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Material Control and Accountability Procedures for a Waste Isolation Repository

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OAK RIDGE NATIONAL LABORATORY
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CONTENTS

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ABSTRACT

The material control and accountability needs of a waste isolation repository are examined. Three levels of control are discussed: (1) item identification and control, (2) tamper indication, and (3) quantitative material assay. A summary of waste characteristics is presented and, based on these, plus a consideration of the accessibility of the various types of waste, material control by item identification and accountability (where the individual waste container is the basic unit) is recommended. Tamper indicating procedures are also recommended for the intermediate and low level waste categories.

1. INTRODUCTION

This report addresses the special nuclear material* (SNM) control and accountability needs and requirements of a nuclear waste terminal storage facility. In a companion document[1] we have reviewed the status and capabilities of nondestructive assay technology, and assessed the potential for application of those techniques to the material accountability and control problems peculiar to a nuclear waste storage facility. The conclusions reached in that work, reproduced in summary form here in Sect. 7, indicate substantial limitations in the applicability of nondestructive methods to nuclear waste assay at a storage facility. Thus, we here address alternative methods of material control which are available for safeguards and accountability purposes, and present our opinions of what will constitute an acceptable system.

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*Special nuclear material is defined in 10CFR 70.4 paragraph (m) to mean (1) plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the commission, pursuant to the provisions of Section 51 of the Atomic Energy Act of 1954, determines to be special nuclear material; or (2) any material artificially enriched by the foregoing but does not include source material.

This study was performed for the Office of Waste Isolation (OWI) which is responsible for the National Waste Terminal Storage (NWTS) program. The opinions and recommendations expressed in this report are, however, the authors', and in no way represent OWI policy.

A waste terminal storage facility will require safeguards similar to that of any nuclear facility.[2] The purpose of the system will be to protect the health and welfare of the public by preventing the theft, diversion or loss of nuclear material and thus its subsequent use by unauthorized personnel for any purpose.

The level of protection demanded of the safeguards system will depend to a large extent on material characteristics. If nuclear material is in an undesirable form, or is not a significant threat material, the safeguards measures need not be as stringent as for more attractive or hazardous nuclear material.

Some guidelines on safeguards requirements are available in the Code of Federal Regulations[2] and in a number of the Nuclear Regulatory Commission's Regulatory Guides.[3-10] However, many of the problems peculiar to a waste repository have not yet been explicitly addressed. It is clear, however, that the safeguards system must consist of a physical security component and a material control and accountability component. The physical security system functions to prevent the unauthorized movement of nuclear materials and persons into and out of the facility. The material control and accountability system provides means for detecting and quantifying possible losses of materials.

The report consists of seven sections. The next presents in summary form, a description of the chemical and radiological characteristics of the four anticipated types of waste materials, the container geometries, and the anticipated throughputs. These factors all influence both the requirements for material control and the ability to implement various accountability techniques. The third section describes three general levels of material control, the lowest of which requires only a system to count and verify receipt of waste containers; while the highest implies installation of a system where the contents of each container is quantitatively determined. In the fourth section we examine those characteristics of each waste type which determine the level of accountability required, and recommend a generic accountability level for each type. Following sections discuss the technical options available to implement the recommended level of control, and the final section presents a summary and our recommendations.

2. WASTE CHARACTERISTICS AFFECTING ACCOUNTABILITY

Material characteristics including chemical form, SNM concentration, radiation levels, and container size all influence both the need for a certain level of material accountability and the ability of given techniques to meet these needs.

It was assumed for this evaluation that the nuclear waste accepted at the reference design waste repository[11] will consist of four basic types: high level waste (HLW), cladding waste (CW), intermediate level waste (ILW), and low level waste (LLW). Descriptions of each of these waste types are presented in Table 1, and physical and chemical characteristics of each waste type are presented in Table 2. Table 3 lists the approximate isotopic distribution of actinides expected in spent fuel and high level waste. The actinide isotopics in cladding wastes will be similar to that of spent fuel. Intermediate level wastes will contain actinides in variable isotopic concentrations intermediate between the two listed tabulations. Table 4 gives estimates of the neutron production rates per cubic meter from each type of waste. These values are only approximate since the composition of the waste types are variable, especially ILW and LLW, and hence the (α,n) contributions are difficult to estimate. Figure 1 illustrates the range of densities and radiation levels anticipated from each of the four waste categories. These waste characteristics are based on the assumption that spent fuel is reprocessed and plutonium is recycled.

It is assumed that standard containers will be used for storage of each waste type. High level waste, cladding waste, and intermediate level waste require external shielding and the reference design calls for canisters identical in design, each having a waste volume of .18 cubic meters. A proposed canister design is shown in Fig. 2. Low level waste does not require external shielding and will probably be delivered in 55-gal drums each having a waste volume of .21 cubic meters.

Table 1. Descriptions of nuclear waste types accepted at the reference design waste terminal storage facility

High level wastes (HLW) are solidified composites of liquid waste arising from reprocessing of spent fuels

High level wastes contain:

1. 99.9% of nonvolatile fission products in spent fuel
2. 0.5% of uranium and plutonium in spent fuel
3. Virtually all the actinides other than Pu and U produced by transmutation of uranium and plutonium in the reactor

Cladding wastes (CW) are solid fragments of Zircaloy and stainless steel and other structural components of fuel assemblies that remain after the fuel cores have been dissolved

Cladding wastes contain:

1. Neutron-induced radioactive products
2. 0.05% of actinides in spent fuel
3. 0.05% of nonvolatile fission products

Intermediate-level transuranic wastes (ILW) are those solid or solidified materials that contain long-lived alpha emitters at concentrations greater than 10nCi/g, and have typical surface dose rates between 10 and 1000 millirems/hr after packaging

Low-level transuranic wastes (LLW) are those solid or solidified materials that contain plutonium or other long-lived alpha emitters in known or suspected concentrations greater than 10nCi/g, and have sufficiently low external radiation levels that they can be handled directly

Table 2. Characteristics of nuclear waste types accepted at the reference design waste terminal storage facility

Waste type	Approximate density	Approximate composition	Approximate actinide content	Approximate surface dose rate
HLW	3.3 g/cc	SiO_2 25–40 wt% B_2O_3 10–15 wt% Waste oxides 20–35 wt% ZnO 5–10 wt% Alkali metal oxides 5–10 wt%	70 kg/m^3	10^5–10^6 rem/hr at canister surface
CW	4.5 g/cc	Zircaloy 88 wt%[a] Stainless steel 9 wt%[a] Inconel 2.5 wt%[a]	6.65 kg/m^3	10^3 rem/hr at canister surface
ILW	2 g/cc (compacted)	Metals, ceramics, ash fission products, actinides	10 g/m^3	10–1000 mrem/hr at canister surface
LLW	2 g/cc (compacted)	Same as for ILW	50–100 g/m^3	<10 mrem/hr at canister surface

[a] For LWR cladding waste. For LMFBR, ∿100 wt% is stainless steel.

Table 3. Grams of heavy metals in spent fuel and reprocessed nuclear waste for one MT of PWR fuel[a]

Nuclide	Spent fuel		Reprocessed waste (HLW)	
	Initial	10-year decay	Initial	10-year decay
Pb-208	4.59 E-7	4.15 E-5	7.88 E-7	3.47 E-6
Th-288	1.82 E-6	1.94 E-5	2.76 E-6	1.72 E-7
Th-230	9.13 E-4	4.44 E-3	1.06 E-3	1.08 E-3
Th-232	2.34 E-4	1.53 E-3	2.90 E-4	2.97 E-4
Th-234	1.36 E-5	1.36 E-5	1.36 E-5	6.79 E-8
Pa-231	5.13 E-4	5.91 E-4	5.17 E-4	5.17 E-4
Pa-233	1.58 E-5	1.17 E-5	1.66 E-5	1.67 E-5
U-232	2.83 E-4	8.13 E-4	1.74 E-6	4.08 E-6
U-233	4.80 E-3	6.34 E-3	2.45 E-5	1.73 E-3
U-234	121	134	.610	1.02
U-235	7980	7980	39.9	39.9
U-236	4550	4550	22.7	22.7
U-237	10.6	1.92 E-5	1.55 E-7	9.41 E-8
U-238	9.43 E+5	9.43 E+5	4710	4710
Np-237	472	486	482	483
Np-239	79.7	7.81 E-5	7.82 E-5	7.82 E-5
Pu-236	6.57 E-4	5.81 E-5	2.97 E-6	2.60 E-7
Pu-238	161	160	.836	5.50
Pu-239	5190	5270	26.3	26.4
Pu-240	2170	2170	10.8	20.1
Pu-241	1030	643	5.06	3.15
Pu-242	354	354	1.77	1.78
Am-241	25.1	412	46.3	47.5
Am-242m	.942	.900	.940	.899
Am-242	.0783	1.08 E-5		
Am-243	94.3	94.4	94.4	94.4
Cm-242	10.1	2.17 E-3	5.14	2.17 E-3
Cm-243	.0807	.0650	.0799	.0643
Cm-244	30.2	20.6	29.7	20.2
Cm-245	1.93	1.93	1.93	1.93
Cm-246	.222	.221	.222	.221
Cm-247	2.86 E-3	2.86 E-3	2.86 E-3	2.86 E-3
Cm-248	1.93 E-4	1.93 E-4	1.93 E-4	1.93 E-4

[a] 3.3% enriched U-235; 33,000 MWD burnup.

Table 4. Estimated (α,n) and spontaneous fission neutron production rates in nuclear wastes (per m^3 of waste)

Waste type	Neutron source	Initial ($n/s - m^3$)	One year ($n/s - m^3$)	Ten years ($n/s - m^3$)
HLW	S. F.	5.65×10^9	4.46×10^9	2.98×10^9
	(α,n)	7.13×10^8	2.12×10^8	5.82×10^7
	Total	6.36×10^9	4.67×10^9	3.04×10^9
CW (compacted)	S.F.	2.96×10^6	2.52×10^6	1.60×10^6
	(α,n)	4.16×10^5	2.25×10^5	9.04×10^4
	Total	3.38×10^6	2.75×10^6	1.69×10^6
ILW[a]	S.F.	4.99×10^5	4.25×10^5	2.70×10^5
	(α,n)	7.02×10^4	3.81×10^4	1.52×10^4
	Total	5.64×10^5	4.63×10^5	2.85×10^5
LLW[a]	S.F.	$\sim 2.9 \times 10^4$	$\sim 2.9 \times 10^4$	$\sim 2.9 \times 10^4$
	(α,n)	$\sim 6.4 \times 10^4$	$\sim 6.7 \times 10^4$	$\sim 8.5 \times 10^4$
	Total	$\sim 9.3 \times 10^4$	$\sim 9.6 \times 10^4$	$\sim 1.1 \times 10^5$

[a] Both wastes are compacted with densities of about 2 g/cc.

One projection[12,13] of waste flows into the reference design repository is given in Table 5. In the year 2005, the projected annual number of HLW, CW, and ILW canisters is 35,320. The number of drums of LLW for the same year is 76,000. This converts to an average of about 1400 drums per week or about 200 drums per day. Thus, any material control and accountability system and its associated record keeping must be designed for high throughputs.

Wastes other than the four types described in Table 1 may be accepted at waste terminal storage facilities in the event that spent fuel is not reprocessed or plutonium is not recycled. These include spent fuel elements and high level waste containing unseparated plutonium. These alternate waste types are described and the accountability requirements for a waste repository handling such waste types are briefly discussed in Appendix A.

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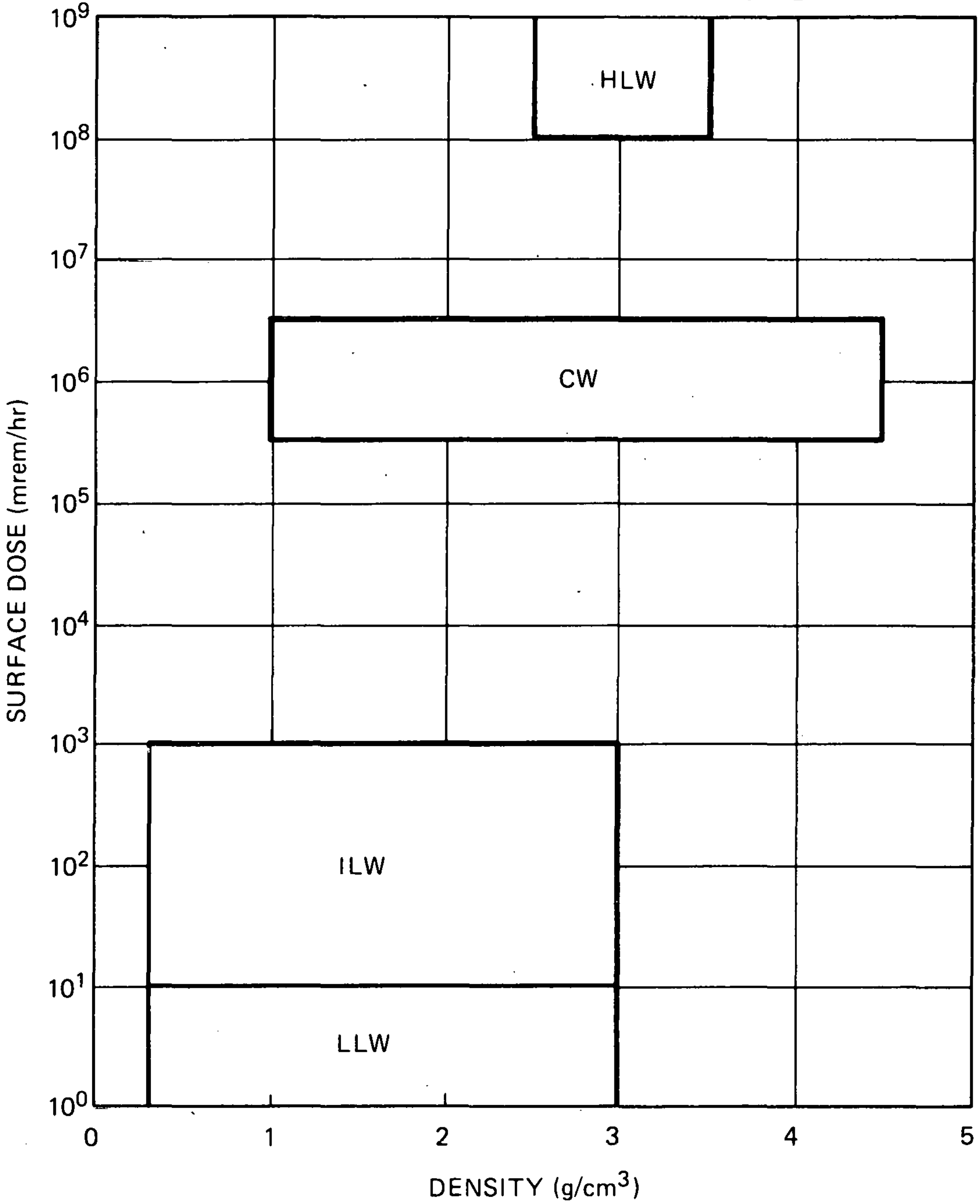

Fig. 1. Estimated ranges of density and surface dose rate for nuclear wastes.

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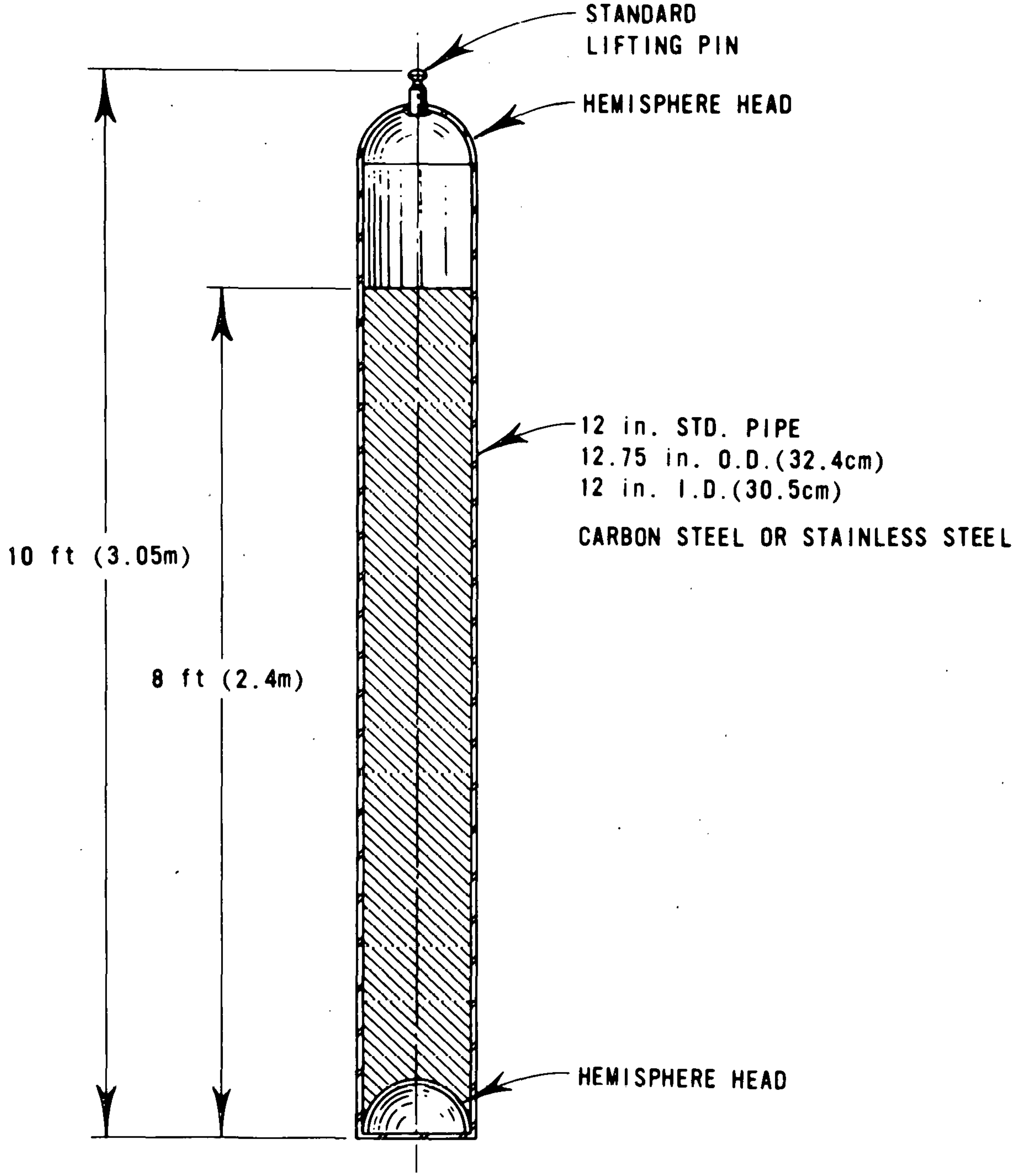

Fig. 2. Assumed standard canister for high-level, cladding, and intermediate-level wastes (generic repository description) (original figure: OWI-76-301).

Table 5. Projection of number of waste units to be available for storage[a,b]

Year	High level		Intermediate level and cladding		Low level	
	Annual	Accumulated	Annual	Accumulated	Annual	Accumulated
1983			1,930	1,930	480	480
1984			4,360	6,290	1,440	1,920
1985			8,080	14,370	2,440	4,330
1986			9,890	24,260	13,900	18,300
1987			8,760	33,020	22,100	40,400
1988	230	230	7,070	40,090	29,800	70,200
1989	510	730	7,850	47,940	16,800	87,000
1990	850	1,580	9,150	57,090	18,300	105,000
1991	1,020	2,600	9,950	67,040	20,200	125,000
1992	1,020	3,620	11,420	78,460	22,600	148,000
1993	1,020	4,630	8,480	86,940	22,600	171,000
1994	1,240	5,880	9,260	96,200	24,500	195,000
1995	1,470	7,340	11,190	107,390	25,000	220,000
1996	1,750	9,100	12,570	119,960	26,400	247,000
1997	2,150	11,200	14,500	134,460	31,300	278,000
1998	2,030	13,000	15,880	150,340	32,700	311,000
1999	2,320	15,600	17,260	167,600	35,100	346,000
2000	2,540	18,100	18,750	186,350	38,500	324,000
2001	2,830	21,000	20,790	207,140	42,800	427,000
2002	3,110	24,100	22,720	229,860	47,600	475,000
2003	3,450	27,500	25,360	255,220	54,800	529,000
2004	3,730	31,200	28,560	283,780	66,300	596,000
2005	4,070	35,300	31,250	315,030	76,000	672,000

[a] 12-inch canister for HLW, ILW, and CW.

[b] Standard 55-gal drum for LLW.

3. LEVELS OF MATERIAL CONTROL

Control and accountability of special nuclear material at waste terminal storage facilities can be performed at three levels. These are: identification and item control, tamper-indication, and quantitative material assay. At the item control and identification level, one would either insure that the proper number of containers had been received, and each container could be given a unique identification for control and record management. Tamper-indication procedures would be employed to determine whether material had been diverted during shipment. Material assay procedures including detailed record management would be required to account quantitatively for the special nuclear material in waste. Each higher level of accountability presupposes the existence of the lower ones.

The various identification procedures, tamper-indication procedures, and material accountability procedures discussed in this paper are given in Table 6.

Table 6. Methods for special nuclear material accountability at waste terminal storage facilities

- Level 1 — Identification
  - Alphanumeric identification labels
  - Magnetic strips
  - Inscribed identification numbers
  - Bar-coded identification labels
  - Notched binary identification numbers
- Level 2 — Tamper-indication
  - Sealing systems
  - Weight measurements
  - Radiation scans
  - Radiation signatures
- Level 3 — Material accountability (includes record management)
  - SNM measurement by nondestructive assay techniques

4. EVALUATION OF MATERIAL CONTROL AND ACCOUNTABILITY NEEDS

The waste materials to be handled at the terminal storage facility are generally unattractive targets for diversion. Radiation levels are often high, SNM content is dilute and the form of the waste makes recovery difficult. Nevertheless, adequate control of this material is essential because of its radioactivity and because it is necessary to assure that all waste materials shipped from production facilities have been received without alteration and are properly stored at the repository.

Clearly the most satisfying solution is to account in detail for the constituents of each container, both prior to shipment and after receipt. Such quantitative assay would not only insure the integrity of the package but would also serve to close the SNM material balance loop by providing an independent and final determination on the amount of material discarded. Unfortunately, as described in our technical evaluation, the physical and radiological characteristics of all four waste types make such measurements, to the accuracy required to insure integrity of the shipment, extremely difficult and, in many cases, impossible. Hence some lower levels of material control must be implemented. The appropriate and reasonable level for each type of waste will be considered below.

High level waste is generated at the downstream end of a fuel reprocessing plant. It will be produced initially in liquid form and stored in large (∿500,000 gal) tanks for a significant length of time. Prior to encapsulation it will be solidified and bound in a nonleachable matrix.

The properties of this material make it almost inconceivable that anyone would attempt its diversion in transit in order to gain access to its SNM content. First, the material incorporates the bulk of the radioactive fission products with their associated lethal radiation levels. Second, since a major effort will already have been expended to extract the plutonium while the material was in liquid form and since the material has subsequently been rendered even less accessible by solidification, the difficulty of extracting usable amounts of plutonium, even if one had access to the material, is enormous. Accordingly, we conclude that item accountability and identification (Level 1 material control measures) are sufficient for high level waste canisters.

Cladding wastes are similar in that they too have high radiation levels and the residual SNM is insoluble. Here again, material control measures are needed only to insure and demonstrate safe delivery of the material. We conclude Level 1 measures will suffice.

Since both high level and cladding wastes will be delivered in welded containers, and since they will almost certainly be checked for integrity on receipt, tamper indication control measures are, in fact, also being practiced. Because of the material characteristics described above, breach of containment on these materials might incur concern about possible en route loss and contamination but should not cause concern from an SNM diversion point of view.

Intermediate level waste does not have the valuable (from a safeguards point of view) attribute of surrounding itself with lethal radiation levels. In addition, while its average SNM content per cubic meter is low, its polymorphic composition admits the possibility of significant SNM in a single container and its relatively low radiation level is insufficient to defer a dedicated diverter. We therefore conclude that the second level of material control should be explicitly required for ILW, i.e., both item identification and explicit tamper indication checks.

If, as we hypothesize in this paper, ILW is delivered in sealed welded containers, additional tamper indicators would be unnecessary. Leak tests, contamination wipes or visual inspection for possible intrusion would be sufficient to determine if the integrity of the container had been breached.

Low level waste presents by far the greatest problem from a material accountability and control point of view. It originates from a variety of sources both in fuel reprocessing and refabrication and in many cases may result from personnel accessible operations, e.g., equipment maintenance, waste sorting and processing, and canister filling. For these reasons the possibility of inclusion of off spec amounts of special nuclear material, either by error or by design, is greater than for the other waste types. It is our opinion, however, that the place to affect the required levels of material control to insure that such errors or diversions do not occur is at the point where the waste materials are encapsulated. The material balance for a given facility, with respect to its off site waste shipments, should be closed when the material is sealed in the cans, and a verification by the waste repository as to explicit contents of individual drums should not be necessary.

The reasons for this are threefold. First, the shipper has access to the material prior to encapsulation and can therefore implement much more accurate material measurement techniques either by sampling or by assay of individual components prior to canning.

Second, if assay of encapsulated wastes is deemed necessary, the shipper will have access to the data on the material composition of each drum and will be able to construct and maintain calibration standards peculiar to his types of waste. In addition, since the variety of wastes from a given shipper will certainly be less than the total spectrum received by a repository, the shipper can design and implement NDA techniques suited to and optimized for his particular types of waste.

Third, since one purpose of material control is the timely detection of loss or diversion of special nuclear material, the discovery of inconsistencies in container contents on receipt at the repository will probably be too late to be effective.

In summary, responsibility for detailed material accountability in LLW should be the responsibility of the shipper. Processes and regulations should be designed accordingly. The waste repository should verify that it received, intact, what was shipped and hence item accountability and tamper indication procedures should be sufficient.

5. TECHNICAL OPTIONS FOR ITEM CONTROL

The waste container is the basic unit for the item accountability level of material management at a repository. We have already expressed the opinion that item accountability be applied to all waste types, that each container should be uniquely identified, and that simple enumeration of containers is insufficient. The hostile nature of nuclear waste, the loss of public confidence in the event of container loss or misplacement, and the fact that all 55-gal drums and 12-in. pipes look very much alike make the additional chores involved in the marking of waste canisters and the associated record keeping seem small in comparison to the added assurance gained by implementing such a system.

There are certain characteristics that identifications selected for waste containers should have. The identifications should not be easily damaged. The identifications should be difficult to alter or duplicate. Due to the high volumes which must be processed and the radiation levels associated with three of the four types of waste, the identifications would have to be adaptable to automatic reading.

There are many identification procedures that can be used for nuclear waste containers. Five are considered in this paper and an infinite number of variations on these five procedures are possible. The five identifications discussed are: alphanumeric identification labels, magnetic strips, inscribed identification numbers, bar-coded identification, and notched binary identification numbers.

Labels written in alphanumeric characters are possibly the simplest form of identification. There are several disadvantages however. The labels are sensitive to damage, easily duplicated, and difficult to read automatically.

Magnetic strips containing the identification information are more difficult to alter or duplicate and can be read automatically. However, they are susceptible to damage especially by strong magnetic fields.

Both labels and magnetic strips suffer from the fact that the high temperatures associated with HLW might tend to decompose or obscure the information.

Identification numbers inscribed on the metal waste containers have the advantage of insensitivity to accidental damage (e.g., intense heat or mechanical abrasion) and are difficult to alter. However, inscribed numbers are not easily adaptable to automatic reading.

Identifications using bar codes such as the Universal Product Code (UPC) have several advantages. The bar-coded information can be painted or inscribed on the container surface or put on labels which are then attached to the container. The information can be automatically read. The coding system can be unique making alteration or duplication very difficult. A large amount of information can be contained in each bar-coded label. The coded information could include: container identification number, shipper identification number, SNM content, total weight, surface radiation level, etc. In addition a coded check number to determine whether the information has been correctly read or altered can be included. A disadvantage of bar code labels is that they may be damaged during shipment as discussed above. However, the codes can be inscribed into the container surface to reduce the possibility of identification being obliterated.

An alternate coded identification technique is notched binary. In notched binary identifications, a series of notches are placed at a specific axial location along the circumference of the waste container. Each notch or absence of a notch would represent the binary digit 1 or 0. If there are 17 notch locations, any decimal number up to 131071 can be uniquely determined. To read the identification number, a mechanism would move over the notch locations recording the presence or absence of notches.

These last two identification procedures have several advantages. The identifications would be insensitive to damage, difficult to alter or duplicate, and adaptable to automatic reading. However, they require that shippers have either prefabricated marked waste containers or machines for cutting the identifications. Also, shippers and the waste terminal storage facility would have to have mechanical devices to read the inscribed identifications.

Table 7 summarizes the advantages and disadvantages of the various identification systems.

Our preference, in light of the considerations listed above, is that permanent identification (notched binary alphameric or UPC) be inscribed in the container surface. Further study will be required to determine the optimum system for each waste type.

6. TECHNICAL OPTIONS FOR TAMPER INDICATION

We have recommended that level 2, e.g., tamper indication procedures, be applied to ILW and LLW waste containers because these containers lack the protection against diversion afforded by high radiation levels and may, on occasion, contain significant amounts of nuclear material.

Sealing systems have been successfully used in the transportation industry for many years. Sealing systems employ mechanical seals to indicate tampering. If entry or tampering occurs during shipment, the seals are damaged. The seals would be placed on the outside of the cargo access of the waste carrier and on the shipment containers of the waste canisters. A disadvantage of sealing systems is that occasionally seals are accidentally damaged and back-up procedures to indicate tampering

Table 7. Advantages and disadvantages of identification procedures

Identification procedure	Advantages	Disadvantages
Alphanumeric identification labels	Conventional procedure easy to implement	Susceptible to duplication or alteration Susceptible to accidental damage Difficult to read automatically
Magnetic strips	Difficult to alter or duplicate Adaptable to automatic reading	Susceptible to accidental damage
Inscribed identification numbers	Conventional procedure easy to implement Resistant to accidental damage	Difficult to read automatically. Most applicable to LLW cans.
Bar-coded identification labels	Adaptable to automatic reading Difficult to alter or duplicate	Susceptible to accidental damage unless inscribed
Notched binary identification numbers	Adaptable to automatic reading Resistant to accidental damage Difficult to alter	Not commonly used procedure Development work needed (mechanical reader devices and machines for making notched identifications)

are required. For nuclear waste containers, back-up tamper-indicating procedures may be weight measurements and radiation scans.

Weight measurements and radiation scans can be used to indicate material loss and to supplement sealing systems. In weight measurement procedures, the weight of the container and contents would be accurately measured and compared with shipper values. In radiation scan procedures, the gross gamma and/or neutron radiation levels would be measured at a specific distance from the container and compared to shipper values. Elaborate instrumentation would not be required for weight or radiation scan measurements.

Radiation signature procedures could be employed to give nearly positive indication of whether tampering had occurred. Radiation signatures are measurements of certain energy gammas or gamma energy spectra and/or neutron energy spectra. The radiation signatures would be taken by the shipper before shipment and by the repository after shipment. If the signatures do not match, tampering would be assumed. There are many disadvantages of this procedure. Elaborate instrumentation is required and all shippers and the repository would have to have identical instrumentation for valid signature comparison. In addition, different instrumentation may be required for each waste type as the emitted radiation differs significantly for different waste types. Also, computer data analysis systems and possibly several instruments for each waste type would be required. Additional personnel would also be required at the waste terminal storage facility to operate and service the radiation signature instrumentation.

Table 8 lists the advantages and disadvantages of the various tamper-indicating systems. Our preference is for a well designed sealing system with weight and radiation level measurements for backup.

Table 8. Advantages and disadvantages of tamper-indicating procedures

Tamper-indicating procedure	Advantages	Disadvantages
Sealing systems	Well developed-commonly used in transportation industry	Seals susceptible to accidental damage-need backup procedure
Weight measurements	Easy to implement	Not a positive tamper-indicating procedure
Radiation scans	Easy to implement Difficult to duplicate	Not a positive tamper-procedure
Radiation signatures	Nearly positive tamper-indicator	Idendical instrumentation required by all shippers and the repository Repository design and operation complicated

7. TECHNICAL OPTIONS FOR SNM ASSAY

We have, in the preceding discussion, rather summarily dismissed quantitative material assay from an important role in the material accountability procedures at a waste repository. This dismissal rests on the unfortunate reality that the physical and radiological characteristics of the various waste materials preclude measurements of sufficient accuracy to provide information of any great value.

In our technical evaluation[1] we analyzed the various NDA technologies and their applicability to the several waste types and arrived at the following conclusions.

1. It is not technologically reasonable to attempt to assay high level and cladding waste. The radiation levels and low SNM contents exclude practical application of both passive and active techniques.
2. The properties of low level and intermediate level waste also make assay very difficult. The measurement accuracy for NDA methods is generally low for high density material, for low SNM concentrations, for high background radiation levels, for heterogeneous material mixtures, and for large container volumes. Both LLW and ILW have these properties in varying degrees. Also for independent NDA analysis at the waste storage facility, the chemical composition of the waste, the homogeneity of the SNM distribution, and the isotopic composition of the SNM must be known. This further complicates the assay of these wastes at the repository.
3. If SNM measurement is implemented at the waste storage facility, effects on the facility design could be significant. Separate shielded assay rooms in the facility would be necessary. Automated waste container flow systems coupled with container identification instrumentation and computer data analysis systems would be required. Different NDA instrumentation would be necessary for each waste type since different types have differing SNM contents, container sizes, radiation levels, etc. Several standard waste samples of each waste type would be

necessary for NDA analysis. Assay times are long (of the order of 20 min) and several flow lines would be necessary to prevent pile-ups in the surface storage areas. In addition, an increase in personnel at the waste terminal storage facility would be required to operate and service the assay equipment. If, despite the above complications, quantitative assay is attempted, accuracies in the 15 to 30% range are probably all that can be achieved.

It is possible that regulatory decisions may require nondestructive assay techniques at a repository despite the limitations described above. In this event, the following technical considerations should be considered in the selection and implementation of specific assay instrumentation.

1. Calorimetric techniques are not applicable to the types of material and containers expected at a waste repository.
2. Assay of High Level and Cladding Waste canisters by nondestructive techniques to determine residual fissile material content is almost impossible using available technology. The probability of success for developing such techniques for routine application is very small.
3. Assay of Intermediate Level Waste canisters for fissile content using passive gamma or neutron techniques is not feasible because of the high fission product gamma activity and neutron activity from the higher actinides.
4. Assay of Low Level Waste by passive gamma methods is possible but severely complicated by the high density and variability of the waste material and by the need to calibrate measured results against representative standards. For well characterized low level wastes, passive gamma techniques can be employed, but the possibility of unknown matrix inhomogeneities reduces confidence in such measurements.
5. Assay of Low Level Waste by passive neutron methods is possible, but complications due to the presence of (α,n) neutrons and uncertainties in plutonium isotopics relegates these methods to the "consistency check" level.

6. Active interrogation methods, using either gammas or neutrons, are the most promising techniques for quantitative determination of the fissile content of intermediate and low level waste containers. Highest accuracies (5–20%) may be achieved on LLW in 55-gal drums using particle accelerators to generate the interrogating radiation but these bring with them the attendant problems of high cost and potential operating and maintenance problems. Isotopic [^{252}Cf or (γ,n)] sources can be successfully employed to assay these types of waste, probably to accuracies of ∿10 to ∿30%. Assay times to achieve these accuracies will be of the order of 10 min/drum.

   Several different devices, tailored to specific waste types within each category, will probably be required to cover the spectrum of materials and activities in the low and intermediate waste categories. Major development work will be required to implement such a system.
7. Attribute measurements, go, no-go measurements, and radiation signature measurements are simpler to make and are well within the range of existing technology. While specific equipment would have to be designed for these applications, we see no severe technical problems. These measurements could be made by passive or by a combination of active-passive techniques using isotopic sources.

8. CONCLUSIONS AND RECOMMENDATIONS

Three levels of material control and accountability procedures for special nuclear material at waste terminal storage facilities have been identified as: identification and item accountability, tamper-indication, and material assay. We have argued that each waste container must have a unique identification for record management and control. Tamper-indicating procedures should be practiced on ILW and LLW canisters to determine if the containers have been breached during shipment. Quantitative assay should not be attempted or required.

Several identification procedures, tamper-indication procedures, and material assay procedures have been considered.

Of the five identification procedures considered, alphanumeric identification labels and magnetic strips are of questionable utility, being too susceptible to accidental damage such as fire, abrasion, or strong magnetic fields. Notched binary identification numbers and inscribed bar-coded identification have the advantage of being adaptable to automatic reading although they are more complex identifications than are inscribed numbers. The waste terminal storage facility and the waste shippers will have to decide if the identification symbols should be automatically read. An identification procedure to allow automatic reading should be considered especially when evaluating HLW, CW, and ILW waste container identification requirements.

Radiation signature verification is an expensive tamper-indicating procedure requiring elaborate instrumentation and complicating the waste repository design and operation. For these reasons it is considered an inappropriate tamper-indicating procedure. Sealing systems are well-developed, are commonly used, and are easy to implement. However, as seals may be accidentally damaged, back-up tamper-indicating procedures are required. Weight measurements and gross radiation scans could satisfy this need. Shippers would be required to weigh and scan each waste container before shipment.

Special nuclear material assay would significantly complicate waste terminal storage facility design and operation. In addition, SNM measurement accuracy would be too low to be useful for absolute verification of shipper measurements. It is not recommended as a material control measure at a waste repository.

In view of the above we recommend the following procedures be followed for material control at a waste repository.

1. High Level Waste. Item control measures with unique container identification. Identification symbols should be inscribed on container surface and should probably be machine readable.
2. Cladding Waste. Same as for High Level Waste.
3. Intermediate Level Waste. In addition to item control measures described above, explicit tamper indication procedures should

be implemented. If container design does not provide sufficient assurance of maintenance of integrity, then a system of tamper-indicating seals with weight and radiation scan backup should be employed.

4. Low Level Waste. Item control measures including unique inscribed identification. Tamper-indicating seals with weight and radiation scan measurements for backup.

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Appendix A

SNM ACCOUNTABILITY FOR ALTERNATE WASTE TYPES

The waste types discussed in the main body of this paper were based on certain reprocessing and fuel recycle assumptions. It was assumed that the fuel was reprocessed and that the plutonium was recycled. Other waste types would result if there was no reprocessing or if the plutonium was not recycled after reprocessing. The alternate waste types considered in this Appendix are described in Table A1.

Table A1. Alternate waste types for waste terminal storage facilities

Waste type	Fuel cycle assumptions	Waste description
Fuel assemblies	No reprocessing, no fuel recycle	Spent fuel assemblies
Plutonium in high level waste	Reprocessing, no plutonium recycle	Same waste types as in Table 2 but HLW has virtually all the Pu in spent fuel

As the SNM content has increased in the waste for these alternate fuel cycle assumptions, the attractiveness of the waste for theft has correspondingly increased. Safeguards measures related to the accountability of SNM at waste terminal storage facilities would have to be more stringent.

If the waste form is fuel assemblies, item accountability would be a reasonable accountability procedure to practice at waste terminal storage facilities. The fuel assemblies are closed containers which remain unopened before and after irradiation and would not be opened at the waste repository. Item accounting is the currently accepted practice at power reactors. Each fuel assembly is identified by a unique inscribed number. Measurements of SNM in the fuel assemblies are not made at power reactors. Similar accountability procedures could be practiced at waste terminal storage facilities. In addition, as the irradiation history of each spent fuel assembly is well known, the SNM content in each assembly could be estimated.

If the plutonium is not recovered and remains in the high level waste, item accountability still remains the reasonable accountability procedure. The high level waste, even with the higher plutonium concentration, is so radioactive that the attractiveness for theft is low. Also, SNM measurement by NDA techniques would be complicated by the high background radiation level of fission products in the high level waste.

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