³⁴ U	Separation+AEA or MS
⁹³ Zr	Separation+LSC	²³⁵ U	Separation+AEA or MS
⁹⁴ Nb	GSA**	²³⁶ U	Separation+AEA or MS
⁹⁴ Nb*	GSA**	²³⁸ U	Separation+AEA or MS
⁹³ Mo	Separation+LEPD	²³⁷ Np	Separation+AEA or AGPC
⁹⁹ Tc	Separation+BGPC or LSC	²³⁸ Pu	Separation+MS or AGPC+AEA
¹⁰⁷ Pd	Separation+LSC	²³⁹ Pu	Separation+MS or AGPC+AEA
^{113m} Cd	Separation+LSC or BGPC	²⁴⁰ Pu	Separation+MS or AGPC+AEA
^{121m} Sn	Separation+LSC or BGPC	²⁴¹ Pu	Separation+MS or BGPC or LSC
¹²⁶ Sn	Separation+BPC, LSC, or LEPD	²⁴² Pu	Separation+MS or AGPC+AEA
¹²⁹ I*	Separation+GSA	²⁴⁴ Pu	Separation+MS or AGPC+AEA
¹³³ Ba	GSA (may require separation)	²⁴¹ Am	Separation+AEA or GSA
¹³⁵ Cs	Separation+GSA+MS	^{242m} Am	Separation+AEA
¹³⁷ Cs	GSA	²⁴³ Am	Separation+AEA or GSA
¹⁴⁷ Sm	Separation+AEA	²⁴³ Cm	Separation+AEA
¹⁵¹ Sm	Separation+LSC	²⁴⁴ Cm	Separation+AEA
¹⁵⁰ Eu	GSA	²⁴⁵ Cm	Separation+AEA
¹⁵² Eu	GSA	²⁴⁶ Cm	Separation+AEA
¹⁵⁴ Eu	GSA	²⁴⁷ Cm	Separation+AEA or GSA
¹⁵² Gd	Separation+MS	²⁴⁸ Cm	Separation+AEA

* Activated metal.

** May be obtained from gross sample GSA depending on the complexity of gamma spectrum.

AEA = Alpha energy analysis.

AGPC = Alpha gas proportional counter.

BGPC = Beta gas proportional counter.

Ge(Li) = Germanium (lithium) drifted detector.

GSA = Gamma spectral analysis (using detectors).

HPGe = High-purity germanium.

LEPD = Low-energy photon detector.

LSC = Liquid scintillation counter.

MS = Mass spectroscopy.

NaI(Tl) = Thallium activated sodium iodide.

ATTACHMENT 3

**U.S. NUCLEAR REGULATORY COMMISSION'S PROPOSED
CONCENTRATION AVERAGING AND ENCAPSULATION
TECHNICAL POSITION**

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WHC-EP-0655, Draft

ATTENTION: Commission Licensees

SUBJECT: Proposed Concentration Averaging and Encapsulation Technical
Position, Revision in Part

The regulation, "Licensing Requirements for Land Disposal of Radioactive Waste," 10 CFR Part 61, establishes a waste classification system based on the concentration of specific radionuclides contained in the waste. The regulation also states, at §§61.55(a)(8), that, "The concentration of a radionuclide [in waste] may be averaged over the volume of the waste, or weight of the waste if the units [on the values tabulated in the concentration tables] are expressed as nanocuries per gram" [text added for clarity].

A technical position on Radioactive Waste Classification was initially developed in 1983. This initial position included a section, "Concentration Volumes and Masses," which provided guidance to waste generators on the interpretation of §§61.55(a)(8) as it applies to a variety of different types and forms of low-level waste. Because of the desirability of attempting to achieve consistent waste classification practices among the Commission and Agreement State regulatory authorities, and because of the impact of waste classification positions on other programs (e.g., DOE's program to accept greater-than Class C waste), this proposed position expands upon, further defines, and replaces the guidance provided in Section C.3 of the original 1983 Technical Position. The recommendations and guidance provided in this proposed technical position are acceptable methods by which specific waste types may be classified against the tabulated concentration values defined in Tables 1 and 2 of §61.55.

The 1983 technical position also addressed three additional topics:

- (1) Materials accountability programs, including acceptable approaches for
 - (a) determining radionuclide concentrations and
 - (b) demonstrating compliance with waste classification requirements;

- (2) Determination and verification of radionuclide concentrations and correlations; and
- (3) Reporting of waste information on shipment manifests.

On the last topic, the Commission has recently proposed amendments to 10 CFR Parts 20 and 61 on low-level waste shipment manifest information and reporting (57 FR 14500 dated April 21, 1992). Following the outcome of the rulemaking process, a further revision of the 1983 technical position is planned.

The proposed technical position on concentration averaging and encapsulation, which represents a revision, in part, to the 1983 technical position, is enclosed. Comments on this technical position paper should be received prior to August 26, 1992, and sent to Chief, Rules and Directives Review Branch, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Questions may be referred to W. LaHS, U.S. Nuclear Regulatory Commission, Mail Stop 5E-2 OWFN, Washington, DC 20555, telephone (301) 504-2569. A final technical position will be issued following NRC staff review of the comments received. The information collections contained in the technical position have been approved under OMB number 3150-0014.

Richard L. Bangart, Director
Division of Low-Level Waste Management
and Decommissioning, NMSS

Enclosure: As stated

[Proposed] Technical Position on Concentration Averaging and Encapsulation

A. INTRODUCTION

The suitability of radioactive waste for near-surface disposal necessitates the proper classification of that waste. The regulation, Licensing Requirements for Land Disposal of Radioactive Waste," 10 CFR Part 61, establishes a waste classification system based on the concentration of specific radionuclides contained in the waste. The regulation also states, at §§61.55(a)(8), that, "The concentration of a radionuclide [in waste] may be averaged over the volume of the waste, or weight of the waste if the units [on the values tabulated in the concentration tables] are expressed as nanocuries per gram" [text added for clarity].

A technical position on Radioactive Waste Classification was initially developed in 1983. This initial position included a section, "Concentration Volumes and Masses," which provided guidance to waste generators on the interpretation of §§61.55(a)(8) as it applies to a variety of different types and forms of low-level waste. This position expands upon, further defines, and replaces the guidance provided in Section C.3 of this original 1983 Technical Position. The recommendations and guidance provided in this technical position are acceptable methods by which specific waste types may be classified against the tabulated concentration values defined in Tables 1 and 2 of §61.55.

B. DISCUSSION

Each shipment of radioactive waste to a licensed operator of a land disposal facility must be accompanied by a shipment manifest. In the manifest, the shipper/consignor-licensee must classify and clearly identify waste as Class A, Class B, or Class C, in accordance with §61.55. Determination of the classification of waste involves two considerations. First, consideration must be given to the concentration of long-lived radionuclides in the waste with respect to the values in Table 1 of §61.55. Second, consideration must be given to the concentration of short-lived radionuclides in the waste with respect to the values in Table 2 of §61.55.

Waste is determined to be generally unacceptable for near-surface disposal if it contains any of the radionuclides listed in Tables 1 and 2 of §61.55 in concentrations exceeding the applicable limits established for the individual radionuclides.

C. REGULATORY POSITION

Volumes and Masses for Determination of Concentration¹

Paragraph 61.55(a)(8) states that, for the purposes of waste classification, the concentration of a radionuclide may be averaged over the volume of the waste, or the weight of the waste for those concentration units in Table 1 that are expressed as nanocuries per gram. This requirement needs interpretation due to different types and forms of low-level waste. Principal considerations include: (1) whether the distribution of radionuclides within the waste can be considered to be reasonably homogeneous; (2) whether the "as-generated" waste has been processed and, if so, what is the mass/volume of the processed waste; (3) whether the waste includes mixtures of various waste types; (4) whether the waste includes mixtures of the same waste type but at differing radioactivity concentration levels; and (5) whether the volume of the waste container, if used to represent the volume of the waste, is significantly larger than the volume of the waste itself, and the differential volume consists largely of void space.

With respect to the above considerations many waste streams may be considered to be homogeneous for purposes of waste classification. Such waste streams would include, for example, spent ion-exchange resins, filter media, solidified liquid, or contaminated soil. Contaminated trash waste streams, which are composed of a variety of miscellaneous materials, may be considered homogeneous for purposes of waste classification when placed in containers. To the extent that contaminated trash and contaminated soil are reasonably packaged in a disposal container,

¹ It should be noted that waste acceptance requirements for Agreement State disposal facilities (e.g., requirements for encapsulated wastes or activated metals) may differ from this guidance. Waste generators should consult specific disposal site license conditions prior to classifying these wastes.

the volumetric-averaged concentration of radionuclides in these waste streams can be based on the fill-volume of the container. Alternatively, the volume of the container can be calculated from the weight of the container contents divided by the density of the contents. A representative density based on a representative distribution of materials as they occur in waste may be used.

For spent ion-exchange resins and filter media, care needs to be taken to differentiate between the volume of the waste form and the volume of the waste container. Although free volume should be reduced to the extent practicable, these wastes may be contained within a disposable demineralizer or liner with some waste-free volume. In such cases, the volume or weight used for waste classification should be the displaced volume or dewatered weight of the resins or filter media rather than the gross internal volume of the container or the weight of the resins prior to dewatering.

Mixing of similar homogeneous waste streams

Mixing of similar homogeneous waste streams (e.g., spent ion-exchange resins or contaminated soils) is permissible. However, mixing with the sole intent to dilute radionuclide concentrations to lower a waste's classification is not permitted. Under this guideline the classification of the mixture using the sum of fractions rule specified in §61.55 should be based on either (a) the highest nuclide concentrations in any of the individual waste streams contributing to the mixture; or (b) the volumetric- or weight-averaged nuclide concentrations of the mixture, provided that the concentrations of the individual waste stream contributors to the mixture are within a factor of 10 of the concentration of the resulting mixture. In either case, in accordance with Section III of Appendix F to 10 CFR Part 20, the licensee classifying the waste must have in place a quality control program to ensure compliance with the waste classification provisions of §61.55. As part of this quality control program, if the classification of a mixture is based on the volumetric- or weight-averaged nuclide concentration of the mixture, as allowed under (b) above, the licensee responsible for classification of the waste should prepare, retain with manifest documentation, and have available for inspection, a record

documenting the licensee's waste classification analyses. The record or analyses should show that the mixing was not undertaken solely to lower the classification of a waste stream contributing to the mixture.

Solidified and absorbed liquids

Classification of liquids or ion-exchange resins solidified in a manner to achieve homogeneity should be based on the volume or mass of the solidified mass. Because absorbed liquid wastes do not appreciably bind nuclides, classification of absorbed liquids should be based on the volume or mass of the liquids prior to absorption.

Mixing of activated or contaminated components

For large components such as contaminated pumps, heat exchangers, or neutron-activated components, the waste classification volume or weight should be taken to be the total weight or displaced volume of the component (i.e., void volume subtracted from the envelope volume). Mixtures of activated or contaminated components in a disposal container are permissible. In this case, because of the non-homogeneity of the waste, the classification of the combined waste within the disposal container, for the predominantly gamma-emitting nuclides (e.g., Co-60, Nb-94, Cs-137/Ba-137) should be based upon the highest average concentration in any of the contaminated/activated components (including individual sections or pieces of components that may result from operational considerations, e.g., packaging and transportation). For all other nuclides, considered individually, the classification of the combined waste should be based on the volumetric- or weight-averaged concentration of the combined components, provided that all the concentrations within the individual components in the container are within a factor of 10 of the averaged concentration.

For activated or contaminated component wastes containing both gamma- and non-gamma emitting radionuclides, otherwise complying with the above guidance, the sum of the fractions rule described in §61.55(a)(7) would apply. Under this guidance, the sum of the fractions rule would involve summing (1) the fraction of the appropriate §61.55 Table 1 or 2 concentration values associated with the component, piece, or section containing the highest concentrations of gamma-emitting radionuclides and (2) the average fraction of concentration values

associated with each of the non-gamma-emitting radionuclides associated with all components, pieces, or sections in the disposal container. In either case, in accordance with Section III of Appendix F to 10 CFR Part 20, the licensee classifying the mixture of contaminated or activated components must have in place a quality control program to ensure compliance with the waste classification provisions of §61.55. As part of this quality control program, if the classification of the mixture of contaminated or activated components is based on the volumetric- or weighted-averaged nuclide concentrations in the components as a whole, as allowed above, the licensee responsible for classification of the waste should prepare, retain with manifest documentation, and have available for inspection, a record documenting the licensee's waste classification analyses. The record or analyses should show that the averaging of concentrations over the components as a whole was not undertaken solely to lower the classification of any of the individual components.

Example: Three equally sized (by volume) pieces of a control rod blade are contained in a liner. The pieces respectively contain concentrations of Nb-94 which are 0.8, 0.7, and 0.5 of the Table 1 value for Nb-94 of 0.2 curies per cubic meter. The pieces also contain Ni-59 in concentrations of 44, 22 and 11 curies per cubic meter. These concentrations are 0.2, 0.1, and 0.05 of the Table 1 value for Ni-59 of 220 curies per cubic meter, respectively. The Ni-59 concentrations in the three pieces are all within a factor of 10 of the average concentration of Ni-59 in the three pieces considered together (i.e., 26 curies per cubic meter). The sum of the fractions for the pieces in the liner would be calculated by summing 0.8 (the fraction for the highest gamma-emitting piece) and 0.12 (the fraction for the non gamma-emitting activity averaged over all three pieces). The sum, 0.92, would qualify the liner as containing Class C waste.

Mixing of cartridge filters

The classification of disposal containers containing multiple cartridge filters should follow the guidance for mixing of activated or contaminated components. Because of the non-homogeneity of the waste, the classification of combined cartridge filters containing the predominately gamma-emitting nuclides (e.g., Co-60, Nb-94, Cs-137) should be based upon the highest average concentration in

any of the individual filters contained in the disposal container. For all other nuclides, considered individually, the classification of the combined cartridge filters should be based on the volumetric- or weight-averaged concentration within the combined filters, provided that all the concentrations within the individual filters in the container are within a factor of 10 of the averaged concentration.

For cartridge filter wastes containing both gamma- and non gamma-emitting radionuclides, otherwise complying with the above guidance, the sum of the fractions rule described in §61.55(a)(7) would apply. Under this guidance the sum of the fractions rule would involve summing (1) the fraction of the appropriate §61.55 Table 1 or 2 concentration values associated with the filter containing the highest concentrations of gamma-emitting radionuclides, and (2) the average fraction of concentration values associated with each of the non gamma-emitting radionuclides associated with all the filters in the disposal container. See example under, "Mixing of activated or contaminated components." In either case, in accordance with Section III of Appendix F to 10 CFR Part 20, the licensee classifying the mixture of cartridge filters must have in place a quality control program to ensure compliance with the waste classification provisions of §61.55. As part of this quality control program, if the classification of the mixture of cartridges filters is based on the volumetric- or weighted-averaged nuclide concentrations in the combined filters as allowed above, the licensee responsible for classification of the waste should prepare, retain with manifest documentation, and have available for inspection, a record documenting the licensee's waste classification analyses. The record or analyses should show that the averaging of concentrations over the the combined filters was not undertaken solely to lower the classification of any individual filter.

Waste in high-integrity containers

In the case of cartridge filters stabilized by emplacement within high integrity containers, the volume or weight used to determine waste classification should be calculated over the displaced volume or weight of the cartridge filter itself rather than the gross volume or weight of the container. Similarly, the volume and mass considered for purposes of waste classification of dewatered ion-exchange resins and filter media placed into high integrity containers should be the

volume and mass of the contained waste. In both these cases, disposal in a high integrity container is not considered to alter the as-buried concentrations of radioactivity.

Encapsulation of solid material

For routine wastes such as filter cartridges or sealed sources centered in an encapsulated mass, classification may be based on the overall volume of the final solidified mass, provided that: (1) the volume and attributes of the encapsulated waste comply with the constraints established in Appendix C; (2) the solidified mass meets the waste form structural stability criteria of §61.56 for Class B and Class C waste; and (3) the disposal unit containing the encapsulated mass is segregated from disposal units containing class A wastes which do not meet the structural stability requirements in §§61.56(b). Under the above provisions, additional protection is provided through the shielding, lack of dispersibility, or identifiability of the encapsulated mass; and, for Class C encapsulated waste, by the land disposal facility operational requirements in §§61.52(a)(2). This additional protection has been considered in the classification position developed in Appendix C and has been balanced against the hypothetical radiological impact caused by potential interactions between assumed intruders and the encapsulated mass.

Mixing of dissimilar waste streams

Classifications may also be needed in situations involving a mixture of miscellaneous waste materials -- e.g., situations in which contaminated valves, piping, or similar components are placed in containers mixed with other trash; or miscellaneous trash or components are mixed with other radioactive materials such as resins or filters. In such cases, because of potential differences in waste interactions with the disposal environment, waste classification involving averaging the total activity over the total volume or mass of the waste in the container will be accepted provided that the classification of the mixture is not lower than the highest waste classification of any individual components of the mixture. This provision does not apply to small concentrated microcurie sources of waste such as check sources or gauges which may be mixed with contaminated trash waste streams. The activity of such check sources or gauges may be averaged over the trash volume.

Alternative provisions

Under §61.58, the Commission, upon request, may authorize other provisions for the classification and characteristics of waste on a specific basis if, after evaluation of the specific characteristics of the waste, disposal site and method of disposal, it finds reasonable assurance of compliance with the performance objectives in Subpart C of 10 CFR Part 61.

Alternatives to the determination of radionuclide concentrations for waste classification purposes, other than those defined in this technical position, may be considered acceptable. If the approaches in this technical position are incorporated as disposal facility license conditions, alternatives would require the approval of or otherwise be authorized by the NRC or Agreement State regulatory agency (e.g., the disposal facility may need to apply for a license amendment from the NRC or Agreement State regulatory agency). The alternatives could be considered acceptable if (1) reasonable assurance is found that the alternative classification approach will result in compliance with the performance objectives in Subpart C of 10 CFR Part 61, and (2) the concentration of the radionuclide is determined to be based on the volume or weight of the waste as defined in §§61.55 (a)(8).

Table 1 provides a summary of the primary aspects of the above guidance.

Table 1 Volumes and Masses for Determination of Concentration

<u>Waste Type</u>	<u>Allowable Classification Volume or Mass</u>
Contaminated trash or soil	Reasonable fill volume of container/mass of waste (<10% void) [±]
Absorbed liquids	Volume/mass of liquid prior to absorption
Solidified liquids	Volume/mass of solidified mass
Solidified ion-exchange resins	Volume/mass of solidified mass*
Dewatered ion-exchange resins in high integrity containers	Displaced volume/dewatered mass of ion-exchange resins
Filter cartridges in high integrity containers	Displaced volume/mass of filters [±]
Activated components	Full density volume/mass of components [±]
Encapsulated filter cartridges or sealed sources	Volume/mass of solidified mass when encapsulated in accordance with the guidance provided in Appendix C

*If homogeneity maintained in solidified mass

[±]Mixtures of waste streams subject to additional guidance defined in text.

APPENDIX C

POSITION ON ENCAPSULATION OF SEALED SOURCES AND OTHER
SOLID LOW-LEVEL RADIOACTIVE WASTES

Encapsulation can mitigate dispersion of waste and can also provide additional shielding to limit external radiation fields. If provided to meet the stability criteria of §61.56(b) and coupled with the technical requirements for land disposal facilities in subpart D of 10 CFR Part 61 (specifically, §61.52), encapsulation will limit the impacts from both (1) the direct exposure, inhalation, and ingestion pathways associated with potential intruder-waste interactions and (2) the potential exposure pathways to individual members of the public involving groundwater and agricultural products.

The amount of credit allowed for encapsulation, though, needs to be limited so that extreme measures cannot be taken solely for the purposes of dilution. To be consistent with the NRC's policy on volume reduction and to limit extremely large "point sources" of radioactivity in the disposal site, limits on minimum and maximum encapsulated waste volumes and masses, nuclide activities and radiation levels are established.

These bounding conditions are as follows:

- (1) The minimum solidified volume or mass for encapsulation should be that which can reasonably be expected to increase the difficulty of an inadvertent intruder moving the waste by hand following the loss of institutional control over the disposal site. This minimum size or weight should preclude any significant movement without the assistance of mechanical equipment.
- (2) The maximum solidified volume or mass for encapsulation (from which concentrations are determined) should be 0.2m³ or 500Kg (typical 55-gallon drum). Larger volumes and masses may be used for encapsulation but no credit beyond the volume or mass indicated should be considered when determining waste concentrations.

Note: The bounding volumes and weights in (1) and (2) will ensure that the potential radiological impacts from encapsulated-discrete source disposals are within the envelope of impacts which would be calculated if the radioactivity was homogeneously distributed throughout the encapsulating media.

- (3) The maximum amount of gamma-emitting radioactivity (e.g., Cs-137/Ba-137, Nb-94) or radioactive material that should be encapsulated is that which, if credit is taken for a 500-year decay period, would result in a dose rate of less than 0.2μSv/hr (0.02mrem/hr) on the surface of the encapsulating media (refer to footnote 1, following page). The calculation to

determine compliance with this criterion may consider the minimum attenuation factor provided by the shielding properties of the encapsulating media but, in no case, should this factor exceed an attenuation factor that would be provided by 15 inches of concrete encapsulating material (refer to footnote 2). Furthermore, the maximum Cs-137/Ba-137 gamma-emitting activity that should be encapsulated in a single disposal container is 1.1 TBq (30 curies) (refer to footnote 3).

- (4) The maximum amount of any radionuclide that should be encapsulated in a single disposal container intended for disposal at a commercial LLW disposal facility is that which, when averaged over the waste and the encapsulating media, does not exceed the maximum concentration limits for Class C waste as defined in Tables 1 and 2 of §61.55 (refer to footnote 4, following page).
- (5) In all cases when a discrete source of radioactive solid waste is encapsulated, written procedures should be established to ensure that the radiation source(s) is reasonably centered within the encapsulating media.

Footnotes

- 1 Presuming the inadvertent intruder has contact with the encapsulated waste as generally defined in the intruder-agricultural scenario (reference NUREG-0945), this dose rate would result in an annual exposure of less than 1/10 of that which would be received if the radioactivity was homogenized over a soil volume equivalent to the encapsulating media. This factor of 10 takes into consideration the possibility that the intruder may be exposed to both (1) other encapsulated waste which may be excavated from the disposal trenches without mixing with uncontaminated cover material and (2) other homogenized waste.
- 2 The 15 inches of concrete shielding is that necessary to ensure that an encapsulated 30 Ci source of Cs-137/Ba-137 could satisfy the 0.2 μ Sv/hr (0.02 mrem/hr) dose criteria (bounding case). Additional shielding thicknesses from the encapsulating or disposal unit materials could be expected to be in existence after 500 years, but because of uncertainties regarding shielding orientations and effectiveness following this time period, no greater credit is considered appropriate. Furthermore, the attenuation of dose provided by this limited amount of shielding is such that, absent any shielding, intruder doses would still be expected to be less than doses which would be received if the radioactivity was homogenized over a soil volume equivalent to the encapsulating media.
- 3 The 30-curie limit on any encapsulated, gamma-emitting radionuclide or radioactive material results from the application of the dose rate and shielding criteria in bounding condition 3 for waste containing Cs-137, the most prevalent gamma-emitting isotope for which encapsulation may be appropriate. The 30-curie limit has been selected to provide assurance that intruders will not receive doses (e.g., from larger activities of waste emitting radiation at lower energies) greater than 1/10 of that which would be received if the radioactivity was homogenized over a soil volume equivalent to the encapsulating media.

- 4 Reasserting the applicability of Tables 1 and 2 of §61.55 emphasizes that, for alpha- or beta-emitting radionuclides, encapsulation under bounding conditions 1 through 3 does not provide an exemption to the classification tables in the regulations. As a result, the largest activity of transuranic, other than Pu-241 and Cm-242, which can be encapsulated in 0.2m³ is about 1.1GBq (30 mCi), presuming the density of the encapsulating mass is 1.3 gm/cm³. The density of the material used for encapsulating alpha- and beta-emitting radionuclides should not exceed 2.5gm/cm³.

ATTACHMENT 4

ANALYTICAL DATA QUALITY

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ANALYTICAL DATA QUALITY

Several variables must be considered in the review of a radioanalytical laboratory's quality control program. For a sample to be analyzed, precise qualitative and quantitative measurements must be made. Prospective laboratories could be evaluated by examining the following:

- Facilities
- Equipment calibration practices
- Analytical and data handling procedures
- Reporting data
- Control standards.

4-1 FACILITIES

A facility description given in most quality control plans will address the following questions to demonstrate that the facilities are adequate for the analysis of radioisotopes.

- Is there sufficient shielding around the counting equipment so that interference from other samples is eliminated?
- Is the reagents purity acceptable?
- Does the method for cleaning glassware meet the requirements and eliminate the possibility of contamination?
- What is the quality of the compressed air?
- Is there an adequate electrical system?
- What type of low background material is used in construction?
- Is there adequate ventilation?
- Is the air temperature and humidity well regulated with positive air pressure applied in the counting laboratory?

The laboratory also requires personnel with various degrees and skills. The waste generator's quality control plan reviews the specific training given to personnel performing the work. Specific procedures for competence and capability verification should be in place for new laboratory analysts as well as requalification of present personnel. Personnel should know the following information:

- The sample processing system and how it works
- Initial treatment of sample
- Routine laboratory equipment use
- Glassware cleaning
- Equipment maintenance.

4-2 EQUIPMENT CALIBRATION PRACTICES

There are generally a wide variety of equipment currently in use in radioanalytical laboratories. In an effective quality control plan, the counting equipment is listed with calibration requirements and a routine calibration schedule. A procedure for tagging any malfunctioning equipment to prevent use should be established. A preventative maintenance schedule represents a quality control plan that ensures the reliability of the counting equipment.

4-3 ANALYTICAL PROCEDURE

A specific procedure is involved in the receipt of the sample. At the start of analysis, verification of the sample integrity determines if a violation of the maximum permissible activity for the U.S. Nuclear Regulatory Commission license has occurred. A laboratory dealing with a large volume of samples can have difficulty achieving an accurate flow of data. Quality of data is directly related to the methods, equipment, reagents, and chemicals as well as personnel training. Close attention should be paid to the particular methods involved in specific radionuclide processing. Methods should follow industry standards established by the American Society for Testing and Materials, the U.S. Environmental Protection Agency, and the U.S. Nuclear Regulatory Commission. A procedure for radioisotope analysis reviews the following questions.

- What levels can be measured with precision and accuracy with known sources of interference?
- What equipment and skills are necessary to complete this analysis?
- What amount of sample is needed?
- What information is available to indicate the validity of this method?

The purity of reagents and chemicals used is the most important factor for the reduction of data error. These samples should be either ACS grade, analytic grade, or spectral grade organic solvents. Chemicals and reagents should be checked closely for deterioration and possible contamination.

An effective laboratory must be able to duplicate its analytical results internally. The procedure should be outlined in the quality control plan. If consistency of the laboratory's results isn't shown, the laboratory should be considered unsuitable.

The most effective type of duplication analysis is the use of a blind sample. The blind sample can be either a standard or a duplicate sample. The blind sample is then introduced into the workload. This procedure denies any prior knowledge of the analyst which could possibly influence the test results. This is not easily achieved in small laboratories where the analysts are aware of all laboratory activities.

Small laboratories base the duplicate analysis pregrain on random samples. This procedure calls for 1 out of every 10 samples to be submitted for each process. These samples will be selected randomly for duplication analysis. All of the samples are then analyzed simultaneously. Using duplicates from a homogeneous mixture with no variations would ensure an effective program. The results of the duplication analysis would be a partial demonstration of the laboratory's capabilities of producing reliable data. Interactive participation with other radioanalytical laboratories is the most efficient way to demonstrate precision and accuracy. Comparison of the results of two identical samples given to two independent laboratories make the best evaluation possible.

A set procedure that is available for verification of the obtained results should validate the data produced. An effective quality control plan for this should contain all of these stipulations.

4-4 REPORTING DATA

Close attention to the significant figures reported and the error minimization computational process is important. Generally, a laboratory reports its findings in less than four significant digits. The reason for this is truncation error and round-off occurring in fractions, irrational numbers (i.e., square root of two), transcendental numbers, and functions that are either exponential, logarithmic, or trigonometric. These truncations have a great potential of producing inaccurate results. By following standard practices a laboratory minimizes the accumulation of these errors.

4-5 CONTROL STANDARDS

To make a quantitative as well as an qualitative analysis, it is necessary that reference material be available. Radioactive material standards used for this purpose have to meet the following criteria:

- Traceable to the National Institute of Standards and Technology or another certified analyst
- Isotope identification and activity with error
- Date of assay
- Half-life
- Mass and volume of reference material.

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ATTACHMENT 5

PARTIAL LIST OF COMMERCIAL ANALYTICAL LABORATORIES

This listing contains the names of some of the laboratories who have responded to the Hanford Site survey. In no way is this list an endorsement of any laboratory.

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PARTIAL LIST OF COMMERCIAL ANALYTICAL LABORATORIES

Addresses of Commercial Analytical Laboratories Who
Responded to the Hanford Site Survey. (2 sheets)

Name of Laboratory: Atlan-Teck Inc.
Name and Title of Contact: Bob Sirpack
Telephone: (404) 442-1067 FAX: (404) 442-8445
Mailing Address: 1345 Hembree Road
City: Roswell State: GA ZIP: 30076

Name of Laboratory: Chem-Nuclear Services
Name and Title of Contact: David Lee
Telephone: (803) 259-1781 FAX:
Mailing Address:
City: State: ZIP:

Name of Laboratory: Data Chem
Name and Title of Contact: Randy Potter (Jim Perkins)
Telephone: (801) 266-7700 FAX: (801) 268-9992
Mailing Address: 960 Levoy Drive
City: Salt Lake City State: UT ZIP: 84123

Name of Laboratory: EcoTek LSI
Name and Title of Contact: Craig Johnson
Telephone: (404) 244-0827 FAX: (404) 243-5355
Mailing Address: 3342 International Park Drive
City: Atlanta State: GA ZIP: 30316

Name of Laboratory: E-Cubed
Name and Title of Contact: Clayton Odum
Telephone: (801) 581-8499 FAX: (801) 581-8692
Mailing Address: P.O. Box 58023
City: Salt Lake City State: UT ZIP: 84158

Name of Laboratory: Halburton NUS
Name and Title of Contact: Ruth Volk
Telephone: (412) 747-2500 FAX: (412) 747-2684
Mailing Address: 2 Marque Plaza Suite 200 5313 Campbelle Run Road
City: Pittsburgh State: PA ZIP: 15204

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Addresses of Commercial Analytical Laboratories Who
Responded to the Hanford Site Survey. (2 sheets)

Name of Laboratory: Isotopic Analysis
Name and Title of Contact: John Harris
Telephone: (918) 622-2464 FAX: None
Mailing Address:
City: State: ZIP:

Name of Laboratory: IT Corp.
Name and Title of Contact: Lance Ydel
Telephone: (509) 375-3131 FAX: (509) 375-5590
Mailing Address:
City: Richland State: WA ZIP: 99352

Name of Laboratory: TCT
Name and Title of Contact: Robert Houser
Telephone: (314) 426-0880 FAX: (314) 426-4212
Mailing Address: 1908 Innerbelt Business Center Dr.
City: St. Louis State: MO ZIP: 63114

Name of Laboratory: Teledyne Isotopes
Name and Title of Contact: David Martin
Telephone: (201) 664-7070 FAX: (201) 664-5586
Mailing Address: 50 Van Buren Avenue
City: West Wood State: NJ ZIP: 07675

Name of Laboratory: TMA/NORCAL
Name and Title of Contact: Dan Stevermer (David Rodiers)
Telephone: (510) 235-2633 FAX: (510) 235-0438
Mailing Address: 2030 Wright Avenue
City: Richmond State: CA ZIP: 94804-00400

ATTACHMENT 6

**U.S. NUCLEAR REGULATORY COMMISSION'S
LOW-LEVEL WASTE CLASSIFICATION**

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Nuclear Regulatory Commission

§ 61.55

§ 61.53 Environmental monitoring.

(a) At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period.

(b) The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of subpart C may not be met.

(c) During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary.

(d) After the disposal site is closed, the licensee responsible for post-operational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary.

§ 61.54 Alternative requirements for design and operations.

The Commission may, upon request or on its own initiative, authorize provisions other than those set forth in §§ 61.51 through 61.53 for the segregation and disposal of waste and for the design and operation of a land disposal facility on a specific basis, if it finds reasonable assurance of compliance with the performance objectives of subpart C of this part.

§ 61.55 Waste classification.

(a) Classification of waste for near surface disposal.

(1) *Considerations.* Determination of the classification of radioactive waste involves two considerations. First, consideration must be given to the concentration of long-lived radionuclides (and their shorter-lived precursors) whose potential hazard will persist long after such precautions as institutional controls, improved waste form, and deeper disposal have ceased to be effective. These precautions delay the time when long-lived radionuclides could cause exposures. In addition, the magnitude of the potential dose is limited by the concentration and availability of the radionuclide at the time of exposure. Second, consideration must be given to the concentration of shorter-lived radionuclides for which requirements on institutional controls, waste form, and disposal methods are effective.

(2) *Classes of waste.* (i) Class A waste is waste that is usually segregated from other waste classes at the disposal site. The physical form and characteristics of Class A waste must meet the minimum requirements set forth in § 61.56(a). If Class A waste also meets the stability requirements set forth in § 61.56(b), it is not necessary to segregate the waste for disposal.

(ii) Class B waste is waste that must meet more rigorous requirements on waste form to ensure stability after disposal. The physical form and characteristics of Class B waste must meet both the minimum and stability requirements set forth in § 61.56.

(iii) Class C waste is waste that not only must meet more rigorous requirements on waste form to ensure stability but also requires additional measures at the disposal facility to protect against inadvertent intrusion. The physical form and characteristics of Class C waste must meet both the minimum and stability requirements set forth in § 61.56.

(iv) Waste that is not generally acceptable for near-surface disposal is waste for which form and disposal methods must be different, and in general more stringent, than those specified for Class C waste. In the absence

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of specific requirements in this part, such waste must be disposed of in a geologic repository as defined in part 60 of this chapter unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the Commission.

(3) Classification determined by long-lived radionuclides. If radioactive waste contains only radionuclides listed in Table 1, classification shall be determined as follows:

(i) If the concentration does not exceed 0.1 times the value in Table 1, the waste is Class A.

(ii) If the concentration exceeds 0.1 times the value in Table 1 but does not exceed the value in Table 1, the waste is Class C.

(iii) If the concentration exceeds the value in Table 1, the waste is not generally acceptable for near-surface disposal.

(iv) For wastes containing mixtures of radionuclides listed in Table 1, the total concentration shall be determined by the sum of fractions rule described in paragraph (a)(7) of this section.

TABLE 1

Radionuclide	Concentration curies per cubic meter
C-14.....	8
C-14 in activated metal.....	80
Ni-59 in activated metal.....	220
Nb-94 in activated metal.....	0.2
Tc-99.....	3
I-129.....	0.08
Alpha emitting transuranic nuclides with half-life greater than five years.....	1,100
Pu-241.....	3,500
Cm-242.....	20,000

¹ Units are nanocuries per gram.

(4) Classification determined by short-lived radionuclides. If radioactive waste does not contain any of the radionuclides listed in Table 1, classification shall be determined based on the concentrations shown in Table 2. However, as specified in paragraph (a)(6) of this section, if radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A.

(i) If the concentration does not exceed the value in Column 1, the waste is Class A.

(ii) If the concentration exceeds the value in Column 1, but does not exceed the value in Column 2, the waste is Class B.

(iii) If the concentration exceeds the value in Column 2, but does not exceed the value in Column 3, the waste is Class C.

(iv) If the concentration exceeds the value in Column 3, the waste is not generally acceptable for near-surface disposal.

(v) For wastes containing mixtures of the nuclides listed in Table 2, the total concentration shall be determined by the sum of fractions rule described in paragraph (a)(7) of this section.

TABLE 2

Radionuclide	Concentration, curies per cubic meter		
	Col. 1	Col. 2	Col. 3
Total of all nuclides with less than 5 year half life.....	700	(¹)	(¹)
H-3.....	40	(¹)	(¹)
Co-60.....	700	(¹)	(¹)
Ni-63.....	3.5	70	700
Ni-63 in activated metal.....	35	700	7000
Sr-90.....	0.04	150	7000
Cs-137.....	1	44	4600

¹ There are no limits established for these radionuclides in Class B or C wastes. 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 2 determine the waste to the Class C independent of these nuclides.

(5) Classification determined by both long- and short-lived radionuclides. If radioactive waste contains a mixture of radionuclides, some of which are listed in Table 1, and some of which are listed in Table 2, classification shall be determined as follows:

(i) If the concentration of a nuclide listed in Table 1 does not exceed 0.1 times the value listed in Table 1, the class shall be that determined by the concentration of nuclides listed in Table 2.

(ii) If the concentration of a nuclide listed in Table 1 exceeds 0.1 times the value listed in Table 1 but does not exceed the value in Table 1, the waste shall be Class C, provided the concen-

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shall be Class C, provided the concentration of nuclides listed in Table 2 does not exceed the value shown in Column 3 of Table 2.

(6) Classification of wastes with radionuclides other than those listed in Tables 1 and 2. If radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A.

(7) The sum of the fractions rule for mixtures of radionuclides. For determining classification for waste that contains a mixture of radionuclides, it is necessary to determine the sum of fractions by dividing each nuclide's concentration by the appropriate limit and adding the resulting values. The appropriate limits must all be taken from the same column of the same table. The sum of the fractions for the column must be less than 1.0 if the waste class is to be determined by that column. Example: A waste contains Sr-90 in a concentration of 50 Ci/m³ and Cs-137 in a concentration of 22 Ci/m³. Since the concentrations both exceed the values in Column 1, Table 2, they must be compared to Column 2 values. For Sr-90 fraction $50/150=0.33$; for Cs-137 fraction, $22/44=0.5$; the sum of the fractions $=0.83$. Since the sum is less than 1.0, the waste is Class B.

(8) *Determination of concentrations in wastes.* The concentration of a radionuclide may be determined by indirect methods such as use of scaling factors which relate the inferred concentration of one radionuclide to another that is measured, or radionuclide material accountability, if there is reasonable assurance that the indirect methods can be correlated with actual measurements. The concentration of a radionuclide may be averaged over the volume of the waste, or weight of the waste if the units are expressed as nanocuries per gram.

[47 FR 57463, Dec. 27, 1982, as amended at 54 FR 22583, May 25, 1989]

§ 61.56 Waste characteristics.

(a) The following requirements are minimum requirements for all classes of waste and are intended to facilitate handling at the disposal site and provide protection of health and safety of personnel at the disposal site.

(1) Waste must not be packaged for disposal in cardboard or fiberboard boxes.

(2) Liquid waste must be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid.

(3) Solid waste containing liquid shall contain as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume.

(4) Waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.

(5) Waste must not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste. This does not apply to radioactive gaseous waste packaged in accordance with paragraph (a)(7) of this section.

(6) Waste must not be pyrophoric. Pyrophoric materials contained in waste shall be treated, prepared, and packaged to be nonflammable.

(7) Waste in a gaseous form must be packaged at a pressure that does not exceed 1.5 atmospheres at 20°C. Total activity must not exceed 100 curies per container.

(8) Waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard from the non-radiological materials.

(b) The requirements in this section are intended to provide stability of the waste. Stability is intended to ensure that the waste does not structurally degrade and affect overall stability of the site through slumping, collapse, or other failure of the disposal unit and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste.

(1) Waste must have structural stability. A structurally stable waste form will generally maintain its physical dimensions and its form, under the expected disposal conditions such as weight of overburden and compaction equipment, the presence of moisture,

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and microbial activity, and internal factors such as radiation effects and chemical changes. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a disposal container or structure that provides stability after disposal.

(2) Notwithstanding the provisions in § 61.56(a) (2) and (3), liquid wastes, or wastes containing liquid, must be converted into a form that contains as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume of the waste when the waste is in a disposal container designed to ensure stability, or 0.5% of the volume of the waste for waste processed to a stable form.

(3) Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.

§ 61.57 Labeling.

Each package of waste must be clearly labeled to identify whether it is Class A waste, Class B waste, or Class C waste, in accordance with § 61.55.

§ 61.58 Alternative requirements for waste classification and characteristics.

The Commission may, upon request or on its own initiative, authorize other provisions for the classification and characteristics of waste on a specific basis, if, after evaluation, of the specific characteristics of the waste, disposal site, and method of disposal, it finds reasonable assurance of compliance with the performance objectives in subpart C of this part.

§ 61.59 Institutional requirements.

(a) *Land ownership.* Disposal of radioactive waste received from other persons may be permitted only on land owned in fee by the Federal or a State government.

(b) *Institutional control.* The land owner or custodial agency shall carry out an institutional control program to physically control access to the disposal site following transfer of control of the disposal site from the disposal site operator. The institutional control program must also include, but not be limited to, carrying out an environ-

mental monitoring program at the disposal site, periodic surveillance, minor custodial care, and other requirements as determined by the Commission; and administration of funds to cover the costs for these activities. The period of institutional controls will be determined by the Commission, but institutional controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the owner.

Subpart E—Financial Assurances

§ 61.61 Applicant qualifications and assurances.

Each applicant shall show that it either possesses the necessary funds or has reasonable assurance of obtaining the necessary funds, or by a combination of the two, to cover the estimated costs of conducting all licensed activities over the planned operating life of the project, including costs of construction and disposal.

§ 61.62 Funding for disposal site closure and stabilization.

(a) The applicant shall provide assurance that sufficient funds will be available to carry out disposal site closure and stabilization, including: (1) Decontamination or dismantlement of land disposal facility structures; and (2) closure and stabilization of the disposal site so that following transfer of the disposal site to the site owner, the need for ongoing active maintenance is eliminated to the extent practicable and only minor custodial care, surveillance, and monitoring are required. These assurances shall be based on Commission-approved cost estimates reflecting the Commission-approved plan for disposal site closure and stabilization. The applicant's cost estimates must take into account total capital costs that would be incurred if an independent contractor were hired to perform the closure and stabilization work.

(b) In order to avoid unnecessary duplication and expense, the Commission will accept financial sureties that have been consolidated with earmarked financial or surety arrangements established to meet requirements of other

ATTACHMENT 7

**GROSS CALCULATION FOR THE RADIOLOGICAL
CHARACTERIZATION OF HANFORD SITE WASTE**

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GROSS CALCULATION FOR THE RADIOLOGICAL CHARACTERIZATION OF HANFORD SITE WASTE

This attachment contains cost-effective methodology for performing the radiological characterization of Hanford Site waste. The methodology consists of classifying the waste into types (slurry, aqueous, etc.) with known radionuclide ratios established from process knowledge. Taking the dose rate measurements of a sample and using the standard dose-to-curie conversions methods, the concentration of each radionuclide can be established from the radionuclide ratios known from the process knowledge. The average error in using the methodology is not expected to be any larger than the variability of each waste package.

This is an approximation method and should be used with caution. In case of doubt direct radiation measurements will be taken to substantiate the results.

Some examples are given for the characterization of Hanford Site wastes which are slurry, salt cake, sludge, aqueous, highly differentiated, and variable type. These examples only refer to the wastes that are generated in the process of cleaning up ponds, evaporator basins, soils extracted from drain trenches and monitoring wells.

7-1 SLURRY TYPE WASTE

For slurry waste, the isotopic contents can be assumed to be those given by DOE/RW-0006, Rev. 5, *Integrated Database for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, Table 2.16, "Slurry" (DOE 1992). This may be more accurate than using ORIGEN2 (Coff 1980), since there is some differentiation of mixed fission products when spent fuel is dissolved (i.e., volatiles are lost). The isotopic fractions for the radionuclides that make up at least 99% of the waste and the fractions for all Category 1 or 3 radionuclides (from WHC-EP-0063-3 [WHC 1991]) are given in Table 7-1, "Isotopic Fractions In Slurry Type Waste."

Slurry type waste has a $^{137}\text{Cs}/^{90}\text{Sr}$ ratio of about 0.3 to 6.0 and includes prevalent isotopes of ruthenium, cerium, praseodymium, and promethium. The isotopic fractions, as determined by laboratory analyses of wipes and other specific samples, will not agree very well with the isotopic fractions in Table 7-1. The reasons for this include the heterogeneity of the contamination, counting errors, and sampling errors (e.g., wipes pick up some radionuclides preferentially over others). The isotopic ratios of Table 7-1 would probably become demonstrated only after averaging many samples with no bias (i.e., no wipes).

It appears that the Plutonium-Uranium Extraction (PUREX) Plant and Double-Shell Tank Farm waste could use the isotopic fractions in Table 7-1 by verifying the $^{137}\text{Cs}/^{90}\text{Sr}$ ratio and the presence of the other prevalent isotopes.

7-2 SALT CAKE TYPE WASTE

At the Hanford Site various processes have been used to differentiate the basic mixed fission products. Besides uranium and plutonium removal in the slurry, ^{137}Cs and ^{90}Sr have been encapsulated, and processes such as evaporation and decay have changed the basic isotopic ratios. Salt cake is a good example. Salt cake is present in single-shell tanks and in the evaporators. The $^{137}\text{Cs}/^{90}\text{Sr}$ ratio of this waste is similar to slurry waste (0.3 to 6.0); the waste is enhanced in ^{14}C and has no other prevalent radionuclides. Table 7-2 gives the isotopic fractions for this type of contamination, derived from DOE/RW-0006, Rev. 5, Table 2.16, "Salt Cake" (DOE 1992).

7-3 SLUDGE TYPE WASTE

This waste is characterized by a $^{137}\text{Cs}/^{90}\text{Sr}$ ratio of 0.02 to 0.3 with enhanced ^{63}Ni and the absence of other prevalent beta emitters. The less soluble radionuclides are concentrated in sludge, such as transuranic (TRU) and ^{90}Sr . The estimated isotopic fractions for this waste are given in Table 7-3. These fractions were derived from DOE/RW-0006, Rev. 5, Table 2.16, "Sludge" (DOE 1992). Single sample results may not agree with the isotopic fractions in Table 7-3.

Some Single-Shell Tank Farm waste and Evaporator waste may fit into this category.

7-4 AQUEOUS WASTE

Table 7-4, "Isotopic Fractions In Aqueous Waste," should be used for waste where the more soluble radionuclides reside. The isotopic fractions for Table 7-5 were derived from DOE/RW-0006, Rev. 5, Table 2.16, "Liquid" (DOE 1992). The $^{137}\text{Cs}/^{90}\text{Sr}$ ratio is high (from 6 to 95) and the waste is characterized by enhanced concentrations of ^{99}Tc and ^{14}C . Again, some Tank Farm and Evaporator contamination would fit these isotopic ratios.

7-5 HIGHLY DIFFERENTIATED WASTE

Some Hanford Site waste has been highly differentiated by chemical or environmental processes. The contamination at B Plant, UO_3 , the Plutonium Finishing Plant, cribs, ponds, and ditches are examples. Tumble weeds and the ash from burning tumble weeds are other good examples. Tumble weeds concentrate ^{90}Sr and there is some evidence that ^{99}Tc is also taken up by these plants. It appears that ^{137}Cs is more mobile than ^{90}Sr in the environment, and the Category 1 and 3 beta emitters are much more mobile than ^{137}Cs . In cases of highly differentiated waste, isotopic ratios should be determined by sampling. However, normally it would not be necessary to analyze for every potential radionuclide. Some guidance for analyses is provided in Section 7-7, "Determining Type of Waste."

7-6 VARIABLE WASTE

For the purpose of this document, variable waste includes undifferentiated waste such as fuel rod contamination and N Reactor waste, and uniquely derived waste such as laboratory waste and laundry waste. Such contamination should be characterized through sampling and analyses. Very little can be assumed or deduced relative to its isotopic fractions; however, the guidance below should help mitigate the cost of characterization.

7-7 DETERMINING TYPE OF WASTE

The following are some useful assumptions that can be made to facilitate radiological characterization.

1. $^{137}\text{Cs}/^{90}\text{Sr}$ ratios indicate a great deal about the waste. Sampling should be performed to determine this average ratio. The ratio indicates the type of waste (slurry, sludge, salt cake, or aqueous), or the potential prevalence of soluble or insoluble radionuclides. A high ratio (>10) means that it is likely that there will be no significant insoluble radionuclides present, including TRU. A low ratio means that significant TRU could be present. In either case, a few samples should be taken to verify the premise.

For a facility like T Plant, the ^{137}Cs ratios should be determined for various areas in the plant, such as the canyon and the 2706 Building. To the extent possible, the type of waste in these areas should be identified. The isotopic ratios in the attached tables could then be used. If the waste in the canyon was extremely heterogeneous, it should be acceptable to assume the slurry isotopic ratios of Table 7-1 (if ruthenium, cerium, praseodymium, or promethium was present) or the sludge isotopic fractions of Table 7-3 (if only cesium and strontium were prevalent).

2. ^{137}Cs ratios relative to the Category 1 and 3 beta emitters should be relatively constant for some highly differentiated waste (e.g., where ^{137}Cs has been enhanced). It is suggested that ^{99}Tc be used as a "key". That is, for slurry contamination, the $^{137}\text{Cs}/^{99}\text{Tc}$ ratio is 1,270. If contamination is found where this ratio is higher, say 10 times as large, this means that the ^{99}Tc and other Category 1 and 3 beta emitters have been depleted by a factor of 10. On the other hand, if the ratio is larger, then the beta emitters have been enhanced somehow. In other words, the concentrations of Category 1 and 3 beta emitters can be deduced from the $^{137}\text{Cs}/^{99}\text{Tc}$ ratio.
3. In cases of highly variable waste, such as waste from the laundry or the laboratory, some conservative assumptions could be made to simplify characterization and to save a great deal on the cost of sampling and analysis. For one thing, if it appears that the waste is a mixture of slurry type, salt cake type, sludge type, or aqueous type, it would make sense to assume slurry type waste or sludge type waste and use the isotopic fractions of Table 7-1 or Table 7-3, depending on the presence of ruthenium, cerium, praseodymium, or

promethium. This assumption would be conservative but justifiable because of the high heterogeneity. The alternative would be to fully characterize each waste package, which would be very expensive and unwarranted.

There may be some concern about using simplifying assumptions and erroneously labeling a waste relative to category. This concern is addressed in Section 7-8.

7-8 WASTE CATEGORY

Table 7-4 summarizes some of the characteristics of various types of waste described in previous sections. It is assumed that the waste is loaded into a 55-gal drum, the waste matrix consists of paper, rags, and plastic that fills up the drum (density 0.65 g/cc), and there is a unit curie of total activity in the drum. The total activity consists of radionuclides in the isotopic fractions given in the previous tables.

Dose rates, total activity, and sum of fractions are all proportional. That is, if the dose rate from a unit curie drum is 684 mrem/h, then the dose rate from half a curie is 342 mrem/h. If the sum of the Category 1 fractions of the unit drum is 137, then for a drum with 100 times less activity or dose rate, the sum of the Category 1 fractions would be 1.37.

A possible point of confusion is the term "total activity". In computing the sum of the fractions, daughters such as ^{90}Y and ^{137}Ba are not counted. This is consistent with WHC-EP-0063-3 (WHC 1991). In determining isotopic ratios and dose rate, the daughters are counted.

The following points can be deduced from Table 7-5.

- If the reference drum of slurry waste reads less than 5 mrem/h, it is less than Category 1. If a drum of slurry type waste reads 17,100 mrem/h, it exceeds Category 3.
- If the reference drum of salt cake reads less than 5 mrem/h, it does not exceed Category 1. If it reads 2,025 rem/h, it exceeds Category 3.
- If the reference drum of sludge type waste reads less than 0.3 mrem/h, the waste is less than Category 1. If it reads 3,160 mrem/h, it exceeds Category 3.
- If the reference drum of aqueous type waste reads less than 13 mrem/h, it is less than Category 1. If it reads 472 rem/h, it exceeds Category 3.

The calculations of Attachments 1 through 4 could be repeated for various types of drums and packages, enabling the waste to be fully characterized by the external dose rate measurements. If a package has no detectable external dose rate, then it should be acceptable to report "less than values", which can be calculated easily from the detection capability of instrumentation.

Table 7-1. Isotopic Fractions in Slurry Type Waste.

WHC-EP-0063-3 Radionuclides	Isotopic fraction ¹	Other radionuclides	Isotopic fraction
³ H	--	¹⁰⁶ Ru*	0.0383
¹⁴ C ¹	4.7 E-6	¹⁰⁶ Rh*	0.0383
⁶⁰ Co	9.6 E-5	¹⁴⁴ Ce*	0.128
⁵⁹ Ni	3.0 E-8	¹⁴⁴ Pr	0.128
⁶³ Ni ¹	6.1 E-6	^{144m} Pr	1.53 E-3
⁹⁰ Sr*	0.105	¹²⁵ Sb	6.92 E-3
⁹⁰ Y*	0.105	^{125m} Te	1.68 E-3
⁹⁴ Nb		¹³⁴ Cs	4.50 E-3
⁹⁹ Tc	1.17 E-4	¹⁵¹ Sm	2.07 E-3
¹²⁹ I	2.0 E-9	¹⁵⁵ Eu	1.49 E-3
¹³⁷ Cs*	0.149	¹⁴⁷ Pm*	0.15
¹³⁷ Ba*	0.141		
²⁴¹ Pu	3.6 E-4		
²⁴² Cm	8.0 E-9		
⁷⁹ Se	5.8 E-7		
TRU Alpha ²	5.2 E-4		
²³⁸ Pu	2.7 E-6		
²³⁹ Pu	3.0 E-5		
²⁴⁰ U	8.1 E-6		
²⁴¹ U	4.8 E-4		
²³⁴ U	5.0 E-11		
²³⁵ U	4.5 E-10		
²³⁶ U	1.1 E-9		
²³⁸ U	8.2 E-9		

¹No entry means 0.0. Since activation products cannot be readily distinguished from fission products by analyses, no distinction is made in this table. The lower fission product Category 1 or 3 limits should be assumed when determining the category.

²In this table it is assumed that all TRU alpha is ²³⁸Pu + ²³⁹Pu + ²⁴⁰Pu + ²⁴¹Am. This is a conservative assumption relative to determining waste category and is justifiable because the plutonium isotopes plus ²⁴¹Am are by far the predominate radionuclides for TRU alpha.

*The sum of the radionuclides with asterisks comprises over 99% of the total activity; therefore, all other radionuclides can be ignored relative to labeling and disposal. This does not mean that isotopes such as ²³⁹Pu are not present. It only means that such isotopes comprise a very small fraction of the total activity.

Table 7-2. Isotopic Fractions in Salt Cake Type Waste.

WHC-EP-0063-3 Radionuclides	Isotopic fraction ¹	Other radionuclides	Isotopic fraction
³ H		¹⁰⁶ Ru	
¹⁴ C	2.0 E-4	¹⁰⁶ Rh	
⁶⁰ Co		¹⁴⁴ Ce	
⁵⁹ Ni		¹⁴⁴ Pr	
⁶³ Ni		^{144m} Pr	
⁹⁰ Sr*	0.191	¹²⁵ Sb	
⁹⁰ Y*	0.191	^{125m} Te	
⁹⁴ Nb		¹³⁴ Cs	
⁹⁹ Tc		¹⁵¹ Sm	
¹²⁹ I		¹⁵⁵ Eu	
¹³⁷ Cs*	0.316	¹⁴⁷ Pm	
¹³⁷ Ba*	0.301		
²⁴¹ Pu			
²⁴² Cm			
⁷⁹ Se			
TRU Alpha ² ²³⁸ Pu ²³⁹ Pu ²⁴⁰ Pu ²⁴¹ Am			
²³⁴ U			
²³⁵ U			
²³⁶ U			
²³⁸ U			

¹No entry means 0.0. Since activation products cannot be readily distinguished from fission products by analyses, no distinction is made in this table. The lower fission product Category 1 or 3 limits should be assumed when determining the category.

²In this table it is assumed that all TRU alpha is ²³⁸Pu + ²³⁹Pu + ²⁴⁰Pu + ²⁴¹Am. This is a conservative assumption relative to determining waste category and is justifiable because the plutonium isotopes plus ²⁴¹Am are by far the predominate radionuclides for TRU alpha.

*The sum of the radionuclides with asterisks comprises over 99% of the total activity; therefore, all other radionuclides can be ignored relative to labeling and disposal. This does not mean that isotopes such as ²³⁹Pu are not present. It only means that such isotopes comprise a very small fraction of the total activity.

Table 7-3. Isotopic Fractions in Sludge Cake Type Waste.

WHC-EP-0063-3 Radionuclides	Isotopic fraction ¹	Other radionuclides	Isotopic fraction
³ H		¹⁰⁶ Ru	
¹⁴ C		¹⁰⁶ Rh	
⁶⁰ Co	4.5 E-5	¹⁴⁴ Ce	
⁵⁹ Ni		¹⁴⁴ Pr	
⁶³ Ni	2.6 E-3	^{144m} Pr	
⁹⁰ Sr*	0.464	¹²⁵ Sb	
⁹⁰ Y*	0.464	^{125m} Te	
⁹⁴ Nb		¹³⁴ Cs	
⁹⁹ Tc		¹⁵¹ Sm	
¹²⁹ I		¹⁵⁵ Eu	
¹³⁷ Cs*	0.033	¹⁴⁷ Pm	
¹³⁷ Ba*	0.039		
²⁴¹ Pu	5.3 E-4		
²⁴² Cm			
⁷⁹ Se			
TRU Alpha ²	6.0 E-4		
²³⁸ Pu			
²³⁹ Pu	1.8 E-4		
²⁴⁰ Pu	4.4 E-5		
²⁴¹ Am	3.7 E-4		
²³⁴ U			
²³⁵ U			
²³⁶ U			
²³⁸ U			

¹No entry means 0.0. Since activation products cannot be readily distinguished from fission products by analyses, no distinction is made in this table. The lower fission product Category 1 or 3 limits should be assumed when determining the category.

²In this table it is assumed that all TRU alpha is ²³⁸Pu + ²³⁹Pu + ²⁴⁰Pu + ²⁴¹Am. This is a conservative assumption relative to determining waste category and is justifiable because the plutonium isotopes plus ²⁴¹Am are by far the predominate radionuclides for TRU alpha.

*The sum of the radionuclides with asterisks comprises over 99% of the total activity; therefore, all other radionuclides can be ignored relative to labeling and disposal. This does not mean that isotopes such as ²³⁹Pu are not present. It only means that such isotopes comprise a very small fraction of the total activity.

Table 7-4. Isotopic Fractions in Aqueous Type Waste.

WHC-EP-0063-3 Radionuclides	Isotopic fraction ¹	Other radionuclides	Isotopic fraction
³ H		¹⁰⁶ Ru	
¹⁴ C	8.0 E-5	¹⁰⁶ Rh	
⁶⁰ Co		¹⁴⁴ Ce	
⁵⁹ Ni		¹⁴⁴ Pr	
⁶³ Ni		^{144m} Pr	
⁹⁰ Sr*	0.02	¹²⁵ Sb	
⁹⁰ Y*	0.02	^{125m} Te	
⁹⁴ Nb		¹³⁴ Cs	
⁹⁹ Tc	8.0 E-4	¹⁵¹ Sm	
¹²⁹ I		¹⁵⁵ Eu	
¹³⁷ Cs*	0.493	¹⁴⁷ Pm	
¹³⁷ Ba*	0.467		
²⁴¹ Pu			
²⁴² Cm			
⁷⁹ Se			
TRU Alpha ² ²³⁸ Pu ²³⁹ Pu ²⁴⁰ Pu ²⁴¹ Am	3.3 E-5 3.3 E-5		
²³⁴ U			
²³⁵ U			
²³⁶ U			
²³⁸ U			

¹No entry means 0.0. Since activation products cannot be readily distinguished from fission products by analyses, no distinction is made in this table. The lower fission product Category 1 or 3 limits should be assumed when determining the category.

²In this table it is assumed that all TRU alpha is ²³⁸Pu + ²³⁹Pu + ²⁴⁰Pu + ²⁴¹Am. This is a conservative assumption relative to determining waste category and is justifiable because the plutonium isotopes plus ²⁴¹Am are by far the predominate radionuclides for TRU alpha.

*The sum of the radionuclides with asterisks comprises over 99% of the total activity; therefore, all other radionuclides can be ignored relative to labeling and disposal. This does not mean that isotopes such as ²³⁹Pu are not present. It only means that such isotopes comprise a very small fraction of the total activity.

Table 7-5. Waste Characteristics.

Waste type	$^{137}\text{Cs}/^{90}\text{Sr}$ Ratio	Sum of fractions ¹		Dose rate/curie (mrem/h) ²
		Category 1	Category 3	
Slurry	0.3 to 6.0	137	0.04	684
Salt cake	0.3 to 6.0	261	0.0006	1,215
Sludge	0.02 to .3	455	0.05	158
Aqueous	6.0 to 95	139	0.004	1,886

¹The sum of the fractions for a drum determines waste category (WHC-EP-0063-3 [WHC 1991]). The sum of the fractions is the sum of the ratios of radionuclide quantity in the drum to that radionuclide Category 1 or 3 limit for the drum. If the sum of the fractions exceeds unity, the waste exceeds that category.

²The dose rate is at contact, at the center of the drum's side. For a given waste type, the dose rates, the total activity, and the sum of fractions are all proportional. This should allow characterization of the waste from only external dose rate measurements. Gamma dose rates from various isotopics are given in Attachment 2, Table 2-5.

7-9 REFERENCES

- Croff, A. G., 1980, *A User's Manual for the ORIGEN2 Computer Code*, ORNL/TM-717 5, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- DOE, 1992, *Integrated Database for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, U.S. Department of Energy — Office of Civilian Radioactive Waste Management, Washington, D.C.
- WHC, 1991, *Hanford Solid Waste Acceptance Criteria*, WHC-EP-0063-3, Westinghouse Hanford Company, Richland, Washington.

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ATTACHMENT 8

ADDITIONAL BACKGROUND INFORMATION

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ADDITIONAL BACKGROUND INFORMATION

This attachment provides additional information dealing with state and Federal regulations (including U.S. Department of Energy [DOE] orders) Hanford Site requirements, and other rules, regulations, guidelines, and standards as they apply to characterization. The U.S. Department of Transportation (DOT), U.S. Environmental Protection Agency (EPA), U.S. Nuclear Regulatory Commission (NRC), DOE, individual states, and other regulatory bodies have established standards for radiation and environmental protection. The regulations established by DOT address the transportation issues. DOE, EPA, NRC, and individual states have established regulations concerning public, worker, and environmental protection. Some of these regulations are specific and others are a set of performance objectives that all sites must observe. These objectives are keeping the public's dose rate below a fixed level (consistent with keeping exposure as low as reasonably achievable [ALARA]), prevention of intrusion after loss of institutional control, protection of workers, designing a site that ensures long-term stability of waste with a reduction of active maintenance, and protecting the environment.

As a prelude to meeting these regulations and performance objectives all radioactive wastes need to be characterized so that the radiological properties are known. Some of these properties included half-life of the isotopes, activity level, type of radiation (alpha, beta, gamma, and neutrons) and the physical and chemical properties of the waste material. Based on these properties DOT has established categories of radioactive waste designated as Limited Quantity (LQ), Low Specific Activity (LSA), Type A, Type B, and Highway Route Controlled Quantities (HRCQ). All the commonly known isotopes are divided into these categories in terms of curie content or specific activity.

Similarly DOE, NRC, and EPA have certain categories of radioactive waste such as Transuranic (TRU), Low Level (LL), Contact Handled (CH), Remote Handled (RH), Category A, Category C, Greater than Category 3 (GTC3), Class 1, Class 2, Class 3, and Greater Than Class C (GTCC). For each of these categories there are some regulations as to the treatment, handling, packaging, storing, and disposal. The definition of the various waste categories is given in government documents or in the waste acceptance criteria of waste disposal sites. The regulations for public exposure are defined in the DOE's Order 5400.5 (DOE 1991) and in the NRC's Title 10, *Code of Federal Regulations* (CFR) Part 20. Health standards for workers are given in DOE's Order 5480.11 (DOE 1991) and the NRC's 10 CFR 20. DOT regulations are covered in 49 CFR 100-500. Environmental regulations are listed in 40 CFR. The guidelines to operate DOE sites are given in DOE Order 5820.2A (DOE 1988).

Besides these documents, some requirements come from the performance assessment conducted for each radioactive waste disposal site. The Category 1 and 3 values for the Hanford Site come from the preliminary performance assessment. A revision of these limits is expected in 1993. Note that for the NRC sites, the classification notation is Class A, B, and C. The list of isotopes and concentration limits defined for the Hanford Site results from an analysis similar to that used by the NRC to define inventory limits in 10 CFR 61. Some significant differences in modeling assumptions do exist.

For example the Hanford Site model calculates dose estimates on the basis of the International Commission on Radiological Protection (ICRP) Publication 30 (ICRP 1979) and ICRP-48 instead of ICRP-2 (ICRP 1959) used by the NRC. Because of the different dose methodology and changes in scenario assumptions the NRC Class A and C values are somewhat different from the Hanford Site Category 1 and 3 values.

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- DOE, 1990, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5, U.S. Department of Energy, Washington, D.C.
- DOE, 1991, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, U.S. Department of Energy, Washington, D.C.
- ICRP, 1959, *Report of Committee II on Permissible Dose for Internal Radiation*, Publication 2, International Commission on Radiological Protection, Pergamon Press, Oxford, England.
- ICRP, 1979, *Limits on Intakes of Radionuclides by Workers*, Publication 30, International Commission on Radiological Protection, Elmsford, New York.
- 10 CFR 20, 1992, "Standards for Protection Against Radiation," *Code of Federal Regulations*, as amended.
- 10 CFR 61, 1992, "Licensing Requirements for Land Disposal of Radioactive Waste," Title 10, *Code of Federal Regulation*, as amended.
- 40 CFR, 1992, "Environmental Regulations," *Code of Federal Regulations*, as amended.
- 49 CFR 100-500, Subtitle B, 1991, "Other Regulations Relating to Transportation," *Code of Federal Regulations*, as amended.

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